UNIVERSIDADE BEIRA INTERIOR

Coopetition Technology-Enabled Service Ecosystems

A Framework to Improve the Portuguese Ornamental Stone Sector

Agostinho Manuel Antunes da Silva

Tese para obtenção do Grau de Doutor em

Engenharia e Gestão Industrial

(3º ciclo de estudos)

Orientador: Prof. Doutor António João Marques Cardoso

Junho de 2025

Folha em branco

Coopetition Technology-Enabled Service Ecosystems

A Framework to Improve the Portuguese Ornamental Stone Sector

Agostinho Manuel Antunes da Silva

Tese para obtenção do Grau de Doutor em
Engenharia e Gestão Industrial
(3º ciclo de estudos)

Orientador: Prof. Doutor António João Marques Cardoso

Provas de Doutoramento: 27 de maio de 2025

Júri:
Presidente:
Prof. Doutor Mário Marques Ferreira

Vogais:
Prof. Doutor Luís Manuel Camarinha-Matos
Prof. Doutor António João Marques Cardoso
Prof. Doutora Cesaltina Maria Pacheco Pires
Prof. Doutor João Carlos Correia Leitão
Prof. Doutor Mário José Baptista Franco

Folha em branco

Declaração de Integridade

Eu, Agostinho Manuel Antunes da Silva, que abaixo assino, estudante com o número de inscrição D3408 do curso de Engenharia e Gestão Industrial (3º ciclo de estudos) da Faculdade de Engenharia, declaro ter desenvolvido o presente trabalho e elaborado o presente texto em total consonância com o **Código de Integridades da Universidade da Beira Interior**.

Mais concretamente afirmo não ter incorrido em qualquer das variedades de Fraude Académica, e que aqui declaro conhecer, que em particular atendi à exigida referenciação de frases, extratos, imagens e outras formas de trabalho intelectual, e assumindo assim na íntegra as responsabilidades da autoria.

Universidade da Beira Interior, Covilhã 16/06/2025

Assinado por: **AGOSTINHO MANUEL ANTUNES DA SILVA**
Num. de Identificação: 04383581
Data: 2025.06.16 15:22:53+01'00'

Folha em branco

Dedication

This thesis is dedicated to the memory of my father, whose enduring love of science continues to guide and inspire me, even in his absence.

To my son, João, the strength of my life—you are my motivation and joy.

Folha em branco

Acknowledgements

Completing this PhD has been an incredible journey, made possible by the support and guidance of numerous individuals whose impact has been invaluable. I am profoundly grateful for their contributions.

I extend my deepest gratitude to Professor António João Marques Cardoso, my PhD Program Supervisor and CISE scientific coordinator, whose joy, willingness, and enthusiasm have profoundly influenced my academic pursuits. Sylvie Santos, the CISE Science and Technology Manager, and all CISE researchers and collaborators have provided essential support and insight, enriching my research experience.

My thanks also go to all colleagues and partners from CEI-Zipor, IPLeiria, and ISG for their collaboration and encouragement throughout this process.

A special acknowledgement is due to my friends who have made this journey memorable: José Julio, Marcelo Gaspar, António Marques, Amelia Almeida, Peter Mulbach, José Barroso, Carlos Capela, Jan Janssen, Joel Vasco, Carlos Rabadão, Marco Lopes, José Mirão, Isabel Almeida, Jorge Cristino, Fernando Silva, Gorete Marques, Marisa Dinis, Carlos Vieira, António Marcos, Vasco Almeida, António Prata, Rui Carvalho, João Paulo, Neto Filipe, Samuel Delgado, Marta Peres, Filipe Miguel, Paulo Durão, Tomané Marcos, Luis Oliveira, Luis Lopes, Victor Franco, Miguel Varela, João Heitor, Rosa Rodrigues, Catarina Afonso, Joaquim Vicente, Daniela, Vasco e Ana. Your friendship and support have been a cornerstone of my resilience and success.

My family has been my foundation and greatest blessing. To my wife Olivia, my beloved son João and his love Ines, and my dear sisters Ana Maria and Elisabete—your love, patience, and unwavering support have sustained me. A special tribute to my dear mother, who has been my inspiration and strength. My father's memory and his enduring love of science continue to guide and inspire me, even in his absence.

I am immensely thankful to Professors Jim Spohrer, Paul Maglio, Melissa Akaka, and especially Professor Steve Vargo, whose guidance has significantly shaped my academic development.

I also want to acknowledge my colleagues at Cluster Portugal Mineral Resources, especially Luis, Marta, Tânia, André, Ines, and Claudia, whose support has been crucial in my research endeavors.

This thesis would not have been possible without everyone’s collective support and encouragement. Thank you all for being part of my PhD journey.

Agostinho da Silva
Covilhã, 2025

Folha em branco

Resumo

Esta tese analisa criticamente o design, implementação e impacto de redes de coopetição entre PMEs em cadeias de abastecimento digitais e globais. Foca-se nos desafios que essas empresas enfrentam, como limitações financeiras, baixa eficiência, falta de escala, satisfação do cliente e pressões ambientais. Para responder a esses desafios, é proposto e testado empiricamente um Quadro Teórico de Redes de Coopetição para a Cocriação de Valor (CN-VCC), operacionalizado com tecnologia IIoT, resultando no ecossistema tecnológico CN-EcoTech.

Com base na lógica dominante do serviço e na metodologia Design Science Research (DSR), o CN-EcoTech foi desenvolvido e validado no setor de pedra ornamental em Portugal (OS-PT), que enfrenta novas exigências com a adoção global do BIM na Arquitetura, Engenharia e Construção (AEC). Após uma prova de conceito e um projeto piloto, observou-se que as PMEs mais comprometidas com o CN-EcoTech apresentaram melhores resultados operacionais, maior satisfação dos clientes e redução da pegada ecológica.

A investigação demonstra que o CN-EcoTech promove a colaboração eficaz entre PMEs e pode ser aplicado a outros setores semelhantes. Além de avançar academicamente o estudo das redes de coopetição, a tese oferece recomendações práticas para a indústria e políticas públicas, contribuindo para a competitividade e sustentabilidade das PMEs alinhadas com os Objetivos de Desenvolvimento Sustentável (ODS). Sugere-se ainda a exploração da escalabilidade do modelo em futuras investigações.

Palavras-chave

Coopetição; Lógica Dominante de Serviço; Industrial IoT; Industria de Rochas Ornamentais; PME; Design Science Research (DSR)

Folha em branco

Abstract

This doctoral thesis critically examines the design, implementation, and effectiveness of coopetition networks among small and medium-sized enterprises (SMEs) within the dynamic and complex realms of digital and global supply chains. The study addresses the challenges that SMEs face, including financial constraints, operational inefficiencies, scalability issues, customer satisfaction demands, and pressures related to ecological sustainability. To address these challenges, the research introduces and empirically tests the Coopetition Network for Value Cocreation (CN-VCC) framework, subsequently operationalized through the Industrial Internet of Things (IIoT) as the Coopetition Technology-enabled Service Ecosystem (CN-EcoTech). The Design Science Research (DSR) methodology, integrated with Service-Dominant (S-D) Logic, underpins the framework's development and validation, with a specific focus on the Portuguese ornamental stone sector (OS-PT), an industry of significant economic importance that is yet to be fully challenged by digital transformation and global market integration.

Following the DSR stages of designing and developing an artefact, implementing a Proof-of-Concept (PoC), and an Experimental Pilot Project, the thesis assesses the CN-EcoTech artefacts's impact across multiple dimensions: operational efficiency, scale, customer satisfaction, and ecological sustainability. The findings reveal that engagement levels within the CN-EcoTech framework correlate with significant improvements in OS.PT SMEs. Specifically, SMEs fully engaged in the framework demonstrated enhanced deal closures, robust customer relationships, and superior operational outcomes compared to their less-engaged counterparts. This differential highlights the potential of deep integration into technology-based coopetition frameworks to overcome traditional and emerging market challenges.

The thesis confirms that the CN-EcoTech framework facilitates long-term collaboration among SMEs and effectively addresses the challenges of digital and global supply chains. It extends beyond the immediate empirical setting of the OS-PT sector, suggesting broader applicability to similar SME-dominated industries facing digital integration challenges.

Academically, this research augments the understanding of coopetition dynamics and provides a structured approach to evaluating and implementing technology-enabled service ecosystems. However, more importantly, it offers actionable insights for industry stakeholders and policymakers, empowering them with strategies to enhance SME competitiveness and sustainability in line with the United Nations Sustainable Development Goals (SDGs). This thesis lays a foundation for future research to explore the scalability of the CN-EcoTech framework across diverse sectors. It offers a robust model for enhancing SME resilience and innovation capacity in a globally interconnected economy.

Keywords

Coopetition; Service Dominant Logic; Industrial IoT; Ornamental Stone Industry; SME; Design Science Research.

Folha em branco

Contents

Dedication vii
Acknowledgements ix
Resumo xi
Palavras-chave xi
Abstract xiii
Keywords xiii
Contents xv
List of Figures xxi
List of Tables xxiv
Abbreviations and Acronyms xxvi
Chapter 1. Introduction 1
1.1 Contextualization 1
1.2 The Problem: Challenges and Dynamics of Coopetition Networks 3
1.3 Research Problem and Objective 3
1.4 Research Motivation and Relevance 4
1.5 Methodological Overview 4
1.6 Thesis Structure 5
Chapter 1. Summary 6
Chapter 2. Relevance and Challenges in the Portuguese Stone Sector 8
2.1 BIM-Driven AEC Supply Chains 9
2.2 Challenges for the Portuguese Stone SMEs 9
2.3 Strategic Collaboration in the Portuguese Stone Sector 10
2.4 The Way Forward 12
Chapter 2. Summary 12
Chapter 3. Literature Review 13
3.1 Coopetition Overview 14
3.2 Identifying Research Gaps in Coopetition Networks 16
3.2.1 Value Cocreation in Coopetition Networks (RG1) 16
3.2.2 The Role of Technology in Coopetition Networks (RG2) 17
3.2.3 Coordination Mechanisms in Coopetition Networks (RG3) 17
3.3 Bridging Coopetition Gaps: Paving the Way for S-D Logic in Coopetition Networks 17
3.4 A Service Ecosystem for Value Cocreation 18
3.5 Fractal Approach to Value Cocreation 20
3.5.1 Institutional Perspective on Coopetition and Value Cocreation 21
3.5.1.1. Coopetition 21
3.5.1.2 Value Cocreation 22

3.5.2 Institutional Reconciliation of Coopetition and Value Cocreation 23
3.5.3 An institutional Perspective on Networks, Technology and Service Ecosystems 25
3.5.3.1 Networks 25
3.5.5.2. Value Networks 26
3.5.3.3 Technology-Enabled Networks 27
3.5.4. Institutional Work in Networks 28
3.5.5. Institutional Convergence on Networks and Service Ecosystems 29
3.6. Addressing Research Gaps: A Service Ecosystems Perspective 30
3.6.1 Addressing Research Gap 1: Value Cocreation in Coopetition Networks 31
3.6.2. Addressing Research Gap 2: The Role of Technology in Coopetition Networks 32
3.6.3. Addressing Research Gap 3: Enhancing Coordination of Coopetition Networks 33
3.7. Institutional Foundation for Coopetition Networks for Value Cocreation 33
3.8. Structural Constructs for Coopetition Networks for Value Cocreation 34
3.9. Ensuring Long-Term Coopetition Networks for Value Cocreation 35
Chapter 3. Summary 36
Chapter 4. Methodology 37
4.1 Research Paradigm 37
4.2 Methodological Foundations and Approaches in Research 38
4.2.1 DSR Methodology: Origins and Core Principles 38
4.2.2 The Supportive Role of S-D Logic 40
4.2.3 Ontological Alignment with Research Objectives 40
4.2.4 Epistemological Contributions through DSR 41
4.2.5 Applicability of DSR in Developing and Evaluating Technology-Based Solutions 41
4.3 Designing a Methodological DSR Framework for Ornamental Stone SMEs 41
4.3.1 DSR Activities 1 and 2: Problem, Motivation, Requirements, and Objectives for a Solution 42
4.3.2 DSR Activity 3: Designing a Coopetition Network for Value Cocreation 43
4.3.3 DSR Activity 4: Proof-of-Concept of the CN-EcoTech 44
4.3.4 DSR Activity 5: Assessing the Impact of the CN-EcoTech on OS-PT SMEs 45
4.3.5 DSR Activity 6: Findings Communication 46
4.4 Ethical Considerations 46
Chapter 4 Summary 46
Chapter 5. Requirements and Objectives of Coopetition Networks for Value Cocreation 48
5.1 Performative Constructs for Coopetition Networks for Value Cocreation 48

5.1.1 Systemic Guidelines for Coopetition Networks for Value Cocreation 49
5.1.1.1 The Role of Technology: Resource Integration in Coopetition Networks Value Cocreation 51
5.1.1.2 Service Exchange: Technology-Driven Interactions for Value Cocreation in Coopetition Networks 52
5.1.1.3 Institutions: Coordination of Coopetition Networks for Value Cocreation 52
5.1.2 Performative Constructs for Service Exchange in Coopetition Networks for Value Cocreation 53
5.2 IIoT-based Technology: Mechanisms for Enhancing Service Innovation in Ecosystems 55
5.2.1 Interoperability Mechanisms 56
5.2.2 Usability and Accessibility Mechanisms 57
5.3 Objectives and SDG Alignment 58
5.4 Preliminary Evaluation Survey of the CN-VCC Framework 59
Chapter 5. Summary 61
Chapter 6. Designing Coopetition Networks for Value Cocreation 62
6.1 Building Blocks for Coopetition Networks for Value Cocreation 63
6.2 Theoretical Background: Coopetition Networks for Value Cocreation 63
6.3 Systemic Building Blocks for Coopetition Networks for Value Cocreation 64
6.4 Framing Actors and Resources 65
6.4.1 Providers' Resources in Coopetition Networks for Value Cocreation 66
6.4.2 Coopetitors' Resources in Coopetition Networks for Value Cocreation 66
6.4.3 The Role of Customers 67
6.4.4 The Role of Competitors 67
6.5 Industrial IoT for Coopetition Enabling 68
6.6 Integrating Industrial IoT in Coopetition Networks for Value Cocreation 69
6.6.1 Embedding Industrial IoT in Coopetition Networks for Value Cocreation 69
6.6.2 Industrial IoT Advancements: Cockpit4.0+ 70
6.6.2.1 Operant Capabilities 71
6.6.2.2 Interoperability Mechanisms 71
6.6.2.3 Network Actors' Accessibility and Usability 72
6.6.3 Algorithm: Cockpit4.0+ Development 73
6.7 Survey for Preliminary Evaluation of the Cockpit4.0+ 75
6.8 Coopetition Technology-Enabled Service Ecosystems 77
6.9 Lifecycle and Instantiation of a CN-EcoTech 78

6.9.1 Tracing the Lifecycle of CN-EcoTechs 78
6.9.2 Instantiation Methodology for CN-EcoTechs 79
6.9.2.1 Initiation Stage: Launching CN-EcoTech 80
6.9.2.2 Operation Stage: Dynamism in a CN-EcoTech 81
6.9.2.3 Metamorphosis Stage: A Strategic Shift 83
6.9.2.4 Dissolution Stage: The Final Act of CN-EcoTechs 84
Chapter 6. Summary 86
Chapter 7. CN-EcoTech Proof-of-Concept in the OS-PT sector 87
7.1 Service Blueprint for Outcomes Evaluation in a CN-EcoTech 88
7.1.1 Redefining Line of (Cyber) Interactions 89
7.1.2 Mapping Dynamic (Cyber) Resource Sharing 90
7.1.3 Reimagining Interaction Frameworks: Stages and Lanes in CN-EcoTechs 91
7.2 Service Blueprint Framework for CN-EcoTechs 92
7.2.1 Assessing the Effectiveness of the Service Blueprint Framework 92
7.2.2 ISPAR: Outcomes Evaluation Throughout the Service Journey 93
7.3 Proof-of-Concept for the CN-EcoTech in the OS-PT sector 94
7.3.1 Initiation Phase - Selection of OS-PT SMEs 94
7.3.2 PoC Operationalization: Actors and Resources 95
7.3.2.1 Provider Resources 96
7.3.2.2 Coopetitor Resources 96
7.4 Data Collection and Service Journey 96
7.4.1 Findings from the SMEs Acting Independently 97
7.4.2 Findings from the SMEs Acting Partially in the CN-EcoTech 97
7.4.3 Findings from the SMEs Acting fully engaged in the CN-EcoTech Ecosystem 98
7.5 Comparative Insights from the Proof-of-Concept 99
Chapter 7. Summary 99
Chapter 8. Assessing the Impact of CN-EcoTech on OS-PT SMEs 101
8.1 SME Selection Process and Experimental Pilot Project Implementation 102
8.1.1 Establishment of Metrics and KPIs in OS-PT SMEs 104
8.1.2 Operational Efficiency-related Metrics, KPIs and Innovation Outcomes 104
8.1.3 Operational Scale-related Metrics, KPIs and IOs 106
8.1.4 Customer Satisfaction Determinants-related Metrics, KPIs, and IOs 108
8.1.5 Ecological Footprint-related Metrics, KPIs, and IOs 110

8.2 Data Collection and Procedures 112
8.3 Findings 112
8.3.1 Operational Efficiency 112
8.3.2 Operational Scale 115
8.3.3 Customer Satisfaction Determinants 118
8.3.4 Ecological Footprint Analysis 120
8.4 Innovation Outcomes Assessment 122
8.4.1 Operational Efficiency Improving 122
8.4.2 Operational Scale Impact 125
8.4.3 Enhancements in Customer Satisfaction Determinants 128
8.4.4 Ecological Footprint Impact 130
8.4.5 Iterative Review and Redesign 133
Chapter 8. Summary 133
Chapter 9. Dissemination of Findings 134
9.1 Academic Audience Outreach 134
9.2 Industry Audience Outreach 137
Chapter 10. Conclusions 138
Answering RQ2: Impact of CN-EcoTech on Operational Efficiency 139
Answering RQ3: Impact of CN-EcoTech on Operational Scale 140
Answering RQ4: Enhancements in Customer Satisfaction Determinants via CN-EcoTech 141
Answering RQ5: Impact of CN-EcoTech on Ecological Footprint 142
Final Conclusions 142
Academic Implications 143
Practical Implications 144
Challenges and Constraints 144
Recommendations for Future Work 145
List of References 146
Appendix I. Tables 166
Appendix II. Figures 182
Appendix III. Scientific Publications 184

Folha em branco

List of Figures

Figure 1. Variation in Coopetition Propensity Relative to the Digital Maturity of OS-PT SMEs. .11

Figure 2. Chapter 3 Graphical Abstract: Fractal approach to Coopetition Networks in Value Cocreation. 13

Figure 3. Design Science Research Methodological Framework for OS-PT SMEs. 42

Figure 4. Systemic Constructs for Coopetition Networks for Value Cocreation 50

Figure 5. Institutionalization Process of Coopetition Networks for Value Cocreation 54

Figure 6. IIoT-Based System: Mechanisms for Enhancing Service Innovation in Ecosystems, Adapted from Ng & Wakenshaw (2017) 58

Figure 7. Survey Outputs: Preliminary Evaluation of the CN-VCC Framework Based on Interviews with OS-PT SMEs. 60

Figure 8. Chapter 6 Graphical Abstract: The Building Blocks Approach for Coopetition Networks. 62

Figure 9. Building blocks for Coopetition Networks for Value Cocreation. 65

Figure 10. Leveraging OPC UA to Enhance the Cockpit4.0+'s Interoperability. 72

Figure 11. Accessibility and Usability Mechanisms for Cockpit4.0+. 73

Figure 12. Operational Cockpit4.0+'s Interface. 75

Figure 13. Evaluation of Cockpit4.0+ Functionalities by OS-PT SMEs. 77

Figure 14. CN-EcoTechs Lifecycle. 79

Figure 15. The Initiation Stage of the CN-EcoTechs. 80

Figure 16. The Operation and Evolution Stage of a CN-EcoTech. 82

Figure 17. Metamorphosis stage of a CN-EcoTech. 83

Figure 18. Dissolution Stage of CN-EcoTechs. 85

Figure 19. Chapter 7 Graphical Abstract: Service Blueprint Approach for CN-EcoTech. 87

Figure 20. Service Blueprint's user-friendliness evaluation for the CN-EcoTech practices. 93

Figure 21. Chapter 8 Graphical Abstract: Evaluating the Benefits of CN-EcoTech in the OS-PT Sector. 101

Figure 22. Overview of the Experimental Pilot Project for OS-PT SMEs under the CN.P. 103

Figure 23. The trend in Average Daily Production of Good Parts under CN.P 114

Figure 24. The trend in Average Daily Successful Leads under CN.P 117

Figure 25. The Trend in Average Daily On-Time Delivered Parts under CN.P 120

Figure 26. Daily Trend in KPIPE under Coopetition Practices. 123

Figure 27. CN-EcoTech Impact on the Operational Efficiency-Related Determinants in the OS-PT SMEs. 124

Figure 28. Daily Trend in KPICR under Coopetition Practices. 126

Figure 29. CN-EcoTech Impact on the Operational Scale-Related Determinants in the OS-PT SMEs. 127

Figure 30. Enhancement in Operational Flexibility under CN.P **Error! Bookmark not defined.**

Figure 31. Daily Trend in KPICcR under Coopetition Practices. 129

Figure 32. CN-EcoTech Impact on the Customer Satisfaction Determinants in the OS-PT SMEs. 130

Figure 33. CN-EcoTech Impact on the Ecological Footprint -related Determinants in the OS-PT SMEs. 131

Figure 34. Impact of CN-EcoTech on CO_2 Emissions in OS-PT SMEs 132

Folha em branco

List of Tables

Table 1. Formulation of the Efficiency-related KPIs 104

Table 2. Formulation of the Efficiency-related IOs 105

Table 3. Formulation of the Scale-related KPIs 106

Table 4. Formulation of the Scale-related IOs 107

Table 5. Formulation of the Satisfaction Determinants-related KPIs 108

Table 6. Formulation of the Satisfaction Determinants-related IOs 109

Table 7. Ecological Footprint-related Metrics and KPIs 110

Table 8. Ecological Footprint-related IOs 111

Table 9. Summary of Average data collected for Efficiency-related (CB.P) 113

Table 10. Summary of Average data collected for Efficiency-related (CN.P) 113

Table 11. Comparative Efficiency-related KPIs Assessment for CB.P and CN.P 113

Table 12. Summary of Average data collected for Scale-related (CB.P) 115

Table 13. Summary of Average data collected for Scale-related (CN.P) 116

Table 14. Comparative Operational Scale-related KPIs Assessment for CB.P and CN.P 116

Table 15. Summary of Average data collected for Customer Satisfaction Determinants-related (CB.P) 118

Table 16. Summary of Average data collected for Customer Satisfaction Determinants-related (CN.P) 118

Table 17. Comparative Customer Satisfaction Determinants-related KPIs Assessment for CB.P and CN.P 119

Table 18. Summary of Average Daily Ecological Footprint -related Metrics Under CB.P 121

Table 19. Summary of Average Daily Ecological Footprint -related Metrics Under CN.P 121

Table 20. Comparative Ecological Footprint -related KPIs Assessment for CB.P and CN.P 121

Table 21. Summary of Operational Efficiency-Related Findings through CN-EcoTech in OS-PT SMEs 123

Table 22. Summary of Operational Scale-Related Findings by CN-EcoTech in OS-PT SMEs 125

Table 23. Summary of Cust. Satisfaction Determinants -Related Findings from CN-EcoTech in OS-PT SMEs. 128

Table 24. Summary of Ecological Footprint -related Findings through CN-EcoTech in OS-PT SMEs 131

Folha em branco

Abbreviations and Acronyms

AEC	Architecture Engineering and construction
BIM	Building Information Modelling
CB.P	Current Best Practices
CN.P	Coopetition Network Practices
CN-EcoTech	Coopetition Technology-Enabled Service Ecosystem
CN-VCC	Coopetition Network for Value Cocreation
DSR	Design Science Research
DML	Digital Maturity Level
DL	Digital Level
EU	European Union
ICT	Information and Communication Technologies
IIoT	Industrial Internet of Things
IO	Innovation Outcomes
IoT	Industrial Internet of Things
KPI	Key Performance Indicators
KPICcR	KPI for Customer Complaint Ratio
KPICO2-eq	KPI for Carbon Footprint Emissions
KPICR	KPI for Conversion Rate
KPIEE	KPI for Energy Efficiency
KPIFlex	KPI for Production Flexibility
KPIFTT	KPI for First Time Through
KPIFTT	KPI for First Time Through
KPILP	KPI for Labor Productivity
KPIMvA	KPI for Manufacturing Value Added
KPIOtD	KPI for On-Time Delivery Ratio
KPIPE	KPI for Performance Efficiency
KPIPoR	KPI for Production Output Ratio
KPIPsO	KPI for Product Stockouts
KPIRMY	KPI for Raw Material Yield
KPIRMY	KPI for Raw Material Yield
KPIVwR	KPI for Value to Weight Ratio
LCA	Life Cycle Assessment
OPC UA	OPC Unified Architecture
OS-PT	Portuguese Ornamental Stone sector
PoC	Proof-of-Concept
RP	Research Problem
S-D Logic	Service-Dominant Logic Logic
SDG	Sustainable Development Goals (SDGs)
SME	Small and Medium Enterprise

Folha em branco

Chapter 1. Introduction

Ars Conjectandi, (The Art of Conjecturing) - Jacobi Bernoulli

1.1 Contextualization

In the dynamically evolving economic landscape, Small and Medium Enterprises (SMEs) are recognized as foundational pillars within the European Union (EU) and other development regions [1], playing a crucial role in fostering innovation, generating employment, and driving economic growth [2] [3]. The rapid digitalization of economies and the globalization of supply chains have significantly altered procurement behaviors, thrusting SMEs into an era marked by access to expansive, borderless marketplaces [4]. This digital transformation era presents unprecedented growth and expansion opportunities for SMEs [5]. However, it also introduces formidable challenges, particularly for those with limited financial resources [2], including the need to achieve manufacturing efficiency within customized demand models to ensure high levels of customer satisfaction [6] and the imperative to align with the United Nations Sustainable Development Goals (SDGs) amidst the pressing issue of climate change [7] [8].

Navigating the complexities of digital and global supply chains requires SMEs to leverage advanced technological resources and capabilities [9], [10]. The ability of firms to maintain their operations in these markets increasingly relies on their technological adeptness and capacity for innovation, necessitating substantial investments to expand their market presence and achieve critical mass [11]. The shift towards a digital economy, which demands significant organizational transformations, can financially strain SMEs, leading to over-leveraging and potential solvency risks as they strive to finance their digital transitions [3], [12].

SMEs, defined by their number of employees, annual turnover, and total assets, play a vital role in the economy [5]. This study adopts the European Union's classification[1] of SMEs into micro, small, and medium-sized enterprises, reflecting their varied capacities. As of 2020, the EU27 hosted over 20 million SMEs, which constituted 99.8% of all non-financial businesses and provided more than 65% of total employment. These enterprises are recognized as crucial drivers of employment, innovation, and wealth creation, making significant contributions to the EU27's total value-added and generating substantial annual revenue [1]. According to the EU Annual Report on European SMEs, in 2022, SMEs accounted for most of the employment in most industries, notably over 80% in construction and scientific and technical activities. Despite their critical economic role, from 2020 to 2021, SMEs needed to catch up with large enterprises in terms of value added. This performance gap has been consistent since 2008, with large

[1] European Commission Recommendation of 6 May 2003 (2003/361/EC), Official Journal of the European Union, L 124/36, 20 May 2003

enterprises outperforming SMEs. A persistent challenge for SMEs is accessing finance [3] and revenue [1].

In Portugal, for instance, SMEs in traditional sectors like agri-food, footwear, textiles, and ornamental stones have played a crucial role, contributing significantly to exports and highlighting the integral role of SMEs in traditional sector-based economies[2]. However, these SMEs require assistance in integrating into digital and global supply chains, which is limited by their investment capabilities [13] necessary for achieving manufacturing efficiency in customized demand procurement [14] and effectively contributing to the SDGs [8].

The urgent need for innovative management strategies to help SMEs navigate global supply chain challenges is highlighted in the European Commission's 2021 Survey on Access to Finance of Enterprises [3]. Furthermore, aligning SME operations with SDGs is imperative in response to digital and global supply chain challenges [11]. SMEs are integral to the fabric of Europe, essential for its competitiveness, prosperity, and maintaining economic and technological sovereignty, as outlined in the Annual Report on European SMEs [4]. This strategy advocates for supporting and empowering SMEs across all sizes and sectors, from innovative tech startups to traditional crafts [1], [15].

The literature on business management presents a variety of perspectives on the challenges faced by SMEs [16], [17]. However, there is a consensus regarding specific strategic solutions. One key approach is the establishment of long-term partnerships and alliances, as recommended by the European Commission in its Digital Transition Action Plan [18]. Such enhanced strategies empower SMEs to enhance their development and delivery of customer-oriented solutions, significantly improving their ability to meet consumer demands on a global scale. This approach also positions them to contribute to making Europe the first climate-neutral continent [7].

Regardless of their specific format, these alliances or networks are united by a shared objective: to enhance organizational collaboration for better addressing vulnerabilities and capitalizing on the opportunities presented by digital global supply chains [11], [19]. According to the Global Digital Operations Study (2018), European SMEs are well-positioned to transform into interconnected, intelligent ecosystems that optimize efficiency through collaborative efforts [20]. These efforts enable the creation of tailored solutions that significantly improve agility. Such studies highlight the critical role of integrating coopetition strategies within SMEs' strategic frameworks, fostering an organizational ecosystem that promotes competitiveness and innovation [9].

[2] https://www.pordata.pt/

1.2 The Problem: Challenges and Dynamics of Coopetition Networks

Coopetition, which blends the strategic elements of competition and cooperation [21], is viewed by some scholars [22], [23] as a mechanism through which SMEs can leverage collective strengths to enhance global competitiveness. The European Commission also endorses this approach as a crucial strategy for unleashing the full potential of European SMEs [24]. However, transitioning to effective coopetition networks involves significant complexities and challenges [25]. Despite policies supporting these networks, maintaining long-term viability remains a considerable challenge [26], [27].

A study by the BCG Henderson Institute, published in the MIT Sloan Management Review and titled "How Business Ecosystems Rise, and Often Fall," reveals a concerning trend: an analysis of fifty-seven ecosystems across eleven sectors showed an 85% failure rate in the short term, with less than 15% achieving their long-term objectives [28]. This study found that ecosystems led by giants such as Microsoft and Amazon were among the 15% that succeeded, highlighting the volatile and complex nature of ecosystems based on coopetition. Furthermore, while these dominant companies bolster the ecosystem and generate significant profits, secondary members often depend more on the leading firm than on the ecosystem itself.

Critiques of coopetition have also highlighted its potential drawbacks, including the risk of inter-firm tensions that may compromise organizational performance [29]. As it is sometimes referred to, the "dark side" of competition illustrates the challenges and potential pitfalls of engaging in competitive and cooperative interactions with competitors [25].

1.3 Research Problem and Objective

In coopetition networks, firms face crucial decisions in balancing collaboration and competition for opportunities, thereby testing the resilience of the network and the integrity of relationships within it [29]. In the end, the success of coopetition networks often depends on the presence of a keystone entity [30], a challenging role for SMEs to fulfil, mainly when they operate at similar levels within clusters [31]. This issue, along with an inherent competitive orientation [32], poses significant obstacles to forming effective coopetition networks among SMEs. The lack of a collaborative ethos among SMEs has been identified as a significant impediment to achieving Europe's digital goals, underscoring the need for nuanced strategies and a thorough understanding of coopetition dynamics to overcome barriers such as inter-firm tensions [33], the critical role of keystone entities [34], and a prevalent competitive mindset [35].

Research Problem: What framework for coopetition networks can be effectively implemented to ensure long-term collaboration among SMEs, and what impact does this framework have on addressing the challenges posed by digital and global supply chains?

Main Research Objective: The primary goal of this research is to develop and empirically evaluate a comprehensive framework designed to establish and maintain effective coopetition

networks among SMEs. This study examines how such a framework can facilitate sustained collaboration, augment digital and operational capabilities, and assist SMEs in managing the complexities of global supply chains. Focusing on the Portuguese Ornamental Stone (OS-PT) sector as the empirical field, this research assesses the impact of the implemented cooperation framework on enhancing the concerns of OS-PT SMEs.

1.4 Research Motivation and Relevance

This research examines the pressing challenges faced by SMEs within global and digital supply chains. By examining the multifaceted impact of these challenges, the study seeks to underscore both the economic and social benefits of enhancing SME operational effectiveness through coopetition strategies. These strategies, which blend competition with cooperation, could significantly bolster economic growth and job creation, a crucial factor for the vitality of economies within the European Union and beyond.

Furthermore, the research contributes to a better understanding of coopetition networks by developing a framework that supports effective collaborations among SMEs. This framework fosters innovative operations models and encourages resilient practices essential in today's dynamic market environments. By enhancing SMEs' ability to navigate digital and global supply chains through the integration of advanced technologies and efficient management of cross-border operations, the research aims to streamline processes and enhance adaptability.

The outcomes of this research could have significant implications for policymaking, providing insights that help shape collaboration strategies essential as digital economies evolve. Moreover, this research examines how coopetition networks can contribute to sustainability and align SME operations with the Sustainable Development Goals (SDGs), with a primary focus on environmental and social impacts.

By filling gaps in the existing literature on coopetition and service, this study enriches academic discussions and offers empirical evidence on the strategic benefits of coopetition networks. It also provides practical strategies for SMEs, particularly those in the OS-PT sector, to engage successfully in cooperation networks. It helps overcome common barriers, such as trust issues, misaligned objectives, and resource constraints. Overall, this research is justified by its potential to significantly enhance the competitiveness and innovation capacity of SMEs, contributing valuable insights to both the theoretical and practical aspects of business strategy.

1.5 Methodological Overview

To achieve these objectives, this research employs the Design Science Research (DSR) methodology, integrated with Service-Dominant (S-D) Logic, to investigate Coopetition Networks for Value Cocreation (CN-VCC) among SMEs. The choice of DSR is predicated on its alignment with practical applications, particularly in creating and evaluating artefacts designed to address real-world problems within the context of SMEs operating in global and digital supply chains.

The methodology is structured to navigate complex ecosystems, beginning with problem identification and extending to the communication of findings. This process is deeply rooted in a pragmatist paradigm that supports a flexible yet systematic approach to research, making it suitable for dynamic and evolving business environments. S-D Logic enhances this methodology by providing a theoretical lens through which value cocreation and collaborative, competitive strategies are examined and developed.

This study focuses on the OS-PT sector, which serves as the empirical field for evaluating the effectiveness of the proposed CN-VCCs. Due to its internationalization and digital nature, the OS-PT sector provides an industrial context for examining the potential for value cocreation through networks. This setting is particularly advantageous because it encapsulates a network of intricate, interdependent operations that span various geographical borders and cultural contexts, making it an ideal testbed for studying collaborative competition strategies. By examining how businesses within this sector navigate their complex interactions and leverage shared opportunities, the study seeks to uncover nuanced insights into how coopetition can be successfully implemented and scaled to benefit a broader economic ecosystem.

By adopting this methodological framework, the research aims to offer SMEs actionable insights and practical strategies, thereby enhancing their competitiveness and operational capabilities in an increasingly complex global market. This approach underpins empirical investigation and enriches the theoretical understanding of coopetition and service ecosystems in the academic field of business management and strategy.

1.6 Thesis Structure

This thesis is organized into nine chapters to comprehensively address the research objectives and provide a detailed exploration of CN-VCCs among SMEs. The structure of the thesis is as follows:

Chapter 1. Introduction: This opening chapter sets the stage for the thesis by introducing the background of the Research Problem (RP), detailing the challenges and dynamics of coopetition in SME networks, stating the RP and objective, and outlining the justification and significance of the research. Chapter 2. Relevance, Challenges, and Opportunities in the Portuguese Stone Sector: This chapter focuses on the specific context of the Portuguese ornamental stone sector, discussing its relevance, the challenges within the Building Information Modelling (BIM)-driven Architecture, Engineering, and Construction (AEC) landscape, and strategic collaboration opportunities. Insights from a 2023 survey will be permitted to analyze these challenges further. Chapter 3. Literature Review: This chapter reviews the existing literature on coopetition, the evolution of business strategy, and the theoretical foundations of CN-VCCs. It identifies research gaps and integrates S-D Logic to reconceptualize value and dynamics in coopetition networks. Chapter 4. Methodology: This chapter describes the research paradigm and methodological approaches employed, with a particular emphasis on Design Science Research integrated with Service-Dominant Logic. It details the process from problem identification to

communication of findings within the chosen empirical field. Chapter 5. Requirements and Objectives for Coopetition Networks for Value Cocreation (CN-VCC): Elaborates on the performative and systemic constructs necessary for enhancing coopetition and value cocreation in service networks, including the strategic use of the Industrial Internet of Things (IIoT). Chapter 6. Architecting Coopetition: Designing Networks for Value Cocreation: This chapter discusses and designs the building blocks for effective coopetition networks, detailing the integration of various actors and resources and the transformative role of IIoT in enabling coopetition. Chapter 7. Proof-of-Concept (PoC): Coopetition Technology-Enabled Service Ecosystem (CN-EcoTech): This chapter presents a PoC focusing on its application within the Portuguese ornamental stone sector and evaluating its effectiveness through various stages and interactions. Chapter 8. Assessing the Impact of CN-EcoTech Practices on the OS-PT Sector: This chapter analyses the Impact of the CN-EcoTech Ecosystem on the operational efficiency, scalability, customer satisfaction, and ecological footprint of SMEs in the sector, providing comprehensive metrics. Chapter 9. Bridging Theory and Practice: Effective Dissemination Research Findings: This chapter concludes the thesis by discussing disseminating research findings in academic settings and industry contexts. It highlights the effectiveness and benefits of the CN-EcoTech Ecosystem and promotes further academic and practical applications. Chapter 10. Conclusions: This final chapter synthesizes the thesis findings, reflecting on the research journey and its contributions to coopetition networks. It evaluates the success and limitations of the proposed frameworks and offers directions for future research. This chapter aims to encapsulate the research's theoretical and practical implications, asserting its value to scholars and practitioners interested in the dynamics of coopetition and value cocreation.

Each chapter is designed to build upon the insights of the previous one, ensuring a cohesive and comprehensive understanding of the research topic. This structure supports a systematic exploration of the complex dynamics of coopetition among SMEs, providing both theoretical insights and practical implications.

Chapter 1. Summary

This chapter lays the groundwork for the thesis by examining the crucial challenges and dynamics of cooperation among SMEs. The discussion begins with an overview of the research problem, highlighting the economic and social significance of SMEs and their challenges in navigating the complexities of global and digital supply chains.

The research problem and objectives focus on developing and empirically testing a comprehensive framework for effective cooperation networks. These networks are designed to enhance SMEs' digital and operational capabilities, as well as their global competitiveness. The research's justification and significance are highlighted, showing its potential to spur economic growth, innovation, policy development, and SDG alignment.

The introduction of DSR and S-D Logic prepares for a thorough examination of how these frameworks address real-world challenges faced by SMEs, particularly in the Portuguese ornamental stone sector.

Chapter 2. Relevance and Challenges in the Portuguese Stone Sector

If the facts do not fit the theory, change the facts. - Albert Einstein

The Portuguese Ornamental Stone (OS-PT) sector [36], a cornerstone of Portugal's rich cultural heritage and forward-looking innovation, has been making significant contributions to iconic stone monuments worldwide since the 15th century [38]. Leveraging the unique Portuguese stone, engineering expertise, and generations of accumulated knowledge, the OS-PT sector is deeply ingrained in the nation's identity [39]. As the 21st century progresses, Portugal has solidified its position as a leading producer of stone products, skillfully integrated into the global AEC supply chain, a testament to its competitive edge on the international stage despite the country's modest geographic footprint [40].

Portugal's ornamental stone industry, characterized by its vast and diverse stone reserves, plays a significant role in the global market. The shift towards digital collaborative efforts with customers and architects worldwide underscores a dynamic evolution; the sector's traditional strengths are being repurposed through innovation [41]. This emerging digital engagement, although still in development, is identified as a critical growth avenue for Portuguese stone suppliers.

Recent data from ASSIMAGRA[3] (2023) highlights the sector's substantial economic impact, with exports to 116 countries, ranking as the ninth most significant player in the Global International Stone Trade, and securing the second position globally in terms of international trade per capita. With exports outstripping imports by 660% and a significant share of exports reaching markets outside Europe, the industry boasts a turnover of € 1.23 billion. It supports over 16,600 direct jobs, particularly in inland regions, making it a vital source of employment.

The sector's adaptability and resilience, widely acknowledged in scholarly circles, position the Portuguese OS Sector as a leading industrial force within Europe [36], [42], [43]. The adoption of *Leanstone* practices [44] suggests that companies are strategically positioned to address the shift toward digital procurement models, particularly for projects requiring the use of BIM within the AEC industry [45]. This transition towards a BIM-driven procurement poses multiple challenges and opportunities, necessitating the development of new operational models and sustainable technologies to remain competitive [46].

[3] https://www.assimagra.pt/pt/

2.1 BIM-Driven AEC Supply Chains

The adoption of BIM signifies a significant paradigm shift, transforming the traditional procurement models that have long prevailed in the AEC industry. In BIM, procurement becomes digital, global, and anticipatory, aligning closely with the design phase of projects [47]. Despite the demonstrated resilience of the OS-PT sector, it now stands at a juncture due to the widespread digital transformation sweeping through the AEC industry [48].

Traditionally, the procurement of stone products within the AEC supply chain has adhered to a conventional model, albeit tailored to the unique demands of stone products and market needs [49]. Key procurement activities, such as those for facades and custom paving, have typically relied on extensive market consultations and the use of Computer-Aided Design (CAD) parts lists to generate proposals from potential suppliers [50]. This model, applicable across various market segments, including kitchen worktops and furniture, requires upfront measurements and design inputs before supplier budgeting [51].

The adoption of BIM introduces a transformative shift from these traditional practices. In the BIM framework, building design phases incorporate components in Industrial Foundation Class (IFC) as determined by the ISO 19650-1:2018[4] The standard includes detailed specifications, such as price and maintenance requirements, directly within the virtual building structure via online IFC libraries [52]. This advancement demands that providers adapt their operations to align with BIM specifications, with project approval increasingly dependent on adherence to these detailed requirements [53].

While BIM-induced transparency promotes efficiency and accountability within the AEC industry [47], it poses new challenges for OS-PT providers. The necessity for public disclosure of previously confidential product details, such as prices and deadlines [54] [55], compels a reevaluation of how firms manage proprietary information. The push towards public availability on web platforms for BIM integration sidelines firms that need to adopt this level of openness from the early design phases, jeopardizing their market position [56].

2.2 Challenges for the Portuguese Stone SMEs

The integration of BIM into supply chains poses significant challenges for the Portuguese stone sector, particularly affecting small and SMEs. A detailed survey by Silva and Marques Cardoso (2023a), titled "BIM-Oriented Supply Chains—New Challenges for Stone Companies," sheds light on how digital transformation influences these businesses. The survey highlights critical areas, including market demands, operational efficiency, and investment capabilities, providing a comprehensive picture of the sector's current landscape [57].

This study involved interviews with 670 OS-PT SMEs, representing 67.4% of the sector's population, making the findings highly representative of the sector's population. The

[4] ISO 19650-1:2018: Organization and digitization of information about buildings and civil engineering works, including BIM.

representativeness of the sample is further validated by the companies' turnover, which accounts for 89.3% of the sector, exports at 95.9%, and employment at 88.5% of the total workforce.

Market Demands (65.5% Convergence): A significant portion of the companies expressed concerns related to adapting to evolving market demands. This convergence suggests that most OS-PT SMEs are focused on enhancing their capabilities to respond to real-time market requirements and consumer expectations, which are increasingly influenced by rapid technological advancements and shifting consumer preferences.

Manufacturing Efficiency (66.8% Convergence): Efficiency in manufacturing processes is another primary concern, with nearly two-thirds of the companies surveyed highlighting it as a priority. This includes streamlining operations to minimize waste, optimizing resource utilization, and enhancing production timelines. The emphasis on efficiency is crucial as it directly impacts companies' competitiveness, allowing them to deliver products faster and at lower costs while maintaining high quality.

Investment Capacity (65.6% Convergence): The survey also showed a strong alignment among companies concerning the need for investment to scale operations, enhance efficiency, and meet customer demands within BIM-influenced supply chains. This indicates a growing awareness among SMEs that substantial capital investment is required to upgrade technology, train staff, and reconfigure production lines to facilitate BIM integration. The focus on investment capacity indicates that companies are preparing to make significant financial commitments to leverage the benefits of BIM, ensuring they can adequately meet the new standards and expectations of the AEC sector.

This highlights the pressure on SMEs in the OS-PT sector to adapt and innovate in response to digital transformation challenges. By aligning their strategies in these key areas, they aim to secure a competitive edge in the industry, enhance their operational processes, and effectively meet the evolving needs of their clients and the broader market.

In summary, Silva and Marques Cardoso's (2023a) findings elucidate the multifaceted challenges posed by BIM-driven digital transformation to the Portuguese stone sector. This research offers a crucial roadmap that guides the sector toward better integration, improved efficiency, and heightened competitiveness within the global AEC supply chains.

2.3 Strategic Collaboration in the Portuguese Stone Sector

The survey highlights that adopting BIM in the AEC sector introduces significant challenges for the OS-PT sector, particularly in financing the necessary investments to adapt to BIM-oriented supply chains. For traditional sectors like this, traditional debt financing often remains the primary avenue for securing investment.

On the other hand, while the European Commission (2020) recognizes the potential of collaboration to unlock the full capabilities of European SMEs, viewing it as a way to capitalize on opportunities and counterbalance the investment challenges of digital transformation [2], [3], there is evidence to suggest that enduring collaboration, especially among competitors, remains infrequent [28]. This highlights a significant gap between the theoretical benefits of collaborative strategies and their practical implementation within the business community. Additionally, unlike other traditional sectors [58], OS-PT SMEs need to show more support towards collaborative endeavors. This highlights a significant impediment to fostering sustainable cooperation among OS-PT competitors, particularly in a high-stakes environment characterized by rapid technological advancements.

Amid the complex context facing OS-PT SMEs, Silva and Cardoso (2023b) provide valuable empirical evidence through their work, "Technology Paths towards Coopetition Ecosystems - The Portuguese Stone Sector." This survey assesses the impact of technology-enabled coopetition environments within the OS-PT sector, contributing significant insights to the ongoing discourse [59]. Figure 1 illustrates the correlation between digital maturity level (DML) and the willingness of companies in the Portuguese Stone sector to engage in digitally supported collaboration. It highlights how the DML influences the coopetition propensity of these SMEs.

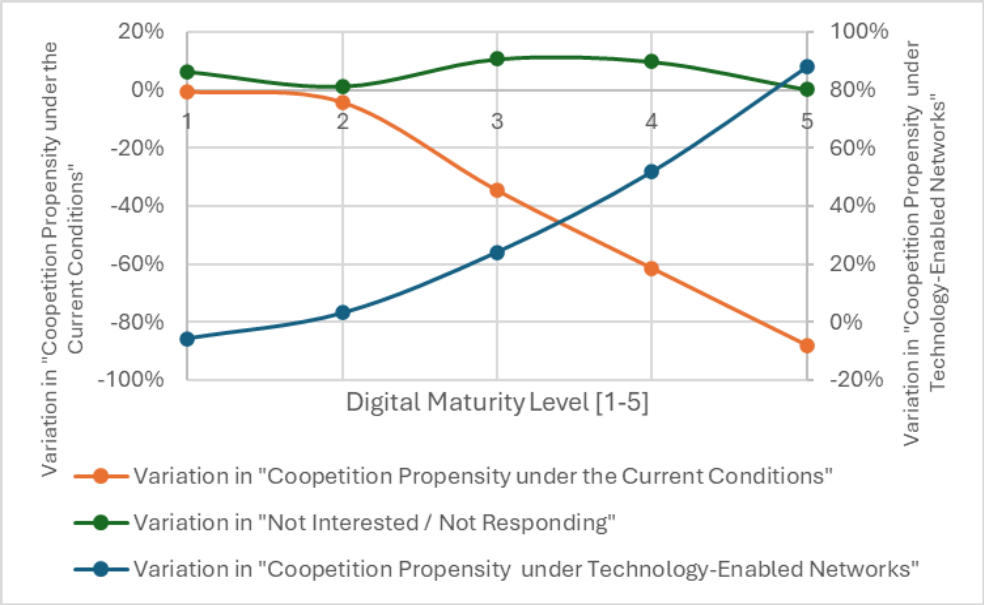


Figure 1. Variation in Coopetition Propensity Relative to the Digital Maturity of OS-PT SMEs.

The survey, covering a representative sample of OS-PT sector's population, reveals that under the current state-of-the-art environment, only 2.2% of today's high "Digital Maturity" OS-PT companies are willing to collaborate with rivals. In contrast, introducing a technology-enabled "secrecy" environment shifts this landscape, with 90.1% of these companies indicating a willingness to collaborate with competitors.

This improvement in collaboration propensity underscores the critical role of digital maturity and the enabling power of secure technological platforms. These platforms safeguard sensitive information and provide a foundation for trust and cooperation among erstwhile competitors, thereby enhancing the sector's collective ability to capitalize on the opportunities presented by BIM and digital transformation.

2.4 The Way Forward

According to Silva and Cardoso (2023), navigating the future of the OS-PT sector in the face of BIM-driven supply chains presents a unique blend of challenges and opportunities. The sector appears poised to adopt 'coopetition' practices—collaborative competition among businesses—that are facilitated by technological advancements. This readiness is crucial for enhancing operational efficiency, achieving scalability, elevating customer satisfaction, and reducing environmental impact, all without resorting to levels of debt that could be considered. By uniting through a technological coopetition network that safeguards proprietary information, firms can collaborate on common goals such as innovation in production processes, development of new sustainable materials, and digital marketing strategies—all while ensuring that individual competitive advantages are preserved. This approach may be the key to addressing the challenges BIM-oriented supply chains pose.

Furthermore, this future coopetition-driven network can streamline operations, leading to more efficient project management and a swifter response to market demands. Such efficiency not only benefits the individual companies but also enhances the sector's ability to compete on a global scale. By adopting these coopetition practices, companies can significantly boost customer satisfaction, as they are better equipped to meet the high standards of quality and service expected in the digital procurement ecosystem.

The path ahead for the OS-PT sector appears to be one of strategic adaptation—embracing digital maturity, fostering a culture of secure collaboration, and leveraging collective strengths to meet the multifaceted demands of the contemporary AEC industry. By doing so, the sector can transform the challenges of digital transformation into opportunities for growth and innovation, thereby securing its reputation as a forward-thinking and resilient contributor to the global market.

Chapter 2. Summary

Chapter 2 provides an in-depth analysis of the OS-PT sector, highlighting its economic significance and global impact. It highlights the sector's historical resilience and adaptability while also addressing the challenges posed by adopting Building Information Modelling (BIM) in the evolving Architecture, Engineering, and Construction (AEC) industry. The chapter highlights the sector's crucial role in the national economy and the potential threat that BIM poses to its long-term viability if not adequately addressed.

Chapter 3. Literature Review

The truth is more important than the facts. - Frank Lloyd Wright

Building on the discussion from the previous chapter, this literature review explores the concept of coopetition, aiming to develop a knowledge-based framework to support SMEs in establishing and managing coopetition networks. This review employs a fractal approach, systematically integrating various strategic steps to navigate the complexities of these networks. The essence of this methodology is illustrated in Figure 2, which presents a graphical abstract of a fractal approach to Coopetition Networks in Value Cocreation.

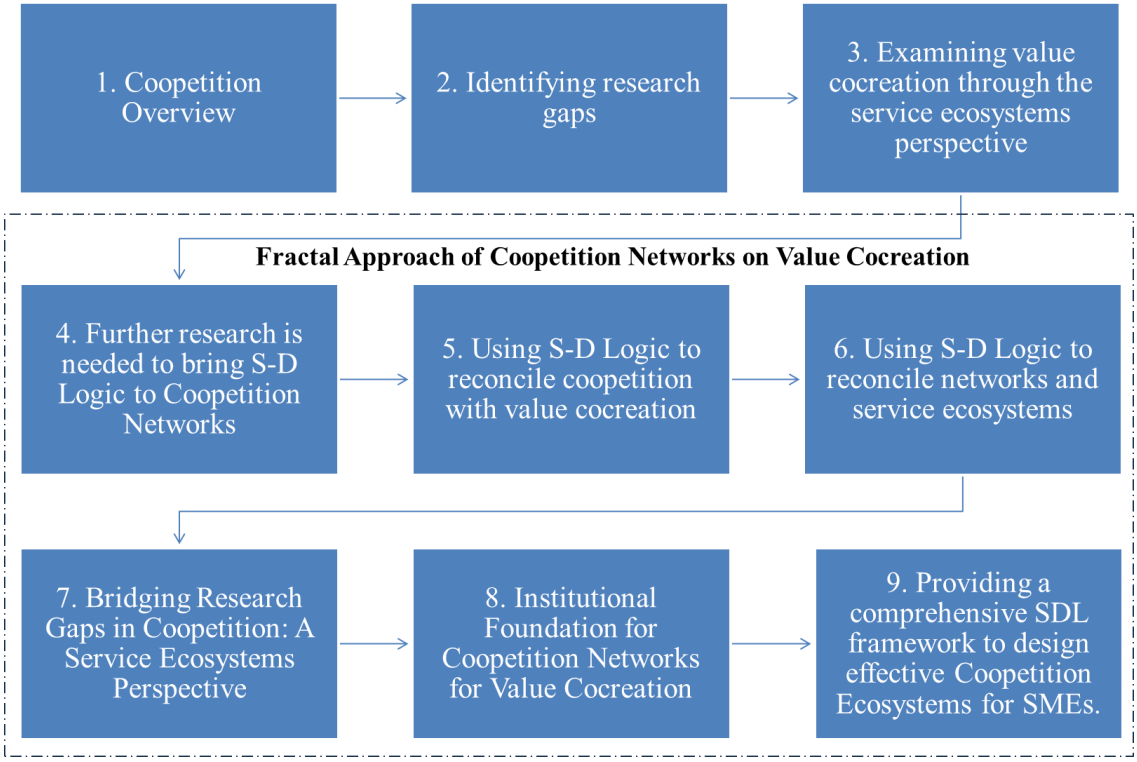


Figure 2. Chapter 3 Graphical Abstract: Fractal Approach to Coopetition Networks in Value Cocreation.

This approach is designed to unearth new insights and management practices crucial for maximizing synergies and effectively navigating the inherent tensions within coopetition [25]. By weaving together theoretical perspectives and practical applications, this review seeks to deepen the understanding of coopetition and demonstrate its transformative potential within the broader framework of service ecosystems [60]. Special attention is given to SMEs, emphasizing how S-D Logic can be leveraged to craft effective coopetition strategies, thereby enhancing our understanding of its role in shaping dynamic business networks.

3.1 Coopetition Overview

The concept of "coopetition," a blend of cooperation and competition, was initially introduced into the strategic management lexicon by Ray Noorda, the founder and CEO of Novell, during the 1980s [61]. It gained prominence in business strategy through the influential work of Nalebuff and Brandenburger (1997), which marked a significant shift in understanding competitive dynamics [62]. This approach highlighted that competition and cooperation are both coexistent and synergistic forces that drive innovation and success for entities ranging from individuals to firms [63], [64]. Over the years, coopetition has garnered substantial attention within strategic management, evolving through various interpretations and applications [65].

Despite its widespread discussion, the definition of coopetition remains varied, with interpretations spanning different goals, relationships, and organizational contexts [66], [67]. It has been described as a strategy that encompasses the simultaneous pursuit of cooperation and competition among firms [68], a hybrid activity within the same business entities, and a complex interplay that affects competitive dynamics among different market players [69]–[71].

The academic discourse on coopetition also identifies various typologies of coopetition relationships. For instance, Bengtsson and Kock (2003) introduce "reciprocal coopetition" as a relationship in which two firms engage in both competition and cooperation on an equal footing [72]. Other scholars view coopetition as inter-firm relationships born from a partial alignment of interests, manifesting in simultaneous cooperative and competitive interactions across different business operations [73], [74].

Despite the diversity in definitions, the essence of coopetition converges on the notion of a hybrid relationship where competition and collaboration intertwine to benefit the intervenient companies [75], [76]. However, Bengtsson (2016) critiques the field for its fragmentation and the lack of theoretical cohesion in how to address coopetition in networks, a sentiment echoed by other scholars who highlight the tendency of the existing literature to treat competition and cooperation theories in isolation [65], [19], [77].

At the nexus of coopetition and networks, a strategic orientation centered around innovation emerges, essential for firms seeking to bridge competitive gaps and effectively manage market challenges [78]. This orientation emphasizes the role of coopetition in navigating competitive terrains and highlights its potential as a catalyst for transformative growth and resilience [19].

Despite broad agreement on the strategic importance of coopetition for fostering innovation and competitive advantage, the academic discourse presents a fragmented view of the value creation mechanisms within coopetition networks [79]. Studies show a wide range of findings, underscoring the need for a more unified and in-depth exploration of value cocreation processes in these complex networks [19], [80].

A comprehensive review by Meena, Dhir, and Sushil (2023) reveals that coopetition has been examined through various theoretical lenses, including Game Theory, Resource-Based View,

Paradox Theory, Transaction Cost Theory, and Network Theory. Each perspective, while insightful, often addresses the concept within its specific confines [81].

When analyzed through the lens of Game Theory, coopetition networks are examined to determine the optimal strategies for companies to manage competition and cooperation simultaneously (Klimas et al., 2023). This approach provides a mathematical foundation for understanding strategic decision-making under conditions of mutual dependence. However, the application of Game Theory to coopetition faces challenges in real-world scenarios due to assumptions about information symmetry and rational behavior [31]. These issues necessitate adaptations to the theoretical models to accommodate information asymmetries and non-rational behaviors, making them more applicable to practical coopetition dynamics [82].

The Resource-Based View posits that coopetition enables firms to expand and enrich their resource pools, amplifying their potential for innovation and strengthening their competitive stance [70]. Even with this view emphasizing resource acquisition and development, it still needs to fully address the value cocreation that can emerge from competitive arrangements. Additionally, the Resource-Based framework emphasizes the importance of resource management to ensure that sharing critical assets does not inadvertently compromise a firm's unique competitive advantage [80].

Paradox Theory acknowledges the contradictions in coopetition, perceiving the concurrent forces of cooperation and competition as avenues for strategic innovation and organizational learning [29]. While this Theory considers the dualistic nature of coopetition, it extensively explores the process of value cocreation that often unfolds within these complex relationships, where competing entities actively collaborate to generate mutual benefits and shared value (Bengtsson et al., 2016).

Transaction Cost centers on reducing the expenses incurred from economic transactions in coopetition networks, highlighting the importance of controlling opportunism and protecting strategic interests [83]. This perspective primarily addresses the cost-efficiency of exchanges. It needs to sufficiently consider the collaborative processes of value cocreation that can arise through coopetition, where combined efforts lead to new forms of value that benefit all parties involved [84].

Network Theory underscores the significance of a firm's strategic placement within business networks, suggesting that optimal positioning can significantly enhance access to resources and collaborative opportunities [85]. While this Theory elaborates on the advantages of network positioning, it less frequently addresses the collaborative mechanisms of value cocreation that can emerge through coopetition [86]. Specifically, it needs to fully explore how strategically positioned firms can actively create shared value, which is central to the dynamics of coopetition relationships [87].

Other less commonly utilized theories also provide insights into coopetition. Resource Dependence Theory explores the power dynamics between rival firms, highlighting how

managers exploit dependencies to maximize profits [88]. Institutional Theory predicts firm behavior within competitive contexts, influenced by the quality of institutional frameworks which dictate strategic choices [70]. This Theory also suggests that strengthening institutional cores can enhance a rival firm's performance. Additionally, it examines exploitative and exploratory innovations to achieve strategic goals contingent on effective knowledge sharing between competitors [89].

All these theoretical frameworks provide valuable insights into the strategic dynamics of coopetition networks [90]. However, they also need to highlight significant gaps in understanding their practical implementation and long-term sustainability [22]. The varied approaches emphasize the need for an integrated perspective, considering the complex interdependencies and strategic nuances of coopetition [91].

Building on the diverse theoretical insights previously discussed and informed by recent findings from Meena et al. (2023), Corbo et al. (2023), and Manzhynski & Biedenbach (2023), the following section explores the research gaps within coopetition networks. This examination aims to identify new research directions to deepen the understanding of how coopetition strategies can be effectively implemented and sustained within the dynamically evolving business landscape.

3.2 Identifying Research Gaps in Coopetition Networks

While coopetition networks among SMEs often tend to dissolve prematurely before achieving their intended lifespan [28], the integration of insights from Game Theory, Resource-Based View, Paradox Theory, Transaction Cost Theory, Network Theory, and others have marked significant advances [81]. However, critical gaps in literature persist, particularly concerning the mechanisms of value cocreation, the role of technology, and actor coordination within coopetition networks.

3.2.1 Value Cocreation in Coopetition Networks (RG1)

Exploring value creation within coopetition networks reveals a significant oversight: the prevailing theories must adequately capture the dynamic and emergent nature of value generation [78]. Although Game Theory provides a strategic framework for analyzing interactions, it tends to oversimplify the complex processes involved, neglecting the depths of collaborative innovation inherent in coopetition. Similarly, the Resource-Based View emphasizes internal resources as competitive advantages but often needs to recognize how inter-firm collaboration can enhance value creation. Transaction Cost Economics primarily focuses on the efficiency of exchanges and frequently overlooks the potential for emergent value creation. While Paradox Theory addresses the dual nature of cooperation and competition, it does not examine how this duality translates into innovative practices. Network Theory

underscores the strategic significance of network positions yet frequently omits a detailed explanation of how these dynamics directly contribute to value cocreation.

3.2.2 The Role of Technology in Coopetition Networks (RG2)

The role of technology in reshaping the dynamics of coopetition networks is acknowledged but still needs to be explored in academic literature [19], [90]. Traditional frameworks, such as Game Theory and Transaction Cost Economics, often fail to emphasize the transformative potential of technology, frequently treating it as a static factor rather than a dynamic agent of change. The Resource-Based View, while focusing on internal capabilities, typically overlooks how technology shared among firms in coopetition can spawn unique capabilities or innovative value propositions. Similarly, Paradox Theory, which provides insights into managing dualities, often needs to pay more attention to how technology can both facilitate and complicate interactions within coopetition networks. This oversight across theories highlights a critical gap in understanding the integral role of technology in enabling and shaping the cocreation of value.

3.2.3 Coordination Mechanisms in Coopetition Networks (RG3)

Existing theoretical frameworks still need to address effective coordination in coopetition networks, mainly orchestrating actors with competing interests [21]. Current theories focus on strategic interactions and resource exchanges but often overlook the nuanced coordination mechanisms essential for successful coopetition. These mechanisms are vital for managing potential conflicts and building trust, which is crucial for sustaining cooperative and competitive relationships over time.

Recognizing these deficiencies requires a more in-depth investigation into the structures and processes that underpin successful coopetition networks. The forthcoming section explores potential strategies to bridge these gaps, aiming to develop more comprehensive theoretical models that can be applied to address these challenges. These models seek to incorporate the complexities of technology, enhance the understanding of dynamic value creation, and refine the organic coordination mechanisms within coopetition networks. By addressing these critical areas, this research aims to provide actionable insights for firms seeking to fully leverage coopetition strategies in an increasingly interconnected and digitalized business landscape.

3.3 Bridging Coopetition Gaps: Paving the Way for S-D Logic in Coopetition Networks

Recent literature emphasizes the critical role of institutional enhancement in improving firm performance within coopetition networks [70], [81]. It suggests that firms engage in exploitative and exploratory innovations to achieve strategic objectives, highlighting the need for a seamless knowledge flow between competing partners to unlock innovative capabilities [92]. Additionally, theories such as Stakeholder Theory, Social Network Theory, and Social Capital Theory have

been applied to understand the nuances of coopetition, revealing the importance of relational dynamics and network positions in leveraging social capital for competitive advantage [93], [94].

While existing theoretical frameworks provide valuable insights into coopetition networks, their complexity and dynamism suggest that these frameworks may not fully capture the evolving nature of coopetition strategies or adequately address the mechanisms of value creation, technology integration, coordination, and long-term sustainability [95]. This limitation underscores the need for an innovative perspective that can comprehensively encompass the diverse aspects of coopetition networks.

With its emphasis on service ecosystems, S-D Logic offers a promising avenue for reinterpreting and enriching the understanding of cooperation networks. Examining cooperation through the S-D Logic perspective addresses the previously identified gaps and lays the groundwork for a dynamic, value-centric approach to analyzing cooperation [96].

The S-D Logic framework, notably articulated by Vargo and Lusch (2017), highlights the importance of value cocreation, actor-to-actor networks, and the crucial roles of institutions and technology [97]. This approach provides a foundation for exploring the dynamics of coopetition [98]. By adopting this perspective, the analysis will delve into how coopetition networks function as service ecosystems, where seamless knowledge integration, strategic technology use, and effective coordination among diverse actors are essential for fostering innovation, growth, and sustainability.

3.4 A Service Ecosystem for Value Cocreation

Throughout the evolution of marketing and strategic thought, the conceptualization of "service" has undergone a profound transformation. Beginning with Frederick Bastiat's seminal assertion in 1848 that "services are exchanged for services," the discourse surrounding service has progressively challenged and reshaped traditional marketing paradigms [99]. A crucial turning point in this discourse occurred in 2004, when Vargo and Lusch introduced S-D Logic, which shifted the marketing focus from a goods-centred to a service-centred perspective [100]. This shift fundamentally altered conventional understandings of how products and services are perceived and valued in the marketplace [101].

S-D Logic advocates for a paradigmatic shift away from an operand-resource focus, which traditionally emphasizes tangible goods as the primary carriers of value, to an operant-resource orientation [102]. This new focus highlights intangible processes, knowledge, and skills as the core drivers of value cocreation [103]. This reconceptualization challenges the traditional goods-dominant logic, which positions the producer as the sole value creator and the consumer as a passive recipient [104].

Under S-D Logic, goods are reimagined not as production endpoints but as facilitators or appliances that deliver service and assist in benefit provision [105]. This perspective not only

elevates service to the primary basis of economic exchange but also underscores the role of specialized competencies in creating value [106]. This approach aligns with and expands upon resource-based theories by suggesting that the actual value of resources stems from their utility in service provision rather than from their inherent properties [107] [17].

Drawing on Scott (2001), the S-D Logic framework defines institutions as rules, norms, and beliefs developed by humans that both facilitate and constrain actions [108], thereby imparting predictability and meaning to social interactions [104]. These institutions manifest in various forms, from strictly enforced laws to the more subtle influences of informal social norms and the power of symbolic meanings [109]. They are crucial in guiding the resource integration and service exchange processes, essential components of value cocreation among actors [110]. By regulating actor behavior and establishing shared expectations, institutions reduce uncertainty and enhance the propensity for collaboration, serving as critical scaffolding for interactions within these ecosystems [111], [112].

Scott (2014) elaborated on institutions as entities comprising regulative, normative, and cognitive-cultural pillars that collectively infuse stability and meaning into social interactions [112]. The regulative components are characterized by formal rules, laws, and punitive measures that govern and restrain behaviors, ensuring order within social systems [113]. On the other hand, normative elements are shaped by societal norms and values that instruct and guide individual and collective actions, suggesting what is appropriate within a given context [60]. These values represent the ideals and benchmarks against which actions and societal structures are evaluated, while norms provide specific guidelines for executing these actions [111]. Such elements steer the aims of individuals and groups, dictating the pathways to their realization through social obligations and a deep-seated adherence to shared norms and values [112]. Cognitive components, meanwhile, relate to the mental models and perceptions that actors hold about their reality, encompassing the beliefs and understanding frameworks that facilitate a shared logic and sense of purpose among participants [114]. These elements underscore the multifaceted nature of institutions, highlighting their role in orchestrating the social fabric and guiding its interactions [115].

Edvardsson et al. (2014) illuminate how regulative elements sway actor behavior through the dual forces of self-interest and the deterrence of adverse outcomes [111]. Normative elements exert influence by imposing social constraints or bestowing benefits, thereby guiding actors toward socially endorsed behaviors. On the other hand, cognitive elements foster behaviors that actors accept as naturally given, engrained in their perception of how things should be [116]. The synergy of these regulative, normative, and cognitive facets forms a complex network that dictates and shapes the behavior of actors within ecosystems [112]. Institutions in such ecosystems cannot be conceptualized as standalone entities but as a cohesive network of rules, norms, and shared meanings that intertwine [104]. This ecosystem requires overlapping and interdependent institutions that reciprocally influence each other, collectively steering actor behavior towards fostering a conducive environment for value cocreation and underpinning the

collaborative actions of the ecosystem's actors [98]. This dynamic interplay highlights a bidirectional influence where institutions shape actor behaviors and, conversely, actors contribute to the evolution of these institutions through their actions [117], emphasizing the fluid and cocreative nature of institutional impact within collaborative ecosystems [114].

Institutional frameworks uniquely delineate the prevailing logic within distinct socio-cultural milieus, notably within contexts such as networks [118]. The influence of these institutional logics on ecosystem actors is profound, as they delineate and reinforce a collective framework of rules, norms, and beliefs [107]. This governance shapes actor behaviors, guiding their decisions, interactions, and perceptions, thus cultivating a communal sense of direction and cohesion [119]. Although institutional logic is indispensable for orchestrating harmony within partner collaboration ecosystems, it paradoxically may precipitate imbalances [98]. Cross-organizational collaborations are particularly prone to reconciling disparate or conflicting institutional logic, which can impede cooperative endeavors [22]. The intersection of differing logics creates a terrain rife with conflict and tension as actors grapple with competing interests and objectives [120], leading to strained relations and a potential derailment of collaborative efforts [28], which underscores the complexity of managing institutional diversity within coopetition frameworks.

Building on the foundational concepts of service ecosystems as detailed in S-D Logic, this section explores the application of a fractal approach to coopetition networks. This approach explores how the recursive replication of coopetition dynamics across different scales within these networks can further enhance value cocreation. Examining coopetition through a fractal lens uncovers new insights into the structural and operational dynamics that enable these networks to adapt and thrive in the complex landscape of modern business ecosystems.

3.5 Fractal Approach to Value Cocreation

The concept of fractal analysis, pioneered by Mandelbrot in the mid-20th century, represents a transformative approach to understanding complex systems [121]. Conceptualized initially to describe natural phenomena [122], such as the seemingly endless variability of the British coastline, fractal analysis provides a lens for observing the recursive [123], self-similar patterns of objects that reveal underlying structures across different scales [124]. This methodological approach challenges conventional linear analyses by embracing the nonlinearity and inherent unpredictability found within complex systems [125].

Fractal analysis has expanded beyond its mathematical and physical origins to find applications in various fields, including biology [126], medicine, computer science, management, and economics [127]. Within the business domain, fractal concepts gain insights into strategic alliances, collaborative networks, and service ecosystem dynamics. This approach provides a nuanced perspective on how entities within these systems interact, share value, and cocreate, thereby enhancing the understanding of complex interdependencies [123].

Mandelbrot's foundational work introduced fractal geometry as a framework for analyzing and interpreting patterns in the natural world, as well as in economic and business ecosystems [128]. This framework highlights the importance of considering micro and macro perspectives, showing how individual components or actions reflect broader systemic behaviours and interactions [129].

Despite some critiques—such as debates over the precision of fractal models in ecological studies—fractal analysis remains a valuable tool for exploring and predicting patterns at multiple scales. It has proven particularly effective in designing frameworks across various industries, enabling a deeper understanding of the dynamics of complex systems, from market movements to organizational structures.

The application of fractal methodology in social systems underscores its potential to capture the essence of complex entities [130] comprehensively. Researchers like Kuhn and Woog have explored fractal properties within social structures, demonstrating how fractal analysis can articulate the coherence of values, experiences, and systemic interactions [129]. This perspective supports the idea that while each part may mirror the whole, the entirety encompasses more than the sum of its parts [131].

Fractal analysis thus offers a methodological shift in studying complex systems, providing a versatile framework that transcends disciplinary boundaries [132]. Its integration into the study of business and economics enriches the understanding of networks and ecosystems. It guides strategic thinking and decision-making in an increasingly interconnected and multifaceted global landscape [127].

Building on the foundation of fractal analysis, the following sections explore how this approach can be applied specifically to understand the complexities of coopetition networks. By adopting a fractal perspective, the recursive and scalable nature of interactions within coopetition networks is explored to foster more effective and sustainable value cocreation strategies.

3.5.1 Institutional Perspective on Coopetition and Value Cocreation

3.5.1.1. Coopetition

Coopetition has been broadly acknowledged within business literature as a strategic approach to enhancing firm competitiveness and fostering the formation of dynamic networks [133] [134]. Although it has attracted considerable attention in recent years [135], critics argue that research on coopetition remains fragmented, especially in coordinating networks and sustaining their viability over time [136].

Traditionally, the coopetition narrative has been dominated by a firm-centric view, focusing on maximizing outputs and strategic actions to achieve market dominance [137] [81]. This perspective is primarily concerned with how firms individually leverage coopetition for

competitive advantage, often overlooking the broader implications of these interactions within their networks [29].

Among the multiple views, the resource-based view presents coopetition as a means to independently access new resources and capabilities that would be unattainable, aligning with strategic business model innovations [25]. This view emphasizes the mutual benefits of coopetition, including market expansion [138], external knowledge acquisition [139], cost and risk sharing [75], business scaling (Park et al., 2014), and asset complementarity [89].

Recent discussions highlight the role of coopetition in innovation ecosystems, which encompasses multiple ongoing processes, including logistics, learning, and knowledge transfer [140]. These ecosystems promote a coopetition mindset that encourages resource sharing among actors, enhancing the collective capability to drive profitable innovations [141] [65].

This evolving understanding of coopetition aligns closely with the principles of S-D Logic, which posits that dynamic reconfiguration processes within institutional spaces drive and are driven by innovation [110]. Moreover, the S-D Logic's foundations are consistent with resource-based Theory [142], the competencies core theory [143], corporation core competencies theory [144] in the way that dynamic competencies [145] grow and help deliver value propositions for mutual benefit, all the above inputs were adopted by the S-D Logic foundational premises (FPs) [146].

Under this S-D Logic view, coopetition impacts value creation and facilitates the emergence, stabilization, and transformation of institutional processes [147]. Moreover, S-D Logic emphasizes the ongoing, interactive nature of these processes, aligning with Lindström et al. (2016) view that coopetition fosters a collaborative forum for entrepreneurs to exchange ideas and address challenges collectively [136]. This convergence of coopetition with S-D Logic marks a significant shift in business strategy literature, transitioning from a firm-centric to a network-oriented paradigm, with a focus on value cocreation and collective innovation.

3.5.1.2 Value Cocreation

Value cocreation represents a significant paradigm shift in understanding economic transactions and value generation, as reflected in both historical economic theories and contemporary business practices. While early economists, such as Adam Smith and David Ricardo, explored value primarily through the Labor Theory of Value [148], modern interpretations, including those proposed by S-D Logic, extend these concepts to encompass a more complex and multifaceted view [149]. This modern perspective highlights terms such as value-in-exchange, value proposition, value cocreation, and value-in-use, each reflecting the dynamic and relational nature of value in today's economy [150].

Adam Smith's dual conception of value, which focuses on both its utility (value-in-use) and its capacity to be exchanged for other goods (value-in-exchange), lays the foundation for understanding value as a dynamic and relational concept [151]. This duality becomes particularly relevant in a service-dominated global economy, where the inseparability of production and consumption highlights the significance of value-in-use, shifting the focus of

value creation from exchange-centric to use-centric [152]. This shift emphasizes the importance of integrating resources and service processes over the production of output units.

Normann and Ramirez expanded on this notion of value creation by advocating for co-production with various stakeholders as the core of value generation [153]. This evolution of thought paved the way for value cocreation, a cornerstone of S-D Logic introduced by Vargo and Lusch [100]. Under S-D Logic, customers are envisioned not as passive recipients but as active participants in relational exchanges and co-production. It marks a departure from traditional views of value propositions as firm-centric offerings to customer-centric, benefit-driven interactions [102].

As articulated by researchers like McColl-Kennedy (2020), value cocreation in service ecosystems occurs through the integration of resources, activities, and interactions within the customer service network. This highlights the interconnectedness and active participation of all network actors in the value cocreation process [154]. This reconceptualization aligns with the broader service literature's emphasis on many-to-many interactions within service ecosystems, where the exchange of services, rather than goods, forms the basis of economic activity [151].

In service ecosystems, value is not merely delivered; it is cocreated. However, it is offered through value propositions that cater to the needs of multiple actors [115], fostering connections and relationships crucial for cocreating value. S-D Logic emphasizes that "service" is the fundamental basis of exchange and that value is cocreated by multiple actors, including the beneficiary [110]. This perspective positions all social and economic actors as resource integrators whose application of resources is aimed at benefiting others, thereby emphasizing the phenomenological determination of value by the beneficiary [97].

This more profound exploration of value cocreation serves as a theoretical construct and a practical framework, enhancing the understanding of how value is generated and shared in the modern economy. It provides invaluable insights into developing collaborative, dynamic, and sustainable value-creation models. These models are crucial for navigating the complexities of networks effectively, enabling organizations to better manage the interplay between cooperation and competition in a way that fosters growth and sustainability.

Building on these foundational principles of value cocreation within the S-D Logic framework, the subsequent section will explore the concept of Value Networks. This exploration will delve into how these networks operationalize the principles of S-D Logic to facilitate the interconnected and cocreative activities essential for generating and sustaining value in service ecosystems, highlighting the structural and relational dynamics that enable these processes.

3.5.2 Institutional Reconciliation of Coopetition and Value Cocreation

The theoretical advancements in S-D Logic, encompassing meta-theoretical and mid-range frameworks [97], facilitate its integration with other theoretical approaches. Coopetition

networks can be effectively analyzed and structured through an institutional lens, which aligns with S-D Logic's emphasis on service ecosystems [110].

From an S-D Logic perspective, Akaka, Vargo, and Schau (2015) suggest that all social and economic actors integrate resources in culturally rich experiential contexts, underscoring the phenomenological aspects of value exchange among diverse stakeholders [155]. For S-D Logic proponents, value cocreation is fundamentally about resource integration to benefit others, necessitating coordinated efforts [105]. Institutions underscore this coordination—humanly devised rules, norms, and beliefs that actors generate to facilitate resource integration within service ecosystems [156].

Institutions are understood as the regulative, normative, and cultural-cognitive structures that provide stability and meaning to social interactions [157]. These can be formal, such as laws and contracts, or informal, based on relational norms and shared expectations [158]. Institutions and institutional arrangements, as assemblages of interdependent institutions, both enable and constrain actions within value cocreation processes, serving as integrable resources continually assembled to frame social contexts ([110].

Mainstream literature on coopetition often discusses the simultaneous but paradoxical nature of collaboration and competition [78]. While some studies depict these as parallel lanes—one for cooperation and another for competition [135]—others view them as intertwined, where firms engage in syncretic rent-seeking behaviors that blend competitive and collaborative efforts [159]. This paradoxical duality leads to 'coopetition intensity', a dynamic that intensifies the need for institutions that can guide collaborative norms and manage tensions [142] (Eriksson, 2008).

Integrating institutional frameworks with coopetition strategies aligns with the S-D Logic perspective, which emphasizes the performative nature of ecosystems where actors' experiences shape and are shaped by institutional norms [155]. These interactions contribute to the survival and evolution of coopetition networks, where institutions play a crucial role in enabling and constraining value cocreation activities [160]. Furthermore, institutional arrangements are seen as higher-order assemblages that embody institutional logics, symbols, and organizing principles necessary for performative actions within ecosystems [109] articulate that S-D Logic’s development was driven by a need to simplify and resolve tensions inherent in such paradoxical settings, advocating for institutionalizing coopetition networks as a means to manage these challenges [97].

In coopetition, firms enhance their competitive advantage and innovation capacity by acquiring and integrating third-party resources and capabilities [161]. S-D Logic positions all social and economic actors as resource integrators, where institutions—defined as rules, norms, and meanings—play a crucial role in coordinating interactions for value cocreation within ecosystems [97]. Anchored in S-D Logic foundations, service ecosystems are complex adaptive systems where institutions facilitate and regulate value-creation actions [162]. These ecosystems

are dynamic, with patterns emerging from the interactions of actors, showcasing the unpredictable nature of resource integration and service provision [163]. Coopetition networks serve as critical conduits for resource integration, fostering the creation of new, exchangeable resources through service exchanges. The effectiveness of value cocreation within these networks hinges on well-coordinated ecosystem governance. This interplay between systemic structures and institutional frameworks is detailed in Appendix I, Table 3.1, which illustrates the convergence of systemic and institutional perspectives on coopetition and value cocreation.

The creative destruction of existing solutions influences the viability of coopetition networks over time, a phenomenon termed 'institutional disruption,' which is essential for ongoing institutional change and alignment [164]. Norms and shared expectations play crucial roles in structuring economically efficient relationships among firms [165], highlighting the importance of institutional stability influenced by path dependence and lock-in effects [166]. Ultimately, by framing coopetition within S-D Logic, it focuses on value creation through service ecosystems, acknowledging the central role of institutions in coordinating networks and ensuring their sustainability over time.

3.5.3 An institutional Perspective on Networks, Technology and Service Ecosystems

3.5.3.1 Networks

The term "network," derived from "net + work," serves both as a verb and a noun[5]. As a verb, it relates to interactions aimed at exchanging information and developing professional or social contacts. As a noun, its meaning shifts depending on the context: a social network refers to a group exchanging information and resources, while a computer network denotes a system where computers and devices share data and resources.

Though not new, the network concept has gained significant prominence across various academic disciplines in recent decades [167]. For example, in fields like biology, mathematics, and engineering, the term illustrates the interconnected nature of systems [168].

In business contexts, networks are often discussed in terms of strategic alliances and collaborative frameworks [169]. These networks, which may include firms, customers, and public and private organizations, are primarily seen as avenues for collaboration within the same value chain, whether involving direct rivals or not [170]. Normann and Ramirez (1993) highlight a strategic imperative for firms' networks to reconfigure roles and relationships to spur value creation through new combinations of actors [153]. Different types of business networks include industrial ecosystems, digital business ecosystems, innovation ecosystems, and service ecosystems, each representing unique perspectives and challenges, such as attracting capital, partners, and customers [171].

[5] Oxford Dictionary

Despite earlier criticisms regarding the lack of systematic guidance for managers navigating strategic changes [61], contemporary business literature has made significant advancements in articulating foundational network assumptions. These assumptions are now clearly outlined and detailed in Appendix I, Table 3.2, which provides a comprehensive overview of network foundational assumptions.

Strategic networks are particularly emphasized for their positive impact on firm performance through stable, strategically significant inter-organizational ties [172]. These networks are typically formalized through joint ventures or similar alliances, with value creation extending beyond immediate firm outputs [173], [174], [175], [174].

An alternative view, presented by Camarinha-Matos and Afsarmanesh (2005), describes collaborative networks where cooperation and competition coexist, focusing on the structure, behavior, and dynamics of networks of autonomous, geographically distributed entities collaborating towards common goals [169].

Both strategic and collaborative network perspectives address networks through a firm-centric lens. However, they differ in focus: strategic networks emphasize cooperative relationships as a source of competitive strength [176], while collaborative networks enhance firm structure and behavior to achieve goals more effectively [177]. At a policy level, networks have been identified as cooperative frameworks involving enterprises from different regions, sizes, and sectors working together towards common objectives [178].

In conclusion, while traditional network theories, primarily concerned with sociology or organizational theory, have focused on the implications of network structure for value creation [172], there is a growing call for theory refinement to better connect academic research with real-world business applications [85]. In these networks, every actor is seen as an interconnected resource integrator and active value cocreator [151].

3.5.5.2. Value Networks

Mariotti (2002) introduces a value network as an "interactive combination of information, machines, and people concentrated on creating value at each node, facilitated by technology that enhances exchange relationships among customers distributed across space and time." [179]. This paradigm shift emphasizes the organizations within networks and the value generated throughout the network [180].

In light of the global shift towards services [181], business literature has seen a corresponding pivot to service-oriented frameworks [182], underscoring the pervasive role of value in these networks [183]. S-D Logic framework further refines this perspective, positing that value in networks should be viewed as a cocreative process [184]. According to S-D Logic, all actors, whether providers or customers, are seen as networking service providers, with each network node representing a dyadic relationship between the service provider and the recipient [185].

Despite the value network concept's emphasis on value creation at each node and its portrayal as an interactive combination of diverse elements, there is a need for more literature on the specific mechanisms that facilitate value creation or the coordination underlying these networks [182]. As these networks expand globally and become complex, attributes such as agility, adaptability, and continuous learning become crucial for survival and growth [186]. This necessitates a continual reconfiguration of business processes in terms of form, time, place, and resource management, improving both relieving and enabling processes [185].

Building on the value network concept, Lusch, Vargo, and Tanniru (2010) developed a model to theorize the complex and adaptive elements of value networks. They redefine the value network as "a spontaneously sensing and responding spatial and temporal structure of largely loosely coupled value-proposing social and economic actors interacting through institutions and technology to co-produce service offerings, exchange service offerings, and cocreate value." [185]. This framework highlights the benefits of digital transformation, emphasizing the ability to "liquefy" information resources to simplify coordination and communication within networks [102] [187]. By integrating, processing, distributing, and selling information independently from tangible goods, firms can enhance their adaptability and improve service to other actors [188].

3.5.3.3 Technology-Enabled Networks

Arthur (2009) broadens the definition of technology beyond mere physical devices, presenting it as a complex amalgamation of practices, processes, and components engineered to fulfil human objectives [189]. This expanded view encompasses tangible devices and the methodologies and processes involved in technological advancement, positioning technology as the recombination of helpful knowledge. Similarly, Hughes (1989) and Mokyr (2004) abstract technology even further [145], respectively defining it as an organizational effort for problem-solving and as broadly construed practical knowledge [190]. These perspectives align technology with broader concepts, such as knowledge, competencies, and capabilities, viewing them as interconnected resource combinations that synergistically integrate [191].

As discussed by Hunt (2000), the social construction of technology underscores the significant role that social groups play in shaping technology's development and its perceived value [192]. This viewpoint challenges the traditional notion that technologies possess inherent value, suggesting that institutional arrangements are crucial in framing how technologies are understood and valued [193]. Akaka et al. (2013) support this view by demonstrating how technology in service ecosystems is both influenced by and an influencer of various institutions [194], endorsing the idea of interpretive flexibility as proposed by Pinch and Bijker (1984). This concept highlights that actors may ascribe different meanings to technologies based on their institutional contexts [147], which affects how technologies are integrated, evaluated, and utilised [194].

Contrary to the view that technologies inherently contain latent value [195], it is posited that perceptions of value are actively constructed through institutional processes and the integration

of technology with other resources. These processes are instrumental in the emergence, stabilization, and evolution of dominant meanings and technology applications [115]. It emphasizes the importance of considering technological advancements from an institutional perspective [196], illustrating that technology adoption and evolution are dynamic processes shaped by the continuous recombination of knowledge and the evolution of institutional arrangements among network participants [119].

3.5.4. Institutional Work in Networks

The concept of institutional work, introduced in organization studies, examines the deliberate actions individuals and organizations undertake to create, maintain, or disrupt institutions [164]. This concept is central to understanding the dynamics of ecosystems, particularly how actors shape institutional arrangements for value cocreation [197]. At the same time, institutions are organized around the cognitive, normative, and regulative pillars as outlined by Scott (2014), each influencing ecosystems through mechanisms ranging from formal legal obligations to informal social norms and shared understandings [198].

Institutional work suggests that actors can actively mold institutions to facilitate value cocreation, with these institutions acting as frameworks that guide action [197]. It leads to what is known as the "paradox of embedded agency", which highlights the tension between the choices actors make and the institutional mechanisms that coordinate social actions [199].

Efforts in institutional work are essential for transforming networks and enhancing their adaptability [200], as well as addressing the tensions and conflicts that arise within overlapping institutions [113]. The mechanisms for creating, disrupting, and maintaining institutions involve a wide range of actions, from regulating changes in belief systems to managing institutional boundaries [201]. Maintaining institutions requires continuous efforts to ensure stability and compliance, especially in response to organizational or environmental changes within the ecosystem [197].

These forms of institutional work are not sequential but occur concurrently, where the creation and disruption of institutions often lead to the maintenance of existing ones [109]. While some activities may be overt and readily observable, most institutional work consists of subtle, everyday adaptations and compromises [197].

Enabling value cocreation in coopetition networks involves sustaining and continually reshaping institutional arrangements, a complex process marked by conflicts and tensions [33]. As institutional work encompasses multiple actors influenced by various arrangements, the institutionalization of a mutual value cocreation logic evolves through multiple adjustments until a standard model is accepted and shared across the network [114].

3.5.5. Institutional Convergence on Networks and Service Ecosystems

The analysis of value networks has shifted towards understanding how loosely coupled collaborations between autonomous service providers can be effectively coordinated within a service ecosystem. Ruokolainen and Kutvonen (2019) characterized the service ecosystem as a "socio-technical, complex adaptive system" involving metamodels that connect domain ontologies with infrastructure services and production facilities [202]. They later noted that service ecosystems might arise spontaneously from shared interests or strategic planning [203].

Despite partners' autonomy and the need for adaptability in changing business environments, these authors suggest governance principles based on regulation, management, and alignment to maintain the ecosystem's sustainability. However, their perspective still reflects traditional views of value exchange, primarily focusing on value addition for market capture within networked businesses [204].

Progressing from these concepts, Vargo and Lush (2011) evolved the terminology from "value network" to "service ecosystem," a transition rooted in S-D Logic, which suggests reconsidering certain aspects to refine the definition of service ecosystems [106]. Vargo and Akaka (2012) emphasized resource integration as a central theme, describing service ecosystems as "relatively self-contained, self-adjusting systems of resource-integrating actors connected by shared institutional logics and mutual value creation through service exchange" [160]. This evolution from value networks to service ecosystems underscores the role of institutions in facilitating service innovation and value cocreation, which is crucial for the viability and sustainability of networks [162].

As Scott (2001) described, institutional work within these ecosystems involves humanly devised rules, norms, and beliefs that make social life predictable and meaningful [108]. These institutions, or institutional logics, operate supra-organizationally [205], forming a material-symbolic language that shapes the governance of service ecosystems [206].

Service science, a discipline underpinned by S-D Logic, explores how structures (service system entities and the resources they manage) and actions (value propositions and governance interactions) co-evolve [98]. This field views service systems and S-D Logic as interlinked, with overlapping concepts and community members. Nevertheless, some distinctions remain, particularly in how service ecosystems are conceptualized compared to service systems in service science. Ng et al. (2018) propose an extension to "service system ecology," representing the broader interactions among various types of service system entities [207].

The inherent paradoxical nature of coopetition networks can lead to challenges, including the risk of premature dissolutions [208]. Institutions and institutional arrangements are essential for overcoming these challenges by providing the necessary structure for actor coordination, collaboration, and cooperation [97], [157]. Successfully navigating coopetition involves striking a balance between collaboration and competition, with the network's sustainability relying on

effective coordination mechanisms [209]. This perspective demands a shift towards viewing business opportunities as ongoing service processes where resource integration and value proposition development are collaboratively managed. This approach is supported by shared institutions that facilitate the seamless functioning of these processes [104]. For a detailed illustration of how these elements converge systematically and institutionally, see Appendix I, Table 3.3, which outlines the systemic and institutional convergence on networks and service ecosystems.

Despite these theoretical nuances, the core of S-D Logic remains focused on institutions. Alderson (1957) suggested that in ecological systems, institutions emerge from bottom-up interactions among community members [210], supporting the focus on institutional arrangements within service ecosystems [110]. In summary, the convergence of value networks, technology, and institutional frameworks within service ecosystems highlights a complex interplay where service science and S-D Logic provide foundational insights [201]. These insights help design, govern, and sustain coopetition networks, emphasizing the role of institutions in anchoring and coordinating the network's activities to achieve a comprehensive understanding and operational viability.

3.6. Addressing Research Gaps: A Service Ecosystems Perspective

Significant gaps were identified in understanding coopetition dynamics, especially regarding value creation, the impact of technology, coordination mechanisms, and sustainability. The fractal approach to value cocreation, applied through the application of S-D Logic, offers a nuanced lens through which to explore and address these complexities. This logic emphasizes value cocreation, actor-to-actor networks, and institutional facilitation, providing a framework for analyzing coopetition.

From the discussions, clear connections have emerged between coopetition and value cocreation, as well as between networks and service ecosystems. It sets the stage for applying S-D Logic to examine and bridge the identified gaps in coopetition research critically. The following areas explore the processes where cooperation and competition intersect, leading to value creation, and assessing technology's transformative effects within these interactions. Additionally, the coordination mechanisms supporting effective coopetition will be clarified, and strategies to ensure its enduring viability will be proposed:

Value Creation Dynamics: Leveraging S-D Logic, this discussion will explore how the integration and interaction of diverse actors within service ecosystems contribute to emergent properties of value creation. It requires a deeper understanding of how resources are shared and integrated in contexts where actors simultaneously cooperate and compete, emphasizing the continuous interplay and mutual enhancement of cooperative and competitive actions.

Technology as Facilitator and Initiator: This section examines the role of technology in reshaping the landscapes of cooperation, highlighting how digital tools and platforms enable

new forms of interaction and integration among competing entities within ecosystems. It will also discuss how technological advancements can catalyze new cooperation strategies and facilitate more dynamic and responsive interactions among network actors.

Coordination Mechanisms: Drawing on insights from S-D Logic, this exploration will detail how institutions and institutional arrangements can facilitate the complex coordination required in coopetition settings. It involves analyzing governance structures and social norms that enable actors to effectively balance collaboration and competition, ensuring that both elements contribute positively to the network's objectives.

Sustainability of coopetition networks: The discussion will then turn to the long-term viability of coopetition strategies. It will address how ongoing adaptation and strategic alignment with evolving market conditions and technological advancements can sustain the benefits of coopetition over time. This part will evaluate the resilience of coopetition networks in adapting to environmental changes and sustaining competitive advantage.

This section aims to comprehensively understand how coopetition can be effectively managed and optimized within service ecosystems by synthesizing insights from S-D Logic with the challenges and opportunities inherent in coopetition. This approach fills existing research gaps and enhances our understanding of coopetition as a dynamic, emergent strategy that drives innovation, strategic growth, and sustainable competitive advantage in a digitally interconnected world.

3.6.1 Addressing Research Gap 1: Value Cocreation in Coopetition Networks

Addressing Research Gap 1 involves a profound reassessment of value creation mechanisms within coopetition networks through the lens of S-D Logic. This paradigm shift emphasizes value as an emergent property arising from the networked interactions among various stakeholders, including firms, customers, and broader community participants [98]. Unlike traditional views that confine value within products or specific transactions, S-D Logic posits that value materializes dynamically through collaborative efforts and the integration of operant resources such as knowledge, skills, and information [188] [201].

Within coopetition networks, the simultaneous competitive and cooperative interactions among firms catalyze unique, unattainable value-creation pathways in isolation. This collaborative pooling of competencies across competitive lines fosters innovation and enhances responsiveness to market changes, thus redefining the avenues for strategic agility [81].

S-D Logic further redefines the ecosystems of value creation, viewing service ecosystems as collaborative platforms where value is co-produced. In this framework, value is not merely exchanged but cocreated through active and ongoing interactions steered by institutional frameworks that facilitate and regulate these interactions [209]. This reconceptualization shifts the perception of markets from mere competition to collaborative environments where

competition and cooperation are intertwined, enriching each other within relational networks [97].

Embracing the inherent and emergent properties of service ecosystems under S-D Logic enables a comprehensive understanding of value as a collectively achieved outcome [113]. This perspective encourages an in-depth examination of how strategic coopetition can be leveraged within these ecosystems to innovate, expand markets, and enhance customer experiences effectively [119].

By grounding in understanding the principles of S-D Logic, it uncovers the complex, multifaceted nature of value creation within coopetition networks. This approach highlights the need for adaptive, collaborative strategies that leverage both competitive and cooperative dynamics, thereby fostering sustained innovation and differentiation in today's interconnected market landscape.

3.6.2. Addressing Research Gap 2: The Role of Technology in Coopetition Networks

S-D Logic significantly reshapes the understanding of technology within coopetition networks, portraying these networks as competitive battlegrounds and collaborative platforms for value creation [97]. This perspective emphasizes the role of technology as both a facilitator and an active participant in the dynamics of coopetition, enriching the ecosystem through synergetic engagements among all actors [98].

S-D Logic suggests that value is an emergent property arising from the collective interactions within these networks. This prompts a deeper investigation into how strategic collaboration among competitors, enabled and amplified by technological advances, can foster innovation, enhance market access, and improve customer experiences [113]. In this framework, technology is not merely supportive but a crucial force shaping the cocreative processes vital for navigating the complexities of modern service ecosystems [98].

Adopting the S-D Logic perspective allows a richer understanding of value cocreation within contemporary markets. It frames coopetition as a dynamic strategy instrumental in evolving the service ecosystem, highlighting how technology can drive cooperative and competitive interactions towards shared innovation and collective success.

This exploration highlights the dual role of digital technologies in either facilitating or hindering the delicate balance between competition and collaboration. It calls for an adaptive and responsive approach to coopetition strategy and execution. It advocates for a culture of innovation where technology is central to sustainable value creation within the complex interplay of economic ecosystems.

3.6.3. Addressing Research Gap 3: Enhancing Coordination of Coopetition Networks

In exploring coordination mechanisms within coopetition networks, S-D Logic provides vital insights into the role of institutional work and technology in shaping the operational frameworks of these networks [211]. This approach emphasizes the importance of actively constructing, disrupting, and maintaining institutions, which are essential for fostering a collaborative environment that promotes mutual value creation [97]. This dynamic process highlights the importance of not only formal structures (regulative aspects) but also shared norms and values (normative aspects) and a collective understanding of collaborative goals (cognitive aspects), which collectively underpin effective coordination within these ecosystems [212].

S-D Logic further posits that technology enables and intensifies interactions and integration among ecosystem actors, thus enhancing the cocreation of value [98]. It emphasizes the importance of finely tuned institutional arrangements, facilitated through institutional work and technology, for the seamless orchestration of coopetition networks [213]. This often requires iterative adjustments, aligning existing and emerging institutional frameworks to support collaborative efforts [197].

Moreover, this perspective sheds light on the critical roles of regulative, normative, and cognitive components in laying the groundwork for effective coopetition. It advocates for establishing governance structures and articulating shared values and expectations that direct interactions within the ecosystem, fostering a culture where cooperative competition can thrive [214] [196].

By integrating S-D Logic into the analysis of coordination mechanisms in coopetition networks, a comprehensive framework can be developed for navigating the complexities inherent in these dynamic environments [118]. This enriched understanding necessitates adaptive, integrated strategies that leverage institutional frameworks and technology to foster an ecosystem conducive to innovation, market access, and enhanced customer experiences through cooperative competition [98]. This approach bridges the identified gap and paves the way for future research and practice, highlighting the potential of S-D Logic as a foundational perspective for orchestrating effective coordination in coopetition networks, thereby promoting sustained success.

3.7. Institutional Foundation for Coopetition Networks for Value Cocreation

S-D Logic offers a service-oriented perspective for understanding the complex dynamics of networks, with a particular emphasis on the critical role of institutions [188]. These institutions, essential for fostering environments conducive to innovation and value cocreation, are characterized by their regulative, normative, and cultural-cognitive elements. These elements significantly shape the behaviors and interactions of network participants [164]. Adopting a

service ecosystems perspective enhances understanding of the processes involved in value cocreation and the potential for value destruction within coopetition networks. This perspective illuminates paths for more effective management and sustained operation, offering strategic insights into how coopetition can be structured to foster ongoing collaboration and competitive advantage.

Exploring service ecosystems in the context of coopetition and value cocreation reveals significant linkages between coopetition dynamics and service ecosystems. By integrating this shared institutional view with previous institutional work in S-D Logic [215], it becomes evident that CN-VCCs can be strategically designed under the S-D Logic narrative. This approach leverages the foundational principles of S-D Logic to enhance the design and governance of coopetition networks, ensuring they are well-positioned to capitalize on emergent opportunities for value creation. Appendix I, Table 3.4, summarizes the institutional convergencies on coopetition, value cocreation, networks and service ecosystems.

As highlighted by the service ecosystems perspective, the performative nature of business models and technologies significantly influences how coopetition unfolds within technological networks [216]. In these settings, actors leverage existing business models and institutional frameworks to manage and exploit technological networks ([217].

Building on this fractal approach, a clear connection emerges between networks and service ecosystems, as well as between coopetition and value cocreation. While various research priorities have been identified, it becomes evident that coopetition and networks share a common institutional foundation with business models. This shared foundation is crucial for understanding the interactions among these elements within service ecosystems. For further details on the key terms and definitions associated with institutional CN-VCCs, see Appendix I, Table 3.5.

3.8. Structural Constructs for Coopetition Networks for Value Cocreation

Institutions encompass regulative, normative, and cultural-cognitive elements and play a crucial role in forming and operating coopetition networks [157]. They emerge when organized actors, often called institutional entrepreneurs, identify opportunities to advance highly valued interests within these networks [164]. This recognition leads to developing cognitive institutional arrangements or interconnected sets of institutions, transforming the ecosystem into a fertile ground for coopetition and value cocreation. Under the foundations of S-D Logic, the structural constructs for coopetition ecosystems can be established to facilitate value cocreation through business models:

Micro-exchange Embedded in Ecosystems of Exchange: At the micro-level, firms and customers function as actors within a coopetition network, interacting through access to diverse resources to foster value cocreation. This dynamic network, driven by the motivation of all actors to engage in resource exchange processes, embodies interactions typically classified in business

literature as B2C, B2B, and C2C, among others. The success of value cocreation outcomes hinges on the effective coordination of resource access, which is regulated and facilitated by institutions and institutional arrangements.

Resource Integration and the Structuration of Service Ecosystems: Institutions often emerge from a bottom-up, organic adoption process that begins at the micro-level. As specific behavior patterns become normalized at this level, institutions manifest and influence the broader ecosystem, ascending towards the meso-level. These meso-level institutions and their corresponding institutional arrangements within the coopetition ecosystems then provide the contextual framework that shapes future interactions back at the micro-level.

3.9. Ensuring Long-Term Coopetition Networks for Value Cocreation

Exploring the long-term viability of CN-VCCs through the lens of S-D Logic provides a framework for understanding and ensuring their sustainability over time [118]. This perspective recognizes coopetition networks as dynamic entities that require adaptive management and continuous institutional work to align with evolving internal and external conditions [201].

S-D Logic emphasizes the need for ongoing maintenance and realignment of institutional arrangements, highlighting the importance of managing the regulative, normative, and cognitive foundations that support effective coopetition [198]. It acknowledges the potential for institutional disruption and the creation of new forms of collaboration as external and internal dynamics change [109], necessitating flexible governance mechanisms and collaborative innovation processes [60].

From a regulative standpoint, attention must be given to the evolving regulatory landscape and the adaptation of formal rules to ensure that the governance structures of the ecosystem remain adequate and pertinent [111]. Normatively, the ecosystem should continuously cultivate a culture of trust, shared objectives, and a collaborative ethos through open dialogue, codes of conduct, and regular reassessment of shared values and norms [114]. Cognitively, fostering collective understanding and reflexivity among ecosystem actors is crucial to ensure all participants remain aligned with the overarching goals and comprehend their roles within the collaborative framework [60].

This refined approach, deeply embedded in S-D Logic and the concept of service ecosystems, provides a strategic pathway to manage the complexities of coopetition. It emphasizes a dynamic and iterative process of adjusting institutional frameworks and leveraging technology to foster an environment conducive to sustained value cocreation. Coopetition networks can evolve, adapt, and thrive by adopting these principles, ensuring sustainability amid shifting market conditions and competitive landscapes [211]. This perspective bridges the identified gap and lays a blueprint for cultivating enduring success in coopetition networks through strategic adaptation and collaborative innovation.

Chapter 3. Summary

The literature review chapter aimed to explore and address the complexities of coopetition networks to design and implement effective strategies for SMEs. A fractal approach was adopted to delve deeply into the layers of existing coopetition literature, identifying and understanding how coopetition unfolds within networks. This investigation highlighted several gaps, particularly in how value is cocreated within these networks. These gaps were further examined through the lens of S-D Logic, which emphasizes value cocreation in service ecosystems, providing a nuanced understanding necessary for bridging these gaps.

This exploration facilitated the reconciliation of coopetition with value cocreation and networks with service ecosystems, culminating in a comprehensive knowledge framework. CN-VCC framework is instrumental for SMEs to craft practical solutions in designing and managing coopetition networks effectively. The insights gained enrich the theoretical discourse on coopetition and offer practical implications for SMEs operating within complex networked environments.

Chapter 4. Methodology

Predicting is very difficult, especially about the future. - Niels Bohr

This chapter outlines the methodology used to explore CN-VCCs within SMEs, as discussed in the literature review. It outlines the research paradigms and methodological frameworks that guide this investigation, with a particular emphasis on the integration of DSR with the performative nature of the S-D Logic of value creation [119].

The discussion begins by examining various research paradigms, including post-positivism, constructivism, transformative research, and pragmatism. It emphasizes how pragmatism, with its adaptive and solution-oriented nature, synchronizes with the dynamic and integrative aspects of S-D Logic. This alignment underpins a robust approach to navigating complex service ecosystems.

Following this, the chapter explores the specifics of adopting DSR, a methodology particularly suited for its practical application and emphasizes creating and evaluating artefacts designed to address real-world challenges. The critical phases of DSR—problem identification, objective setting, design and development, demonstration, evaluation, and communication of findings—are thoroughly explored. This methodological framework is instrumental in ensuring a structured and systematic approach to the research, laying a solid foundation for the empirical studies detailed in subsequent chapters.

4.1 Research Paradigm

At the outset of this research, identifying and establishing the guiding worldview or paradigm is paramount. As noted by [218] and reiterated by [219], a paradigm serves as "a basic set of beliefs that guides action, providing a general philosophical orientation about the world and the nature of research that a researcher brings to a study." This foundational philosophy shapes both the approach to the research and significantly influences the interpretation of its outcomes.

Paradigm Dimensions: Epistemology: Investigates the relationship between the researcher and what can be known, focusing on how knowledge is acquired and its validity within the research context [220]. Ontology: Examines the fundamental nature of reality, exploring what constitutes truth and how these truths are articulated and recognized within the study [219]. Methodology: Outlines the specific methods and procedures used to engage with, observe, and derive knowledge from the research subject [221]. These dimensions collectively scaffold the researcher's approach, guiding the study's conduct and analytical perspective.

Research paradigms, mainly categorized into post-positivism, constructivism, transformative, and pragmatism [222], serve as perspectives that guide the formulation and exploration of research questions. Each paradigm offers a unique lens [219]: Post-positivism posits that reality

can be addressed by testing and refining theories despite potential biases introduced by the researcher's values and prior knowledge [223]. Constructivism emphasizes the subjective construction of meaning, advocating for understanding the multiplicity of perspectives and acknowledging that individuals' experiences and backgrounds shape reality (Creswell, 2014). Transformative research is linked to agendas for social change, addressing social injustices and promoting equity [224]. Pragmatism advocates a problem-focused approach that values practical outcomes, employing qualitative and quantitative methods to tackle research questions with a view towards social justice and sustainability [220].

The pragmatist paradigm, particularly resonant with S-D Logic, views reality as dynamic, evolutionary [17], and interactive—suitable for analyzing value cocreation in service ecosystems [225]. It facilitates the integration of qualitative and quantitative data, enabling a comprehensive understanding of empirical realities and the development of theories that reflect these realities [226].

This paradigmatic framework underpins the study's approach, enabling the exploration of complex research questions while accommodating a rich blend of empirical data and theoretical insights. Thus, it enriches the understanding and development of applicable solutions within the field.

4.2 Methodological Foundations and Approaches in Research

A methodology constitutes a comprehensive system of principles, practices, and procedures tailored to a particular field of study, fundamentally guided by the logic of structuring various research endeavors [227]. In information systems and technology management, selecting a suitable methodological approach is critical to ensuring the research's effectiveness and relevance [228]. As researchers navigate the extensive methodological landscape of this domain, they are presented with a range of options. These range from conventional empirical research methods, such as surveys and case studies, to innovative methodologies like Action Research [229] and DSR [230]. Each methodological approach offers unique advantages and presents specific limitations contingent upon the research goals, the challenges being addressed, and the anticipated outcomes.

4.2.1 DSR Methodology: Origins and Core Principles

As outlined in previous chapters, the primary goal of this research is to develop and sustainably maintain effective coopetition networks among SMEs. Among various methodologies, DSR is particularly well-suited for projects that aim to create and evaluate new artefacts, such as processes, tools, and models, designed to address complex problems [231]. Rooted in the broader realm of sciences dedicated to the artificial, DSR emphasizes knowledge production through the design of practical artefacts, a concept championed by Herbert Simon in 1969 [156].

This methodology is predicated on the idea that our world is increasingly shaped by human ingenuity rather than natural processes, necessitating a deliberate focus on crafting solutions that serve specific purposes across various fields, including engineering, computing, and education [230]. Simon further elaborated (1988) that design is fundamentally about envisaging desirable futures and creating artefacts that achieve specific objectives [156], thereby establishing design science as a disciplined inquiry into both the creation and utility of such artefacts [232].

The designer's concept of formulating strategies to transform current states into preferred ones further integrates research design [233], viewed as a structured plan to collect and analyze data, thereby facilitating the achievement of research objectives [234]. This integration ties theoretical frameworks, research questions, and objectives to suitable resources and tools for artefact creation [235].

DSR merges design science and research design principles, advocating for a paradigm where design encapsulates how things should be, thereby bridging positivist, interpretive, and critical research perspectives [156]. This methodology focuses on creating artefacts to address real-world problems and enhance knowledge [231]. Over recent decades, DSR has evolved into a methodology characterized by synthetic and analytical approaches, particularly relevant to information and technology research [236]. It aims to produce and evaluate artefacts that solve practical organizational problems and contribute to the academic field [237], [238].

With its foundation in both the process and product of design [236], DSR encompasses the creation and evaluation of constructs, models, methods, and instantiations supported by a substantial and expanding body of literature [156]. This methodology's application extends beyond theoretical knowledge, utilizing task-specific knowledge to develop practical artefacts, thereby gaining traction in service research [239].

Hevner (2007) delineates a triadic view of DSR utilization, comprising relevance, rigor, and design cycles [240]. These cycles emphasize the identification of real problems, the application of existing knowledge to drive innovation, and the iterative development and evaluation of design alternatives. With its foundation in both the process and product of design [236], DSR encompasses the creation and evaluation of constructs, models, methods, and instantiations [240]. This framework has proven effective in various service research projects [239], particularly from a service ecosystem perspective. This viewpoint considers innovation through the collaborative and combinatorial evolution of practices, resulting in novel solutions to challenges [189]. Moreover, it views technology as a dynamic asset and business models as established solutions within self-regulating systems of resource-integrating actors connected by shared institutional logic. These ecosystems facilitate value cocreation, evolving globally through networks of interdependent actors [98], [241].

Originating in the engineering and computer science disciplines, DSR has been increasingly adopted within business and information systems research due to its rigorous yet flexible framework [227]. The core principles of DSR revolve around creating and evaluating innovative

artefacts, with a strong emphasis on addressing practical problems while contributing to theoretical foundations [242]. Its applicability to developing and evaluating technology solutions within business contexts is well-documented, making it an ideal choice for research that bridges theoretical knowledge and practical application [156].

4.2.2 The Supportive Role of S-D Logic

As described, the DSR is a methodology that guides the creation and evaluation of artefacts designed to solve specific problems [230]. Its core lies in generating innovative solutions that contribute to both advancing scientific knowledge and practical applications in the real world. DSR's iterative process—encompassing the design, development, implementation, and testing of artefacts—uniquely suits it to investigate complex issues where traditional research methodologies may fall short [243].

S-D Logic supports enhancing the DSR methodology [235], especially in this study, which focuses on cooperation networks among SMEs. With its emphasis on value cocreation, actor-to-actor networks, and institutional arrangements, S-D Logic provides a conceptual foundation that complements the DSR approach in several ways. Appendix I, Table 4.1, illustrates how S-D Logic's principles have been integrated into the DSR methodology, showcasing the complementary enhancements to this theoretical framework.

In integrating S-D Logic with the DSR methodology, this study leverages S-D Logic's comprehensive view of value creation, actor interactions, and institutional contexts to inform the development and refinement of artefacts [118]. This integration ensures that the artefacts designed address the technical aspects of CN-VCCs and consider the broader economic, social, and institutional dynamics at play [33]. Thus, S-D Logic supports the DSR methodology by providing a deeper, more nuanced understanding of the ecosystems within which these artefacts will operate, ensuring their relevance, effectiveness, and sustainability in addressing the challenges and opportunities of coopetition among SMEs.

4.2.3 Ontological Alignment with Research Objectives

The ontological alignment of DSR with the research objectives is fundamentally rooted in its practical and constructive nature [242], which resonates with the S-D Logic foundations and the focus on service ecosystems [60]. This alignment is particularly evident when considering the research objective of developing and evaluating a CN-VCC framework for SMEs to enhance their competitiveness in digital and global markets. Here is how DSR's ontology aligns with the research objectives. Appendix I, Table 4.2, illustrates the alignment of the ontological assumptions of Design Science Research with the specific objectives of this research.

The ontological alignment of DSR with the research objectives underscores the methodology's suitability for developing a framework for CN-VCCs grounded in S-D Logic foundations [160]. This alignment ensures that the research contributes to theoretical knowledge and offers

practical, actionable insights for manufacturing SMEs striving to navigate the complexities of digital and global markets.

4.2.4 Epistemological Contributions through DSR

The epistemological contributions of Design Science Research (DSR) to developing and evaluating frameworks for CN-VCCs, particularly those grounded in S-D Logic and service ecosystems, are profound and multifaceted. Epistemology, which examines the nature and scope of knowledge, focuses on how knowledge is understood [122]. DSR enhances this understanding by offering rigorous methods for creating and assessing frameworks that address complex challenges in coopetition. The specific epistemological contributions of DSR to understanding Coopetition Networks are outlined in Appendix I, Table 4.3.

The epistemological contributions of this research through DSR are significant. It offers new ways of understanding and leveraging the principles of S-D Logic in creating practical, impactful artefacts. This approach advances theoretical knowledge and provides tangible benefits for SMEs in competitive digital and global markets.

4.2.5 Applicability of DSR in Developing and Evaluating Technology-Based Solutions

The ontological and epistemological underpinnings of DSR render particularly well-suited to studies that aim to integrate theoretical insights with practical applications in business and technology management. DSR's emphasis on creating artefacts aligns with the pragmatic needs of business technology management, where concrete, empirical solutions are pursued to tackle defined problems [227]. This methodology facilitates the development of these solutions and ensures their theoretical integrity and practical utility by grounding them in a constructivist epistemology. Such an approach ensures that practical ventures make meaningful contributions to the broader body of knowledge, yielding academically rigorous and directly applicable insights.

The selection of the DSR methodology, as outlined by Peffers et al. (2007), is firmly grounded in its suitability from both ontological and epistemological standpoints to meet the research objectives [227]. DSR's dedication to generating practical artefacts, underpinned by a constructivist approach to knowledge creation, lays a robust foundation for developing a framework tailored to CN-VCCs for SMEs. It ensures that the research yields tangible benefits and adheres to intellectual rigor, making a significant contribution to the field of study and the practical domain it seeks to influence.

4.3 Designing a Methodological DSR Framework for Ornamental Stone SMEs

Building on the objectives established in this thesis's introduction, the design of a "solution for the identified problem" necessitates its evaluation within a real-world context. As detailed in

Chapter 2, the Portuguese ornamental stone sector has been selected as the empirical field for this study due to its significance and inherent challenges.

Within the OS-PT sector, insights from a survey conducted by Silva and Marques Cardoso (2023a) pinpoint vital areas, including customer satisfaction, operational efficiency, and the need for scaling production capabilities [57]. These findings underscore the urgency for the OS-PT sector to upgrade its digital infrastructure and foster collaboration, as it heavily relies on traditional financing methods and the significant role of SMEs. Furthermore, additional insights from Silva and Marques Cardoso (2023b) stress the importance of addressing BIM-related challenges and adapting to the broader digital transformation within the OS-PT sector [59]. Through the strategic use of technology to establish secure, confidential environments, OS-PT firms can substantially enhance their collaborative efforts, particularly those with advanced digital capabilities. According to Peffers et al. (2007), the DSR methodology comprises several distinct Activities [227], as depicted in Figure 3.

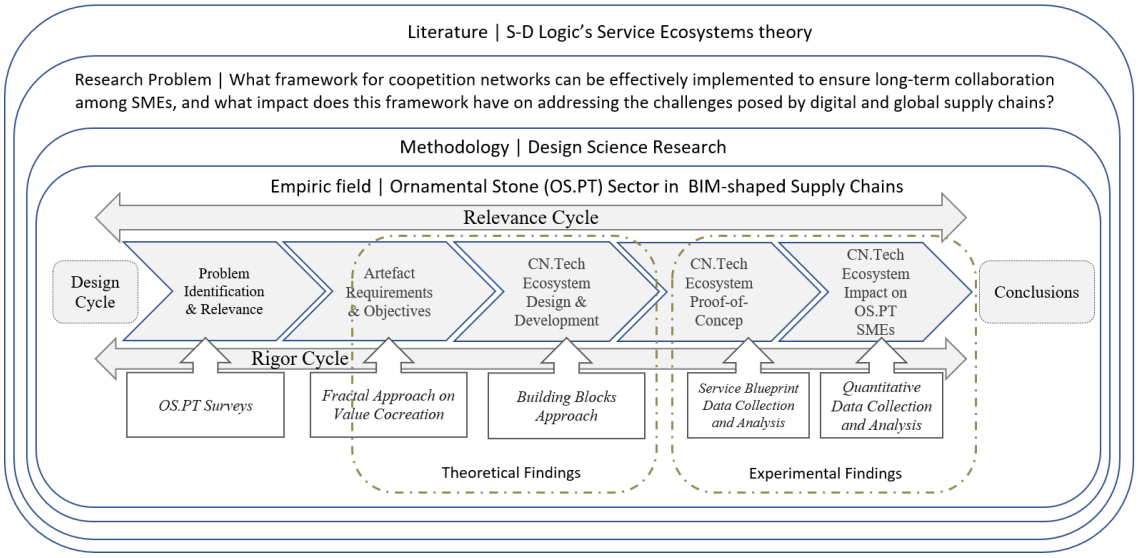


Figure 3. Design Science Research Methodological Framework for OS-PT SMEs.

This structure ensures that each phase of the DSR methodology is aligned with the specific challenges within the OS-PT sector, facilitating a focused and effective implementation of the CN-VCCs.

4.3.1 DSR Activities 1 and 2: Problem, Motivation, Requirements, and Objectives for a Solution

According to Peffers et al. (2007), DSR Activity 1 focuses on identifying the research problem and justifying the need for a solution [227]. This activity is crucial as the problem definition triggers the development of a compelling artefact to address the identified issue. Insights from Silva and Marques Cardoso (2023) highlight critical concerns among Portuguese SMEs in the BIM-shaped supply chains within the AEC sector [57], [59]. These insights also reveal a high

readiness among these SMEs to engage in collaborative modes, provided they can maintain operational independence. Once the problem is identified, DSR Activity 2 aims to establish objectives for a potential solution. This includes:

Specific Objective: Utilizing the S-D Logic's service ecosystems theory to refine the necessary performative constructs and technologies. This objective guides the design of future Coopetition Networks to address specific challenges SMEs encounter.

Research Approach: Anchored in S-D Logic and guided by DSR methodology, this activity is executed through three sequential steps:

Performative Constructs: Describe systemic constructs that facilitate the formation of effective CN-VCCs. This step outlines the architectural and functional components for building future technology-enabled coopetition ecosystems.
The Role of Technology: Specify the technology mechanisms that operationalize effective CN-VCCs.
Objectives and SDG Alignment: Focus on SDGs, establishing measurable outcomes to achieve within SMEs.

This methodological structure provides a comprehensive framework for Coopetition Networks, tailored to enhance coopetition and offer actionable insights for SMEs in a collaborative environment.

4.3.2 DSR Activity 3: Designing a Coopetition Network for Value Cocreation

Following the guidelines by Peffers et al. (2007), DSR Activity 3 necessitates designing a practical knowledge-based solution [227]. Specifically, the S-D Logic underpins the creation of a framework tailored for Coopetition Networks aimed at Value Cocreation. This activity involves developing technology to operationalize this framework within OS-PT SMEs effectively. This phase marks a transition from theoretical groundwork to actionable design, focusing on developing an architectural framework that addresses the complexities of global and digital supply chains.

Specific Objective: This activity aims to design and develop a robust framework for Coopetition Networks to facilitate Value Cocreation and a corresponding technology to operationalize the framework. This design will address SMEs' unique global and digital market challenges. The framework and technology will align with the SDGs, incorporating key actors, resource flows, and institutional arrangements necessary for effective coopetition.

Research Approach: Anchored in S-D Logic and guided by the DSR methodology, this activity unfolds in three sequential steps:

Systemic Building Blocks: Identify and describe the technological, organizational, and cultural building blocks derived from S-D Logic principles that underpin the coopetition framework.

Industrial IoT-based System: Develop an IIoT system to connect key stakeholders and facilitate effective coopetition within SMEs. This system will integrate advanced technologies, including real-time data analytics, machine learning for predictive insights, and secure cloud infrastructure, to ensure seamless interaction and data exchange among network actors. By strategically embedding this IIoT system into the CN-VCC framework, the resultant integration forms a robust, fully realized entity known as the Coopetition Technology-enabled Service Ecosystem (CN-EcoTech). This ecosystem supports day-to-day operational coopetition dynamics, reinforcing the network's capacity for sustainable value cocreation.

Lifecycle and Instantiation: Outline the comprehensive CN-EcoTech implementation, operation, and evolution process to ensure adaptability through instantiation.

This methodological approach ensures that the designed CN-EcoTech addresses current challenges and is equipped to adapt to future dynamics, maintaining long-term relevance and effectiveness within SMEs.

4.3.3 DSR Activity 4: Proof-of-Concept of the CN-EcoTech

According to the methodology proposed by Peffers et al. (2007), this activity aims to demonstrate the feasibility and practical applicability of CN-EcoTech—a previously conceptualized framework [227]. A PoC is carried out among a select group of SMEs in the Portuguese ornamental stone sector. These SMEs have been chosen to represent various coopetition scenarios within the industry. This step answers the research question (RQ1): How does the CN-EcoTech enable current state-of-the-art coopetition instances within OS-PT SMEs?

Specific Objective: This activity aims to demonstrate the practical application of the CN-EcoTech in real-world settings. This involves showcasing its capabilities to address and resolve the identified challenges associated with cooperation.

Research Approach: Grounded in S-D Logic and following the DSR methodology, this activity will be executed through three sequential steps:

Advancing the Service Blueprint Method: Tailor the current service blueprint method to reflect the specific needs and dynamics of the CN-EcoTech. This adapted blueprint will capture the unique coopetition journey within the network, highlighting the interactions between cooperation and competition.

Monitoring and Documenting: Utilise the adapted service blueprint to engage with selected SMEs, monitoring and record interactions throughout the commercial opportunity lifecycle, from initial engagement to outcome realization. This detailed documentation will track the evolution of cooperative and competitive dynamics, providing insights into the journey transformations within these interactions.

Service Outcomes Evaluation: Evaluate the effectiveness of the CN-EcoTech practices by comparing the service outcomes to those managed through existing practices within the selected

SMEs. This comparative analysis will highlight CN-EcoTech's operational and strategic coopetition enhancements.

Activity 4 transitions from theoretical design to practical application, demonstrating the CN-EcoTech's viability in real-world settings. By providing empirical evidence of the system's capacity to innovate cooperation strategies within the OS-PT sector, this PoC aims to set a benchmark for future innovations in global SMEs.

4.3.4 DSR Activity 5: Assessing the Impact of the CN-EcoTech on OS-PT SMEs

This activity, guided by the frameworks proposed by Peffers et al. (2007), involves evaluating the effectiveness of the CN-EcoTech through an Experimental Pilot Project within the OS-PT sector. This phase involves a detailed quantitative analysis of the benefits of implementing CN-EcoTech practices among a select group of small and medium-sized enterprises (SMEs).

These SMEs are selected based on their representation of the sector's state-of-the-art, willingness to participate in the study, and sufficient size to ensure robust data collection. The research addresses the following specific questions: How does CN-EcoTech impact the operational efficiency (RQ2), operational scale (RQ3), customer satisfaction determinants (RQ4), and ecological footprint (RQ5) of OS-PT SMEs?

Specific Objectives: This activity aims to conduct an Experimental Pilot Project that measures the tangible benefits of CN-EcoTech in terms of operational efficiency, scale, customer satisfaction, and ecological footprint within selected OS-PT SMEs. This assessment will focus on aligning with the SDGs and considering broader societal and environmental impacts.

Anchored in S-D Logic and utilizing the DSR methodology, this activity will proceed through five sequential steps:

Companies Selection: Identify and onboard SMEs for the Experimental Pilot Project, utilizing the instantiation methodology to deploy the CN-EcoTech within these environments.

Metrics and KPIs: Develop quantitative metrics and KPIs to measure improvements across operational efficiency, scalability, customer satisfaction, and ecological impact.

Data Collection: Gather comprehensive baseline and post-implementation data to enable practical comparative analysis.

Performance Analysis: Analyze the collected data using the predefined KPIs to assess the quantitative changes brought about by CN-EcoTech.

Innovation Outcomes Assessment: Evaluate the overall gains from CN-EcoTech, primarily assessing how these gains contribute to achieving the SDGs and assess the ecosystem's ability to foster innovation within the sector.

As per DSR methodology [227], a critical review must be conducted post-assessment. Suppose CN-EcoTech does not meet the expected benefits. In that case, this activity may involve a

reevaluation and potential redesign to better align with the needs and objectives of the OS-PT sector.

4.3.5 DSR Activity 6: Findings Communication

As determined by Peffers et al. (2007), to communicate the problem and its importance, the solution developed, its utility and novelty, the rigor of its design, and its effectiveness to researchers and other relevant audiences, such as practicing professionals, are part of the DSR methodology [227].

This requires identifying the key elements of communication and target audiences, namely **Academic Community and Industry Practitioners.** The dissemination of research findings is a critical component of the DSR methodology.

4.4 Ethical Considerations

In the context of conducting research within the OS-PT sector, focusing on a sample of SMEs, ethical considerations play a crucial role in ensuring the study's integrity and credibility. When collecting data from multiple companies, it is essential to adhere to strict ethical guidelines that protect the privacy, confidentiality, and voluntary participation of the companies involved. Here are the key ethical considerations that will guide the data collection process:

Anonymity and Confidentiality: (1) Anonymity of Participants - all participating companies will be guaranteed anonymity, and (2) Confidentiality of Data - all data collected from the SMEs must be treated with the utmost confidentiality, and information stored securely, with access limited to the research team.
Informed Consent: (1) Voluntary Participation - participation in the study will be entirely voluntary. Moreover, (2) Informed Consent Agreement - before data collection begins, each participating company will obtain a formal informed consent agreement.
Data Use and Publication: (1) Use of Data for Stated Research Purposes Only - the data collected will be used strictly for the purposes outlined in the research objectives, and (2) Transparency in Reporting - when disseminating research findings, care will be taken to ensure that the presentation of data is truthful and reflects the collected data accurately, without revealing the identity of participating companies.

This research aims to build a trusting relationship with participating SMEs in the OS-PT sector by adhering to these strict ethical guidelines. Ensuring the privacy, confidentiality, and voluntary participation of these companies is crucial for maintaining the integrity and credibility of the study. This ethical framework not only safeguards the participants but also strengthens the overall quality and reliability of the research findings.

Chapter 4 Summary

Chapter 4 outlines the research methodology, utilizing DSR to develop and evaluate CN-VCCs in the OS-PT sector. Emphasizing a pragmatist paradigm and S-D Logic, the chapter highlights the

use of DSR for its effectiveness in designing and assessing practical artefacts to address complex challenges. S-D Logic provided a theoretical basis for artefact design, promoting coopetition and value cocreation among SMEs.

The chapter details the systematic process of designing, developing, and evaluating the coopetition network, confirming its practical relevance within the OS-PT sector. Ethical considerations were rigorously upheld to ensure participant confidentiality and research credibility. Chapter 5 then shifts focus to defining requirements and objectives for CN-VCCs within OS-PT SMEs.

Chapter 5. Requirements and Objectives of Coopetition Networks for Value Cocreation

In the future, everyone will be famous for fifteen minutes. - Andy Warhol

This chapter examines DSR Activity 2, which outlines the requirements and objectives for fostering coopetition networks for value cocreation among OS-PT SMEs. This activity aims to develop a robust framework for enhancing coopetition, drawing inspiration from Peffers et al. (2007) and incorporating principles from the S-D Logic's service ecosystems theory. The framework is designed to help SMEs align their operational strategies with broader SDGs, thereby synchronizing business success with social progress.

The chapter systematically analyzes constructs, mechanisms, and expected outcomes. It establishes the foundational elements necessary for designing effective and sustainable Coopetition Networks. It builds on the insights from the previous chapters and uses the S-D Logic to refine the performative constructs and technologies critical for these networks. The framework addresses the challenges faced by SMEs and supports their growth and sustainability goals.

This activity, rooted in S-D Logic and steered by the DSR methodology, unfolds through three sequential steps: (1) describing systemic constructs that aid in the formation of effective Coopetition Networks, outlining both the architectural and functional components necessary for building future technology-enabled coopetition ecosystems; (2) specifying the technological mechanisms that operationalize the Coopetition Networks, ensuring their effectiveness in value cocreation; and (3) aligning with SDGs by establishing measurable outcomes that SMEs should aim to achieve.

By organising this chapter around the development of a comprehensive framework, the research not only elucidates theoretical concepts but also provides actionable insights for practical application.

5.1 Performative Constructs for Coopetition Networks for Value Cocreation

Building on the fractal approach to value creation discussed in the literature review chapter, Coopetition Networks can be analyzed through the lens of the S-D Logic's service ecosystems framework, as proposed by Lusch et al. (2016).

Based on this service ecosystems' perspective, coopetition is understood not as sporadic cooperation and competition but as a dynamic, self-similar process occurring at multiple scales within and between companies [244]. It underscores the adaptability of strategies for managing

coopetition, acknowledging that solutions effective in one context may be scalable and replicable in another, albeit with necessary adjustments for local nuances [105].

The fractal analysis presented in the literature review reframes networks as structures that demonstrate similar patterns of connection and interaction at multiple levels [129]. This view challenges the notion of networks as static or homogeneous entities, instead portraying them as inherently variable and adaptable, much like the fractal structures observed in nature [245]. Such an approach emphasizes the importance of examining macro-level network configurations and their micro-level counterparts to understand how information, resources, and influence are disseminated thoroughly. It also suggests that interventions aimed at boosting network performance should account for the fractal nature of these networks, utilizing recursive patterns of successful interactions to enhance connectivity and resilience [246].

From the service ecosystem's perspective, coopetition networks are depicted as exhibiting recurring patterns of value cocreation activities across various scales, ranging from individual service encounters to broader market dynamics [215]. This perspective elucidates how value cocreation is a nested process, with each interaction layer containing smaller, self-similar processes of resource integration and exchange. Viewing CN-VCC (CN-VCC) as fractal structures accentuates the recursive nature of institutional arrangements and norms that enable and restrict value cocreation [33]. Moreover, it implies that strategies to foster innovation and sustainability within these networks should contemplate the configurations of actors, resources, and institutions to fully leverage the network's dynamic, self-organizing capabilities [60]. As demonstrated in the previous chapter, applying fractal analysis to coopetition networks and service ecosystems has provided profound insights into the intricate, multi-layered nature of these phenomena [118]. Anchored in S-D Logic, it is now possible to move towards the practical application of these networks to benefit SMEs and society.

5.1.1 Systemic Guidelines for Coopetition Networks for Value Cocreation

Building on the concept of service ecosystems [160], systemic constructs essential for shaping CN-VCC can be outlined, providing a comprehensive framework to understand the complex interplay of interactions and dynamics within these networks. This framework emphasizes the coordination of actors and the balance between competition and collaboration, highlighting the roles of institutional arrangements, technologies, and institutional work in shaping the network [241]. As depicted in Figure 4, the following guidelines are central to our understanding:

Institutions and Institutional Arrangements: At the heart of CN-VCC are institutions and institutional arrangements—complex tapestries woven from regulative, normative, and cognitive threads [110]. These arrangements go beyond mere governance structures; they are vital for the network, dictating the flow of interactions, behaviors, and collaborations [157]. By establishing clear rules, fostering shared norms, and nurturing a collective cognitive framework, these institutions and arrangements provide fertile ground for both cooperative and competitive

dynamics to thrive. They ensure that network participants are aligned yet remain flexible enough to adapt to the evolving market demands and regulatory landscapes [188].

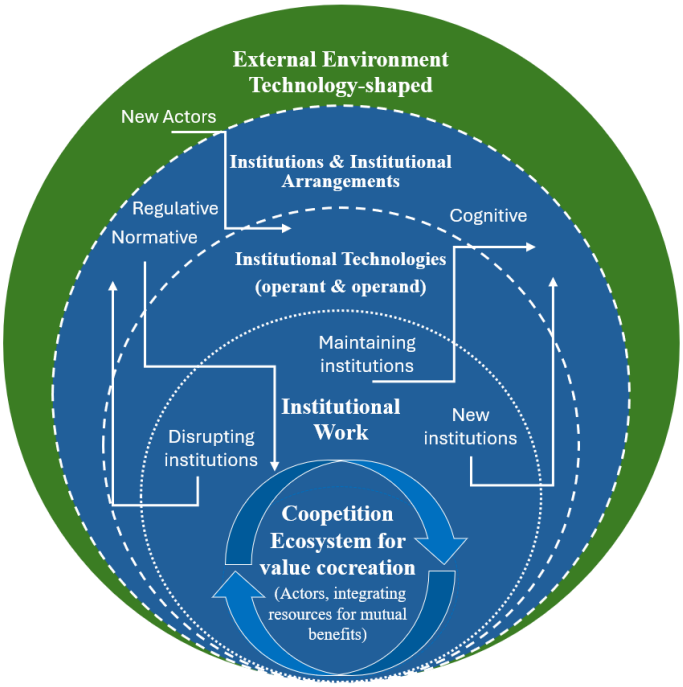


Figure 4. Systemic Constructs for Coopetition Networks for Value Cocreation

Institutionalized Technology (Operant and Operand): Technology is essential in fostering collaboration and driving coopetition. In the digital transformation era, these technologies transcended their traditional roles as mere tools, emerging as strategic assets that catalyze new paradigms of innovation and interaction. Arthur (2009) underscores the importance of practices—routinized activities—in technological developments, characterizing technological advancement as the (re)combination of helpful knowledge [189]. He defines technology as an assemblage of practices and components designed to fulfil human purposes. Similarly, Akaka and Vargo (2013) propose a framework demonstrating how technology within service ecosystems shapes and is shaped by various institutional influences [103]. This view aligns with the concept of interpretive flexibility [247], which illustrates how different actors, guided by their own rules, norms, and beliefs, can construct vastly different meanings for technologies. From cloud computing and artificial intelligence to blockchain and the Internet of Things, technologies in coopetition networks dismantle traditional barriers, facilitating seamless resource integration and fostering groundbreaking innovations [248]. Guided by institutions and institutional arrangements, these technologies empower participants in Networks to cocreate value and redefine the boundaries of what is achievable in a digitally interconnected world.

Institutional Work: The dynamism of CN-VCC necessitates ongoing institutional work—a strategic endeavor by actors to mold, refine, and sometimes disrupt the institutional landscape [164]. This institutional work is central to the ecosystem's resilience and evolution, enabling it to

adapt to new challenges and opportunities [212]. Through creative innovation, actors continuously shape and reshape the network, ensuring it remains robust and responsive [197]. This institutional work acts as the glue that binds the ecosystem together, a testament to the collective will of its participants to forge a path of sustained growth and shared success [60].

Informed by S-D Logic foundations [110], this framework sheds light on the network's institutional foundations—encompassing rules, norms, meanings, and symbols—while highlighting the practices of systemic actors in service ecosystems governed by interdependent institutional arrangements. The CN-VCC, through the lens of S-D Logic's service ecosystems literature, emerges as both a narrative and calculative network. It empowers entrepreneurs to explore markets and play a performative role in constructing the techno-economic coopetition ecosystem.

5.1.1.1 The Role of Technology: Resource Integration in Coopetition Networks Value Cocreation

S-D Logic posits that economic exchanges are centred around applying specialized competencies or services by actors—including individuals, organizations, and increasingly, technology—to cocreate shareable benefits [249]. This perspective views firms, customers, and other entities not merely as participants but as active integrators and providers of resources, all aimed at the collective goal of value cocreation [250]. In value networks, which are defined as architectures of service and information flows, actors assume roles that involve not only contributions but also potential benefits and sources of revenue, underscoring the importance of clearly identifying these roles and their economic impacts [251].

In the domain of "smart" technologies, there is a pronounced shift toward a new generation of technologies marked by self-governing behaviors and autonomous decision-making capabilities [252]. These advanced technologies—including artificial intelligence, the Internet of Things (IoT), and extensive data-driven systems—have evolved beyond their traditional facilitative roles [253]. They are now recognized as active participants within service ecosystems, capable of taking independent actions that contribute significantly to value cocreation [254].

The concept of operant resources in S-D Logic, which includes the autonomy of resources under three logics—legislative authority, self-sufficiency, and independence from external control (Degani et al., 2017), highlights the role of technology not just as an enabler but also as an initiator in the value creation process [188]. This enhanced role facilitates dynamic interactions within networks where technology shapes service outcomes and cocreation opportunities.

This S-D Logic-based exploration reaffirms the foundational role of actors, including emerging technologies, as pivotal to resource integration and service exchange within coopetition ecosystems [122]. Recognizing technologies as active participants enriches the value cocreation narrative, expanding the scope of interactions and cocreation possibilities within these ecosystems [191]. This perspective supports a more integrated and dynamic understanding of how diverse entities contribute to and benefit from shared value networks.

5.1.1.2 Service Exchange: Technology-Driven Interactions for Value Cocreation in Coopetition Networks

S-D Logic recasts all social and economic actors as resource integrators within a network of networks, providing a foundational perspective on value creation in complex ecosystems [105]. This framework challenges traditional classifications of resources as operant (active) and operand (passive), emphasizing the importance of managing ephemeral aspects and the costs associated with using resources, among other factors.

Understanding resource integration in value networks requires examining how resources can initiate interactions [255] and how the nature of a resource's rights affects its capability to engage in contracts or agreements. This examination helps clarify the roles of accountable actors within these exchanges [256]. The distinction between the physical and non-physical nature of resources further delineates their tangibility and dependency within the Service Science literature [99].

Emerging technologies capable of self-governing behaviors and autonomously producing algorithms introduce a new dimension to resource integration [257]. These technologies, serving as operand and operant resources, assume dual roles in service innovation, potentially facilitating access to resources across competing actors within the network [258].

This evolving view of technology within coopetition networks as an initiator and enabler mechanism for value cocreation among actors highlights the critical role of operant and operand technologies in mitigating coopetition tensions [259] [26]. Utilizing technology as a reliable intermediary can bolster the acceptance of collaboration proposals among rivals, leveraging technology's impartiality to enhance trust and cooperation [260].

This exploration underscores the central role of technology in facilitating resource integration and service exchange within Coopetition Networks. By acting as both initiator and enabler, technology transcends traditional roles, becoming an essential facilitator of coopetition. Anchored in S-D Logic, integrating resources through operant and operand technology increases resource density. It enhances value cocreation processes among competing actors.

5.1.1.3 Institutions: Coordination of Coopetition Networks for Value Cocreation

Drawing from Scott's (2013) definition, Vargo and Lusch (2016) highlight the vital role of institutions within ecosystems as constructs comprising humanly devised rules, norms, and beliefs [157]. These constructs facilitate and limit actions, rendering social life predictable and meaningful [110]. This perspective has prompted a shift in S-D Logic literature towards a more dynamic and comprehensive view of value creation through exchange, offering insights into the ecosystem's structure that might remain obscured from a narrower dyadic perspective [115].

Technology, defined broadly as applied practical knowledge [261], intertwines with the institutional fabric of society, influencing and being influenced by the knowledge that constitutes our social structures [262]. Herbert Simon (1988) views design as a resource

reconfiguration to solve problems, positioning technology as an assembly of practices and components to fulfil human objectives [156]. In this context, social technologies—institutions [108]—embody the intersection of technology with institutional phenomena [110].

Within CN-VCC, technology enhances institutionalization, easing tensions and fostering positive outcomes from interactions among coopetitors. Technology serves both as a medium for conveying embedded knowledge and skills and as a mechanism for institutionalization [213].

Focusing on technology as an enabler and facilitator of service exchange, this perspective aligns with advancements in understanding Coopetition Networks [263] [81]. Shared institutions that underpin these exchanges underscore the role of technology as a repository of potentially valuable knowledge for future interactions within service ecosystems [264].

From the fractal approach presented in the previous chapter, by anchoring on S-D Logic's conceptualization of operant and operand technologies [265], the role of technology is recognized as central in facilitating value cocreation within Coopetition Networks. Institutional arrangements, defined as guiding institutions that shape thought and behavior through a framework of value assumptions, cognitive frames, rules, and routines [98], highlight the interplay between institutions and technology. This synergy suggests that embedding valuable knowledge within technological artefacts may offer innovative solutions to new and existing problems within service ecosystems [201].

This exploration underscores the integral role of technology as both an operand (enabler) and operant (initiator) resource within CN-VCC. By framing technology in its dual capacity, the discourse extends beyond traditional views, positioning technology as a central player in the institutional mechanisms that underpin value cocreation. This innovative approach to conceptualizing technology within the ecosystem facilitates a deeper understanding of how coopetition and institutional arrangements interlace, paving the way for practical solutions that harness the full potential of coopetition networks.

5.1.2 Performative Constructs for Service Exchange in Coopetition Networks for Value Cocreation

Building on the theoretical foundations as discussed, it is possible to outline the essential modular components—systemic constructs—crucial for constructing robust CN-VCC. Each construct addresses resource integration, service exchange, and institutional arrangements, focusing on how these elements interact to foster value cocreation within the network. This approach's core is the principle of mutual value cocreation, a fundamental tenet of S-D Logic, which unites resource integrators (actors) through service exchange coordinated by institutions and institutional arrangements [110]. This narrative highlights the intricate and dynamic nature of resource integration contexts, underpinned by the foundational axioms and meta-theoretical constructs of S-D Logic. These emphasize actor-to-actor networks, resource liquefaction, density, and integration as essential elements for service innovation [188]. Figure 5 illustrates the institutionalization process within CN-VCC at the meso-level.

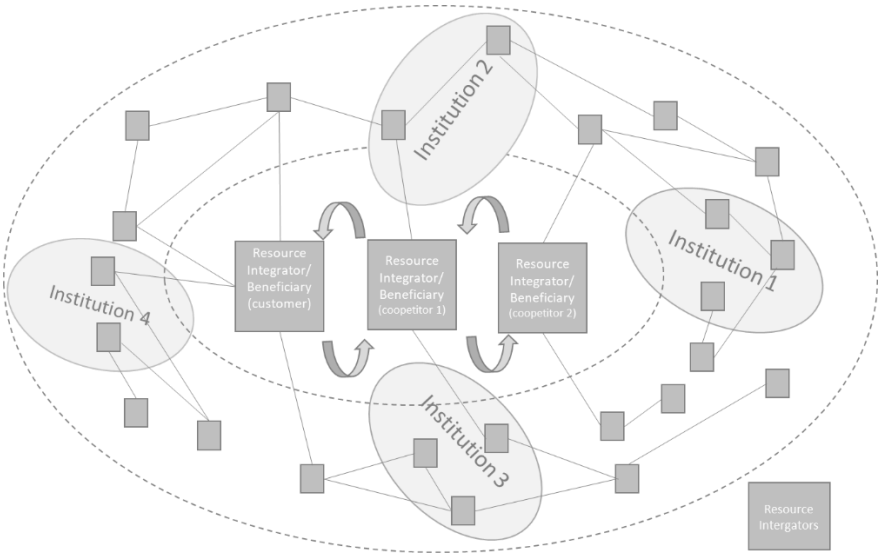


Figure 5. Institutionalization Process of Coopetition Networks for Value Cocreation

Performative Construct #1 (Coopetitors as Resource Integrators): This construct emphasizes the role of multiple actors—including customers, providers, competitors, and coopetitors—in integrating diverse resources such as market-facing, technological, financial, and public assets within actor-to-actor networks [266]. CN-VCC recognizes all these participants as potential innovators or value cocreators. Value arises from collective interactions, which combine and leverage these resources in a dynamic and innovative manner [209]. This approach positions each actor as an integral component of the ecosystem's overall functionality and success, highlighting the importance of active and strategic resource integration for sustained value creation [119].

Performative Construct #2 - Beneficiary-Centric Value Propositions: This construct focuses on the value propositions within the CN-VCC, uniquely shaped by the beneficiaries' experiences and perspectives. It involves the use of operant resources (initiators) and operand resources (facilitators) that together create new resources, thereby enriching the ecosystem's value [260]. It underscores the direct involvement of providers and coopetitors in service exchanges, enhancing resource density and amplifying ecosystem-wide value cocreation [188]. It highlights how actively engaging all stakeholders in shaping value propositions can lead to more effective and sustainable outcomes for all, including coopetitors.

Performative Construct #3 (Technology-Enabled Institutional Arrangements): This construct emphasizes the role of technology as a facilitator for new institutions and arrangements in shaping service exchanges among coopetitors. It posits that these institutions facilitate a structured yet dynamic cocreation process, effectively coordinating the CN-VCC interactions. Reflecting the S-D Logic perspective, these institutional arrangements are crucial for integrating resources and facilitating service exchange, ensuring that each interaction contributes positively to the ecosystem's value creation [225] [110].

Perceptions of technological value are shaped by institutional processes and practices that integrate it with other resources. These institutional processes are dynamic, facilitating the emergence, stabilization, and eventual disruption of predominant meanings and uses of technology [247]. Thus, in line with the emphasized role of institutions in market (re)formation, it is essential to view technological developments through an institutional lens. This perspective underscores the crucial importance of leveraging technology to enhance institutional effectiveness among coopetitors and to foster adaptability in rapidly evolving environments.

Performative Construct #4 (Institutionalization Process of Coopetition Networks): This construct emphasizes the central role of technology in the institutionalization process of CN-VCC. It demonstrates how operant (initiator) and operand (enabler) technologies contribute to the liquefaction of resources, thereby facilitating the establishment of new institutional arrangements [188]. These arrangements foster coopetition and value cocreation within ecosystems [260], [267]. By harnessing both facets of technology, this construct highlights the transformative potential of technological advancements in reshaping institutional landscapes and augmenting the collaborative capabilities of diverse ecosystem participants.

These constructs establish a robust framework for developing CN-VCC, which is designed to foster innovation, enhance resource integration, and create sustainable value through collaborative efforts. Each construct builds upon the others, forming a cohesive strategy that harnesses technology and institutional structures to enable effective and efficient networks. By leveraging insights from S-D Logic service ecosystems theory, these performative constructs define the core elements essential for the future development of CN-VCC.

5.2 IIoT-based Technology: Mechanisms for Enhancing Service Innovation in Ecosystems

The emergence of the IoT and embedded systems heralds a transformative era in which technology has a significant impact on ecosystems, a concept also embraced by S-D Logic [268]. IoT plays an instrumental role within these networks, linking actors via sophisticated sensor technologies [118].

Building on traditional IoT frameworks, the IIoT introduces heightened levels of efficiency and intelligence to industrial settings. This evolution enhances global connectivity and facilitates direct device communication [269]. These advancements support the creation of intelligent artefacts that participate in and actively enhance value cocreation processes, dynamically adapting to user interactions [253].

Empirical evidence underscores the transformative potential of IIoT-based innovations in fostering novel service offerings [270]. Companies leveraging IoT capabilities can extend their service portfolio to include options such as remote control and predictive maintenance solutions, which enhance operational efficiency and open new avenues for value cocreation within coopetition frameworks [271]. This technological integration catalysis the development of ecosystems where companies, by harnessing IIoT, transcend traditional competitive boundaries,

facilitating seamless resource exchange and collaboration among previously competing entities [270]. Through enhanced connectivity and data exchange, actors within networks can unlock new potentials for cooperation, driving forward the principles of S-D logic by expanding the scope and scale of value cocreation in the digital age.

In this context, an IIoT-based artefact represents significant potential in operationalizing CN-VCCs among SMEs. As established by the DSR methodology and building on the constructs described above, the subsequent sections will outline the mechanisms and strategic objectives that address the specific challenges of SMEs. This alignment with the SDGs ensures that the networks contribute to sustainable business practices.

5.2.1 Interoperability Mechanisms

Interoperability is fundamental to fostering effective collaboration within networks, facilitating the achievement of mutual goals, or enabling the controlled dissolution of cooperation in case of faults [272]. In the context of CN-VCC, exchanging information between operand and operant technology resources is crucial [273]. This necessitates that any IIoT-based system designed to enable coopetition within networks embeds mechanisms to address interoperability, focusing on semantic and pragmatic issues to ensure network capabilities are fully leveraged [274].

Semantic interoperability ensures that the meaning of exchanged information is understood across different systems, while pragmatic interoperability effectively uses this information in operational contexts [275]. Addressing these interoperability dimensions within IoT-based systems is crucial for enabling the seamless integration of diverse technologies and facilitating collaborative environments that foster coopetition [253].

Akaka and Vargo (2014) connected IoT to S-D Logic, emphasizing the crucial role of systemic interoperability in digital technologies within ecosystems. They highlighted how IoT systems embed service mechanisms that enhance interoperability and facilitate seamless integration. These mechanisms include:

Resource Density Mechanisms: These involve processing and analyzing information to support decision-making and action-taking processes. By enhancing the density of available resources [260], IoT systems can provide more nuanced insights and foster more informed cooperative and competitive strategies [268].

Digital Materiality refers to the capacity of software embedded in physical objects to manipulate their digital representations, thereby enabling new functionalities and interactions [268]. Digital materiality bridges the gap between the physical and digital realms, opening up new avenues for innovation and collaboration within collaboration networks [168].

By integrating these mechanisms, IoT-based systems designed for coopetition enablement in networks can support the dynamic exchange of service innovation [119], fostering an environment where collaborative and competitive interactions can thrive. This approach not only enhances the efficacy of coopetition strategies but also aligns with the evolving demands of

IoT-based networks, ensuring that networks remain adaptable, responsive, and capable of leveraging the full potential of IoT for value creation.

5.2.2 Usability and Accessibility Mechanisms

Usability and accessibility are foundational pillars in the architecture of coopetition networks [276], playing a pivotal role in ensuring the secure and efficient exchange of services among competing entities. These elements are crucial for leveraging interactions that enhance value creation within the ecosystem, perfectly aligning with the S-D Logic and principles of service science [60]. The orchestration of systemic assemblages [113] and architectural modules [277], specifically designed for seamless transactions and service delivery, falls under the strategic oversight of institutions and their governing arrangements [115].

The deployment of a knowledge-based system is central to facilitating this interaction within coopetition networks. This system combines operant resources, such as artificial intelligence or cognitive assistant modules [278], with operand resources, allowing for dynamic interactions on behalf of network participants [279]. Although this system actively contributes to the network's functioning, it inherently needs more legal accountability due to the absence of rights and duties typically associated with legal entities [280]. Integrating human resources into the system's operational framework is essential to bridge this gap. These individuals, skilled in maneuvering operant and operand technologies, ensure seamless operation, interaction, and collaboration within the network. Among them, a designated responsible party serves as the legal and operational nexus for the network actors, guaranteeing accountability and providing essential oversight. By integrating these mechanisms, a future IoT-based system can facilitate interaction by acting discreetly on behalf of coopetitors within the network, as described in Figure 6.

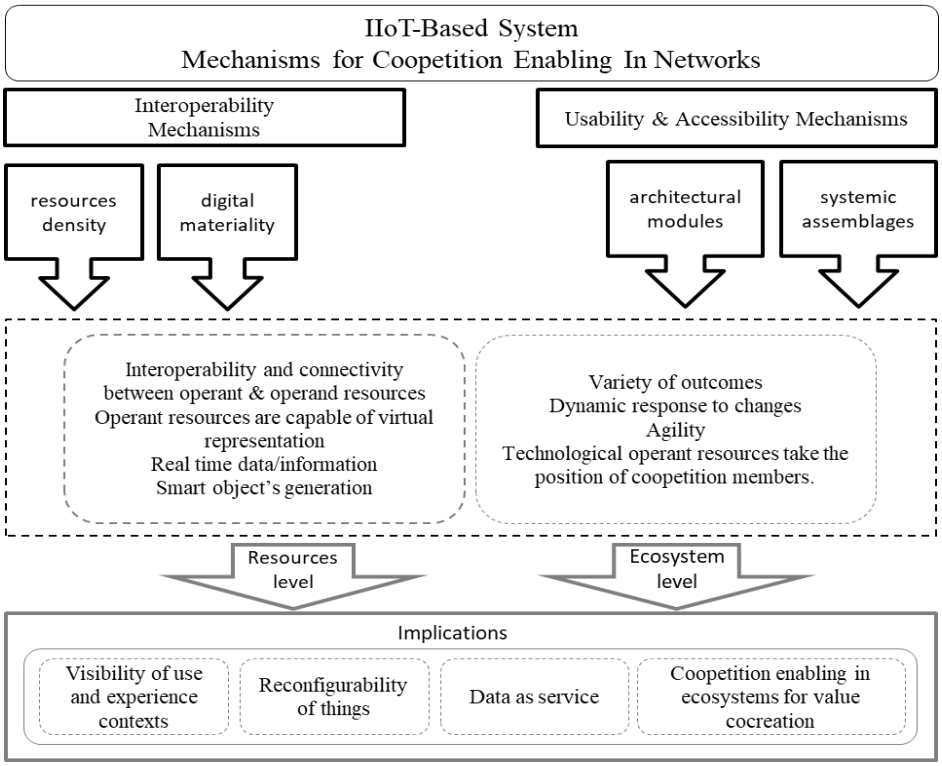


Figure 6. IIoT-Based System: Mechanisms for Enhancing Service Innovation in Ecosystems, Adapted from Ng & Wakenshaw (2017).

Physical Resources: This category encompasses the ICT infrastructure and hardware necessary for the technical foundation and operational capabilities of the CN-VCC.

Physical Resources with Rights: Human resources fall into this category, providing necessary oversight, decision-making capabilities, and legal accountability within CN-VCC.

Non-physical-with-no-rights Resources: This includes data and software elements (operand and operant) that facilitate the digital interactions and processes within the CN-VCC.

By equipping the system with these diverse resource types, CN-VCC can effectively manage usability and accessibility, fostering secure and productive exchanges of service. This approach enhances the potential for value creation within the ecosystem. It addresses the legal and operational challenges of integrating advanced technologies like IoT into coopetition strategies.

5.3 Objectives and SDG Alignment

As outlined in the methodology chapter, the purpose of the CN-VCC framework includes the design and development of the IIoT-based system and its practical application in the real world. This framework is intended for use in the Portuguese Ornamental Stone Sector to demonstrate its impact on crucial SME metrics. Consequently, as inferred from surveys conducted by Silva and Cardoso (2023), for the framework acceptance as a viable solution, it must ensure positive improvements within the participating SMEs in areas such as process efficiency, scalability, customer satisfaction, and ecological impact reduction [57], [59].

It involves conducting an Experimental Pilot Project systematically collecting empirical data and feedback from participating SMEs. The goal is not only to assess the effectiveness of the artefact but also to identify opportunities for further refinement and improvement. Additionally, this study aims to explore how the CN-VCC aligns with and contributes to the SDGs [281], providing insights into its broader societal and environmental impacts. Particular attention is given to SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). This alignment will be scrutinized to understand how coopetition in the Portuguese Ornamental Stone sector can advance global efforts towards sustainable development.

5.4 Preliminary Evaluation Survey of the CN-VCC Framework

A preliminary evaluation was conducted to assess the CN-VCC concept's potential to address challenges faced by OS-PT SMEs in the BIM-influenced supply chains of the AEC.

The evaluation utilized a survey targeting managers from 24 OS-PT SMEs that were strategically chosen to represent a spectrum of digital maturity levels within the industry. This selection ensured a diverse and representative sample, providing valuable insights about the CN-VCC concept at various stages of digital readiness among the participating SMEs.

For the survey, each participating company was assigned the digital level (DL) based on comprehensive site visits, categorized as follows: DL0: No digital tools are used; DL1: At least one computerized machine on the manufacturing shop floor; DL2: All machines are computerized; DL3: All machines are computerized and connected to the ERP system; and DL4: All machines are connected to the ERP system and can connect to BIM architects' stations. The survey included a comprehensive assessment covering each company's operations. It focused on evaluating the digital production equipment, management practices, integration of processes within production settings, and the companies' engagement with digital marketplaces. To effectively gather this information, the questionnaire was structured into four distinct actions:

Action 1—Introduction to Respondents: Participants were briefed on the evolving landscape in the construction industry. According to experts, including Blanco and Chen (2014), building designs will increasingly utilize BIM technology. This shift is expected to change material procurement practices [282] significantly. Providers, such as ornamental stone companies, must enhance scale, price flexibility, and delivery speed to maintain competitiveness under these new conditions. Such improvements may only be feasible through collaborative approaches with competitors.

Action 2 - Hypothetical Scenario: Respondents were presented with a hypothetical scenario in which they might use technology, such as home banking systems, to facilitate collaboration with competitors under strict commercial secrecy until the buyer decides. This technology would be specifically developed to enhance company operations.

Action 3 - Importance Rating Question: In this new technological environment, participants were asked to rate the importance of various factors to their company on a scale from 1 to 5. These factors included operational efficiency, scale, customer satisfaction, and energy reduction.

Action 4—Data Collection: Throughout 2023, selected managers from the participating companies were interviewed face-to-face. The names of the companies were not disclosed to keep confidentiality. The survey results were systematically recorded in an Excel file.

The preliminary evaluation of the CN-VCC framework yielded an encouraging average rating of 3.8 out of 5, reflecting strong endorsement by OS-PT managers. This positive response underscores respondents' belief that a system based on the CN-VCC concept can significantly mitigate industry-specific challenges. Furthermore, the results demonstrate a clear positive correlation between digital advancement and managers' confidence in the CN-VCC system's ability to address these challenges. Visual summaries of these findings are presented in Figure 7.

A slope of 0.465 reveals a positive and moderate performance improvement rate as the digital level increases. This implies that higher levels of digital integration are potentially associated with substantial enhancements in operational and competitive capabilities within the coopetition network. The 0.465 unit increase per level of digital maturity is significant, indicating that as companies adopt advanced digital technologies, they experience notable improvements in performance metrics, including scaling, production efficiency, supply chain efficiency, and customer satisfaction. With an R^2 value of 0.926, 92.6% of the variability in performance improvement can be explained by digital maturity, indicating a strong fit of the linear model and highlighting digital maturity as a key predictor of performance gains in technology-enabled coopetition.

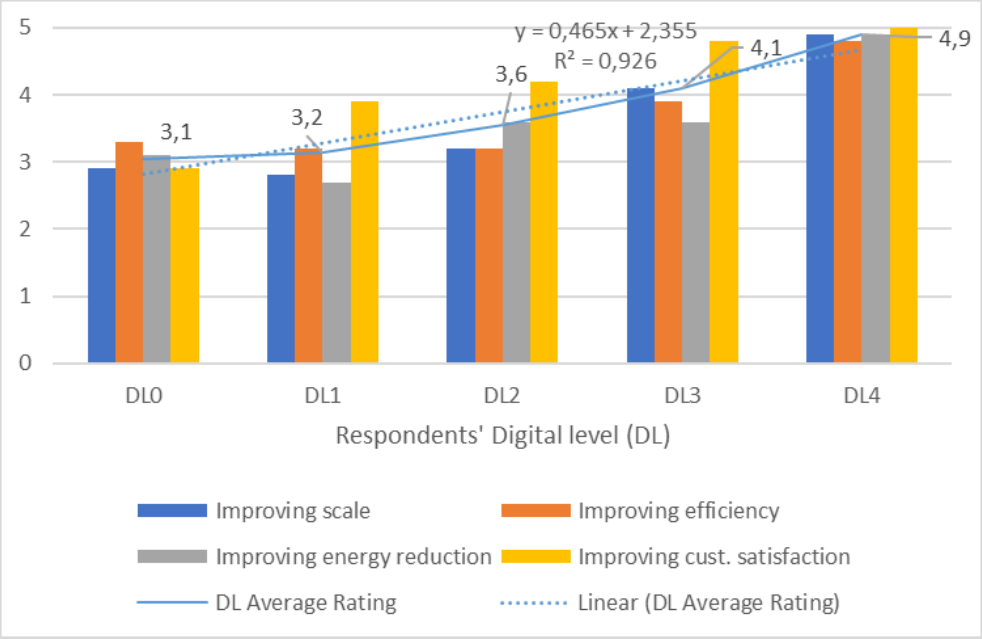


Figure 7. Survey Outputs: Preliminary Evaluation of the CN-VCC Framework Based on Interviews with OS-PT SMEs.

This enthusiastic feedback highlights the CN-VCC architecture's potential to tackle the pressing issues of the OS-PT. These insights will be instrumental in guiding the design of the artefact, ensuring it is tailored to meet the evolving needs of OS-PT SMEs. This strategic focus aims to harness the untapped potential of coopetition to foster sustainable and innovative growth within the sector.

Chapter 5. Summary

This chapter establishes the foundation for designing effective and sustainable Coopetition Networks, refining key constructs and technologies for SMEs by drawing on insights from previous chapters and S-D Logic. The framework developed addresses specific challenges faced by SMEs, supporting their growth and sustainability.

A preliminary evaluation of the CN-VCC concept was conducted through a survey of 24 OS-PT SME managers with varying levels of digital maturity. The positive feedback highlights the CN-VCC architecture's potential to address key challenges in the BIM-influenced AEC sector.

These findings will guide the design of a CN-VCC framework in the next chapter, which will also develop an innovative IIoT-based system for integration.

Chapter 6. Designing Coopetition Networks for Value Cocreation

A wise man will make more opportunities than he finds. - Sir Francis Bacon

Building on the foundational insights from previous DSR activities, Activity 3 transitions from theoretical exploration to the practical design and implementation of a Coopetition Network for Value Cocreation (CN-VCC). This chapter shifts the focus towards technology-enabled solutions for fostering coopetition among SMEs. Following the DSR guidelines [227], the emphasis is on designing a knowledge-based solution rooted in S-D Logic.

The primary objective is to develop a robust CN-VCC framework that operates effectively within global and digital supply chains. This effort involves creating both a conceptual framework and an operational technology known as the Coopetition Technology-Enabled Service Ecosystem (CN-EcoTech), specifically tailored to address the unique challenges faced by SMEs (illustrated in Figure 8).

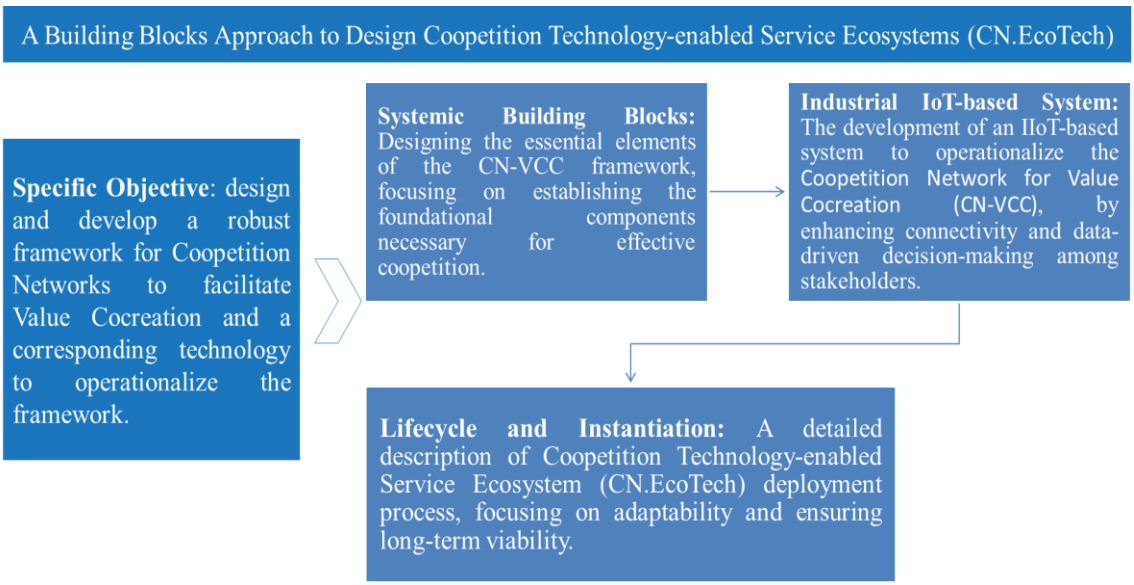


Figure 8. Chapter 6 Graphical Abstract: The Building Blocks Approach for Coopetition Networks.

The design process is organized into three strategic steps throughout the chapter, each grounded in S-D Logic and DSR methodology. This structured approach is visually represented through a graphical abstract that illustrates a fractal approach to designing CN-VCCs.

6.1 Building Blocks for Coopetition Networks for Value Cocreation

The Building Blocks approach offers a systematic framework for developing complex systems by breaking them into simpler, manageable components [283]. As detailed by Krishnan, Kim, and Kota (2012), this approach facilitates the modular assembly of these components, enhancing the structure and efficiency of the development process [284]. The method begins with the most fundamental units, known as "coupons," and progresses through elements, sub-components, and full-scale components, culminating in comprehensive system testing [285].

Historically, this approach has been pivotal in developing systems like trains, planes, automobiles, and electronic gadgets, enabling designers and engineers to concentrate on efficiently designing and testing each component [286]. By decomposing these complex systems into smaller subsystems or building blocks, the development process becomes more streamlined, enhancing the precision and reliability of the overall system.

In modern applications, the building blocks methodology transcends traditional design and production, serving as a versatile tool for developing structured processes and models that adapt to the dynamic requirements of various industries. This approach supports iterative design, testing, and integration processes through modularizing system components, allowing for the controlled evolution of complex systems [284].

Applying this methodology to design a Competition Network for Value Creation provides a strategic framework for decomposing the ecosystem into manageable modules. This structured approach enables the precise identification and integration of essential functionalities, from resource integration and service exchange to the establishment of institutional arrangements, ensuring a cohesive and scalable coopetition network architecture.

By leveraging a modular and structured approach, CN-VCC development can advance in a phased and iterative manner. This modularity allows for design flexibility, accommodating adjustments and enhancements based on stakeholder feedback and evolving sector needs, thus ensuring the coopetition's long-term viability and effectiveness. This strategic implementation fosters robust coopetition networks among SMEs, enhancing their ability to create value collaboratively while maintaining competitive integrity.

6.2 Theoretical Background: Coopetition Networks for Value Cocreation

The journey of DSR methodology extends into synthetic and analytical exploration, utilizing technology systems to enhance business and organizational processes [287]. S-D Logic enriches this exploration by recognizing technology as operant and operand within ecosystems [191]. Moreover, discussions on coopetition networks highlight technology-based strategic alliances as critical to fostering innovation [288].

Within networks, the fluidity of roles—where providers and coopetitors interchange—highlights the dynamic service processes that characterize these ecosystems [289]. DSR provides pragmatic lenses that offer researchers a non-intrusive perspective to observe these dynamic interactions [290] [291], while S-D Logic emphasizes the performative aspect of addressing real-world challenges. This approach examines the collaborative efforts among service objects, technology systems, organisations, and individuals to cocreate value within an actor-driven system, continually evolving through reciprocal value propositions [113]. However, a knowledge gap remains concerning the specific roles of coopetition actors as resource integrators [136].

The viability of coopetition depends on creating environments that are conducive to future resource integration and service exchange, thereby fostering long-term relationships among rival firms [78]. Viewing this issue through the outlined S-D Logic's ecosystems requirements in the previews chapter suggests that envisioned coopetition networks should be self-contained, self-adjusting systems of resource-integrating actors [209]. These actors, connected by shared institutions, facilitate mutual value creation through multi-level service exchanges [198], requiring an in-depth exploration of the interactive dynamics and orientations of coopetition as a significant contribution to knowledge and practice.

6.3 Systemic Building Blocks for Coopetition Networks for Value Cocreation

Anchored in S-D Logic's service ecosystems framework, the building blocks form the foundation for developing effective Competition Networks for Value Cocreation. They encapsulate the systemic elements that facilitate value co-

creation in coopetition networks. Drawing from established systemic constructs, these Building Blocks illustrate how coopetition unfolds strategically, engaging various actors in a dance of collaboration and competition that enriches the service ecosystem.

Recognizing that coopetition is inherent to some degree in every ecosystem [288], the systemic constructs of CN-VCCs are fundamentally based on S-D Logic. Additionally, given the performative nature of service ecosystems [215], these networks, coordinated through shared institutions and institutional arrangements, contribute to the formation of nested and overlapping service ecosystems [97].

By adopting this institutional perspective, coopetition within networks for value cocreation unfolds through a coherent value creation narrative via resource integration and service exchange. These processes are coordinated by shared institutional arrangements that define nested and overlapping service ecosystems [196]. Specifically, from a service ecosystems perspective, the building blocks for CN-VCCs are (1) coopetition actors, (2) engaged in resource integration, (3) facilitating service exchanges, which are enabled and constrained by (4) endogenously generated institutions and institutional arrangements. These elements establish (5) nested and overlapping service ecosystems, (6) forming the context for future resource

integration, service exchange, and enhancements—thereby boosting the dynamics of coopetition in network value creation.

Figure 9 succinctly captures these systemic building blocks essential for forming CN-VCCs from this framework. It demonstrates their interconnected roles in facilitating the growth and development of such networks.

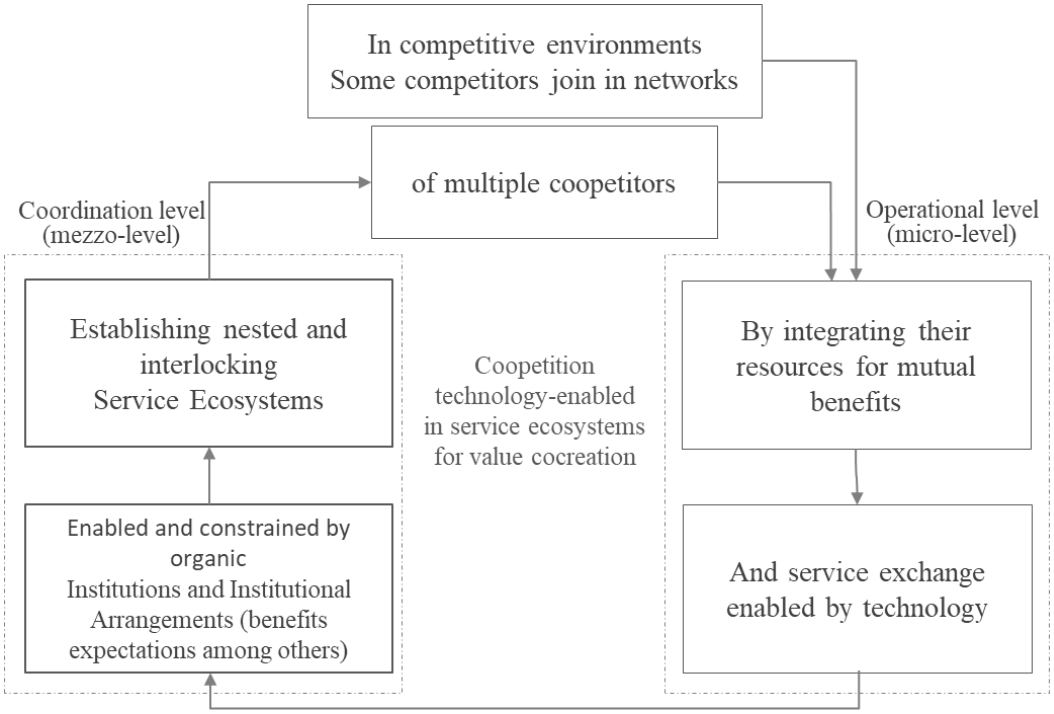


Figure 9. Building Blocks for Coopetition Networks: Value Cocreation.

For comprehensive details on the Building Blocks, please refer to Appendix I, specifically Table 6.1, where each element is thoroughly described within the context of their application in CN-VCCs.

6.4 Framing Actors and Resources

S-D Logic posits that in service ecosystems, providers extend value propositions that leverage their specialized knowledge and skills to benefit others, primarily customers who derive value through utilization or experiential interaction [60]. Moreover, economic exchange is viewed not just as a transaction but as the application of competencies for mutual benefit, emphasising that value is cocreated, with goods simply facilitating this process [184]. These propositions are seen as algorithmic requests between actors, shaped by culturally informed value principles and the diverse perspectives of all actors involved—customers, providers, authorities, and competitors [292]. The iterative cycle of these value propositions leads to value cocreation, which stimulates further propositions dependent on effective resource integration. Failures in resource integration can lead to breakdowns in the network's functioning [146].

Providers' willingness to engage in coopetition—collaborative interactions with potential competitors—highlights a strategic approach to enhancing value creation by leveraging shared resources [72]. These engagements enrich the ecosystem's resource density and exemplify the emergence of CN-VCCs, where competitors directly participate in value cocreation processes [194].

6.4.1 Providers' Resources in Coopetition Networks for Value Cocreation

In CN-VCCs, providers transcend traditional roles, serving as suppliers and facilitators within the S-D Logic framework [105]. This role emphasizes the critical importance of customer engagement in the value creation process, where value is derived from transactions and the integration of the provider's offerings with customers' experiences [113].

The digitalization of supply chains has significantly increased reliance on advanced technologies, enabling providers to meet the growing demand for personalized and customized products from consumers. This shift requires innovative strategies to capture and retain customer interest [293], fostering a positive value cocreation environment through technological enhancements that cater to personalized experiences [294], either without direct customer input or through customization that solicits customer preferences [270].

Anchored in the CN-VCCs framework described above, providers can be classified into two distinct categories: 'providers,' who compete autonomously, and 'coopetitors,' who engage through the Coopetition Network. This classification elucidates the varied roles and strategies within the network. Providers contribute a comprehensive range of resources to CN-VCCs, including direct customer-facing resources and backend support, as detailed in Appendix I, Table 6.2. By leveraging these diverse resources, providers aim to enhance their competitive position within global and digital supply chains, thereby significantly contributing to the ecosystem's profitability and long-term sustainability [295]. This approach aligns with the overarching goals of S-D Logic, which promotes a more integrated and cooperative competitive environment [76].

6.4.2 Coopetitors' Resources in Coopetition Networks for Value Cocreation

In Competition Networks for Value Cocreation, the transformative approach involves providers extending their roles beyond conventional limits to collaborate with competitors, sharing both operant and operand technology resources [71]. This evolution is grounded in the S-D Logic, which recognizes the intricate dynamics of both cooperation and competition [244]. The goal is to increase resource density and foster innovation, thereby enhancing the viability and value creation within the network [288].

"Coopetitors" are a distinct class of providers who voluntarily share and access specific, ecosystem-aligned resources, acting as crucial players in amplifying the network's

competitiveness and sustainability [72]. Their role is vital in facilitating value creation, impacting not just direct interactions with customers but also the collective capability across the entire ecosystem [29].

The resources that Competitors contribute to the Competition Networks for Value Creation are diverse and multifaceted, as comprehensively detailed in Appendix I, Table 6.3. By strategically leveraging these varied resources, competitors not only strengthen their competitive positions within global and digital supply chains but also make substantial contributions to the ecosystem's profitability and sustainability. This strategic utilization of resources facilitates a synergistic environment that enhances collective capabilities and drives long-term viability within the network.

6.4.3 The Role of Customers

In CN-VCCs, customers play a role that transcends traditional purchasing activities. According to S-D Logic, customers actively acquire value propositions that facilitate service exchange and cocreation of value rather than merely buying goods or services [185]. This perspective views customers as vital participants in the value cocreation process, who assess offerings based on their experiences and the utility derived from usage [266].

In these networks, customers utilize digital global marketplaces to access a diverse range of resources, including expert consultation, strategic partnerships, and exclusive technological insights [296]. S-D Logic emphasizes a value-in-use perspective, where the significance of an offering is measured by the utility and experiences it provides rather than the cost of the transaction [155].

Thus, within CN-VCCs, customers are addressed as dynamic actors whose interactions with providers and the network continually refine value propositions and enhance resource integration. This proactive involvement not only drives the development of the ecosystem but also underscores S-D Logic's core principle that value is cocreated through ongoing, reciprocal service exchanges among all actors within the ecosystem [297].

6.4.4 The Role of Competitors

Competitors play a dynamic role in the nuanced landscape of CN-VCCs, embodying both rivalry and potential collaboration [22]. Their ability to exit the ecosystem at will highlights the fluid boundaries between competition and coopetition, reflecting strategic flexibility that fosters innovation and sustains the ecosystem’s vibrancy [98]. This competitive spirit is essential, catalysing sustainable innovation by ensuring that the ecosystem remains a hotbed of creative, evolutionary advancements [256].

Competitors in CN-VCCs are not only challengers but also complement the ecosystem's fabric through potential substitution and innovation. Thus, competitors are viewed as adversaries and vital components of the ecosystem's diversity, contributing to its resilience and adaptability.

They bring the potential to introduce alternative solutions or substitutes, thereby enhancing the overall value proposition with novel ideas and approaches [298].

This systemic perspective emphasizes the importance of competitors in maintaining the ecosystem's health and dynamism. It underscores that competition and coopetition are interconnected forces that propel the ecosystem forward. By promoting an environment where innovation is both a result of and necessary due to competitive-cooperative interplay, CN-VCCs harness the unique contributions of competitors to ensure continuous improvement, adaptability, and compelling value cocreation among all participants.

6.5 Industrial IoT for Coopetition Enabling

The rapid march toward digitalization has ushered in a new era of interconnectedness and operational efficiency across industrial sectors, significantly driven by the advent of the IoT [299]. This evolution is profoundly reshaping the landscape for manufacturing SMEs, presenting unprecedented opportunities for innovation, collaboration, and value creation within ecosystems [109].

Digitization—transforming analogue information into digital formats—sets the foundation for digitalization [300], which utilizes Information and Communication Technologies (ICT) to integrate digital networks into business operations [301] seamlessly. This integration redefines traditional businesses and workspaces [215], demanding a transformative approach to enterprise development [270].

Initially conceptualized by Kevin Ashton in the late 1990s, the IoT paradigm envisioned a world where every object can connect autonomously to the Internet, enabling a seamless data exchange with minimal human intervention [302]. This vision has become a reality with advances in wireless technology, sensor development, and computing capabilities, enabling uniquely identifiable objects to communicate over the Internet and support services like remote monitoring and predictive maintenance [303].

Expanding on the IoT, the IIoT introduces new levels of efficiency and intelligence into industrial systems, enhancing global connectivity and enabling direct device communications [269]. These capabilities allow for the development of intelligent artefacts that actively participate in value-creation processes, responding dynamically to user interactions [253].

The evolution of IIoT signifies a shift toward a hyper-connected society and a globalized economy, where technologies facilitate complex interactions between machines, providers, customers [276], and even rivals (coopetitors) within technology-enabled networks [304]. These interactions foster a comprehensive approach to value creation, culminating in collective value that aligns with the principles of S-D Logic [201].

This exploration into the roles of digitization, digitalization, and IoT highlights their crucial impact on fostering coopetition within networks, enhancing operational efficiencies, and redefining the dynamics of collaboration and competition. Such technological advancements set

the stage for a future where technological artefacts are central to creating shared value in interconnected industrial ecosystems.

6.6 Integrating Industrial IoT in Coopetition Networks for Value Cocreation

Recent advancements in IIoT technologies have shown significant potential in enhancing service knowledge. However, a gap remains in effectively harnessing these technologies to foster value cocreation through coopetition, particularly within manufacturing SMEs [305]. The S-D Logic view, which highlights the interconnectedness of IoT within ecosystems [118], offers a profound understanding of how actors, linked by sensors, can be located, identified, and influenced remotely, enabling innovative services such as remote control and predictive maintenance [306].

S-D Logic elaborates on value cocreation involving customers through operant (capabilities) and operand (resources) technologies. At the same time, IIoT merges the Internet's global reach with the capacity to manage physical entities—such as goods, machinery, and infrastructure—revolutionizing industrial operations [118]. Despite some intelligent systems exhibiting specific functionalities and responsiveness to user interactions, there is a notable need to enhance creativity in complex scenarios, suggesting that the full potential of smart objects has yet to be fully realised [307].

By adopting an S-D Logic approach, IIoT is positioned as a strategic tool for value cocreation [118]. This approach significantly enhances the flow of information and resource sharing within networks, boosting firms' responsiveness and adaptability [188]. This paradigm shift transforms technology from merely facilitating to actively participating in the service ecosystem, opening new avenues for value creation [119].

Furthermore, IIoT can catalyze both cooperation and competition within SME networks [271], promoting a coopetition framework where firms can share resources and insights while maintaining their competitive edge. This functionality enables SMEs to address inherent challenges, such as scaling, and capitalize on new opportunities without compromising their distinct value propositions [308]. The intricate balance of cooperation and competition, facilitated by Industrial IoT, exemplifies the nuanced dynamics of CN-VCCs, where simultaneous value creation and differentiation thrive and bolster one another.

6.6.1 Embedding Industrial IoT in Coopetition Networks for Value Cocreation

The IIoT represents a transformative force in the manufacturing sector, particularly for SMEs, propelling them toward more intelligent, autonomous, and interconnected processes [276]. This shift toward intelligent manufacturing underscores the IIoT's crucial role in forging a more cohesive, efficient, and competitive industrial landscape [309].

However, the integration of coopetition networks within the IIoT introduces several challenges. The success of these networks often relies on the involvement of key entities, with dominant companies playing a crucial role in ensuring the network's survival and prosperity [310]. Existing literature highlights the difficulty in establishing successful coopetition networks composed solely of SMEs, emphasizing the necessity of 'keystone' players for ecosystem sustainability.

Key challenges include data security and “secrecy”, which is critical in environments where participants may be competitors [59]. Interoperability is another significant issue, requiring various systems and organizations to collaborate effectively while balancing cooperative and competitive interests [311]. Moreover, intellectual property management becomes crucial as companies must navigate the delicate balance of sharing enough to create collective value without undermining their competitive advantages.

As highlighted in the previous chapter, navigating the complexities of Coopetition Networks requires a strategic approach to technology collaboration that focuses on achieving collective wins within the ecosystem. This interconnectedness ensures that advancements in one area can have a positive ripple effect throughout the entire network, exemplifying the intricate and mutually beneficial nature of Industrial IoT-enabled coopetition. To effectively address these challenges within the framework of Service-Dominant Logic, a set of pivotal solutions is essential. These are designed to enhance value cocreation across the network and are thoroughly detailed in Appendix I, Table 6.4.

Focusing on these areas, IIoT, once embedded, can effectively support cooperation strategies among SMEs, fostering innovation, efficiency, and competitive advantage in the rapidly evolving industrial landscape.

6.6.2 Industrial IoT Advancements: Cockpit4.0+

DSR is a distinctive methodological paradigm that surpasses traditional research approaches, including positivist, interpretive, and critical methodologies. It is keenly focused on developing and rigorously evaluating artefacts designed to address practical challenges [291]. As defined by Peffers et al. (2007) and elaborated by Baskerville et al. (2018), DSR involves the creation and assessment of various artefacts, including models, methods, constructs, software, and technological systems, aiming to develop effective solutions that not only solve practical problems but also enhance theoretical understanding of these issues [231]. This approach is particularly relevant in the context of Industrial IoT, where the development of novel artefacts contributes significantly to operational improvements and academic insights.

A notable example within this framework is the Cockpit4.0 system, developed through the Inovstone4.0 R&D Project[6]. Representing the state-of-the-art in OS-PT sector [312], this system has revolutionized the way ornamental stone processing SMEs connect to the digital market,

[6] https://www.inovstone.pt

notably through its 'fingerprint4.0' functionality [313], which refines product specifications and fosters value cocreation between providers and customers, enhancing customization and operational productivity [246]. Recognized as a benchmark in the sector, Cockpit4.0 exemplifies the transformative impact of IIoT in redefining market dynamics through direct engagement and cooperative efforts [312].

Viewed through the S-D Logic lens, Cockpit4.0 is a dynamic enabler of cyber value propositions, improving service delivery [103]. This perspective highlights an opportunity to enhance the technological landscape of the stone processing industry, thereby boosting competitiveness among SMEs. Strategic pooling of resources from rivals could significantly enhance network-wide value creation, delivering superior customer outcomes.

Addressing the challenge of coopetition network frequent failures [28], particularly in the absence of leading players, an enhanced version of the system, named Cockpit4.0+, is proposed in this research. This new iteration aims to bridge the gaps in connectivity, efficiency, and responsiveness, creating an ecosystem where SMEs can prosper through collective innovation and adaptive strategies. Cockpit4.0+ is designed to foster a more cohesive and collaborative industrial environment, where integrating technological innovation and S-D Logic principles ensures sustainable development and increased customer satisfaction.

6.6.2.1 Operant Capabilities

By incorporating artificial intelligence (AI) and machine learning (ML), the Cockpit4.0+ system discreetly enhances the network resources of coopetitors, such as machines and inventory. This integration facilitates sophisticated data analysis, market trend forecasting, and the generation of actionable intelligence. Such capabilities support dynamic pricing strategies, predictive maintenance, and the customization of offerings to meet specific customer needs. The AI module within Cockpit4.0+ provides real-time advisories to each coopetitor about the optimal combination of resources, including those from competitors, throughout the sales cycle, from lead acquisition to the outcome of a deal. Meanwhile, the ML module continuously offers real-time insights into the performance optimization of various resources, including manufacturing assets, human resources, and financial capital.

6.6.2.2 Interoperability Mechanisms

The Cockpit4.0+ system's integration of OPC Unified Architecture (OPC UA) significantly extends its interoperability capabilities, enabling a robust network of adaptable connections across various platforms and devices [253]. This feature is crucial for fostering deeper collaboration among SMEs by effectively utilizing shared resources and capabilities. It ensures that all participants can contribute to and benefit from the value-creation process regardless of their technological infrastructure.

Central to Cockpit4.0+'s functionality are the principles of Resource Density and Digital Materiality [188], which redefine value cocreation within networks by enabling the liquefaction

and segmentation of resources. It facilitates the dynamic combination of capabilities to meet customer needs precisely, enhancing adaptability and innovation potential. The Digital Materiality Mechanism, in particular, merges digital and physical dimensions to enable intricate product development and customization. It is critical for SMEs that aim to differentiate themselves with unique value propositions.

As depicted in Figure 10, implementing OPC UA within the Cockpit4.0+ underscores a strategic commitment to creating a fully interoperable network. This setup allows seamless and secure communication across various operational layers, from machine-to-machine interactions to comprehensive device-to-cloud data exchanges.

OPC UA plays a crucial role in ensuring data integrity and security, particularly when handling sensitive information or executing complex transactions across the network. Additionally, the OPC UA integration supports a pre-validation process that allows stakeholders to assess and refine value propositions before manufacturing begins, which is crucial for maintaining high-quality standards, reducing waste, and optimizing resource efficiency.

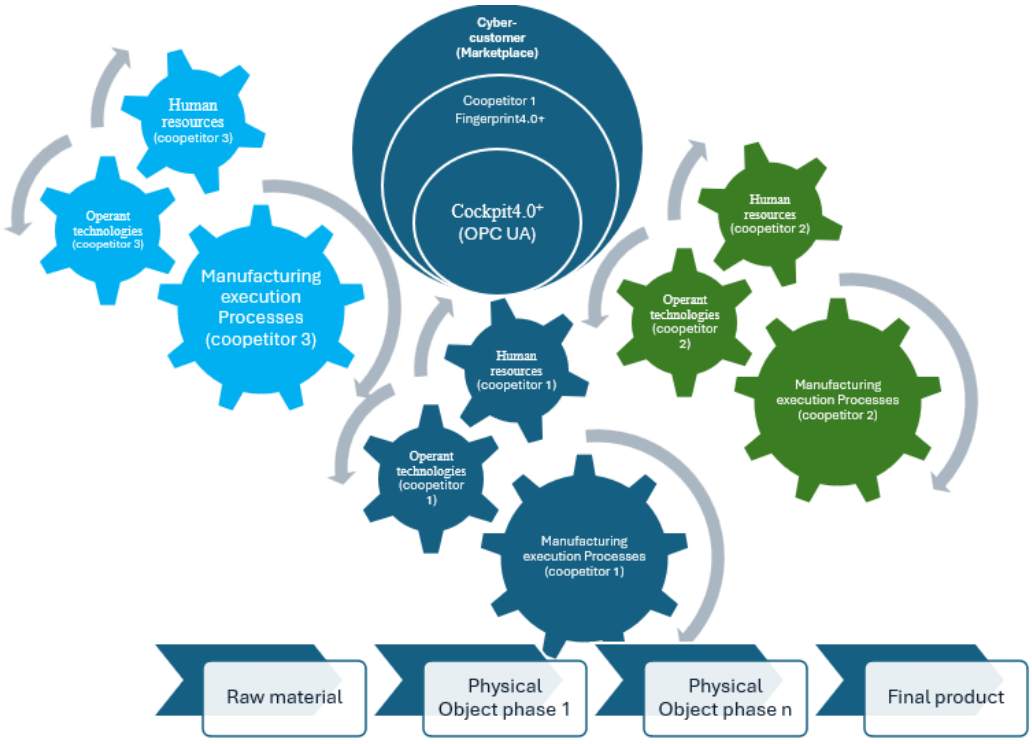


Figure 10. Leveraging OPC UA to Enhance the Cockpit4.0+'s Interoperability.

This approach enhances SMEs' competitiveness and agility in a rapidly evolving market, facilitating a more connected and collaborative industrial environment.

6.6.2.3 Network Actors' Accessibility and Usability

To ensure usability in CN-VCCs, Cockpit4.0+ is committed to creating an accessible and intuitive technological ecosystem available to all network participants whenever needed.

Grounded in human-centered design principles [314], this system aligns with the value cocreation perspective of Service-Dominant Logic. The key features of Cockpit4.0+ are detailed in Appendix I, Table 6.5 and depicted in Figure 11.

The deployment of OPC UA not only enhances security measures but also facilitates a cooperative environment where different instances of Cockpit4.0+ represent various stakeholders, from customers to competitors. This arrangement enables a multifaceted value cocreation process, fostering sustained collaboration throughout the lifecycle of business opportunities—from initiation to conclusion.

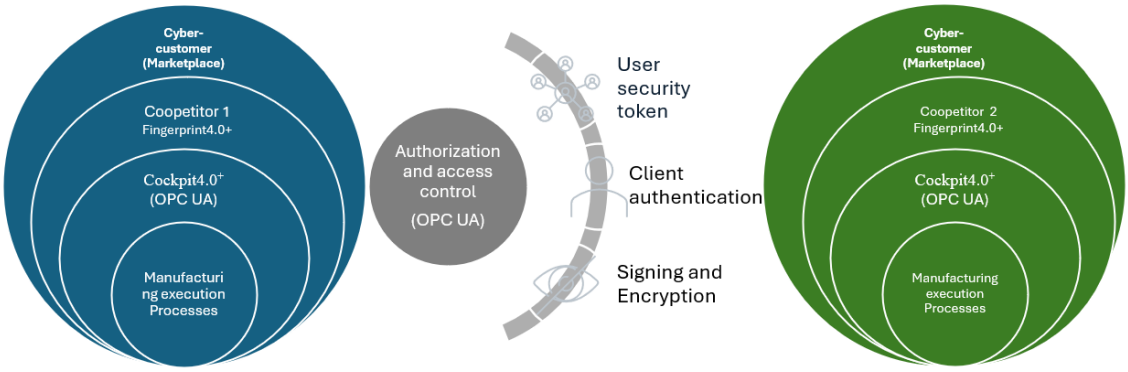


Figure 11. Accessibility and Usability Mechanisms for Cockpit4.0+.

By integrating systemic assemblages and modular designs and augmenting these with OPC UA's robust security and interoperability features, Cockpit4.0+ establishes itself as a secure, adaptable, and user-friendly platform. It facilitates dynamic collaboration and value cocreation, driving technology-enabled networks towards greater inclusivity and a shared commitment to innovation and success.

6.6.3 Algorithm: Cockpit4.0+ Development

The development of the Cockpit4.0+ system initiates by identifying specific features and functionalities critical for addressing the dynamics of coopetition. These elements provide a foundation for understanding, engagement, and the collective pursuit of new business opportunities. The Cockpit4.0+ development process involved designing an algorithm that integrates operant and operand technological capabilities. This integration ensures interoperability across different levels, enhances accessibility and usability for network participants, and promotes effective collaboration among competitors. The algorithm, detailed in Appendix, Table 6.6, encompasses the core functionalities and ensures systematic implementation of the system's features as described below:

Advanced Communication and Data Sharing Tools: (i) Secure Messaging and File Sharing - implementation of encrypted communication channels and secure file-sharing capabilities ensures the safe exchange of information and resources among competitors, maintaining confidentiality and integrity; and (ii) Real-Time Collaboration Spaces - provision of tools like

shared digital whiteboards and co-editing documents facilitates seamless collaboration, enabling participants to work together effectively from various locations.

Access Control and Privacy Mechanisms: (i) Granular Permission Settings - a sophisticated access control system allows precise control over shared data and resources, safeguarding sensitive information by restricting access based on roles or needs; and (ii) Data Anonymization and Aggregation - employing data anonymization techniques to share insights without compromising competitive advantages, enabling collective benefit from aggregated data without revealing proprietary information.

Interoperability and Integration Capabilities: (i) APIs for Third-Party Integration - robust APIs ensure smooth integration with existing systems and platforms, streamlining workflows and facilitating efficient data exchange among competitors; and (ii) Standards Compliance - ensuring the system adheres to industry standards for data exchange and interoperability, facilitating seamless communication and collaboration across diverse technological environments.

Cocreation and Innovation Platforms: (i) Idea Management Tools - tools that support the collection, development, and evaluation of ideas collaboratively, driving innovation within the coopetition framework; and (ii) Prototype Testing Environments - virtual spaces where new products or services can be tested and refined together, speeding up the innovation process and reducing the time to market.

Conflict Resolution and Governance Structures: (i) Transparent Governance Mechanisms - clear rules and governance structures are established for managing coopetition, ensuring all parties have input in decision-making processes and access to dispute resolution mechanisms; and (ii) Performance Tracking and Reporting - integrating tools for monitoring collaboration progress and outcomes, ensuring transparency and accountability for all network participants.

Figure 12 showcases the operational interface of Cockpit4.0+, demonstrating the algorithm's practical application in a system for real-world settings. This interface enables users to efficiently navigate through various modules, access essential information, and engage in cooperative activities, all designed to support Competition Networks for Value Cocreation.

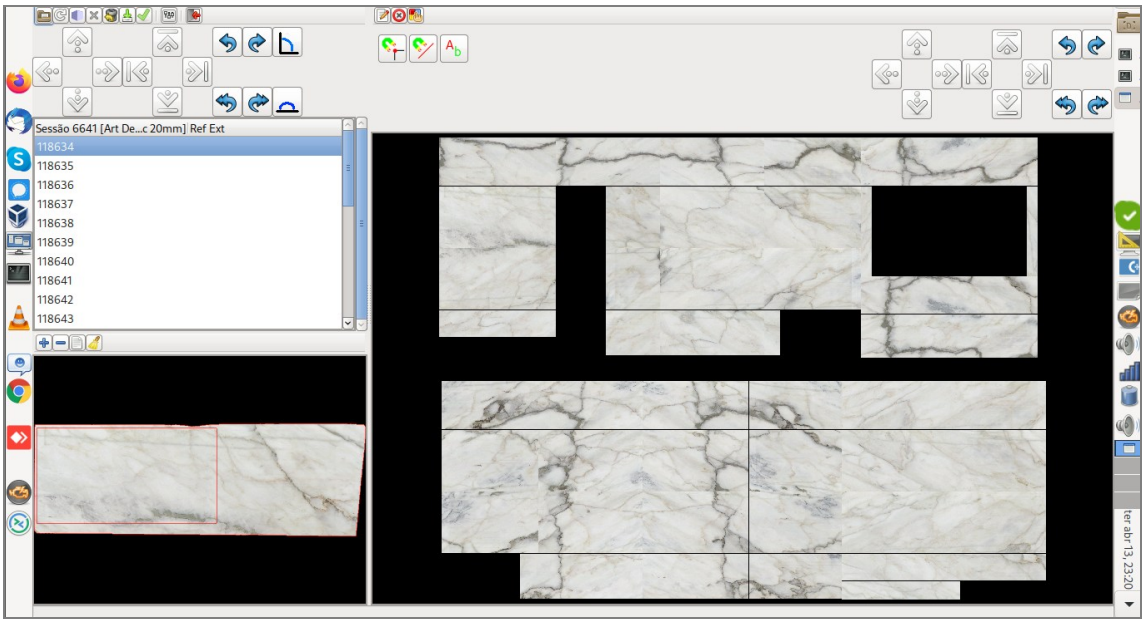


Figure 12. Operational Cockpit4.0+'s Interface.

Trust Building and Relationship Management: (i) Reputation Systems: a system that allows companies to rate their experiences with competitors, fostering trust and reliability within the network; and (ii) Facilitated Networking Events - organizing events and workshops to strengthen relationships among competitors, promoting a culture of openness and mutual respect.

By integrating these features into Cockpit4.0+, the system has been fully developed to support and actively promote collaboration among competitors. The algorithm outlined a structured pathway for developing the Cockpit4.0+ system, ensuring that all critical aspects—from operational and operational technological capabilities to interoperability, usability, and coopetition facilitation—were systematically addressed.

Given the substantial costs associated with a full-scale PoC for the developed Cockpit4.0+ prototype, a preliminary evaluation was undertaken. This assessment aimed to gauge the functional acceptance of Cockpit4.0+ and explore its potential to enhance cooperation among stone SMEs.

6.7 Survey for Preliminary Evaluation of the Cockpit4.0+

A survey involved technical experts and engineers from the 24 ornamental stone SMEs previously mentioned. This method provided valuable insights into the acceptance of the Cockpit4.0+ prototype, examining its functionalities across different levels of digital readiness among SMEs.

Each company was categorized by a digital level (DL) for the study, as outlined in the previous chapter. The evaluation involved a comprehensive review of each company's digital production

equipment, management, integration with production processes, and involvement in digital marketplaces. The survey was divided into four distinct actions:

First Action (Introduction): The shift towards Building Information Modelling (BIM) and the need for stone companies to adapt to BIM-driven procurement in the AEC market were introduced. The Cockpit interface was also introduced.

Second Action (Explanation): Explained the functionalities of the Cockpit concerning innovation, usefulness, cybersecurity, and usability. It highlighted how the system facilitates coopetition among rival SMEs, with features that enable resource sharing without prior knowledge of partners, maintain commercial confidentiality, and automate resource allocation based on buyer decisions.

Third Action (Questions): Participants rated, on a scale of 1 to 5, their views on Cockpit4.0's technological disruptiveness, usefulness, cybersecurity, and usability.

Fourth Action (Data Collection): Conducted throughout 2023, the survey data were anonymized to maintain confidentiality and recorded in an Excel file, with average responses detailed in Appendix I, Table 6.7.

The aggregated ratings from respondents highlighted the perceived innovation of the Cockpit4.0+ system, with an impressive average score of 3.9 out of 5, illustrating the prototype's potential efficacy within the sector. The system's perceived usefulness positively correlated with companies' digital maturity. Among the most digitally advanced respondents (DL3 and DL4), the system achieved high scores, averaging 4.8 out of 5, indicating that greater digital integration enhances the system's effectiveness (Figure 13).

Despite cybersecurity needing improvement, with an average rating of 3.3 out of 5, the prototype showed significant promise in enabling coopetition, especially among SMEs with higher digital levels. Converting the quantitative levels from the questionnaire into percentages revealed an overall positive acceptance rate of 78.9% for the Cockpit4.0+ prototype, demonstrating its considerable potential to facilitate coopetition within OS-PT SME networks. This feedback underscores the system's exceptional value for entities at the forefront of digital integration, effectively supporting complex cooperative and competitive interactions and indicating its strategic fit for digitally advanced environments. However, a focused review and enhancement of the system's security features are recommended due to cybersecurity concerns. Strengthening these aspects will boost confidence in the prototype and improve its overall utility and acceptance among SMEs.

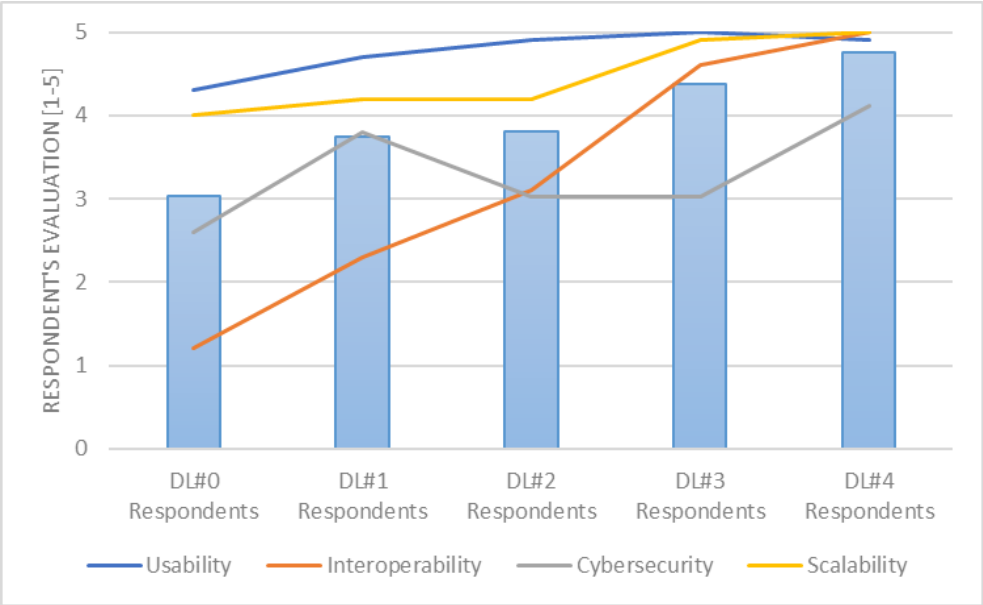


Figure 13. Evaluation of Cockpit4.0+ Functionalities by OS-PT SMEs.

This feedback underscores the system's exceptional value for entities at the forefront of digital integration, effectively supporting complex cooperative and competitive interactions and indicating its strategic fit for digitally advanced environments. However, a focused review and enhancement of the system's security features are recommended due to cybersecurity concerns. Strengthening these aspects will boost confidence in the prototype and improve its overall utility and acceptance among SMEs.

This preliminary functional evaluation of the Cockpit4.0+ prototype has laid a solid foundation for its continued development and refinement. By addressing identified areas for improvement and building on its existing strengths, the system is strategically positioned to advance the digital transformation of the OS-PT sector. Specifically, it holds promise for enhancing dynamic and secure coopetition networks, which is crucial in adapting to evolving competitive landscapes.

6.8 Coopetition Technology-Enabled Service Ecosystems

Building on the positive feedback received, the research advanced to integrate Cockpit4.0+ into the CN-VCC framework. This strategic technological integration combines operant capabilities, which initiate actions, with operand capabilities, which are tangible assets that respond effectively. This synergy not only drives innovation and optimizes operational efficiency but also enhances collaboration among SMEs. Such integration strengthens SME competitiveness and creates an environment conducive to coopetition, blending collaborative and competitive dynamics to unlock new value and opportunities in the marketplace.

By strategically embedding Cockpit4.0's operant and operand capabilities into the CN-VCC, both together represent a robust, fully realized, and comprehensive artefact for enabling

coopetition within SME networks. As it is anchored in service ecosystems and challenges value cocreation henceforth, within this research, this artefact will be referred to as Coopetition Technology-Enabled Service Ecosystem (CN-EcoTech). This designation reflects its role in facilitating coopetition through technology, enhancing the network's capability to create and sustain value for actors.

6.9 Lifecycle and Instantiation of a CN-EcoTech

This section outlines a controlled instantiation methodology, systematically addressing the steps and mechanisms required to establish and define the management functionalities of a CN-EcoTech throughout its entire lifecycle. The development, deployment, and management of CN-EcoTechs necessitate a structured lifecycle and instantiation process that considers the dynamic interplay of cooperation and competition among network entities. This process ensures that these ecosystems are effectively designed, implemented, and maintained, supporting the delicate balance of coopetition where entities collaborate and compete simultaneously.

6.9.1 Tracing the Lifecycle of CN-EcoTechs

Understanding the lifecycle of CN-EcoTechs is crucial for navigating its development from inception to conclusion. This lifecycle is illustrated in Figure 14, which details the phases that characterize the progression and transformations within the ecosystem.

Creation Stage: This foundational phase involves strategic blueprinting, establishing governance structures, and creating a unified ontology for the network. It sets the groundwork by configuring necessary technological infrastructures and preparing the network for interactions.

Initiation Phase: This phase marks the operational startup with activities such as deploying network infrastructure, forming motivator teams, officially launching the coopetition platform, recruiting actors, and ensuring compliance with established standards and objectives.

Operation Stage: The core of coopetition, enabled by advanced technologies, where resources are actively integrated, and service exchanges occur among competitors. This phase fosters the development of vibrant service ecosystems.

Metamorphosis Stage: At this point, significant changes may require a strategic reassessment and network reconfiguration to address emerging challenges or opportunities, possibly leading to relaunch.

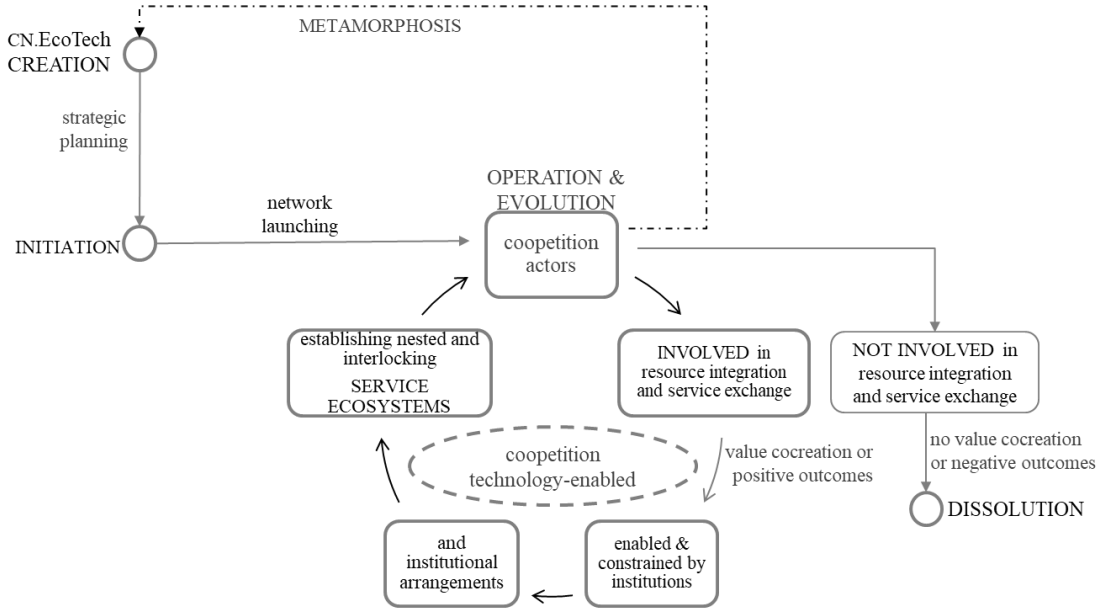


Figure 14. CN-EcoTechs Lifecycle.

Dissolution Stage: The network lifecycle concludes when it no longer delivers sufficient value or fails to meet the participants' expectations. It leads to gradual disengagement and eventual closure as actors withdraw from the resource integration and service exchange processes.

This lifecycle not only outlines the temporal progression of a CN-EcoTech but also emphasizes the self-regulating nature of these networks [315] as resource-integrating entities interlinked by technology. CN-EcoTechs create environments conducive to mutual value creation through seamless service exchanges, aligning closely with the principles of S-D Logic articulated by [316]. This alignment highlights the system's capacity to promote sustainable coopetition among network participants [105].

6.9.2 Instantiation Methodology for CN-EcoTechs

The concept of instantiation in the context of CN-EcoTechs is central, representing the transition from abstract models to tangible implementations within coopetition networks. This process outlines the creation of specific instances derived from theoretical frameworks, thereby operationalizing coopetition strategies through technology-enabled networks [317]. The instantiation process is a critical step in realizing the practical aspects of coopetition by materializing a tailored coopetition technology-enabled ecosystem that embodies the principles and stages outlined in the lifecycle of a CN-EcoTech.

This structured approach to instantiation encompasses a series of steps to craft and deploy a CN-EcoTech, beginning with a deep understanding of the cooperation lifecycle. It integrates strategic planning, technology setup, actor engagement, and network evolution. Each step is geared toward establishing a network that facilitates and optimizes cooperative and competitive interactions among diverse actors within the ecosystem.

The instantiation process is designed to culminate in the creation of a CN-EcoTech. This involves a detailed specification of network components, including the technological infrastructure, governance mechanisms, actor roles, and interaction protocols. By articulating these elements, the process ensures that the theoretical underpinnings of coopetition are translated into a functional ecosystem that supports dynamic resource integration, service exchange, and value cocreation among rivals and partners alike.

In essence, the instantiation process bridges the gap between conceptual models and real-world applications, enabling the strategic deployment of CN-EcoTechs. This procedure not only brings the theoretical framework to life but also provides a practical pathway for organizations to navigate the complexities of coopetition, leveraging technology to forge mutually beneficial relationships and foster innovation within competitive landscapes.

6.9.2.1 Initiation Stage: Launching CN-EcoTech

The Initiation Stage is critical in the lifecycle of CN-EcoTechs, marking the transition from conceptual planning to actionable steps towards value creation (Figure 15).

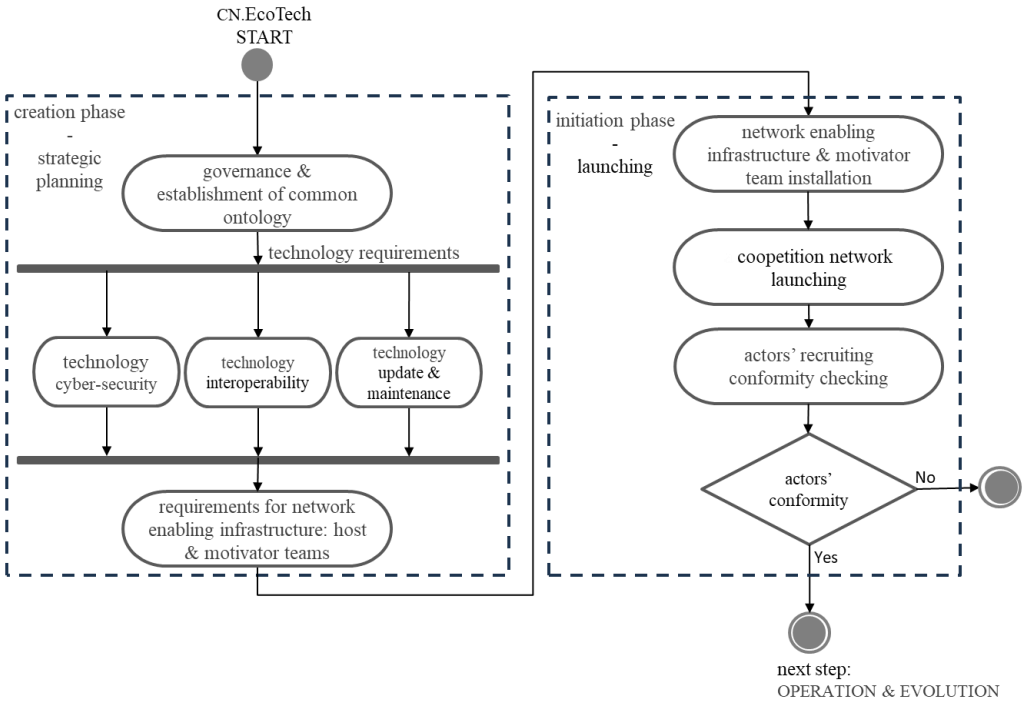


Figure 15. The Initiation Stage of the CN-EcoTechs.

This phase is structured into two main components: the creation and initiation phases, each characterized by specific objectives and activities crucial for the network's success.

Creation Phase

The creation phase lays the groundwork for the CN-EcoTech, emphasizing strategic planning and environmental assessment. This stage is pivotal for aligning technology requirements with

the network's strategic goals, establishing a common ontology, and defining governance structures. These foundational steps ensure that all network participants operate within a shared framework, facilitating seamless integration and collaboration. Key activities include (1) Evaluating the environmental context to identify opportunities and challenges, tailoring the network's strategy to leverage technological advancements and address potential barriers; (2) defining governance structures and standard ontologies, setting clear guidelines for network operation, including roles, responsibilities, and decision-making processes; and (3) establishing technology standards and requirements, focusing on critical areas such as cybersecurity, interoperability, and maintenance protocols to support the network's robust and secure operation.

The culmination of the creation phase involves preparing the network's infrastructure and systems to ensure readiness for actor engagement and active participation.

Initiation Phase

Transitioning into the initiation phase, the focus shifts to launching the network, setting up the necessary infrastructure, and engaging key actors. This phase is instrumental in transforming strategic plans into operational realities, marked by several key activities: (1) Launching the network by operationalizing the governance structures, technology standards, and ontologies defined in the creation phase. This step is crucial for setting clear expectations and fostering shared commitment among participating rivals; (2) setting up technology-enabling infrastructure, laying the technical foundation required for the network's functionalities and services. This includes ensuring all systems are interoperable and meet the established cybersecurity standards; and (3) Recruiting actors and ensuring conformity, focusing on building a diverse yet cohesive network of participants. The motivator team plays a vital role in this process, actively engaging potential actors, assessing their technological compatibility, and ensuring adherence to the network's requirements.

The initiation stage carefully manages these phases, setting the stage for CN-EcoTech to leverage its collective strengths, foster innovation, and create value through collaborative rivalry. This structured approach ensures that the network aligns with strategic objectives and builds a solid foundation for sustainable growth and competitive advantage.

6.9.2.2 Operation Stage: Dynamism in a CN-EcoTech

The Operation Stage represents the operational heartbeat of technology-enabled CN-EcoTechs, where the theoretical framework of S-D Logic is put into practice through the active and dynamic integration of resources and service exchange among competitors (refer to Figure 16 for an overview).

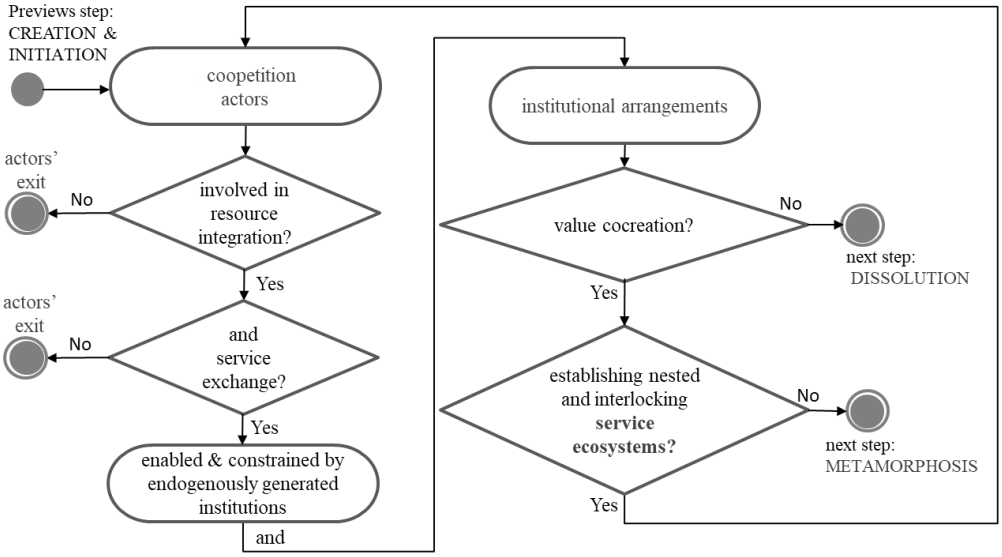


Figure 16. The Operation and Evolution Stage of a CN-EcoTech.

This stage is characterized by the establishment and evolution of service ecosystems, driven by micro-level network activities and meso-level institutional influences.

Micro-Level: CN-EcoTech Activity

At the micro-level, individual actors, recognized as rivals in coopetition, leverage technology to enhance their ability to integrate diverse resources. It includes skills, knowledge, operand resources, and other operant resources, engaging in service exchanges within the network. These exchanges are not isolated transactions but part of a multi-layered interaction framework, facilitated and bounded by the collective institutional arrangements that emerge within the network.

Meso-Level: CN-EcoTech Institutions

The Meso-level captures the emergence of behavior patterns or institutions that serve as the humanly devised rules, norms, and meanings that guide and shape interactions among network actors. These institutions form the backbone of coordinated service ecosystems, providing a structured framework that supports and regulates the ongoing integration of resources and exchange of services. Within these ecosystems, actors navigate the landscape of cooperation and competition, driving forward the creation of value in increasingly complex service exchanges. Guiding the operation of these networks are five core axioms of S-D Logic, which shed light on the multifaceted and dynamic nature of value cocreation within service ecosystems:

Service as the Basis of Exchange: This concept elevates the idea that all interactions can be viewed as service exchanges, highlighting the service nature of economic and social activities.

Cocreation of Value by Multiple Actors: Acknowledges the collaborative effort in value creation, where the beneficiary's involvement is crucial.

Actors as Resource Integrators: Recognizes every participant in the service ecosystem as a contributor to value creation through resource integration.

Value Determined by the Beneficiary: Underlines the subjective nature of value, perceived and defined by the beneficiary.

Coordination through Institutions highlights the critical role of actor-generated institutions and arrangements in facilitating and guiding the value cocreation process.

By understanding and navigating the Operation Stage through these axioms, CN-EcoTechs can foster environments where technological enablement and strategic collaboration converge. This convergence not only catalyzes innovation and efficiency but also amplifies the potential for creating mutual and sustainable value across the ecosystem, ensuring a dynamic and responsive approach to the evolving demands and opportunities of the marketplace.

6.9.2.3 Metamorphosis Stage: A Strategic Shift

The Metamorphosis Stage represents a transformative phase for CN-EcoTechs, characterized by strategic adaptations to maintain competitiveness and respond to changing market dynamics. This stage involves a comprehensive overhaul of network strategies, structures, and technologies to ensure sustained growth and value creation (Figure 17). Several catalysts can trigger the onset of the Metamorphosis Stage, each signalling the need for strategic renewal and realignment.

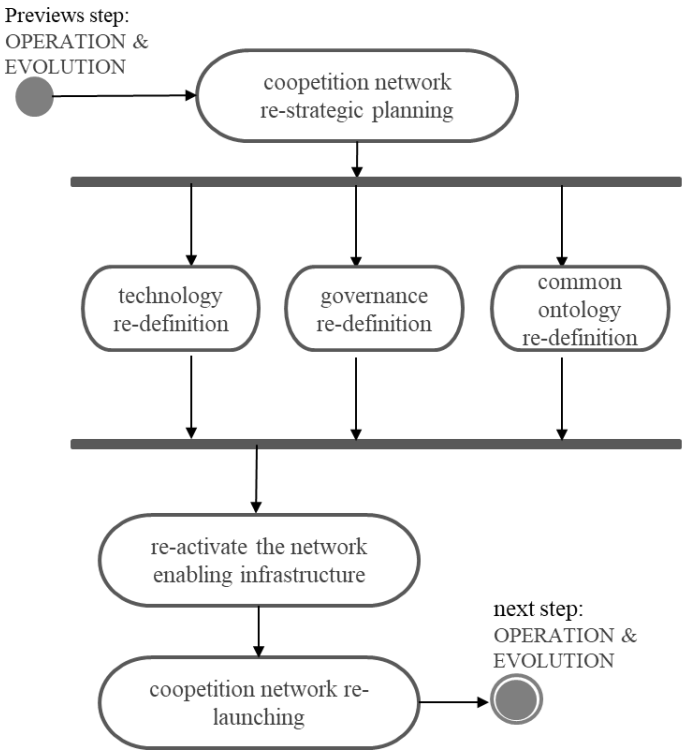


Figure 17. Metamorphosis stage of a CN-EcoTech.

Network Reshaping: This involves reconfiguring the network to better align with evolving market conditions, notably when existing structures no longer support optimal value creation within service ecosystems.

Identifying the Need for Change: Leadership and stakeholders within the network recognize that changes are essential for maintaining competitiveness. This realization often stems from challenges sustaining desired service ecosystems, shifts in market dynamics, or other performance inhibitors:

Strategic Planning: To address these challenges, a new strategic blueprint is developed outlining necessary changes, improvements, and innovations. This plan aims to bolster the network's value creation and competitive edge.

Improving Key Components: The strategic plan targets enhancements in technology, governance structures, ontology, and other critical areas, aiming to elevate the network's capacity for service ecosystem-driven value creation.

Reactivation of Network Infrastructure: The network infrastructure is reactivated following strategic recalibration, incorporating the technological and organizational changes outlined in the strategic plan.

Relaunching: The network is formally relaunched under a new strategic paradigm, signaling a renewed readiness for operation and value cocreation.

(Re)Initiation: These steps ensure that all network participants are aligned with the revised strategic direction. This may involve onboarding new actors, reestablishing commitments, and performing checks for interoperability and cybersecurity in line with the revamped technological framework.

The Metamorphosis Stage marks a critical juncture in CN-EcoTech's lifecycle, characterized by strategic pivots designed to adapt to and capitalize on shifting market conditions and opportunities. Through this stage, the network reaffirms its commitment to fostering an environment conducive to sustained innovation, collaboration, and value cocreation, laying the groundwork for a revitalized and more agile operational model.

6.9.2.4 Dissolution Stage: The Final Act of CN-EcoTechs

The Dissolution Stage marks the end of the road for CN-EcoTechs, depicted in Figure 18, where network operations halt, and the cooperative venture among competitors dissolves. This phase is initiated when the network's value creation fails to meet the actors' expectations or ceases altogether.

As a result, participants begin to retract from their collaborative engagements, halting the integration of resources and the exchange of services, which in turn precipitates the disbandment of the service ecosystem and the CN's subsequent dissolution of CN-EcoTech. The process of dissolution involves several critical steps aimed at orderly winding down the network activities:

Notification of Closure: The network's leadership formally announces the decision to dissolve and communicates the closure to all network stakeholders, including customers, partners, and other relevant parties.

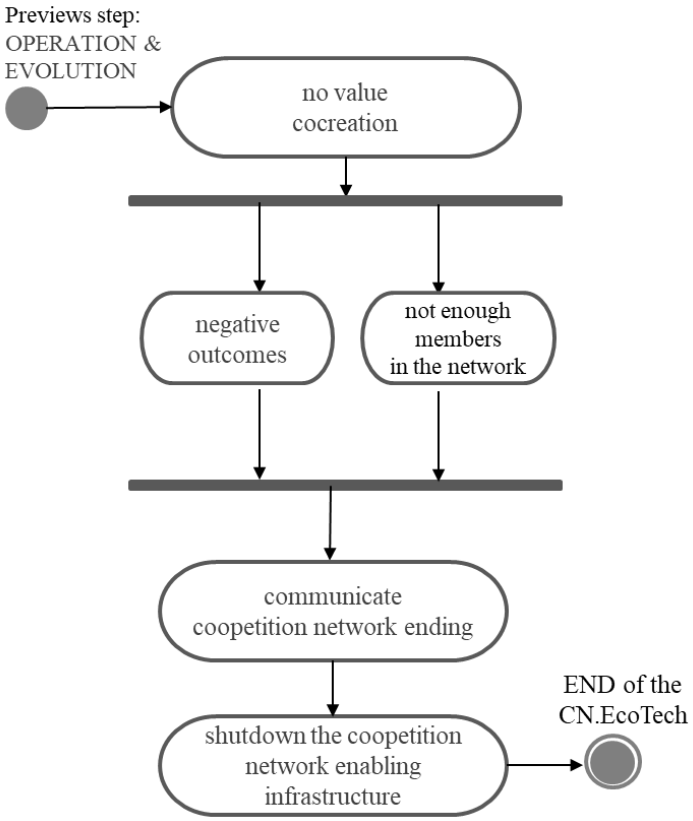


Figure 18. Dissolution Stage of CN-EcoTechs.

Termination of Contracts and Commitments: All ongoing contracts and commitments with network participants are concluded. This step requires meticulous attention to settle all legal and financial obligations in a timely and appropriate manner.

Disabling the Coopetition Infrastructure: The technical infrastructure that supported coopetition activities, including shared platforms, digital tools, and communication systems, is systematically shut down.

Archiving Data and Insights: Critical data, learnings, and insights gained during the network's operation are archived for future reference and use. This might include best practices, challenges faced, and strategies that either contributed to the network's success or led to its downfall.

Debriefing and Feedback: A final debriefing session

with network participants allows for collecting feedback and reflections on the network's lifecycle. This step provides valuable insights that can inform future cooperative ventures or help avoid similar dissolution outcomes.

Formal Closure Announcement: A formal closure announcement is made to the broader community, including industry stakeholders, signaling the end of the network. This announcement often includes a summary of the network's achievements and lessons learned.

While dissolution signifies the end of a specific cooperative venture among competitors, the experiences and lessons gleaned from the process can pave the way for future more resilient and value-driven coopetition arrangements

Chapter 6. Summary

This chapter explores the architectural design and implementation of a CN-EcoTech, integrating S-D Logic with IIoT and supported by DSR methodology. It employed a Building Blocks approach to develop CN-EcoTech, aligning it with the SDGs. The architecture was designed to clarify the roles of various actors, facilitate resource integration and service exchange, and define institutional functions within the network. Through modular and phased development, this research enhances the capability for coopetition and value cocreation, enabling SMEs to navigate global supply chains effectively.

A preliminary evaluation was conducted due to the significant costs of a full-scale PoC for the developed Cockpit4.0+ prototype. The feedback received highlighted the prototype's innovation with an impressive average rating of 3.9 out of 5, suggesting its potential efficacy within the sector. The perceived usefulness of the system was notably higher among the most digitally mature companies (DL#3 and DL#4), averaging 4.8 out of 5, indicating that enhanced digital integration correlates with increased system effectiveness. The chapter also outlined an instantiation process with systematic steps supported by various mechanisms to establish and manage CN-EcoTech's functionalities throughout its lifecycle.

Chapter 7. CN-EcoTech Proof-of-Concept in the OS-PT sector

Science may set limits to knowledge but should not set limits to imagination. - Bertrand Russell

Chapter 7 addresses the DSR Activity 4, as outlined by Peffers et al. (2007), by undertaking a PoC for the CN-EcoTech—the framework previously conceptualized. This activity assesses the feasibility and practical applicability of the CN-EcoTech within a select group of SMEs in the Portuguese ornamental stone sector, chosen to represent diverse coopetition scenarios. This PoC addresses Research Question 1 (RQ1): How do the CN-EcoTech practices enable current state-of-the-art coopetition instances within OS-PT SMEs?

The specific objective of this chapter is to demonstrate the practical application of CN-EcoTech in real-world settings, highlighting its capabilities to tackle challenges associated with cooperation in the sector effectively. The demonstration process unfolds through three strategic steps grounded in S-D Logic and DSR methodology. The graphical abstract of this structured approach is presented in Figure 19, illustrating the Service Blueprint approach tailored to address challenges associated with the developed CN-EcoTech.

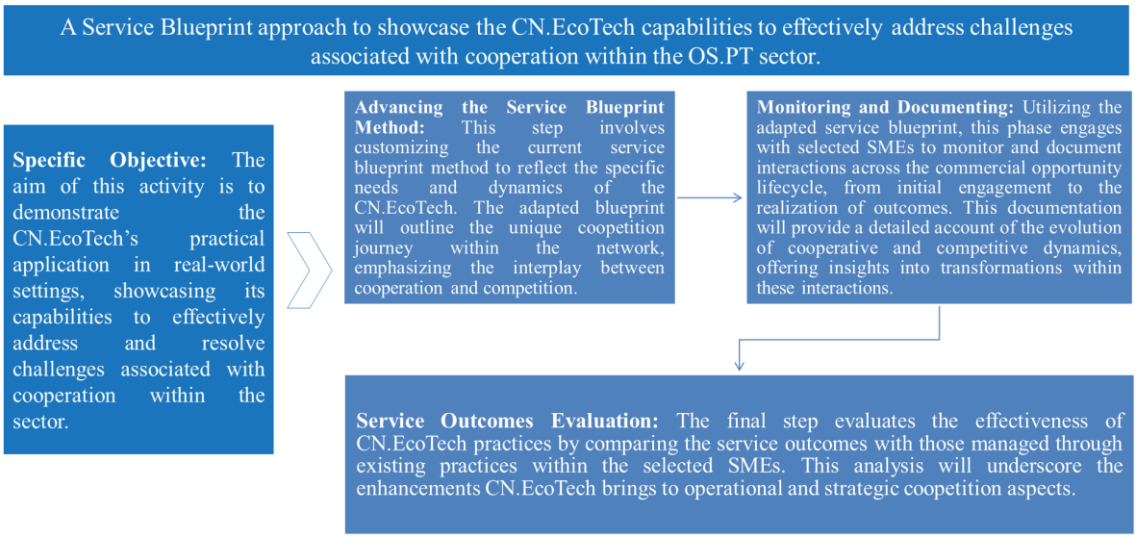


Figure 19. Chapter 7 Graphical Abstract: Service Blueprint Approach for CN-EcoTech.

This chapter marks the transition from theoretical design to practical demonstration, showcasing the viability of CN-EcoTech in real-world settings. By providing empirical evidence of the system's capacity to foster innovative cooperation strategies within the OS-PT sector, this PoC sets a benchmark for future innovations in global SME networks.

7.1 Service Blueprint for Outcomes Evaluation in a CN-EcoTech

The significance of services in economic exchanges has undergone a profound evolution over centuries, culminating in a transformative shift introduced by Stephen L. Vargo and Robert F. Lusch in 2004 with the concept of S-D Logic [100]. They advocated for a paradigm shift in which the core of economic exchange is seen not in the mere transaction of tangible goods but in the provision and reciprocation of intangible services. This perspective challenges the conventional goods-centric models by reconceptualizing products as conduits for service delivery and underscoring the resultant benefits and utilities [102].

S-D Logic enhances the understanding of economic exchanges by emphasizing the cocreation of value through dynamic interactions within networks of actors [60]. It distinguishes between operant resources—such as knowledge and skills—and operand resources, including technologies and physical goods, facilitating service exchanges [113]. This theoretical framework asserts that value is collaboratively crafted, utilizing the diverse resources each actor contributes to these exchanges [263].

As outlined in the Literature Review Chapter, S-D Logic forms the conceptual foundation for the CN-EcoTech, which integrates the IIoT to foster competition and collaboration among SMEs. Through the lens of S-D Logic, the CN-EcoTech creates a complex network of relationships, enriched by the IIoT-enhanced system Cockpit4.0+ and supported by institutional mechanisms that facilitate mutual value creation amid competitive tensions.

The Service Blueprint is a method for evaluating the outcomes of interactions along a service journey [318], rooted in S-D Logic [168] and used in Design Science [319]. First introduced by Shostack in [320] and expanded by Kingman-Brundage [321], the Service Blueprint remains a vital tool for visualizing and enhancing service processes. This method outlines the sequence of service actions across conceptual lines and stages, capturing tangible and intangible aspects of service delivery [322]. Such detailed visibility is vital for boosting the effectiveness of service execution [313].

Nevertheless, traditional Service Blueprints face challenges in CN-EcoTechs, where Industrial IoT technologies enhance connectivity and facilitate interactions. These conventional frameworks require assistance to accurately depict the dynamic, real-time value cocreation processes characteristic of Industrial IoT-based networks, primarily focusing on visualizing the mostly remote practices of CN-EcoTech. This limitation necessitates reevaluating and adapting the Service Blueprint method to suit the evolving technological landscape

Redefining Interactions: In CN-EcoTechs, the Service Blueprint must differentiate between physical and digital interactions across the network journey. It should map direct connections from factory shop floors to customers and align interests among diverse stakeholders—from initial contact to service delivery and post-service support.

Mapping Dynamic Resource Sharing: The blueprint should vividly illustrate the sharing and leveraging of operant and operand resources throughout various service delivery phases. Stakeholders can better understand and optimize value cocreation by clearly showing how resources are shared and utilized.

Reimagining Interaction Frameworks: To effectively accommodate the dynamics of CN-EcoTechs, the Service Blueprint needs to delineate various interaction stages and resource lanes. It includes capturing the multifaceted nature of value cocreation, which is essential for comprehensively managing and understanding the complex relationships within these networks.

By re-envisioning the Service Blueprint through the lens of S-D Logic and integrating advanced operant resources, such as those from Cockpit4.0+, this evolution of the Service Blueprint will not only deepen our understanding of service processes but also enhance the resilience, adaptability, and collaborative capacity of CN-EcoTechs. Incorporating these new functionalities enables a dynamic and real-time view of the coopetition network, highlighting potential areas of discord or misalignment and establishing a landscape for continuous improvement and innovation. This comprehensive approach is crucial for identifying pivotal intervention points that can significantly improve value cocreation, ultimately fostering a more harmonious, efficient, and innovative set of CN-EcoTech practices.

7.1.1 Redefining Line of (Cyber) Interactions

Traditionally, Service Blueprints, as conceptualized by Kingman-Brundage, have been instrumental in mapping out customer and supplier activities via the Customer Interaction Line [323]. This line has been pivotal in visualizing direct interactions, encompassing a spectrum of communication methods, from face-to-face engagements to digital communications, such as emails and phone calls. However, the CN-EcoTech significantly expands the scope and nature of these interactions [17]. Within CN-EcoTech practices, interactions extend into cyber environments, establishing direct links between cyber customers and shop floor operations across various digital interfaces, ranging from small-scale operations to large, interconnected factory networks. This evolution pushes the traditional boundaries of customer-supplier interactions.

To accurately reflect this evolution, it is essential to reconceptualize the traditional Customer Interaction Line into a new Line of Cyber Interaction. This novel construct is designed to encapsulate the digital interconnectivity central to CN-EcoTech practices. The re-envisioned line captures the essence of digital exchanges and the seamless, often instantaneous nature of these interactions, facilitated by the proliferation of advanced digital technologies.

The visual representation of the Line of Cyber Interaction, depicted as a dashed line, serves a dual purpose. Stylistically, it represents the fluid and permeable nature of digital interactions, distinguishing them from the more structured and linear communication modes of the past. This depiction highlights the dynamic and continuously evolving landscape of CN-EcoTechs,

where interactions are not confined by physical proximity or conventional communication channels but are characterized by an ongoing flow of information, resources, and value propositions across the digital environment.

Incorporating the new Line of Cyber Interaction into the Service Blueprint enhances the existing framework, more accurately reflecting the complex and immediate connections between cyber customers and digital shop floors characteristic of the CN-EcoTechs. This adaptation provides a solid foundation for thoroughly understanding and mapping the value propositions and interaction dynamics within CN-EcoTech practices. Highlighting interconnectivity in this way is crucial for ensuring that the Service Blueprint remains a relevant and effective tool for navigating the complexities and opportunities of digital coopetition networks, thereby fostering a deeper comprehension of how value is cocreated in these innovative environments.

7.1.2 Mapping Dynamic (Cyber) Resource Sharing

At the core of S-D Logic is the recognition that all participants—customers, providers, rivals, and others—are active contributors to value creation [160] [213]. This perspective requires that the Service Blueprint accurately maps the (cyber) interactions and exchanges among all actors involved, including competitors, emphasizing their diverse contributions to the value creation dynamics within CN-EcoTech.

The Role of Customers in CN-EcoTechs: In S-D Logic, customers are central to value cocreation [324]. CN-EcoTechs enhances customer involvement by integrating them into the network. This shift necessitates a Service Blueprint that effectively captures the digital customer journey, highlighting their technological interactions with providers and the role of digital interfaces in enabling global procurement processes. The blueprint must evolve to vividly depict these digital touchpoints, ensuring a comprehensive visualization of customer engagement in the value cocreation process.

The Role of Providers in CN-EcoTechs: Aligned with S-D Logic, providers in CN-EcoTechs are not just suppliers but active participants in value cocreation [119]. They offer a spectrum of value propositions, facilitating a collaborative process where value is jointly created. This dynamic underscores that customers are not passive recipients but active integrators of the Provider's offerings into their daily routines. These dynamics must be visually captured in the Service Blueprint, illustrating how providers' services intertwine with customers' daily lives, thus facilitating a deeper understanding of the symbiotic relationship in the cocreation process.

The Role of Coopetitors in CN-EcoTechs: Coopetitors—entities that merge competitive drive with a collaborative spirit—significantly enrich the network's resource pool. The Service Blueprint must delineate this dual role, depicting how coopetitors utilize operant (skills, knowledge) and operand (physical goods, technologies) resources to foster collaboration while managing competitive tensions. This detailed representation is crucial for a holistic understanding of coopetitors' contributions. It highlights their unique capacity to compete and collaborate, driving collective innovation and success within CN-EcoTech.

The Role of Competitors in CN-EcoTechs: According to S-D Logic, posited by Vargo and Lusch (2008), sustainable innovation is intricately linked to the presence of competitors [324]. Competitors are not merely challengers but catalysts in the innovation landscape, providing the necessary drive and incentive for firms to innovate [325]. In the context of CN-EcoTechs, this interplay of coopetition is crucial as it stimulates continuous improvement and encourages the adoption of advanced Industrial IoT technologies. This competitive dynamic ensures that CN-EcoTech adapts and thrives by integrating new solutions that respond to evolving market demands and technological advancements. Therefore, the Service Blueprint should portray competitors as autonomous yet interconnected entities within the ecosystem, emphasizing how competitive pressures spur continual innovation and improvement. This portrayal underscores the importance of maintaining a flexible and responsive framework that can capture the dynamic interplays that foster an environment conducive to innovation and growth.

7.1.3 Reimagining Interaction Frameworks: Stages and Lanes in CN-EcoTechs

In SDL, the dynamic interplay among actors in value cocreation underscores the need for continuous innovation in value propositions [326]. The challenge involves innovating and systematically identifying and integrating the resources essential to these propositions from their inception [327]. In CN-EcoTechs, enhancing the value proposition aims to benefit both individual customers and providers, while enriching the entire network, with coopetition catalyzing innovation [328]. Actors along the service process can refine their value cocreation interactions based on historical insights and future projections, embodying a principle of perpetual enhancement to meet evolving network demands. Consequently, the Service Blueprint tailored for CN-EcoTechs must delineate interaction stages and resource lanes, encapsulating the multifaceted nature of value cocreation. This necessitates introducing new features such as:

Cyber.Frontstage Lane: This lane visualizes frontstage interactions that blend human and technological resources, spotlighting technology-mediated exchanges between cyber customers and providers. It emphasizes the integration of physical and virtual evidence, capturing the essence of digital interactions in the value cocreation process.

Physical.Backstage Lane: This lane reveals behind-the-scenes resources and activities, unravelling the support structures that underpin the cocreation process. It highlights the roles of coopetitors, providing insights into the operational and strategic foundations that enable seamless value delivery within CN-EcoTech.

Support Stage Lane: This lane encompasses the expansive network of partnerships, management resources, and coopetition support frameworks. It underscores the external collaborations and resources that bolster the network, facilitating a robust coopetition infrastructure.

7.2 Service Blueprint Framework for CN-EcoTechs

Building on the above-mentioned insights, a specialized Service Blueprint framework has been adapted specifically for CN-EcoTech. This tailored framework aims to capture the complex dynamics of coopetition and vividly illustrate the interactions and transformations within the coopetition network. This adaptation ensures that the blueprint maps out the service processes and effectively highlights the interplay between cooperation and competition, which is essential for driving innovation in the CN-EcoTech ecosystem.

Appendix II, Figure 7.2, presents the new Service Blueprint framework for CN-EcoTechs, where the delineated lanes and stages become instrumental in mapping and enhancing value interactions among competitors. The framework's dashed lines, representing the Shopfloor Technology Line and the Line of Internal Interactions, symbolize technological transparency and the seamless flow of information that characterizes CN-EcoTech.

Within the Support Stage lanes, support resources engage in tasks vital to the service process, with their openness and fluid exchange of information demarcated by dashed lines. This representation fosters a clear understanding of the roles and contributions of all CN-EcoTech's actors, enhancing governance and strategic decision-making within these collaborative and competitive environments.

At the pinnacle of the comprehensive Service Blueprint for CN-EcoTechs, highlight either Cyber or Physical Evidence or Outcomes which result from cooperative endeavors between the cyber customer and the digital Provider (Kocsi & Oláh, 2017). This section captures the tangible outcomes of collaborative actions, emphasizing the concrete benefits of such partnerships.

By addressing the CN-EcoTech practices' journey, the enhanced Service Blueprint offers a strategic framework for organizations to navigate the complexities of digital coopetition networks. Its comprehensive approach facilitates more profound insights into cocreation interactions and empowers businesses to bolster their collaborative efforts while maintaining a competitive edge. Through its application, organizations can ensure the sustainability and success of their coopetition strategies in the digital era, driving innovation and value creation in an increasingly interconnected marketplace.

7.2.1 Assessing the Effectiveness of the Service Blueprint Framework

Before implementation, the Service Blueprint for CN-EcoTech practices underwent a thorough validation process with the same 24 OS-PT respondents previously categorized by their digital levels (DL) in earlier chapters. This validation aimed to confirm the effectiveness of the Service Blueprint framework through a structured survey divided into four distinct actions:

First Action (Survey Introduction): The purpose of the survey has been introduced to the participants.

Second Action (Explanation): The Service Blueprint Framework has been explained using computer presentations to ensure clear understanding.

Third Action (Question): Respondents were asked to rate the Service Blueprint Framework on a scale of 1 to 5 regarding its effectiveness in identifying potential dysfunctions in inter-company journey relationships within a network.

Fourth Action (Data Collection): The survey was conducted throughout July 2023. The data was anonymized to maintain confidentiality and recorded in an Excel file, with average responses detailed in Figure 20.

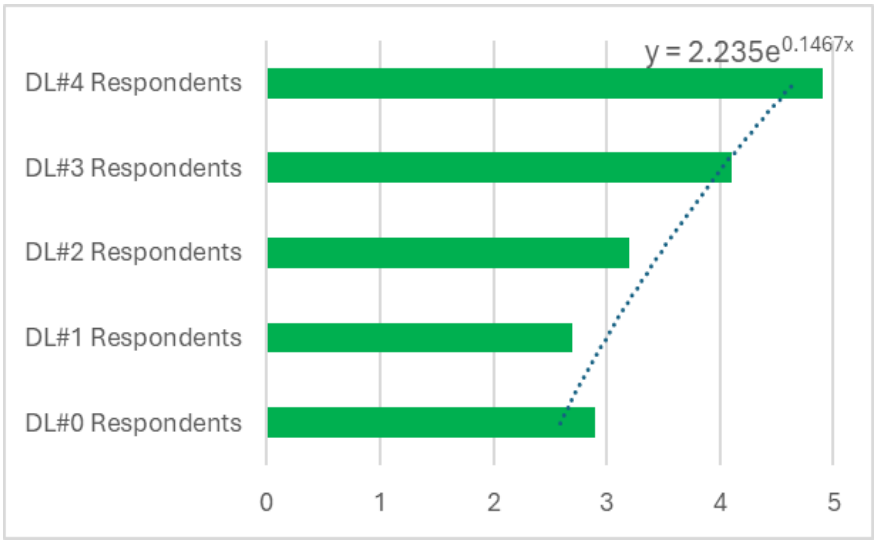


Figure 20. Service Blueprint's user-friendliness evaluation for the CN-EcoTech practices.

The feedback, garnering a favorable average manager rating of 3.6 out of 5, compellingly affirms the efficacy of the newly developed service blueprint framework. This framework is particularly adept at uncovering and rectifying dysfunctions in the relationships among interconnected companies. Its proven utility and relevance in promoting collaborative dynamics underscore its indispensable role in sectors undergoing digital transformation.

The observed exponential growth highlights the intensified inclination towards digitalization, signaling a marked shift towards more digitally oriented operations. However, the relatively modest magnitude of this exponent (0.1467) may also indicate that companies at a lower digital maturity level—predominantly representing the majority of this sector—may experience slower progress toward digitalization. This suggests a pressing need for public initiatives to catalyze the digital transformation journey.

7.2.2 ISPAR: Outcomes Evaluation Throughout the Service Journey

The Interact, Service, Propose, Agree, Realize (ISPAR) is a recognized tool for validating service outcomes across the value cocreation stages [329]. This tool is particularly crucial in validating

interactions throughout the CN-EcoTech service journey. As outlined by Maglio and Spohrer (2008) and further elaborated upon by Akaka et al. (2014), ISPAR offers a structured approach to analyzing service interactions [260]. The core activities of the ISPAR can be summarized:

Formalization of the Value Proposition: This initial activity involves clearly defining and proposing the value expected to be cocreated through the service interaction,
Agreement on the Value Proposition: The subsequent activity focuses on reaching an agreement regarding the proposed value, ensuring mutual understanding and acceptance among all stakeholders, and,
Action Leading to Value Realization: This final activity is dedicated to implementing the agreed-upon proposal to actualize the value.

ISPAR categorizes the outcomes of these activities based on the successful or unsuccessful integration of various resources—economic, social, technical, and emotional—each perceived and valued differently by the stakeholders involved (Appendix I, Table 7.1). These outcomes are instrumental in assessing each step of the service process from multiple stakeholder perspectives, enhancing the understanding of how each interaction contributes to the overall service journey within the CN-EcoTech.

7.3 Proof-of-Concept for the CN-EcoTech in the OS-PT sector

With the Service Blueprint now enhanced and validated, the stage is set for a PoC to demonstrate the practical viability of CN-EcoTech among SMEs in the OS-PT. This PoC adheres to the instantiation process detailed in Chapter 6, commencing with the "Initiation Phase." This initial phase concentrates on the operational start-up of CN-EcoTech, setting the groundwork for a comprehensive evaluation of its application and impact in real-world settings.

7.3.1 Initiation Phase - Selection of OS-PT SMEs

A thorough examination of the OS-PT sector has revealed a uniformity in the types of resources utilised across different stone companies, providing a solid foundation for defining the research population for this PoC. Although resources are generally similar, the primary distinction lies in the scale of these resources, which varies significantly depending on the company size. This variation is critical as it influences the companies' operational capabilities and customer interactions.

Despite the sector's uniform customer base, specific requirements and interactions with these companies show notable differences. These variations, influenced by each company's resource scale and capabilities, underscore the need to understand the specific resource dimensions present in each firm in depth. Such understanding is crucial for accurately mapping the Service Blueprint, which aims to comprehensively depict how different actors and resource configurations impact the service delivery process.

This nuanced understanding of uniformity and variance within the sector is crucial for illuminating the mechanisms of value creation that are unique to the stone industry, characterized by its distinct challenges and operational dynamics. The adapted Service Blueprint framework can be applied through this targeted selection of SMEs to reflect the real-world complexities and facilitate effective interventions within the CN-EcoTech.

For this proof of concept (PoC), companies were selectively chosen from the OS-PT sector, focusing on those that actively process and fulfil real-time orders. The primary criterion for selection was the company's designation as an "SME in OS-PT" sector. Additional criteria included the company's ability to lead and execute orders within the research timeframe, their level of digital maturity, current best practices, and willingness to participate in the PoC while maintaining commercial confidentiality. Nine companies were ultimately selected to participate in the PoC based on these multiple criteria.

First Group: OS-PT SMEs acting independently (traditional competition). This group consisted of three invited OS-PT SMEs who operated as usual. For each SME, a specific commercial opportunity was tracked. Initial outcomes were recorded using Excel, which was later transferred to Service Blueprint charts for detailed analysis.

Second Group: OS-PT SMEs acting partially as CN-EcoTech's members. This group consisted of three OS-PT SMEs who were invited and asked to approach the market flexibly, leaving the CN-EcoTech practices in place before the commercial opportunity was concluded. For each company, a commercial opportunity involving partnership coopetition was selected. The recording and analysis of outcomes were conducted in a similar manner to the first group.

Third Group: OS-PT SMEs fully engaged in CN-EcoTech. This group consisted of three OS-PT SMEs who were fully invited to CN-EcoTech practices. Each company was followed through a commercial opportunity that leveraged Cockpit4.0+ for real-time access to resources. Interaction outcomes were documented in the same format as the other groups to ensure consistency across the study.

This structured approach to sample selection and group categorization was designed to encapsulate different operational modes within the OS-PT sector. By tracking specific commercial opportunities across different operational contexts, the PoC aimed to provide comprehensive insights into the effectiveness of CN-EcoTechs within OS-PT SMEs.

7.3.2 PoC Operationalization: Actors and Resources

The Operation Stage marks a critical phase in evaluating the effectiveness of CN-EcoTech. During this stage, interactions transcend mere transactions and become integral to the ongoing formation and sustenance of the CN-EcoTech ecosystem. Before embarking on the PoC, it is essential to delineate the resources and roles of the actors involved in the service journey. This preparatory step ensures that all participants are clearly defined and their contributions to the ecosystem are understood, setting a solid foundation for the subsequent phases of the PoC.

7.3.2.1 Provider Resources

For companies in the OS-PT sector that have achieved digital maturity, understanding how resources are utilized across various stages of service provision is crucial. Utilizing the Service Blueprint framework, this analysis delineates three primary stages of resource allocation: Cyber Frontstage, Physical Backstage, and Support Stage. Each stage plays a distinct role in ensuring efficient service delivery and fostering value cocreation within SMEs. The Provider's resource categorization for CN-EcoTechs, which is essential for aligning operational strategies with digital capabilities, is detailed in Appendix I, Table 7.2. This structured approach to resource categorization underpins the Service Blueprint's capability to map out and optimize resource deployment effectively, ensuring that each stage contributes optimally to the overarching goal of value cocreation in the CN-EcoTech.

7.3.2.2 Coopetitor Resources

In the CN-EcoTech ecosystem, coopetitors are integral, engaging in mutual sharing and accessing resources specific to the network. These actors are pivotal as direct interfaces with customers, where they act as resource integrators and collaborators. They combine their assets with those of other network members directly in contact with customers, significantly augmenting the ecosystem's value through enhanced cocreation processes. Such collaborative behavior bolsters the network's competitive edge and ensures long-term viability [29].

Within CN-EcoTech, the resources utilized by coopetitors are analogous to those used by service providers. They are categorized into three distinct Service Blueprint stages: Cyber Frontstage, Physical Backstage, and Support Stage. This strategic deployment of resources across these stages fosters coopetition and value cocreation, effectively enhancing the overall competitive landscape. The specifics of this categorization and resource deployment are detailed in Appendix I, Table 7.3. Coopetitors utilise CN-EcoTech practices to actively enhance the value cocreation process by integrating cyber frontstage, physical backstage, and support-stage resources. Their engagement and resource sharing within the network are critical to amplifying competitiveness, driving CN-EcoTech's long-term growth, and ensuring its sustainability.

7.4 Data Collection and Service Journey

This section encompassed an in-depth analysis of the OS-PT SMEs involved in the PoC, revealing significant insights into the customer interaction process across nine distinct stages, ranging from the initial provider search to customer advocacy. Conducted in July 2023, this comprehensive examination systematically captured and analyzed a wealth of data on each interaction stage, including physical and virtual evidence, the resources utilized, and the outcomes achieved.

The data collected during this period was first recorded in Excel files to organize the information and facilitate detailed analysis and interpretation. Subsequently, the data was visually

articulated through Service Blueprint charts, which helped map the entire customer journey and depict the interaction dynamics within the collaboration network.

These visual representations clarified the intricate relationships and resource exchanges that characterize the coopetition network. They highlighted how different stages of customer interaction contribute to overall value creation, offering valuable insights into the effectiveness of current practices and potential areas for improvement.

The findings from this PoC are crucial, as they validate CN-EcoTech and shed light on the operational dynamics and collaboration patterns within the ornamental stone industry. This more profound insight into collaboration-based interactions helps pinpoint leverage points for enhancing business processes and customer satisfaction, ultimately contributing to sustained competitive advantage and market growth.

7.4.1 Findings from the SMEs Acting Independently

This phase of the PoC focused on SMEs approaching the market as “independent providers”.

As depicted in Appendix II, Figure 7.4, the service process analyzed commenced with "Provider Search (Lead Generation)"—Step 1, where resources primarily from the "Cyber Frontstage" were utilized extensively. Several critical stages followed this initial step: Provider Selection (Lead Qualification) - Step 2; Providers Evaluation (Lead Nurturing) - Step 3; Provider Selection (Opportunity Generation) - Step 4; Offers Evaluation (Product Demonstration) - Step 5; Negotiation - Step 6.

Throughout these steps, the ISPAR model rated the Service Outcomes as "R" (Realized) in the three companies, indicating successful value creation up to the end of Step 5. However, a notable shift occurred at the conclusion of Step 6 during the "Negotiation". The ISPAR outcome transitioned to "-A" (Proposal not accepted), signifying that, although there was no dispute, the value was not realized, and the service process ceased.

This pattern was consistently observed across the three participating companies in this first group. This recurring "-A" service outcome at the negotiation stage underscores a systemic challenge. These companies face significant challenges in securing deals when navigating the market independently, highlighting a critical area for potential improvement in their approach to negotiations and deal closure. These findings underscore the need for SMEs to reassess their negotiation strategies or refine their capabilities in identifying and closing opportunities, thereby ensuring they can effectively convert leads into successful transactions in a competitive market.

7.4.2 Findings from the SMEs Acting Partially in the CN-EcoTech

Along with this PoC, this group of OS-PT SMEs initiates the opportunities as CN-EcoTech’s members but somehow jumps out of CN-EcoTech ecosystem in the middle of the opportunity to follow up by themselves (alone).

As detailed in the Appendix II, Figure 7.5, the service journey of these companies demonstrated a distinct operational pattern: Provider Search (Lead Generation) - Step 1: This initial phase involved extensive use of Cyber Front-stage, Technology Operand Resources, and Physical Backstage resources; Provider Selection (Lead Qualification) - Step 2; Providers Evaluation (Lead Nurturing) - Step 3; Provider Selection (Opportunity Generation) - Step 4; Offers Evaluation (Product Demonstration) - Step 5; Negotiation - Step 6; Closing the Deal - Step 7: Until this stage, the ISPAR Outcome was rated as “R”, indicating that the value was successfully realized as proposed; Post-Sale Evaluation (Customer Follow-Up) - Step 8: This stage introduced complications; issues related to product delivery failed to meet expectations, resulting in an ISPAR evaluation of “-K”, indicating unresolved disputes; Resolution Attempts - Step 9: The ISPAR outlook here shifted to “K”, signifying that disputes remained unresolved, leading to a negative customer experience.

This pattern was consistently observed across the three participating companies in this second group. While the SMEs effectively secured deals up to the closing stage, the 'Post-Sale Evaluation' phase often led to partner disputes, negatively impacting customer experiences. These findings underscore a critical area for improvement in managing post-sale relationships and expectations. The repeated issues at this stage suggest a need for enhanced clarity in communication and agreement on post-sale support and product quality standards among partners. These findings highlight the dual challenges of maintaining partnership integrity and ensuring customer satisfaction in post-sale scenarios. Addressing these issues is crucial for SMEs to leverage their cooperative strategies effectively and sustain positive customer relationships and a good reputation in the competitive market.

7.4.3 Findings from the SMEs Acting fully engaged in the CN-EcoTech Ecosystem

This group comprises companies that have embraced the opportunity to partner with rivals within the CN-EcoTech ecosystem for more significant opportunities, demonstrating a successful pattern of engagement along the opportunity (from the lead to win or lose).

As detailed in Appendix II, Figure 7.6, throughout the service process, which extended to Step 9, the ISPAR Service Outcome consistently remained at “R”, indicating that the value was performed as proposed, expectations were met, and "positive experiences" were generated for customers. Indeed, these companies, which agreed to keep following the full opportunity pipeline as CN-EcoTech members, exhibited the most favorable outcomes compared to other groups.

The pattern was also consistently observed across the three participating companies. The three companies consistently secured opportunities and maintained amicable relationships with rivals, leading to positive customer experiences throughout the engagement process. This group's success highlights the distinct advantages of active participation within the cooperative framework.

7.5 Comparative Insights from the Proof-of-Concept

Through a detailed analysis of nine SMEs, differentiated Outcomes were found, reflecting the diverse strategies in market approach and their implications.

The SMEs acting independently encountered significant hurdles in deal closure, emphasizing the need for enhanced negotiation capabilities and supportive frameworks to boost market success. Findings emphasize the need for supportive frameworks to enhance the market success rates

of these enterprises.

SMEs that partially adopted CN-EcoTech's practices faced challenges related to post-sale disputes, which adversely affected customer satisfaction. Findings stress the importance of managing relationships within coopetition networks to mitigate potential conflicts and ensure mutual benefits.

The SMEs engaged in CN-EcoTech ecosystem have experienced successful deal closures and positive interactions with competitors and customers. These findings highlight the substantial benefits of participation in coopetition networks, such as enhanced deal closure rates and improved relationships. These outcomes validate CN-EcoTech’s potential to foster compelling and harmonious coopetition among SMEs.

The Service Blueprint framework for CN-EcoTechs has also proven invaluable. It enhances the understanding and optimization of actor interactions along digital service journeys. This framework facilitates the strategic alignment of operations and interactions, ensuring coherence and making a positive contribution to the overall service ecosystem.

Although still in the PoC phase, CN-EcoTech has effectively demonstrated its viability as a solution for enabling coopetition among OS-PT SMEs. It affirms its practical applicability and underscores its transformative potential to address traditional market challenges. By doing so, CN-EcoTechs pave the way for more innovative and collaborative market engagement strategies within the OS-PT sector, potentially extending to other industries.

Chapter 7. Summary

This chapter examines the application of CN-EcoTechs within the OS-PT sector, marking a significant shift from theoretical frameworks to real-world deployment. This exploration employs the DSR methodology to evaluate the artefact's capacity to facilitate coopetition and value cocreation among SMEs. Through the Service Blueprinting method, the chapter vividly captures the dynamics of coopetition interactions and evaluates their effectiveness in fostering cooperative competition across different group dynamics within the sector.

Key activities detailed in this chapter include validating the Service Blueprint through interviews with SME managers and engineers, applying the ISPAR model to evaluate service interaction

outcomes, and conducting a structured PoC involving three distinct groups of SMEs under varying cooperation conditions.

Building on these findings and insights, Chapter 8 extends the evaluation to quantify CN-EcoTech's broader impacts on value cocreation.

Chapter 8. Assessing the Impact of CN-EcoTech on OS-PT SMEs

If I have seen further, it is by standing on the shoulders of giants. - Isaac Newton

Chapter 8 initiates DSR Activity 5, as conceptualized by Peffers et al. (2007), focusing on evaluating the effectiveness of CN-EcoTech through an Experimental Pilot Project within the OS-PT sector. This activity involves a rigorous quantitative analysis of the benefits of implementing CN-EcoTech practices among a select group of SMEs, chosen for their representation of the sector's state-of-the-art, willingness to participate in the study, and sufficient size to ensure robust data collection. This analysis seeks to address specific research questions regarding the impact of CN-EcoTech on operational Efficiency (RQ2), operational Scale (RQ3), customer satisfaction determinants (RQ4), and ecological footprint (RQ5) of the OS-PT SMEs.

The specific objective of this chapter is to execute an Experimental Pilot Project that quantitatively assesses the tangible benefits of the CN-EcoTech practices in terms of Operational Efficiency, Scale, customer satisfaction, and ecological footprint within selected OS-PT SMEs. This evaluation is designed to align with the SDGs and to consider broader societal and environmental impacts. The evaluation process is organized into five strategic steps grounded in S-D Logic and DSR methodology. The structured approach for this evaluation is depicted in Figure 21, which illustrates the experimental methodology specifically tailored to assess the tangible benefits of the CN-EcoTech ecosystem within the OS-PT SME sector.

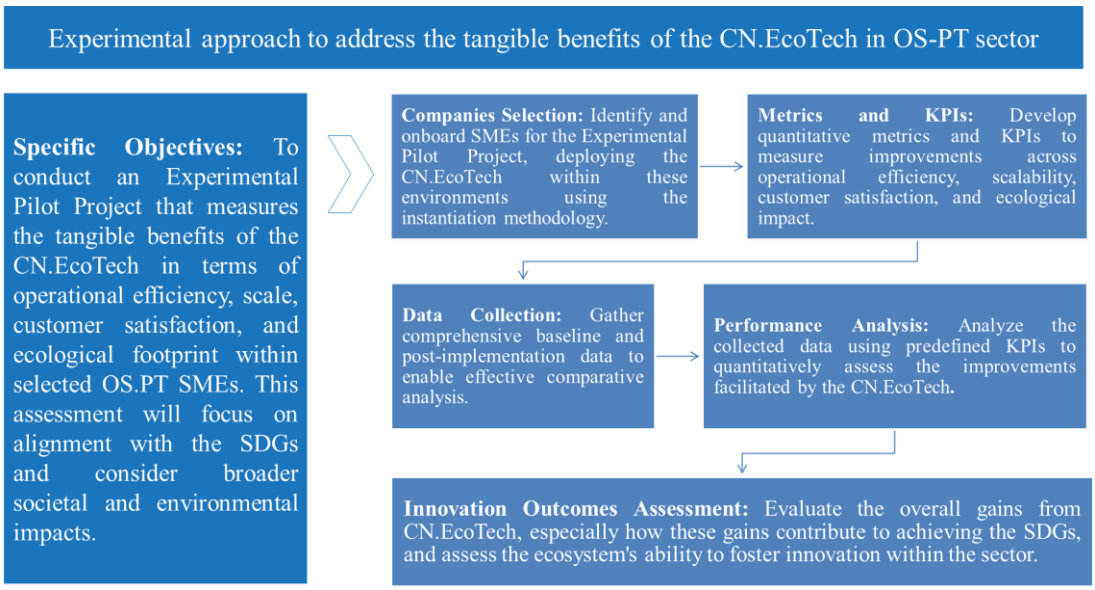


Figure 21. Chapter 8 Graphical Abstract: Evaluating the Benefits of CN-EcoTech in the OS-PT Sector.

Following the DSR methodology, a critical review will be conducted post-assessment. Suppose the CN-EcoTech does not meet the expected benefits. In that case, this activity may involve a reevaluation and potential redesign to better align with the needs and objectives of the OS-PT sector. This chapter marks a crucial step in validating the real-world applicability and effectiveness of CN-EcoTech in enhancing the operational dynamics of SMEs within the sector.

8.1 SME Selection Process and Experimental Pilot Project Implementation

Identifying an appropriate context for empirical investigation is crucial in quantitative research methodologies [330]. The inherent specificity of such research, coupled with the associated costs of data provision and collection, requires a pragmatic approach to selecting sectors and companies. To carry out the DSR Activity 5 [227], the selection of OS-PT companies was primarily driven by convenience factors, including the feasibility of implementing an Experimental Pilot Project, data availability, costs associated with data acquisition and analysis, and their representativeness of the sector's diversity.

The activity was structured in a two-phased approach: An initial assessment phase of current best practices (CB.P) and a subsequent data collection phase following the implementation of the Experimental Pilot Project to collect data from OS-PT SMEs operating under coopetition network practices (CN.P), as depicted in Figure 22.

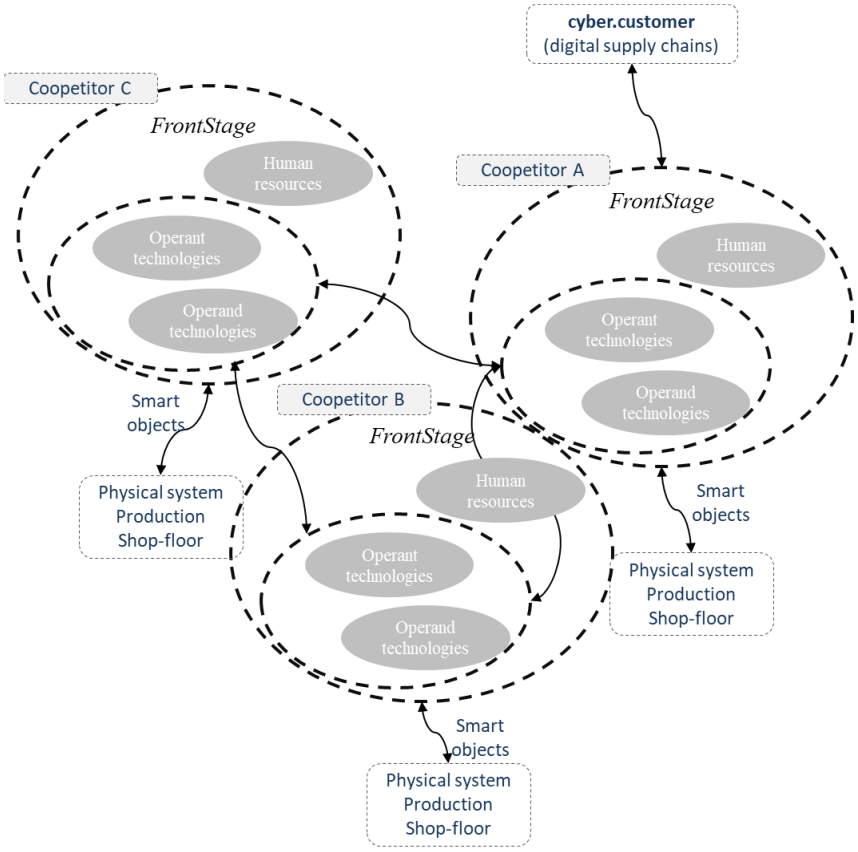


Figure 22. Overview of the Experimental Pilot Project for OS-PT SMEs under the CN.P.

This strategic process commenced with establishing direct and informal communication channels with the companies' managing directors, who were formally invited to participate in the study. A comprehensive confidentiality agreement was drafted to ensure the nondisclosure of sensitive information about the companies' operations, clientele, employees, resources, and competitors.

Following diligent negotiations, three managers from ornamental stone companies representing the sector's diversity agreed to participate in the Experimental Pilot Project, which was deployed using the previously outlined instantiation methodology described in Chapter 6. To maintain confidentiality and anonymity, these companies are henceforth referred to as "Coopetitor A," "Coopetitor B," and "Coopetitor C".

Oversight was rigorously maintained throughout the operational processes to safeguard data integrity and confidentiality. It was achieved through direct, daily monitoring and recording of quantitative data via digital machinery and databases, ensuring the accuracy and privacy of the information collected from these stone production entities.

The approach begins with a baseline assessment of CB.P. within the participating SMEs and then systematically transitions to CN.P. This documented transition captures the nuanced dynamics of change and its immediate impacts.

8.1.1 Establishment of Metrics and KPIs in OS-PT SMEs

Recent surveys by Silva and Cardoso (2023) highlight the critical need for OS-PT SMEs to enhance Operational Efficiency, scalability, customer satisfaction, and ecological sustainability in response to the challenges posed by BIM-oriented supply chains in the AEC sector [57], [59]. To effectively assess the impact of the CN-EcoTech on these SMEs, it is imperative to develop a robust framework for quantitative metrics and Key Performance Indicators (KPIs). This framework is designed to capture and measure tangible improvements across the dimensions, providing a clear, data-driven insight into how CN-EcoTech enhances business processes and contributes to sustainable practices within the sector. Through these metrics, the analysis will delineate the benefits of CN-EcoTech, illustrating its potential to transform operations and drive environmental stewardship.

8.1.2 Operational Efficiency-related Metrics, KPIs and Innovation Outcomes

Assessing and enhancing Efficiency is crucial in the industrial landscape, where production operations, logistics, and business activities intersect. The literature on lean management suggests that Efficiency can be gauged through multiple KPIs, such as First Time Through (FTT), Performance Efficiency (PE), Raw Material Yield (RMY), and Labor Productivity (LP) [331] [332]. These indicators are not just measures of operational success but also serve as beacons for resource optimization and process improvement.

KPI for First Time Through (KPIFTT): Measures the proportion of processes completed correctly on the first attempt, indicating process efficiency and waste reduction. High rates indicate that operations meet quality standards from the outset (Table 1, Eq. 1).

KPI for Performance Efficiency (KPIPE): This KPI measures the speed and accuracy of outputs against benchmarks, with high values indicating optimal resource utilization and efficient work completion (Table 1, Eq. 2).

KPI for Raw Material Yield (KPIRMY): Evaluates the Efficiency of converting raw materials into finished goods, where higher yields indicate less waste and more efficient processes (Table 1, Eq.3).

KPI for Labor Productivity (KPILP): Assesses the output per labor hour, with improvements indicating streamlined operations and efficient labor utilization (Table 1, Eq.4).

Table 1. Formulation of the Efficiency-related KPIs

Equation	KPIs	Description	Formulation
Eq.1	KPI_{FTT} (%)	FFT Quantitative KPI	$\sum_1^n \left(\frac{\sum parts\ produced - defective\ parts\ _{(daily)}}{\sum parts\ produced_{(daily)}} \right) . 100\%$
Eq.2	KPI_{FFT} (parts/hour)	FTT Consistency KPI	$\sum_1^n \left(\frac{\sum good\ parts\ produced\ _{(daily)}}{\sum total\ hours\ (production + setup + maintenance)_{(daily)}} \right)$

Eq.3	KPI_{PE} parts/m2	PE Quantitative KPI	$\sum_1^n \left(\frac{\sum parts_acepted_by_customers_{(daily)}}{\sum total\ raw_materials_used)_{(daily)}} \right)$
Eq.4	KPI_{LP} parts/worker	LP Quantitative gains	$\sum_1^n \left(\frac{\sum good\ parts_produced_{(daily)}}{\sum total_workers_involved)_{(daily)}} \right)$
Eq.5	KPI(σ-Efficiency)	Consistency KPI	$\sqrt[2]{\frac{\sum_1^n [KPI(FFT;PE;RMY;LP)_{(daily)} - \overline{KPI(FFT;PE;RMY;LP)_{(daily)}}]^2}{(Observations(FFT;PE;RMY;LP)_{(test\ period)})}}$

To deepen the insights into potential Efficiency improvements, this methodology introduces an additional metric, KPI(σ-Efficiency), designed to assess efficiency variability throughout the evaluation period (Table 1, Eq.5). This novel indicator provides a nuanced understanding of efficiency trends, offering a measure of consistency or fluctuation in performance metrics over time, thereby enhancing the analysis of stability and reliability in efficiency gains.

To evaluate the impact of adopting CN.P, the service literature introduces the concept of Innovation Outcomes (IOs) [188], which tracks the evolution of KPIs as companies innovate. This approach quantifies the effects of innovations, such as entering coopetition networks or leveraging new technologies, on Operational Efficiency. By measuring changes in KPIs, IOs provide insights into how innovations enhance operational metrics such as productivity, material yield, and process efficiency (Table 2, Eq.6-Eq.14). This framework underscores the benefits of innovation and its pivotal role in enhancing competitiveness and sustainability within the digital supply chain. Innovation Outcomes provide a precise mechanism for gauging the transformative impact of new practices on OS SMEs.

Table 2. Formulation of the Efficiency-related IOs

Equation	**Innovation Outcomes**	**Description**	**Formulation**
Eq.6	$IO_{(QTT)FFT}$	FFT Quantitative gains	$\frac{KPI_{(FTT_COO.N)} - KPI_{(FTT_CBP)})}{KPI_{(FTT_COO.N)}}.100\%$
Eq.7	$IO_{(σ)FFT}$	FFT Consistency gains	$\frac{KPI_{(σFTT_COO.N)} - KPI_{(σFTT_CBP)})}{KPI_{(σFTT_COO.N)}}.100\%$
Eq.8	$IO_{(QTT)PE}$	PE Quantitative gains	$\frac{KPI_{(PE_COO.N)} - KPI_{(PE_CBP)})}{KPI_{(PE_COO.N)}}.100\%$
Eq.9	$IO_{(σ)PE}$	PE Quantitative Consistency gains	$\frac{KPI_{(σPE_COO.N)} - KPI_{(σPE_CBP)})}{KPI_{(σPE_COO.N)}}.100\%$
Eq.10	$IO_{(QTT)RMY}$	RMY quantitative gains	$\frac{KPI_{(RMY_COO.N)} - KPI_{(RMY_CBP)})}{KPI_{(RMY_COO.N)}}.100\%$
Eq.11	$IO_{(σ)RMY}$	RMY Consistency gains	$\frac{KPI_{(σRMY_COO.N)} - KPI_{(σRMY_CBP)})}{KPI_{(σRMY_COO.N)}}.100\%$
Eq.12	$IO_{(QTT)PL}$	PL Quantitative gains	$\frac{KPI_{(PL_COO.N)} - KPI_{(PL_CBP)})}{KPI_{(PL_COO.N)}}.100\%$
Eq.13	$IO_{(σ)PL}$	PL Consistency gains	$\frac{KPI_{(σPL_COO.N)} - KPI_{(σPL_CBP)})}{KPI_{(σPL_COO.N)}}.100\%$
Eq.14	$IO_{(QTT)Efficiency}$	Efficiency Quantitative gains	$\frac{IO_{(QTT)FFT} + IO_{(QTT)PE} + IO_{(QTT)RMY}\ IO_{(QTT)PL}}{4}.100\%$

Eq.15	$IO_{(\sigma)Efficiency}$	Efficiency Consistency gains	$\frac{IO_{(\sigma)FFT} + IO_{(\sigma)PE} + IO_{(\sigma)RMY}\ IO_{(\sigma)PL}}{4}.100\%$

Therefore, IOs are an integral part of this methodology. IOFFT, IOPE, IORMY, and IOPL represent the quantitative gains in the first through performance, material yield, and labor productivity facilitated by cooperation. Moreover, a metric IO(σ) is introduced to assess the variability or consistency gain in innovation outcomes over the testing period, utilizing standard deviation to provide insights into how Efficiency and operational performance evolve (Table 8.2, Eq. 15).

8.1.3 Operational Scale-related Metrics, KPIs and IOs

When scaling business operations, understanding the multifaceted nature of scale—particularly its dependency on factors such as production processes, logistics, and overarching business strategies—is essential. Drawing on insights from technology management literature [276], this research highlights the critical role of KPIs in evaluating scalability enhancements. Indicators such as Conversion Rate (CR), Product Stockouts (PsO), Manufacturing Value Added (MvA), and Production Output Ratio (PoR) are essential for assessing scale capacity effectively. These KPIs enable businesses to comprehensively evaluate and optimize their capacity to respond to global scale demands.

KPI for Conversion Rate (KPICR): This KPI measures the effectiveness of converting leads into customers, reflecting the company's ability to capitalize on opportunities within digital and global supply chains (Table 3, Equation 1).

KPI for Product Stockouts (KPIPsO): This KPI indicates the frequency of inventory shortages that fail to meet customer demand, highlighting supply chain agility and responsiveness (Table 3, Eq.2). KPI for Manufacturing Value Added (KPIMvA): This KPI assesses the value added by manufacturing operations, emphasizing operational Efficiency and product specialization (Table 3, Eq.3). KPI for Production Output Ratio (KPIPoR): This KPI quantifies the volume of units produced relative to resource capacity, evaluating productivity and operational efficacy (Table 3, Eq.4).

Table 3. Formulation of the Scale-related KPIs

Equation	KPIs	Description	Formulation
Eq.1	KPICR (%)	CR Quantitative KPI	$Avarage\left(\frac{\sum Number\ sold\ parts_{(daily)}}{\sum parts\ leaded\ parts_{(daily)}}\right).100\%$
Eq.2	KPIPsO (%)	PsO Consistency KPI	$Avarage\left(\frac{\sum Number\ of\ Stockout\ Incident_{(daily)}}{\sum total_inventory_requests_{(daily)}}\right).100\%$
Eq.3	KPIMvA (%)	MvA Quantitative KPI	$Avarage\left(\frac{\sum Usefull_operations\ to\ finish\ products_{(daily)}}{\sum total\ required\ operations)_{(daily)}}\right).100\%$
Eq.4	KPIPoR (%)	PoR Quantitative KPI	$Avarage\left(\frac{\sum total_units_produced_{(daily)}}{\sum total_resources_capacity)_{(daily)}}\right).100\%$

Eq.5	KPI(σ-scale)	Dispersion KPI	$\sqrt{\frac{\sum_1^n [KPI(CR;PsO;MvA;PoR)_{(daily)} - \overline{KPI(FR;PsO;MvA;PoR)_{(daily)}}]^2}{(Observations(R;PsO;MvA;PoR)_{(test\ period)})}}$

Table 4. Formulation of the Scale-related IOs

Equation	Innovation Outcome	Description	Formulation
Eq.6	$IO_{(QTT)CR}$	QR Quantitative gains	$\frac{KPI_{(CR)CN.P} - KPI_{(CR)CB.P}}{KPI_{(CR)CN.P}}.100\%$
Eq.7	$IO_{(\sigma)CR}$	QR Consistency gains	$\frac{KPI\sigma_{(CR)CN.P} - KPI\sigma_{(CR)CB.P})}{KPI\sigma_{(CR)CN.P}}.100\%$
Eq.8	$IO_{(QTT)PsO}$	PsO Quantitative gains	$\frac{KPI_{(PsO)CN.P} - KPI_{(PsO)CB.P})}{KPI_{(PsO)CN.P}}.100\%$
Eq.9	$IO_{(\sigma)\ PsO}$	PsO Quantitative Consistency gains	$\frac{-(KPI\sigma_{\sigma(PsO)CN.P} - KPI\sigma_{(PsO)CB.P})}{KPI\sigma_{(PsO)CN.P}}.100\%$
Eq.10	$IO_{(QTT)MvA}$	MvA quantitative gains	$\frac{KPI_{(MvA)CN.P} - KPI_{(MvA)CB.P})}{KPI_{(MvA)CN.P}}.100\%$
Eq.11	$IO_{(\sigma)MvA}$	MvA Consistency gains	$\frac{KPI\sigma_{(MvA)CN.P} - KPI\sigma_{(MvA)CB.P})}{KPI\sigma_{(MvA)CN.P}}.100\%$
Eq.12	$IO_{(QTT)PoR}$	PoR Quantitative gains	$\frac{KPI_{(PoR)CN.P} - KPI_{(PoR)CB.P})}{KPI_{(PoR)CN.P}}.100\%$
Eq.13	$IO_{(\sigma)PoR}$	PoR Consistency gains	$\frac{KPI\sigma_{(PoR)CN.P} - KPI\sigma_{(PoR)CB.P}}{KPI\sigma_{(PoR)CB.P}}.100\%$
Eq.14	$IO_{(QTT)SCALE}$	Scale Quantitative gains	$\frac{IO_{(QTT)CR} + IO_{(QTT)PsO} + IO_{(QTT)MvA}\ IO_{(QTT)PoR}}{4}.100\%$
Eq.15	$IO_{(\sigma)SCALE}$	Scale Consistency gains	$\frac{IO_{(\sigma)CR} + IO_{(\sigma)PsO} + IO_{(\sigma)MvA} + IO_{(\sigma)PoR}}{4}.100\%$

The investigation into coopetition dynamics sheds light on their influence on the operational Scale capacity of OS-PT SMEs within digital supply chain contexts. Through quantitative analysis of the KPIs above, this research elucidates the impact of CN.P on scaling efforts. By incorporating the KPI(σ-Scale), the analysis is enriched, focusing on the stability and predictability of scalability enhancements (Table 3, Eq.5)

A detailed examination of shifts in KPI Operational Scale-related IOs provides concrete evidence of significant improvements brought about by adopting CN.P, enhancing scale. This analysis highlights distinct aspects of Scale capacity that have experienced positive transformations, underscoring the pivotal contribution of CN.P to advancing progressive enhancements and fostering an environment of continuous innovation and operational excellence. Table 4, Eq.6-Eq.15 details the equations used to assess the quantitative IO (gains) and its consistency across the CR, PsO, MvA, and PoR KPIs due to coopetition, facilitating a nuanced understanding of Scale enhancement impacts.

8.1.4 Customer Satisfaction Determinants-related Metrics, KPIs, and IOs

In industrial sectors, customer satisfaction is shaped by various factors, including production processes, logistics, and overall business activities. Drawing on insights from management and manufacturing, this methodology highlights the crucial role of KPIs in assessing enhancements to Customer Satisfaction Determinants [333]. This framework focuses on the Value-to-Weight Ratio (VwR), Production Flexibility (Flex), Customer Complaint Ratio (CcR), and On-Time Delivery Ratio (OtD), providing a systematic means to examine and refine operational strategies effectively.

KPI for Value to Weight Ratio (KPIVwR): This KPI assesses the economic value of a product relative to its weight, which is crucial in sectors where shipping costs are a significant component of total costs and perceived value (Table 5, Eq.1).

KPI for Production Flexibility (KPIFlex): Measures a manufacturer's ability to respond to demand fluctuations, production changes, and customization requests without excessive costs or delays (Table 5, Eq.2).

KPI for Customer Complaint Ratio (KPICcR): Calculates the proportion of customer complaints relative to the total number of products or services delivered, indicating product/service quality and customer service Efficiency (Table 5, Eq.3).

KPI for On-Time Delivery Ratio (KPIOtD): Measures the percentage of products or services delivered within the agreed timeframe, reflecting operational Efficiency and reliability (Table 5, Eq.4).

Incorporating the metric KPI(σ-cust.sat.det) to evaluate variability during the assessment period offers a nuanced perspective on customer satisfaction trends (Table 8.5, Eq.5). This approach deepens the understanding of the stability and dependability of customer satisfaction enhancements, enriching the analysis and highlighting the effectiveness of operational strategies.

Improvements documented through IOs pertain to enhancements realized through CN.P. By tracking nuanced shifts in KPIs, these IOs provide evidence of the improvements in customer satisfaction metrics resulting from CN.P adoption. The methodology for assessing these determinants is detailed in Table 6, Eqs. 6-Eq. 15, which includes equations for evaluating the quantitative improvements and consistency in the customer satisfaction determinants.

Table 5. Formulation of the Satisfaction Determinants-related KPIs

Equation	KPIs	Description	Formulation
Eq.1	KPI_{VtW} (%)	VtW Quantitative KPI	$\sum_1^n \left(\frac{\sum total_value_of_goods_{(daily)}}{\sum total_transport_costs_{(daily)}}\right)$

Eq.2	KPI_{Flex} (%)	Flex Consistency KPI	$\sum_1^n \left(\frac{\sum total_parts_customized_{(daily)}}{\sum parts_produced_{(daily)}}\right)$
Eq.3	KPI_{CcR} (%)	CcR Quantitative KPI	$\sum_1^n \left(\frac{\sum total_complained_parts_{(daily)}}{\sum parts_delivered)_{(daily)}}\right)$
Eq.4	KPI_{OtD} (%)	OtD Quantitative KPI	$\sum_1^n \left(\frac{parts_delivered_on_time_{(daily)}}{\sum parts_delivered)_{(daily)}}\right)$
Eq.5	$KPI_{(\sigma)}$	Dispersion KPI	$\sqrt[2]{\frac{\sum_1^n [KPI(VtW;Flex;CcR;OtD)_{(daily)} - \overline{KPI(VtW;Flex;CcR;OtD)_{(daily)}}]^2}{(Observations(VtW;Flex;CcR;OtD)_{(test\ period)})}}$

Table 6. Formulation of the Satisfaction Determinants-related IOs

Equation	Innovation Outcomes	Description	Formulation
Eq.6	$IO_{(QTT)VtW}$	VtW Quantitative gains	$\frac{KPI_{(VtW)CN.P} - KPI_{(VtW)CB.P}}{KPI_{(VtW)CN.P}}.100\%$
Eq.7	$IO_{(\sigma)VtW}$	VtW Consistency gains	$\frac{KPI\sigma_{(VtW)CN.P} - KPI\sigma_{(VtW)CB.P})}{KPI\sigma_{(VtW)CN.P}}.100\%$
Eq.8	$IO_{(QTT)Flex}$	Flex Quantitative gains	$\frac{KPI_{(Flex)CN.P} - KPI_{(Flex)CB.P)}}{KPI_{(Flex)CN.P}}.100\%$
Eq.9	$IO_{(\sigma)\ Flex}$	Flex Quantitative Consistency gains	$\frac{-(KPI\sigma_{\sigma(Flex)CN.P} - KPI\sigma_{(Flex)CB.P)})}{KPI\sigma_{(Flex)CN.P}}.100\%$
Eq.10	$IO_{(QTT)CcR}$	CcR quantitative gains	$\frac{KPI_{(CcR)CN.P} - KPI_{(CcR)CB.P)}}{KPI_{(CcR)CN.P}}.100\%$
Eq.11	$IO_{(\sigma)\ CcR}$	CcR Consistency gains	$\frac{KPI\sigma_{(CcR)CN.P} - KPI\sigma_{(CcR)CB.P})}{KPI\sigma_{(CcR)CN.P}}.100\%$
Eq.12	$IO_{(QTT)OtD}$	OtD Quantitative gains	$\frac{KPI_{(PoR)CN.P} - KPI_{(PoR)CB.P})}{KPI_{(PoR)CN.P}}.100\%$
Eq.13	$IO_{(\sigma)\ OtD}$	OtD Consistency gains	$\frac{KPI\sigma_{(OtD)CN.P} - KPI\sigma_{(OtD)CB.P}}{KPI\sigma_{(OtD)CB.P}}.100\%$
Eq.14	$IO_{(QTT)Cust.Satisf}$	Cust. Satisf. Drivers Quantitative gains	$\frac{IO_{(QTT)VtW} + IO_{(QTT)Flex} + IO_{(QTT)CcR}\ IO_{(QTT)OtD}}{4}.100\%$
Eq.15	$IO_{(\sigma)\ Cust.Satisf}$	Cust. Satisf. Drivers Consist. gains	$\frac{IO_{(\sigma)VtD} + IO_{(\sigma)Flex} + IO_{(\sigma)CcR} + IO_{(\sigma)OtD}}{4}.100\%$

The analysis highlights improvements in consistency across the Value to Weight Ratio, Flexibility, Customer Complaint Ratio, and On-Time Delivery KPIs, which are attributable to coopetition. These enhancements reflect a stabilized and reliable performance in critical aspects of customer satisfaction, underscoring the strategic advantage of coopetition practices and highlighting the transformative impact of CN.P on manufacturing SMEs in enhancing customer satisfaction. This comprehensive view illustrates how coopetition fosters growth by securing competitive advantages through improved customer relations.

8.1.5 Ecological Footprint-related Metrics, KPIs, and IOs

Amid escalating climate challenges and the ambitions of the Paris Agreement to cap global temperature increases, employing Life Cycle Assessment (LCA) methodologies is essential for quantifying the ecological footprint of manufacturing processes [334]. This methodology, rooted in LCA principles, focuses on assessing the impact of CN.P on CO2 emissions and overall ecological sustainability in the manufacturing process.

Methodology Phases: Framework Design - Develop a framework grounded in LCA principles; Framework Application - Apply this framework to evaluate digital interventions in manufacturing processes; and Data Analysis - Analyze data to determine the ecological benefits, emphasizing potential reductions in operational CO2 emissions within the OS-PT sector.

This framework focuses on the First Time Through (KPIFTT), Energy Efficiency (KPIEE), Raw Material Yield (KPIRMY), and Carbon Footprint Emissions (KPICO2-Eq), providing systematic means to examine and refine operational strategies effectively.

KPI for First Time Through (KPIFTT): Measures process efficiency by calculating the proportion of products meeting quality standards on the first attempt, reducing waste and rework (Table 7, Eq.1).

KPI for Energy Efficiency (KPIEE): This KPI quantifies operational Efficiency as the output-to-energy-consumed Ratio, highlighting energy conservation opportunities (Table 7, Eq. 2).

KPI for Raw Material Yield (KPIRMY): This KPI evaluates the effectiveness of raw material usage, which is crucial for minimizing waste and optimizing utilization (Table 7, Eq.3).

KPI for Carbon Footprint Emissions (KPICO2-Eq): This KPI measures carbon emissions associated with manufacturing processes, providing insights into the environmental impact (Table 7, Eq. 4).

KPI for Footprint Dispersion Indicator (KPIσ-CO2-Eq): This KPI measures the variability in environmental performance over time, providing insights into the consistency of ecological impacts (Table 7, Eq. 5).

Table 7. Ecological Footprint-related Metrics and KPIs

Equation	KPIs	Description	Formulation
Eq.1	KPIFTT %	(FFT) First Time Through	$Avarage\left(\frac{\sum parts\,produced - \sum defective\,parts_{(daily)}}{\sum parts\,produced_{(daily)}}\right).100\%$
Eq.2	KPIEE parts/kW	(EE) Energetic Efficiency	$Avarage\left(\frac{\sum parts_produced_{(daily)}}{\sum energy_consumed)_{(daily)}}\right)$
Eq.3	KPIRMY parts/m2	(RMY) Raw Material Yield	$Avarage\left(\frac{\sum parts_acepted_by_customers_{(daily)}}{\sum total\ raw_materials_used)_{(daily)}}\right)$
Eq.4	KPICO2-eq KgCO2	($KPI_{CO2\text{-}Eq}$) Equivalent CO2	$Avarage\left(\frac{\sum parts_delivered_on_time_{(daily)}}{\sum parts_delivered)_{(daily)}}\right)$

Eq.5	KPI(σ-footprint)	Emissions Footprint Consistency Indicator	$\sqrt[2]{\frac{\sum_1^n [KPI(FFT;EE;RMY;CO2eq)_{(daily)} - \overline{KPI(FT;EE;RMY;CO2eq)_{(daily)}}]^2}{(Observations(FT;EE;RMY;CO2eq)_{(daily)})}}$

By examining these KPIs within coopetition networks, the study aims to reveal how CN.P can lead to CO2 emission reductions. This analysis contributes to the broader discourse on sustainable development, exploring how digital technologies and coopetition can help SMEs align with global sustainability goals, particularly those outlined in the Paris Agreement[7]. The objective is to demonstrate the role of coopetition in enhancing ecological sustainability and reducing the environmental impact of business operations, thereby supporting the shift towards more sustainable manufacturing practices.

IOs related to Ecological Footprint: Provide quantifiable evidence of ecological improvements through CN.P (Table 8, Eq.6-Eq.11). By detailing shifts in KPIs, these IOs showcase significant ecological sustainability enhancements resulting from CN.P adoption. The IO(QTT)CO2eq assesses the quantitative CO2eq gains from adopting CN.P (Table 8, Eq.12).

IO(σ-CO2eq): Evaluates the consistency of ecological footprint impacts from these practices (Table 8, Eq.13).

This comprehensive assessment highlights the direct impact of operational and technological innovations on environmental stewardship, enriching our understanding of how coopetition fosters ecological sustainability among SMEs.

Table 8. Ecological Footprint-related IOs

Equation	Innovation Outcome	Description	Formulation
Eq.6	IO(QTT)FFT	FFT Quantitative gains	$\frac{KPI_{(FTT_CN.P)} - KPI_{(FTT_CB.P)})}{KPI_{(FTT_CN.P)}}.100\%$
Eq.7	IO(σ)FFT	FFT Consistency gains	$\frac{KPI_{(\sigma FTT_CN.P)} - KPI_{(\sigma FTT_CB.P)})}{KPI_{(\sigma FTT_CN.P)}}.100\%$
Eq.8	IO(QTT)EE	EE Quantitative gains	$\frac{KPI_{(PE_CN.P)} - KPI_{(PE_CB.P)})}{KPI_{(PE_COO.N)}}.100\%$
Eq.9	IO(σ)EE	EE Quantitative Consistency gains	$\frac{KPI_{(\sigma PE_CN.P)} - KPI_{(\sigma PE_CB.P)})}{KPI_{(\sigma PE_CN.P)}}.100\%$
Eq.10	IO(QTT)RMY	RMY quantitative gains	$\frac{KPI_{(RMY_CN.P)} - KPI_{(RMY_CB.P)})}{KPI_{(RMY_CN.P)}}.100\%$
Eq.11	IO(σ)RMY	RMY Consistency gains	$\frac{KPI_{(\sigma RMY_CN.P)} - KPI_{(\sigma RMY_CB.P)})}{KPI_{(\sigma RMY_COO.N)}}.100\%$
Eq.12	IO(QTT)Co2-eq	CO2eq Quantitative gains	$\frac{KPI_{(\sigma-Co2-Eq_CN.P)} - KPI_{(CO2eq_CB.P)})}{KPI_{(CO2eq_CN.P)}}.100\%$
Eq.13	IO(σ-CO2-eq)	CO2eq Consistency gains	$\frac{KPI_{(\sigma_CO2_Eq_CN.P)} - KPI_{(\sigma-\sigma-CO2eq_CB.P)})}{KPI_{(\sigma_CO2eq_CN.P)}}.100\%$

[7] https://unfccc.int/process-and-meetings/the-paris-agreement

8.2 Data Collection and Procedures

To investigate the transition from CB.P to CN.P, the study employed a data collection strategy over two distinct intervals, each lasting fifty-four days. This approach was chosen to establish a robust comparative analysis of operational outcomes under CB.P and CN-EcoTech-enhanced practices.

Phase 1 - CB.P: The first interval, running from April 17th, 2023, to June 10th, 2023, focused on capturing the standard operations at three anonymized companies, designated as "A," "B," and "C." This baseline phase documented each entity's reliance on its internal resources for production and delivery, providing essential data to serve as a reference for later comparison.

Phase 2 - CN.P: The second interval spanned from September 9th, 2023, to November 14th, 2023. During this phase, the study examined the effects of integrating these entities into a coopetition-based network under CN-EcoTech. This phase marked a significant shift, encouraging coopetition interactions and the shared use of technologies and resources, representing a step forward from standard practices.

Data management and privacy were maintained throughout the study. In compliance with confidentiality agreements, all data were anonymized and referred to only by company labels. Data collection, recording, and exportation procedures were meticulously followed, with results exported to Excel files as detailed in the methodology section. It ensured a secure, consistent approach to data handling, allowing for detailed analysis while safeguarding the privacy and proprietary information of the participating companies. This structured methodology not only facilitated a direct comparison of operational outcomes but also upheld the integrity and confidentiality of the data throughout the research process.

8.3 Findings

In this study phase, a comprehensive analysis of the data collected from the Experimental Pilot Project is conducted. By systematically comparing this data with the pre-established KPIs, the research aims to quantitatively assess the impact of the CN-EcoTech on the operational Efficiency, scalability, customer satisfaction, and ecological footprint in the selected SMEs. This analysis identifies significant patterns, discerns the efficacy of the implemented technology, and measures the extent of improvements or challenges introduced by the CN-EcoTech.

8.3.1 Operational Efficiency

This section evaluates the Operational Efficiency-related KPIs and IOs under categories CB.P and CB.P. The data collected and documented under these categories are stored in an Excel file. The summarized findings, representing an average across three SMEs, are presented in Table 9. This table provides a snapshot of crucial efficiency metrics under CB.P as a baseline for assessing improvements and identifying areas for potential enhancement.

Table 9. Summary of Average data collected for Efficiency-related (CB.P)

Data ID	Description	Current Best Practices (CB.P)	Data (average daily)
Data 1	Parts produced	∑parts_produced	369.9
Data 2	Defective parts	∑defective_parts	31.3
Data 3	Shipped parts	∑good_parts_produced	338.5
Data 4	Producing hours	∑total_time	13.3
Data 5	Parts accepted	∑parts_accepted	323.7
Data 6	Raw material used	∑raw_materials	425.3
Data 7	In production	∑labour_used	49.3

Data collected and documented under CN.P are stored in an Excel file. The findings from these data are summarized in Table 10, which presents the average efficiency-related data for the three SMEs involved in the study. This table offers a comprehensive view of the operational efficiencies observed, facilitating a clear performance assessment across the participating SMEs.

Table 10. Summary of Average data collected for Efficiency-related (CN.P)

Data ID	Description	Coopetition Networks (CN.P)	Data (average daily)
Data 8	Parts produced	∑parts_produced	454.3
Data 9	Defective parts	∑defective_parts	38.5
Data 10	Shipped parts	∑good_parts_produced	415.8
Data 11	Producing hours	∑total_time	13.3
Data 12	Parts accepted	∑parts_accepted	437.1
Data 13	Raw material used	∑raw_materials	454.3
Data 14	In production	∑labour_used	49.3

Using the data collected under CB.P and CNP, the efficiency-related KPIs are calculated as detailed in Table 1, Eq1-Eq5. The results of these assessments for both CB.P and CN.P are shown in Table 11.

Table 11. Comparative Efficiency-related KPIs Assessment for CB.P and CN.P

Key Performance Indicators KPIs)	Current Practices (CB.P)	Coopetition Network (CN.P)
KPI - First Time Through (%)	KPI_{FTT}: 90.9 % $KPI_{(\sigma)FTT}$: 0.0235	KPI_{FTT}: 90.9 % $KPI_{(\sigma)FTT}$: 0.0169
KPI - Performance Efficiency (parts/hour)	KPI_{PE}: 25.0 $KPI_{(\sigma)PE}$: 4.71	KPI_{PE}: 31.6 $KPI_{(\sigma)PE}$: 4.70
KPI - Raw Material Yield (parts/m²)	KPI_{RMY}: 0.752 $KPI_{(\sigma)RMY}$: 0.034	KPI_{RMY}: 0.956 $KPI_{(\sigma)RMY}$: 0.0170
KPI - Labor Productivity (parts/worker)	KPI_{LP}: 6.84 $KPI_{(\sigma)LP}$:1.3153	KPI_{LP}: 8,72 $KPI_{(\sigma)LP}$: 1.3076

First Time Through (FTT)

Under CB.P, the OS-PT SMEs achieved an impressive quality standard, with 90.9% of parts meeting the requisite quality benchmarks on the initial attempt, indicating a high degree of process efficiency and quality control mastery.

Within CN.P: Quality consistency was maintained in the OS-PT SMEs, with 90.9% of parts meeting the first-pass quality standards. Remarkably, production increased to an average of 454.4 parts per day, indicating that integrating cooperative principles has bolstered production capacities without detracting from quality.

Performance Efficiency (PE)

Under CB.P, the KPI assessment showcases OS-PT SMEs achieving an average of 338.3 shipped parts within a 13.3-hour workday, demonstrating a variety of operational tactics. It translated into a PE rate of 25.0 parts per hour. Figure 23 illustrates the trend in average daily good parts produced under CN.P, highlighting a substantial increase in quality and showcasing enhanced Efficiency through coopetition networks.

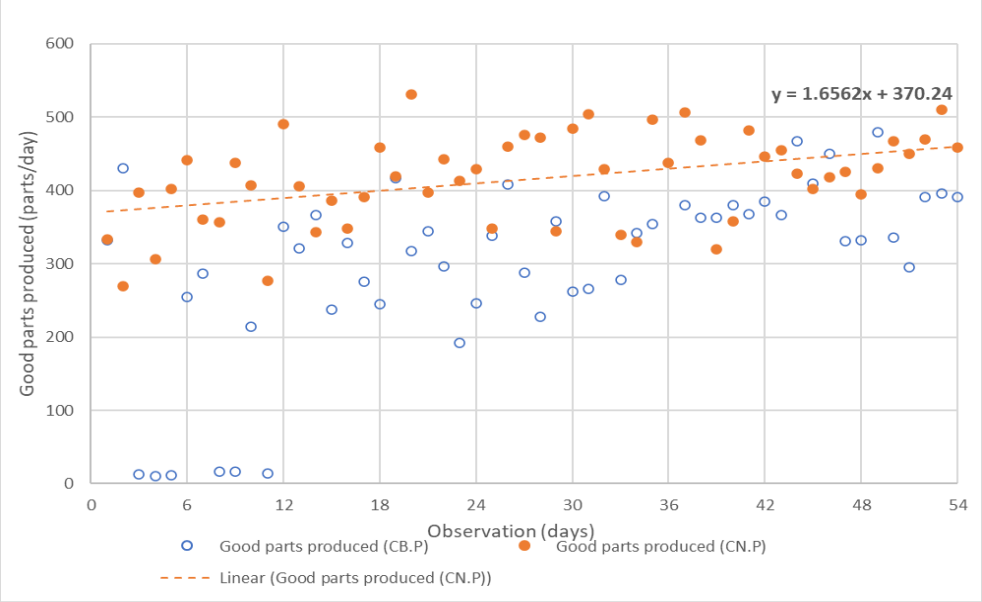


Figure 23. The trend in Average Daily Production of Good Parts under CN.P

The positive slope of the linear equation trend suggests that, on average, the production of good parts increases by approximately 1.66 units per day. This steady rise reflects the effectiveness of the coopetition networks in enhancing both quality and Efficiency, as the collaboration between competing entities leads to shared innovations and optimized processes. The intercept value of 370.24 represents the baseline production level at the start of the observed period, from which the improvement is measured.

The shift to CN.P precipitated a marked increase in productivity, with an average of 415.8 parts shipped daily. It underscores the efficacy of cooperation in augmenting company performance, as reflected in a PE rate of 31.6 parts per hour.

Raw Material Yield (RMY)

Under CB.P: The daily average consumption of raw materials in the OS-PT SMEs stood at 425.3 m^2, culminating in producing 323.7 customer-acceptable parts, achieving an RMY rate of 0.752 per m^2.

Within CN.P: Raw material processing in the OS-PT SMEs increased to 437.1 m^2 daily, significantly enhancing the production of acceptable parts to 454.3 units. This improvement is quantitatively captured, with an RMY rate of 0.956 parts per square meter, signifying a significant leap in material usage efficiency facilitated by cooperation.

Labor Productivity (LP)

Under CB.P: Employing an average workforce of 49.9, the OS-PT SMEs managed a daily shipment of 338.5 parts, establishing a labor productivity rate of 6.84 parts per worker.

Within CN.P: Implementing CN.P in the OS-PT SMEs resulted in an enhanced daily output of 415.8 parts while maintaining the same workforce size. This boosted the labour productivity rate to 8.72 parts per worker, a significant increase that highlights the positive effects of coopetition on labor efficiency.

The juxtaposition of operational data under CB.P and CN.P unveils the substantial efficiency gains facilitated by coopetition in manufacturing settings. Despite the constant quality rates observed (reflected in unchanged FTT metrics), coopetition notably elevated the productivity and Efficiency of manufacturing entities across performance, raw material yield, and labor productivity metrics. This analysis underscores the transformative potential of coopetition networks in rendering manufacturing processes more dynamic, efficient, and productive, thereby heralding a new paradigm in industrial operations Efficiency.

8.3.2 Operational Scale

This section assesses the Scale-related KPIs and IOs under categories CB.P and CN.P. The findings from the data collected under CB.P, which represent an average across three SMEs, are summarized in Table 12. This table provides a consolidated view of the scale metrics, offering insights into the scalability impacts of the interventions across the participating SMEs.

Table 12. Summary of Average data collected for Scale-related (CB.P)

Data ID	Description	Current Practices (CB.P)	Data (average daily)
Data 1	Successful leads	∑Successful leads	2.5
Data 2	Number of daily leads	∑Number leads	8.4
Data 3	Stockout incidents	∑Number stockout incidents	1.6
Data 4	Inventory requests	∑total_inventory_requests	8.4
Data 5	useful operations	∑Usefull_operations	1480
Data 6	Production operations	∑Total_operation	1486
Data 7	Total units produced	∑Total_units_produced	339
Data 8	Resources capacity	∑Resources_capacity	590

The findings under category CN.P are summarized in Table 13, which presents the average operational scale-related metrics for the three SMEs involved in the study. This table provides a detailed overview of the scale impacts, showcasing the effectiveness of the interventions in enhancing scalability within the participating SMEs.

Using the data collected under CB.P and CN.P, the operational scale-related KPIs were calculated, as detailed in Table 3 above and through Equations 1 to 5. The results of these assessments for CB.P and CN.P are compiled and depicted in Table 14, providing a comprehensive analysis of the scale metrics for both categories across the involved SMEs.

Table 13. Summary of Average data collected for Scale-related (CN.P)

Data ID	Description	Coopetition Practices (CN.P)	Data (average daily)
Data 9	Successful leads	∑Successful leads	3.7
Data 10	Number of daily leads	∑Number_leads	8.6
Data 11	Stockout incidents	∑Number of stockout incidents	1.1
Data 12	Inventory requests	∑Total_inventory_requests	8.6
Data 13	useful operations	∑Usefull_operations	1819
Data 14	Production operations	∑Total_operation	1822
Data 15	Total units produced	∑Total_units_produced	416
Data 16	Resources capacity	∑Resources_capacity	590

Table 14. Comparative Operational Scale-related KPIs Assessment for CB.P and CN.P

Key Performance Indicators (KPIs)	Current Practices (CB.P)	Coopetition Practices (CN.P)
KPI - Conversion Rate	KPI_{CR}: 31.36 %	KPI_{CR}: 44.60 %
	$KPI_{(\sigma)CR}$: 0.126	$KPI_{(\sigma)CR}$: 0.140
KPI - Product Stockouts	KPI_{PsO}: 19.01 %	KPI_{PsO}: 12.70 %
	$KPI_{(\sigma)PsO}$: 0.078	$KPI_{(\sigma)PsO}$: 0.640
KPI – Manufact. Value Added	KPI_{MvA}: 99.40 %	KPI_{MvA}: 99,8 %
	$KPI_{(\sigma)MvA}$: 0.003	$KPI_{(\sigma)MvA}$: 0.001
KPI - Production Output Ratio	KPI_{PsO}: 55.57 %	KPI_{PsO}: 69,9 %
	$KPI_{(\sigma)PsO}$: 0.105	$KPI_{(\sigma)PsO}$: 0.102

Conversion Rate (KPICR)

Under CB.P, OS-PT SMEs reported an average daily lead conversion rate of 31.36%, with 2.5 out of 8.4 leads successfully converted. With the adoption of CN.P, both the number of leads and conversions increased, resulting in a KPICR of 44.6%, which demonstrates a significant performance improvement attributed to implementing cooperative practices.

Figure 24 illustrates the trend in average daily successful lead conversions under CN.P, highlighting a substantial increase in the lead acceptance rate and showcasing enhanced scalability through coopetition networks.

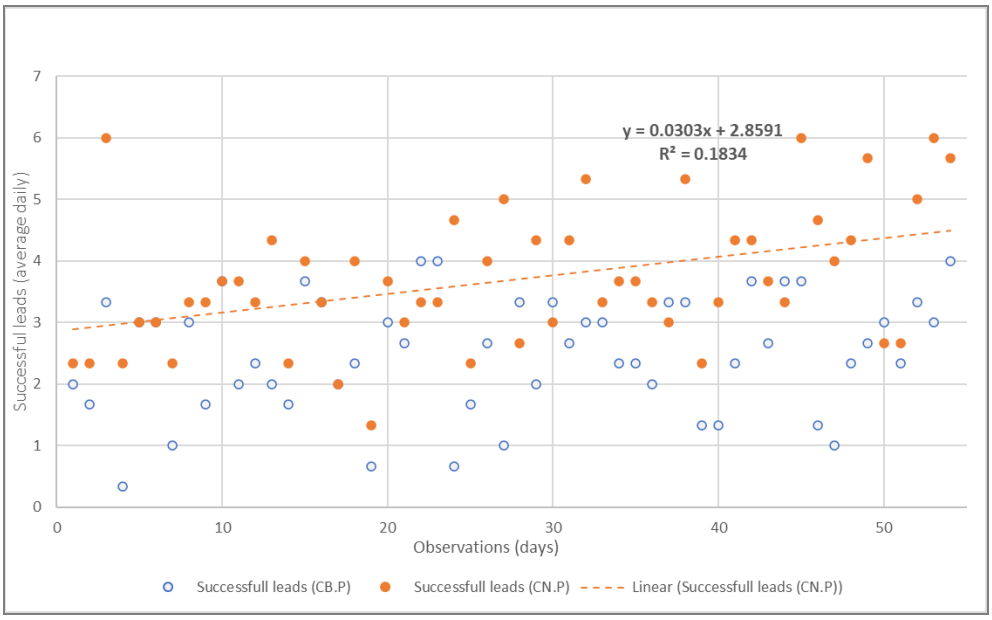


Figure 24. The trend in Average Daily Successful Leads under CN.P

The coefficient of x in the regression equation indicates the average increase in the number of successful leads per day, with a daily increase of approximately 0.0303 successful leads. This positive slope suggests a gradual upward trend in successful leads over time, underscoring the beneficial impact of coopetition practices on lead conversion. The intercept of the regression equation, valued at 2.8591, represents the estimated number of successful leads at the start of the observed period (when x=0). This suggests that the daily average number of successful leads was approximately 2.8591 at the beginning of the observation period.

Product Stockouts (KPIPsO)

Under CB.P: Findings showed an average of 1.6 stockout incidents per day against 8.4 inventory requests, resulting in a 19.0% stockout rate.

Within CN.P: The stockout incidents reduced to 1.1 per day amidst an increase in inventory requests to 6.5, significantly improving inventory management efficiency with a reduced KPIPsO of 7.3%. These improvements underscore the effectiveness of cooperation in optimizing inventory management to meet customer demand better, as evidenced by the significant decrease in stockout incidents.

Manufacturing Value Added (KPIMvA)

Under CB.P: A high KPIMvA of 99.4% was found, indicating that most manufacturing operations added value to the final product.

Within CN.P: Despite an increase in the volume of operations due to scaling, the KPIMvA slightly improved to 99.9%, suggesting enhanced production process efficiency and a reduction in variance.

Production Output Ratio (KPIPoR)

Under CB.P: The analysis revealed a KPIPoR of 55.6%, with companies producing an average of 416 parts daily against a capacity of 590.

Within CN.P: Resulted in an improved KPIPoR of 69.90%, indicating a substantial increase in production Efficiency despite constant production capacity.

The improvement in the Production Output Ratio under CN.P highlights the substantial gains in production efficiency, thereby optimizing resource utilization for manufacturing. The research's comparative analysis elucidates the significant impact of adopting coopetition strategies on enhancing scale capacity across various operational dimensions. By transitioning to CN.P, companies have improved their ability to convert leads, manage inventory effectively and optimize their production processes and output efficiency.

8.3.3 Customer Satisfaction Determinants

This section assesses the Customer Satisfaction Determinants-related KPIs and IOs under categories CB.P and CN.P. The findings from the data collected under CB.P, representing an average across three SMEs, are summarized in Table 15. This table provides a comprehensive overview of the customer satisfaction metrics, offering insights into the impacts of the interventions on customer satisfaction across the participating SMEs.

The findings under category CN.P are summarized in Table 16, which presents the average customer satisfaction-related metrics for the three SMEs involved in the study. This table provides a detailed overview of the impacts on customer satisfaction and shows the effectiveness of the interventions in enhancing customer satisfaction within the participating SMEs.

Using the data collected under CB.P and CN.P, the Customer Satisfaction Determinants-related KPIs were calculated as detailed in Table 5, Eq.1-Eq.5. The results of these assessments are shown in Table 17.

Table 15. Summary of Average data collected for Customer Satisfaction Determinants-related (CB.P)

Data ID	Description	Current Practices (CB.P)	Data (average daily)
Data 1	Total transport costs (€)	∑ total_transport_costs	1724
Data 2	Total value of goods sold €)	∑ total_value_goods_sold	8463
Data 3	Total parts customized	∑ total_parts_customized	52
Data 4	Parts produced	∑ parts_produced	339
Data 5	Total complained parts	∑ total_complained_parts	15
Data 6	Parts delivered	∑ parts_delivered	339
Data 7	Parts delivered on time	∑ parts_delivered_on_time	240
Data 8	Parts delivered	∑ parts_delivered	339

Table 16. Summary of Average data collected for Customer Satisfaction Determinants-related (CN.P)

Data ID	Description	Coopetition Practices (CN.P)	Data (average daily)
Data 9	Total transport costs	∑ total_transport_costs	1376
Data 10	Total value of goods sold	∑ total_value_of_goods_sold	10395

Data 11	Total parts customized	∑ total_parts_customized	157
Data 12	Parts produced	∑ parts_produced	454
Data 13	Total complained parts	∑ total_complained_parts	17
Data 14	Parts delivered	∑ parts_delivered	454
Data 15	Parts delivered on time	∑ parts_delivered_on_time	358
Data 16	Parts delivered	∑ parts_delivered	454

Table 17. Comparative Customer Satisfaction Determinants-related KPIs Assessment for CB.P and CN.P

Key Performance Indicators (KPIs)	Current Practices (CB.P)	Coopetition Network (CN.P)
KPI - Value to Weight Ratio	KPI_{VtW}: 634.8 %	KPI_{VtW}: 908.8 %
	$KPI_{(\sigma)VtW}$: 1,99	$KPI_{(\sigma)\ VtW}$: 1,82
KPI – Flexibility	KPI_{Flex}: 15.4 %	KPI_{Flex}: 34.8 %
	$KPI_{(\sigma)\ Flex}$: 0.02	$KPI_{(\sigma)\ Flex}$: 0.05
KPI – Customer Complain Ratio	KPI_{CcR}: 6.3 %	KPI_{CcR}: 4.4 %
	$KPI_{(\sigma)CcR}$: 0.03	$KPI_{(\sigma)\ CcR}$: 0.02
KPI - On-Time Delivery	KPI_{OtD}: 67.1 %	KPI_{OtD}: 77.5 %
	$KPI_{(\sigma)OtD}$: 0.05	$KPI_{(\sigma)OtD}$: 0.03

Value to Weight Ratio (VwR)

Under CB.P: OS-PT SMEs incurred an average daily transportation cost of € 1,724 for products valued at € 8.463, resulting in a KPIVwR of 634.8%.

Within CN.P: The daily transportation cost was reduced to €1,373 daily for products valued at €10.391, improving the KPIVwR to 908.8%. This improvement signifies a more competitive market response due to CN.P.

Manufacturing Flexibility (KPIFlex)

Under CB.P, the SMEs demonstrated an average capability to customize 52 parts daily from a total production of 339 parts, resulting in a KPIFlex of 15.4%.

Within CN.P, the SMEs increased the daily average of customized parts to 157 out of a total production of 454 parts. This increase in customization capabilities to 38.8% highlights the benefits of collaborative practices in meeting customer demands more precisely.

Customer Complaints Ratio (KPICcR)

Under CB.P: The findings indicated an average daily rejection rate of 17 parts out of 339 dispatched, translating to a KPICcR of 6.3%.

Within CN.P, the SMEs, despite increasing production volume to 454 parts daily, saw an improvement in KPICcR to 4.4%. It reflects a positive shift in customer satisfaction, supported by a decrease in variance, suggesting enhanced consistency in production quality.

On-Time Delivery Ratio (KPIOTD)

Under CB.P: The on-time delivery performance was recorded at 67.1%, with 240 out of 339 parts delivered as scheduled.

Within CN.P, the on-time delivery ratio significantly increased to 77.5%, with 358 out of 454 parts delivered on time. This improvement marks CN.P's efficacy in ensuring more reliable deliveries to customers.

Figure 25 illustrates the trend in average daily on-time delivered parts under CN.P. It highlights a substantial increase in the lead acceptance rate and shows enhanced customer satisfaction through collaboration networks.

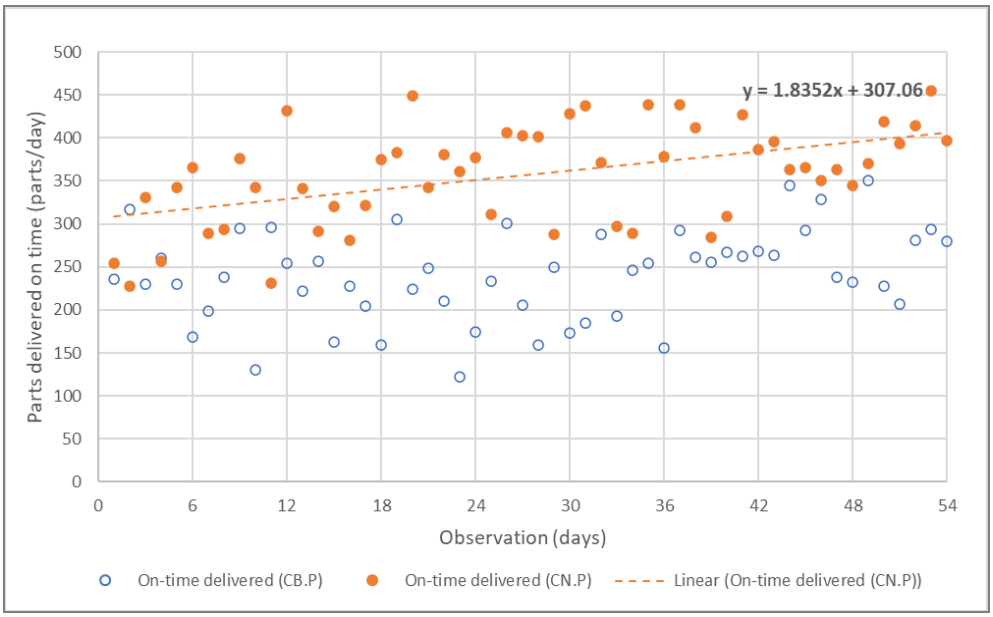


Figure 25. The Trend in Average Daily On-Time Delivered Parts under CN.P

The slope of 1.8352 indicates that, on average, the number of on-time deliveries increases by approximately 1.84 units per day. This trend reflects a significant improvement in lead acceptance rates, directly contributing to enhanced customer satisfaction. The intercept of 307.06 represents the baseline level of on-time deliveries at the start of the observed period, from which the improvements are measured. The results underscore the effectiveness of coopetition networks in optimizing delivery performance and ensuring higher levels of customer satisfaction.

8.3.4 Ecological Footprint Analysis

This section assesses the Ecological Footprint-related KPIs and IOs under CB.P and CB.P. Table 18 presents the summarized findings from this data, representing an average across three SMEs. This table provides a snapshot of crucial ecological footprint metrics under CB.P, offering a baseline for assessing improvements and identifying areas for potential enhancement.

Findings from the data collected and documented under CN.P are summarized in Table 19, which presents the average ecological footprint-related metrics for the three SMEs involved in

the study. This table offers a detailed overview of the environmental impacts, showcasing how the interventions have affected the ecological footprint of the participating SMEs.

Table 18. Summary of Average Daily Ecological Footprint -related Metrics Under CB.P

Data ID	Description	Current Practices (CB.P)	Data (average daily)
Data 1	Parts Produced	∑parts_produced(CB.P)	369.9
Data 2	Defective Parts Found	∑defective_parts(CB.P)	31.3
Data 3	Energy Consumed	∑energy consumed to produce parts (CB.P)	4692
Data 4	Parts Accepted	∑parts_accepted(CB.P)	13.3
Data 5	M2 Of Raw Material Used	∑raw_materials_used(CB.P)	323.7

Table 19. Summary of Average Daily Ecological Footprint -related Metrics Under CN.P

Data ID	Description	Coopetition Network (CN.P)	Data (average daily)
Data 6	Parts produced	∑parts_produced(CN.P)	454.3
Data 7	Defective parts	∑defective_parts(CN.P)	38.5
Data 8	Energy Consumed	∑energy consumed to produce parts (CN.P)	4071
Data 9	Parts accepted	∑parts_accepted(CN.P)	13.3
Data 10	Raw material used	∑raw_materials(CN.P)	437.1

The Ecological Footprint-related KPIs were assessed using the data collected under categories CB.P and CN.P. The results of these assessments for CB.P and CN.P are compiled and depicted in Table 20, providing a comprehensive analysis of the ecological impacts for both categories across the involved SMEs.

Table 20. Comparative Ecological Footprint -related KPIs Assessment for CB.P and CN.P

Key Performance Indicators (KPIs)	Current Practices (CB.P)	Coopetition Network (CN.P)
KPI - First Time Through (%)	KPI_{FTT}: 90.86	KPI_{FTT}: 90.89
	$KPI_{(\sigma)FTT}$: 0.02	$KPI_{(\sigma)FTT}$: 0.01
KPI – Energy Efficiency (parts/kWh)	KPI_{EE}: 0.09	$KPIE_{E}$: 0.13
	$KPI_{(\sigma)EE}$: 0,02	$KPI_{(\sigma)EE}$: 0.04
KPI - Raw Material Yield (parts/m²)	KPI_{RMY}: 0.75	KPI_{RMY}: 0.96
	$KPI_{(\sigma)RMY}$: 0.03	$KPI_{(\sigma)RMY}$: 0.02
KPI – Carbon Emissions (Kg CO2-eq)	KPI_{CFE}: 2.88	KPI_{CFE}: 2.26
	$KPI_{(\sigma)CFE}$:0,60	$KPI_{(\sigma)CFE}$: 0.49

First Time Through (KPIFTT): As described above, SMEs demonstrate precision in manufacturing by maintaining a 90.9% success rate in producing parts that meet quality standards on the first attempt, both before and after adopting CN.P. This consistency, despite increased production volumes, highlights the operational excellence achieved through cooperation.

Energy Efficiency (KPIEE): A pivotal gain was observed in energy efficiency, with energy consumption per part produced improving from 0.09 parts/kWh to 0.13 parts/kWh under CN.P This reflects how coopetition enhances energy utilization, reinforcing the environmental benefits of collaborative operational frameworks.

Material Yield (KPIRMY): The yield rate from raw materials increased from 0.752 to 0.956 parts per m^2, signifying a substantial improvement in material usage optimization. This advancement reduces waste and underscores CN.P's effectiveness in promoting environmental sustainability.

Carbon Footprint Reduction (KPICFR): Crucially, the transition to CN.P decreased CO_2 emissions per part produced, from 2.88 Kg CO_2-eq to 2.26 Kg CO_2-eq. This reduction highlights the significant potential of coopetition networks to lower the carbon footprint of manufacturing activities.

The transition to CN-EcoTech emerges as a strategic pathway to bolster manufacturing efficiency and advance environmental sustainability objectives. The dual achievement of maintaining high-quality standards and enhancing resource efficiency, alongside a notable reduction in carbon emissions, positions coopetition as an effective strategy for SMEs aimed at ecological conservation. The synergistic benefits of combining competitive and collaborative dynamics through coopetition offer a compelling model for sustainable development within the manufacturing sector.

8.4 Innovation Outcomes Assessment

This section evaluates the comprehensive improvements introduced by CN-EcoTech, highlighting its contributions towards achieving the SDGs. It explores the CN-EcoTech's role in driving innovation within the OS-PT sector, highlighting how technological advancements and cooperative strategies have improved operational practices and environmental responsibility. Through detailed analysis, this evaluation aims to quantify the broader impacts of these innovations, providing insights into their effectiveness and identifying opportunities for further enhancements.

8.4.1 Operational Efficiency Improving

The Operational Efficiency-related IOs highlight the tangible benefits of CN-EcoTech, showcasing advancements in manufacturing processes. Table 21 shows the measurable enhancements achieved through CN-EcoTech, demonstrating the benefits of participating in coopetition networks for the involved SMEs.

A closer examination of the First Time Through (FTT) outcomes revealed no quantitative improvement, suggesting that the transition to coopetition did not directly increase the success rate of processes or tasks executed correctly on the first attempt. However, some improvement in consistency suggests the manufacturing processes potentially lead to decreased error rates or less need for rework over time.

Regarding Performance Efficiency (PE), adopting coopetition network practices resulted in an exceptional average increase of 66.1% among OS-PT SMEs. This significant uplift underscores the substantive benefits that coopetition delivers to organizational Efficiency.

Table 21. Summary of Operational Efficiency-Related Findings through CN-EcoTech in OS-PT SMEs

Efficiency-related KPIs	CB.P	CN.P	Quantitative IO	Stability IO
KPI - First Time Through	0.91	0.91	0.0%	0.66%
KPI - Performance Efficiency (parts/hour)	25.02	31.63	66.1%	1.70%
KPI - Raw Material Yield (parts/m²)	0.75	0.96	20.4%	1.72%
KPI - Labor Productivity (parts/worker)	6.84	8.72	187.4%	0.77%
Impact on Op. Efficiency			68.5%	1.2%

Figure 26 highlights the upward trend in Performance Efficiency KPI under Coopetition Practices.

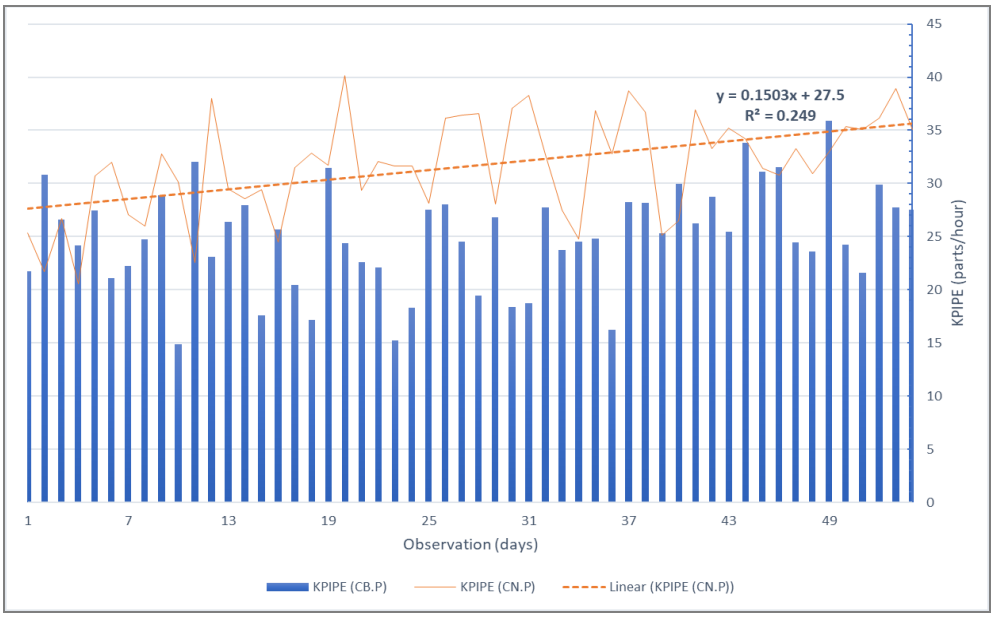


Figure 26. Daily Trend in KPIPE under Coopetition Practices.

This improvement can be attributed to CN.P's synergistic integration of resources, expertise, and capabilities, thereby significantly boosting order fulfilment efficiency and optimizing the production process. Such advancements enhance overall productivity and foster a manufacturing environment that is more adaptable and responsive to fluctuating market demands and consumer expectations.

The IOs highlight the tangible benefits of CN.P, with a markedly improved Raw Material Yield, recording a quantitative gain of 20.4%. This uptick signifies a more efficient use of raw materials, resulting in decreased waste and enhanced production processes. The consistency gain (1.7%) indicates a considerable reduction in variability in material use, ensuring more predictable and efficient resource utilization, which emphasizes the effectiveness of CN.P in resource optimization and waste minimization within the production cycle.

Labor Productivity, for instance, experienced a significant quantitative boost of 187,4%, reflecting an immense enhancement in the output or Efficiency per labor unit. Despite the low consistency of 0.7%, this increase demonstrates that while productivity has improved, achieving uniformity across different scenarios or periods poses a challenge. This surge in labor productivity underscores the benefits of embracing CN.P, where the interplay of coopetition propels productivity optimization. Through CN.P, companies tap into a collective reservoir of expertise, capabilities, and technological advancements, fostering a dynamic and efficient work environment. This strategic orientation not only elevates the productivity of individual employees but also significantly enhances the company's overall operational Efficiency and market competitiveness. Figure 26 showcases the impact on Efficiency from the CN-EcoTech.

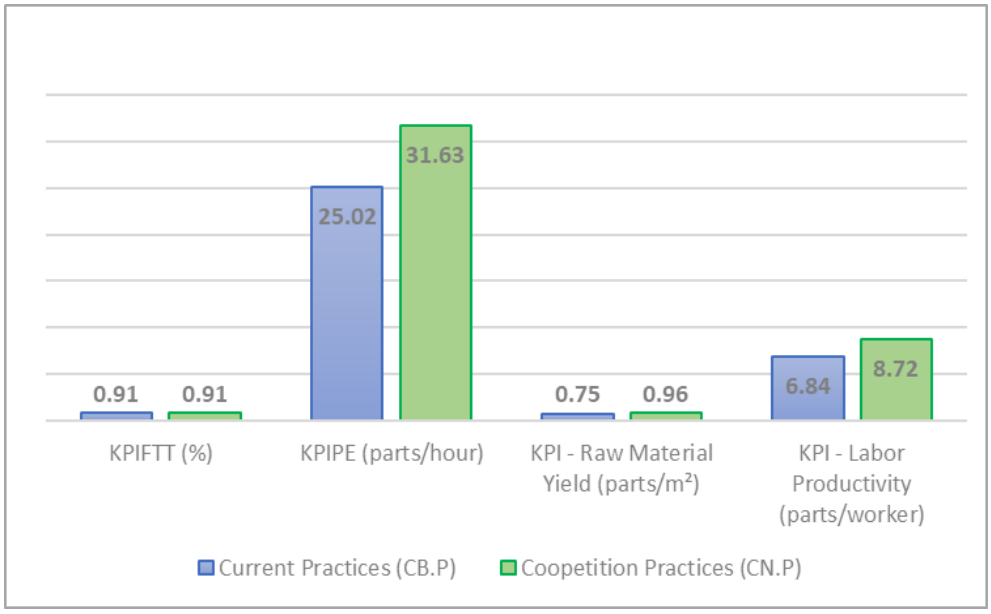


Figure 27. CN-EcoTech Impact on the Operational Efficiency-Related Determinants in the OS-PT SMEs.

The transition from CB.P to CN.P has markedly improved manufacturing efficiency by 68,5%, coupled with a 1,2% increase in the consistency of these outcomes. This compelling evidence supports the adoption of CN.P to enhance operational performance and sustainable growth within the OS sector. These improvements resonate deeply with the SDGs.

SDG 9): Advances in performance efficiency demonstrate how collaboration networks can drive innovation and optimize production processes, contributing to resilient and sustainable industrial infrastructure by minimizing waste and improving task efficiency.

SDG 12 (Responsible Consumption and Production): The CN.P has also increased the raw material yield, promoting more efficient use of materials and reducing waste—core objectives of SDG 12. Furthermore, operational efficiency improvement underlines strides towards more sustainable production practices. These findings underscore significant operational enhancements and highlight the broader ecological and sustainable impact facilitated by the CN.P within the OS-PT sector.

8.4.2 Operational Scale Impact

This section explores the impact of the Operational Scale within OS-PT SMEs, facilitated by the adoption of CN.P. Rooted in the CN-EcoTech framework and operationalized by Cockpit4.0+; these practices aim not only to expand the operational Scale of OS-PT SMEs but also to support the objectives of SDG 9 and 11. The following analysis assesses how CN.P elevate operational scale within the OS-PT sector, examining their effectiveness in aligning with these global sustainability goals.

The exploration of the effectiveness of CN-EcoTech in enhancing scale capacity yields significant insights into its impact on operational scale and competitiveness among SMEs in the OS-PT sector. The IOs from this analysis underscore the tangible benefits realized through engagement in CN.P, showcasing remarkable advancements in operational scale-related metrics. These quantifiable outcomes indicate a broader shift towards more collaborative and competitive operational frameworks, detailed in Table 22.

Table 22. Summary of Operational Scale-Related Findings by CN-EcoTech in OS-PT SMEs

Operation Scale-Related KPIs	CB.P	CN.P	Quantitative IO	Stability IO
KPI - Conversion Rate	0.31	0.45	13.2%	-1.38%
KPI - Product Stockouts	0.19	0.13	6.3%	1.43%
KPI – Manuf. Value Added	0.99	1.00	0.4%	0.18%
KPI – Prod. Output Ratio	0.56	0.70	14.1%	0.26%
Impact on Operational Scale			8.5%	0.1%

Despite some inconsistencies, the data present a notable average quantitative improvement of 13.2% in Conversion Rate outcomes, as illustrated in Figure 27. This enhancement, attributed to the transition towards CN.P, significantly amplifies the number of order confirmations and, consequently, the volume of production work.

The quadratic term indicates that the relationship between the independent variable x (days) and the KPICR is not linear but follows a curved path. The positive coefficient (0.0001) suggests that, over time, the conversion rate initially decreases but eventually begins to increase again as the xxx values get larger. This could imply an initial adjustment period after the implementation of CN.P, followed by an improvement in conversion rates. The linear term −0.0022x represents a negative linear trend in the early stages of the analysis. This suggests that, initially, for each

unit increase in xxx, the conversion rate decreases slightly by 0.0022. This decrease could be due to early challenges or transitional phases as the CN.P practices are being adopted. The intercept value of 0.402 represents the estimated conversion rate at the start of the observation period (when x=0). This indicates that the conversion rate was around 40.2% at the beginning. This result suggests a complex relationship between the independent variable and the KPICR as the CN.P practices are implemented.

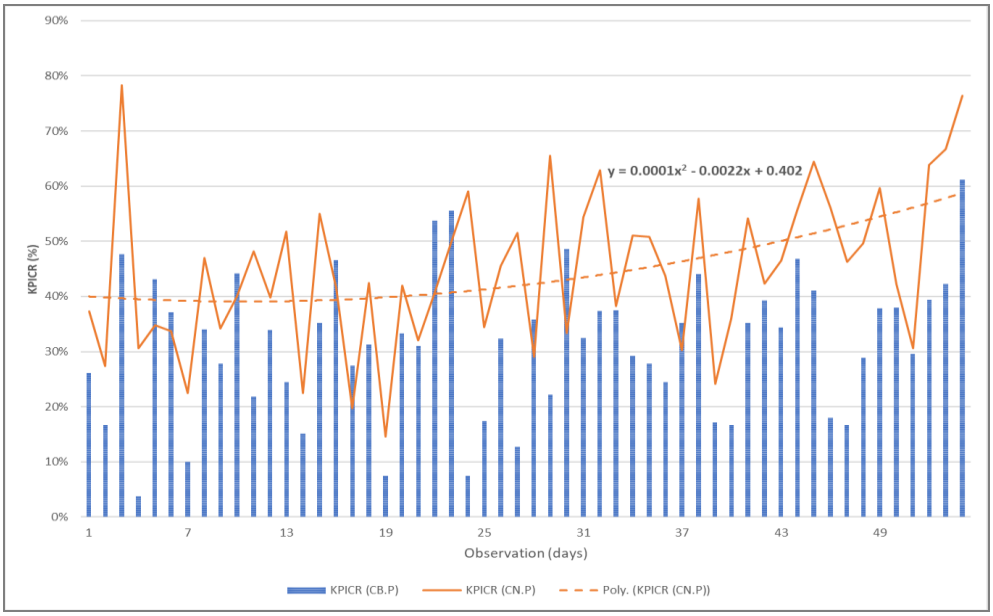


Figure 28. Daily Trend in KPICR under Coopetition Practices.

This indicates that the conversion rate was around 40.2% at the beginning. This result suggests a complex relationship between the independent variable and the KPICR as the CN.P practices are implemented. Initially, there might be a slight decline in the conversion rate due to the challenges of adopting new practices (as indicated by the negative linear term). However, as the quadratic term takes effect, the conversion rate begins to improve, suggesting that once the initial hurdles are overcome, the conversion rate starts to benefit from the efficiencies and advantages brought by CN.P.

An average improvement of 6.3% in stock availability, alongside a 1.43% increase in stability, highlights the effectiveness of CN.P in synchronizing raw material supply with customer demand. This strategic alignment enhances the companies' ability to fulfil large orders promptly, underscoring the advantages of collaborative raw material management.

Although the immediate improvement in MvA is modest (0.4%), a positive enhancement in production process stability is observed. This reflects the strategic predictability introduced by CN.P, which is transforming operational practices within the manufacturing sector.

A substantial increase of 14.1% in the Production Output Ratio demonstrates the significant benefits of CN.P adoption. This improvement signifies enhanced utilization of production

capacities facilitated by the coopetition's collaborative dynamics. Figure 29 encapsulates the transformation in KPIs as OS-PT SMEs shift towards CN.P. The depicted evolution highlights the strategic efficacy of coopetition in expanding operational scale and capacity, while promoting a more predictable and stable performance landscape.

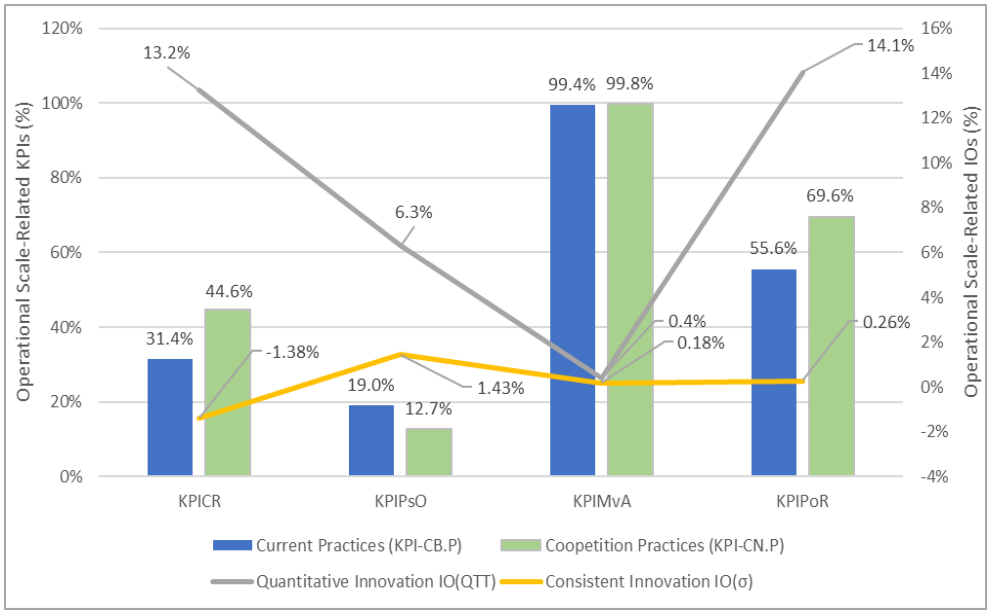


Figure 29. CN-EcoTech Impact on the Operational Scale-Related Determinants in the OS-PT SMEs.

The analysis further elucidates that adopting CN.P leads to positive improvements across all measured metrics, marking a notable quantitative impact on the operational scale. The transition to CN.P is associated with an 8.5% increase in operational scale, accompanied by an improvement in operational consistency.

These findings highlight the substantial benefits on the operational scale of engaging in CN-EcoTech, illustrating its potential role in enhancing the OS-PT sector and underscoring CN as a transformative force, significantly aligned with SDGs 9 and 11.

SDG 9 (Industry, Innovation, and Infrastructure): Improvements in CR and metrics like PsO and MvA enhance industry efficiency and competitiveness. The CN.P fosters a more predictable operational framework, supporting OS-PT SME innovation and market adaptability and boosting the industry's contribution to employment and GDP, in line with SDG 9's goals.

SDG 11 (Sustainable Cities and Communities): Enhancements in PoR and reductions in PsO demonstrate more efficient resource use and synchronization of supply with demand. These improvements support sustainable urban industrial systems and resource-efficient cities, aligning with Sustainable Development Goal 11's objectives for sustainable urbanization. These impacts underscore how the CN.P enhances operational capabilities within the OS-PT sector and advances broader SDGs.

8.4.3 Enhancements in Customer Satisfaction Determinants

Implementing CN.P within the OS-PT sector has led to significant improvements in customer satisfaction determinants. Grounded in the CN-EcoTechs framework, these practices are designed to enhance customer satisfaction and contribute to SDGs 9 and 11, which focus on industry innovation and sustainable urban communities, respectively. This analysis evaluates how CN.P enhances customer satisfaction determinants in the OS-PT sector and assesses their alignment with these global sustainability objectives.

The IO report details how adopting coopetition practices, supported by technology in OS-PT SMEs, boosts the determinants of customer satisfaction. These outcomes demonstrate the tangible benefits of collaborative tech innovations, highlighting improvements in customer satisfaction metrics. A thorough summary of these enhancements, including quantifiable gains and reduced variability for each outcome, is detailed in Table 23, highlighting the practical advantages of adopting CN.P.

Despite some instability, a 6.7% improvement in the Value to Weight Ratio indicator from the CN.P was found. This improvement highlights the economic benefits of adopting CN.P., such as optimizing transportation costs and enhancing delivery performance through synergies with third-party productions.

Under CN.P, a significant enhancement in operational flexibility was observed, with a notable 19.4% increase, on average, as shown in Figure 30.

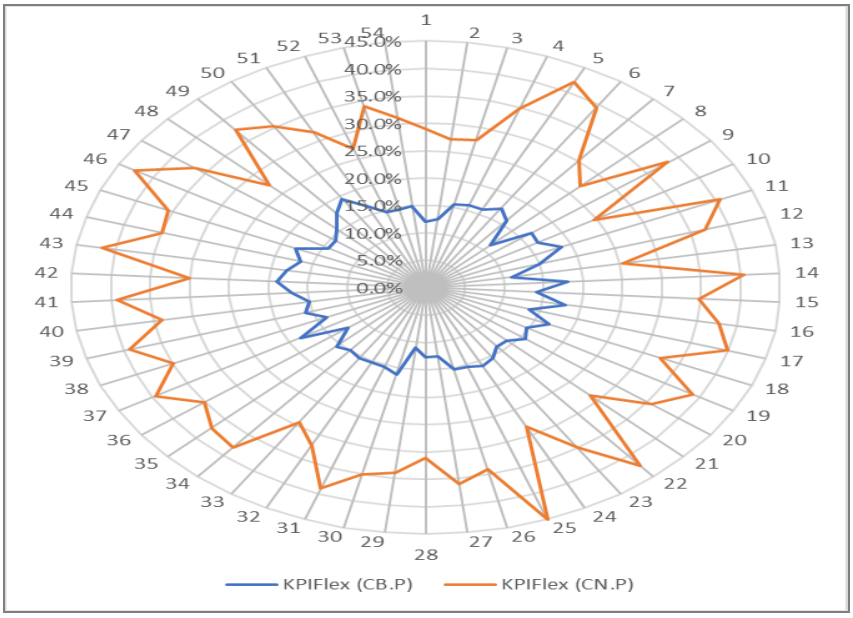


Figure 30. Enhancement in Operational Flexibility under CN.P

Table 23. Summary of Cust. Satisfaction Determinants -Related Findings from CN-EcoTech in OS-PT SMEs.

Customer Satisfaction' Determinants -related KPIs	CB.P	CN.P	Quantitative IO	Stability IO

KPI - Value to Weight Ratio (%)	634.8	908.8	43.2	-7.1
KPI – Flexibility (%)	15.4	34.8	125.7	147.8
KPI – Cust. Complain Ratio (%)	6.3	4.4	29.4	-44.9
KPI - On-Time Delivery (%)	67.1	77.5	15.6	-43.9
Impact on Customer Satisfaction' Determinants			9.6%	2.1%

This improvement reflects an enhanced ability to customize and adapt production processes to meet specific customer demands, boosting agility. By pooling resources and capabilities, companies within the network have increased their production versatility. Additionally, a 2.93% improvement in the consistency of achieving this flexibility, as indicated by IO(σ)Flex, highlights a more predictable and adaptable production process, further reinforcing the reliability of these advancements.

The 29.3% reduction in parts refused by customers indicates direct improvements in product quality and customer satisfaction. A significant 10.5% uplift in the On-Time Delivery Ratio further supports this, reflecting enhanced production and delivery efficiency. This uplift underscores the operational benefits of CN.P, where the dynamics of collaboration and competition foster a more reliable and efficient operational framework.

Figure 31 displays the enhancements in KPIs related to the Customer Satisfaction Determinants after adopting CN.P. It highlights the measurable gains achieved in operational Efficiency, product quality, and delivery metrics, emphasizing the strategic benefits of coopetition.

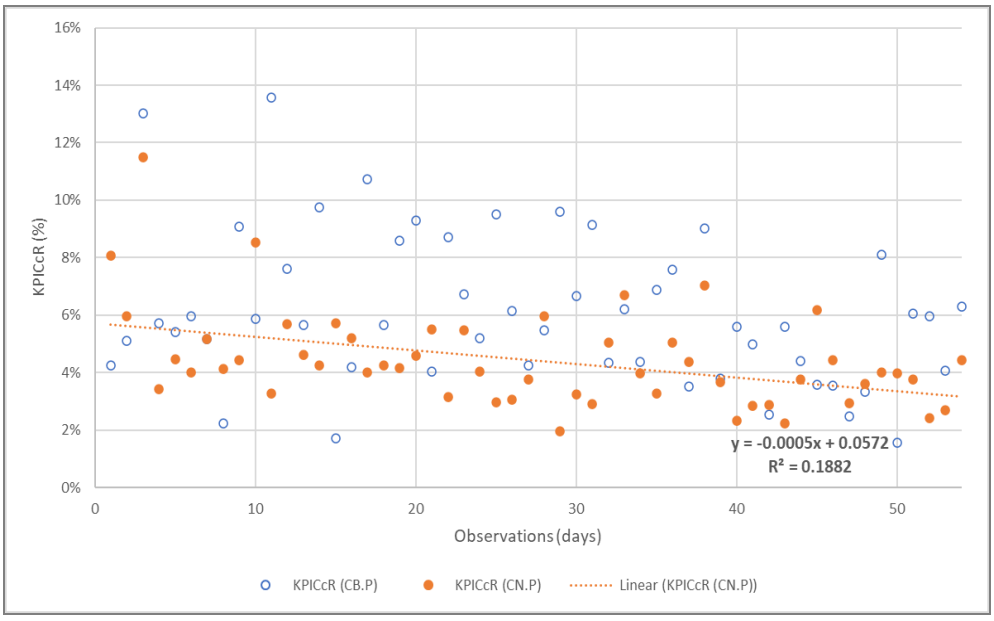


Figure 31. Daily Trend in KPICcR under Coopetition Practices.

The slope of −0.0005 indicates a gradual decrease in the KPICcR over time. Specifically, for each additional day (or unit of time), the customer complaints ratio decreases by 0.0005. Although this decrease is slight, it is consistent, reflecting a steady improvement in customer

satisfaction. The intercept value of 0.0572 represents the estimated KPICcR at the start of the observation period (when x = 0). This suggests that the customer complaints ratio was approximately 5.72% at the beginning of the analyzed period. The R2 value of 0.1882 indicates that approximately 18.82% of the variance in the customer complaints ratio can be explained by the passage of time. This suggests that time contributes to reducing complaints, but other factors not captured by this model also significantly influence the KPICcR.

Through engagement in CN.P., a tangible 9.6% improvement in Customer Satisfaction Determinants has been achieved. This highlights the role of CN-EcoTechs as catalysts for transformative progress in OS-PT SMEs, empowering these businesses to excel in a highly competitive and dynamic environment, as illustrated in Figure 32.

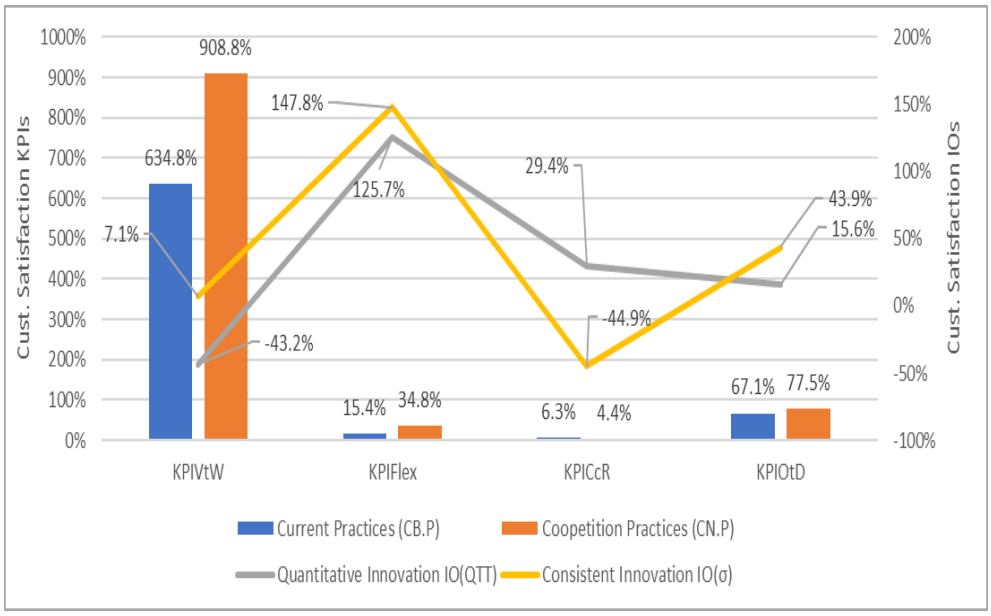


Figure 32. CN-EcoTech Impact on the Customer Satisfaction Determinants in the OS-PT SMEs.

These IOs demonstrate significant alignment with SDG 12, which focuses on ensuring sustainable consumption and production patterns: (1) improvements in operational flexibility and the Value-to-Weight Ratio, demonstrating more efficient use of resources; (2) reduction in the Customer Complaint Ratio suggest fewer products are refused or discarded, which aligns with minimizing waste generation through prevention, reduction, recycling, and reuse, as advocated by SDG 12; and (3) coopetition practices can foster innovation and collaboration that contribute to the development and diffusion of environmentally friendly technologies and processes.

8.4.4 Ecological Footprint Impact

The Ecological Footprint-related IOs highlight the tangible benefits of CN-EcoTech, showcasing the direct contributions to the SDGs. These improvements are summarized in Table 24. This table provides a detailed view of the measurable enhancements achieved through CN-EcoTech,

demonstrating the practical benefits of participating in coopetition networks for the involved SMEs.

Table 24. Summary of Ecological Footprint -related Findings through CN-EcoTech in OS-PT SMEs

Ecological Footprint-related KPIs	Current Practices	Coopetition Practices	Quantitative IO	Stability IO
KPI - First Time Through (parts/parts)	0.91	091	0.03%	28.18%
KPI - Energy Efficiency (kWh/part)	10.68	7.85	26.5%	76.58%
KPI - Raw Material Yield (parts/m²)	0.75	0.96	20.4%	50.33%
KPI - CO2 Emissions (CO2-Eq/part)	2.88	2.26	21.8%	19.10%
Carbon Footprint Reduction			0.63 KgCO2-eq/part	

Regarding Energy Efficiency, the transition to CN.P marked a remarkable improvement of 26,5%. This significant enhancement in energy utilization within SMEs in the ornamental stone sector demonstrates the operational benefits of leveraging shared resources and expertise, thereby contributing significantly to environmental sustainability.

Regarding Raw Material Yield, the shift to CN.P resulted in a 20.4% improvement in material utilization efficiency. This indicates a shift towards more sustainable production practices by minimizing waste. Additionally, a 50.33% increase in consistency for this KPI highlights the role of CN.P in optimizing resource use, further solidifying its value in sustainable industrial practices, as illustrated in Figure 33.

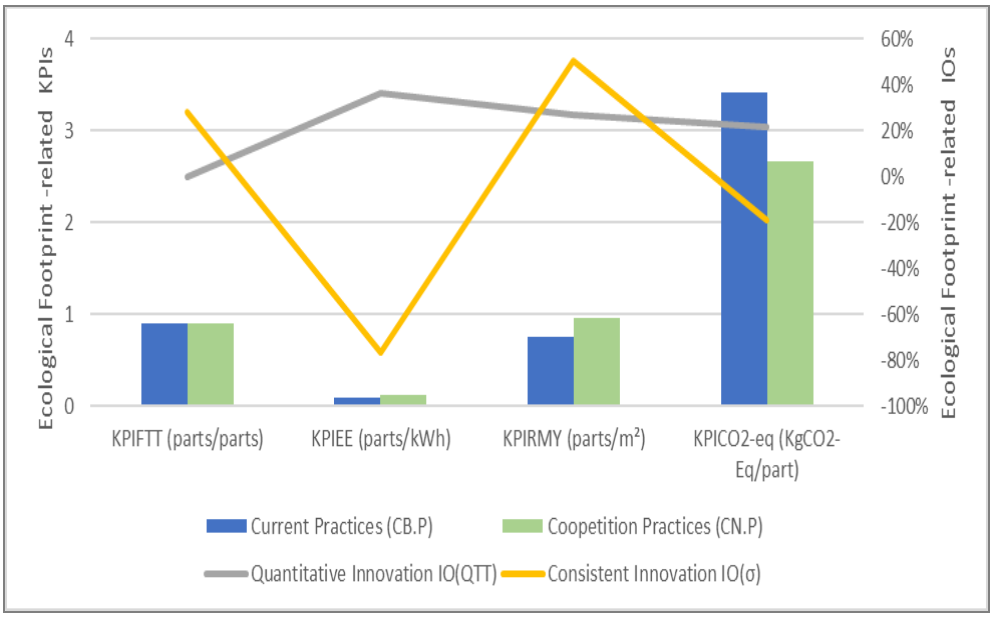


Figure 33. CN-EcoTech Impact on the Ecological Footprint -related Determinants in the OS-PT SMEs.

Regarding KPICO2-eq, there was a tangible reduction with a quantitative gain of 21.8%. This highlights the ecological efficiencies achieved through CN.P, demonstrating substantial progress

in reducing the environmental impact of production activities. Figure 32 showcases the evolution of ecological KPIs as companies transition to CN.P, visually representing the environmental progress made within the OS-PT SMEs.

The comprehensive evaluation of these IOs highlights the effectiveness of CN-EcoTech in advancing ecological sustainability and operational Efficiency within the OS-PT sector. The data show a reduction of 0.63 Kg CO2-Eq per piece produced, serving as a clear indicator of the positive impact of CN.P on reducing CO2 emissions.

These findings advocate for CN-EcoTech as a strategic and sustainable approach, highlighting its potential to drive meaningful ecological improvements and operational efficiencies in the competitive landscape of the OS-PT sector. Moreover, these improvements align strongly with the SDGs, particularly SDG 13, which emphasizes the need for urgent action to combat climate change and its impacts by promoting sustainable practices and reductions in greenhouse gas emissions across all sectors of the economy. The measurable improvements in ecological footprint metrics through coopetition practices underscore this alignment in several key areas: (1) The observed quantitative gain of 21.8% in CO2 reduction directly supports the objectives of SDG 13 by demonstrating a tangible decrease in CO2 emissions per part produced. This reduction signifies the OS SMEs' contribution to mitigating climate change through operational enhancements that lower greenhouse gas emissions. (2) The significant improvement of 26,5% in energy efficiency following the adoption of CN.P highlights the move towards more sustainable energy use within the OS sector (Figure 34).

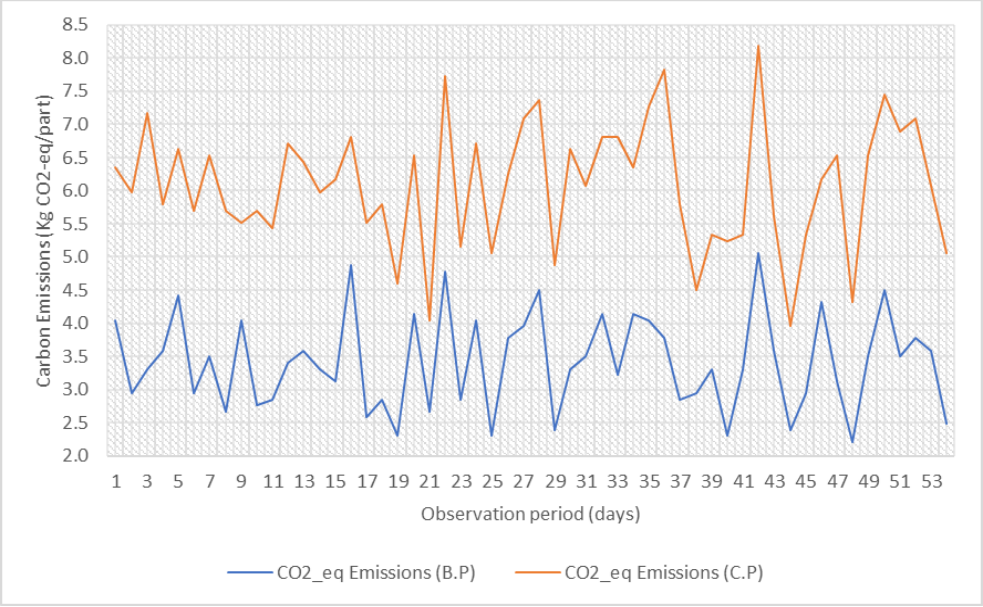


Figure 34. Impact of CN-EcoTech on CO2 Emissions in OS-PT SMEs

Enhanced energy utilization reduces the overall energy demand. It contributes to reducing carbon emissions associated with energy production, aligning with SDG 13's call for improved energy efficiency and sustainable energy consumption patterns. (3) By achieving a 27,1%

improvement in material utilization efficiency, CN.P practices demonstrate a commitment to minimizing waste and optimizing resource use. This approach aligns sustainable production methods, contributing indirectly to climate action by reducing the resources extracted, processed, and, ultimately, the waste generated, all of which have carbon footprints. The encapsulation of these improvements illustrates the daily evolution of CO_2 emissions per part, providing compelling visual evidence of the strides made towards environmental sustainability. Documentation of a 0.63 $KgCO_2$-eq reduction per piece produced as companies transition to CN.P supports the strategic importance of such practices in achieving climate action goals.

These findings highlight the instrumental role of coopetition in advancing sustainability within the OS-PT sector, showcasing how coopetition practices can drive significant ecological improvements.

8.4.5 Iterative Review and Redesign

Given the substantial improvements and gains outlined in the assessment, an immediate iterative review and redesign of CN-EcoTech may be optional. These findings highlight significant enhancements in operational Efficiency, scale capacity, customer satisfaction determinants, and ecological footprint within the OS-PT sector. Additionally, these improvements are well-aligned with specific SDGs. The current configuration of CN-EcoTech effectively meets the established expectations, diminishing the urgency for a redesign.

Chapter 8. Summary

This chapter presented a structured assessment process to evaluate the benefits of CN-EcoTech within a cohort of OS-PT SMEs, emphasizing the alignment of these benefits with the SDGs and their contribution to broader societal and environmental improvements.

Quantitatively, CN-EcoTech has demonstrated substantial benefits in terms of operational Efficiency, scale, customer satisfaction, and ecological footprint, explicitly supporting the objectives of SDGs 9 (Industry, Innovation, and Infrastructure), 11 (Sustainable Cities and Communities), 12 (Responsible Consumption and Production), and 13 (Climate Action).

Following the DSR methodology, Chapter 9 will focus on the broader dissemination of these findings. It will detail strategies for effectively communicating the knowledge and innovations derived from this research over the coming months, ensuring impactful and widespread adoption.

Chapter 9. Dissemination of Findings

Any sufficiently advanced technology is indistinguishable from magic. - Arthur C. Clarke

Effective communication in DSR is paramount and equally critical as the findings themselves. This chapter explores how strategic dissemination within the DSR framework can transcend academic boundaries to inform and influence real-world practices and policymaking. Effective dissemination entails sharing results and making them accessible, comprehensible, and actionable for a varied audience, including academics, industry practitioners, and policymakers.

This chapter uses the CN-EcoTechs in the OS-PT as a case study to illustrate these principles in action. The research enhances its utility, innovation, and effectiveness by extending beyond conventional academic dissemination to engage with real-world applications. Through various channels and strategies, the chapter outlines how thoughtfully communicating DSR findings can influence industry practices, inform policies, and substantially contribute to the academic knowledge base.

9.1 Academic Audience Outreach

A crucial component of academic outreach involves publishing in high-impact, peer-reviewed journals and presenting at leading conferences relevant to information systems, business management, and service science. This section outlines essential considerations for journal submissions and directs them to Appendix III, which lists the papers that disseminate these findings:

1. Paper 1. Coopetition-Driven Excellence: Enhancing Product Quality and Innovation in Manufacturing SMEs through IoT-Enabled Networks. ACCEPTED for oral presentation in 6th International Conference on Quality Engineering and Management (ICQEM 2024), Girona, (2024). Scopus PUBLISHED at https://publicacoes.riqual.org/wp-content/uploads/2024/06/icqem_24_17_29.pdf.
2. Paper 2. Enhancing customer satisfaction through IIoT-Enabled coopetition: Strategic insights and impacts. Journal of Internet of Things: https://doi.org/10.1016/j.iot.2024.101408. Scopus PUBLISHED (Q1).
3. Paper 3. Designing the future of coopetition: An IIoT approach for empowering SME networks. The International Journal of Advanced Manufacturing Technology, 135(1–2), 747–762. https://doi.org/10.1007/s00170-024-14528. Scopus PUBLISHED (Q1).
4. Paper 4. BIM-Oriented Supply Chains in AEC: New Challenges for Portuguese Stone Companies; ACCEPTED for oral presentation in 7th Edition of the Global Stone Congress (Batalha, Portugal 2023). Online Proceedings:

https://dspace.uevora.pt/rdpc/bitstream/10174/36970/1/GSC2023-Conference_Book-Press.pdf Comunicações Geológicas (2024) 111, 91-100 ISSN: 0873-948X; e-ISSN: 1647-581X. Scopus Publication in progress.

5. Paper 5. Technology Paths towards Coopetition Ecosystems: The Portuguese Stone Sector; ACCEPTED for oral presentation in 7th Edition of the Global Stone Congress (Batalha, Portugal 2023). Online Proceedings. https://dspace.uevora.pt/rdpc/bitstream/10174/36970/1/GSC2023-Conference_Book-Press.pdf ISSN: 0873-948X; e-ISSN: 1647-581X. Scopus Publication in Comunicações Geológicas (in progress).
6. Paper 6. Carbon Footprint Reduction on Manufacturing SMEs from Digital Technologies; ACCEPTED for oral presentation in 23rd International Multidisciplinary Scientific GeoConference SGEM (Vienna, 2023). https://doi.org/10.35603/epi24.1.03. Scopus Published.
7. Paper 7. Design Science for Networks Designing: A Service-Dominant Logic Approach. European Conference on Research Methodology for Business and Management Studies. Scopus Published. 23(1), 35–42. https://doi.org/10.34190/ecrm.23.1.2334. Scopus Published.
8. Paper 8. Value Creation in Technology-Driven Ecosystems: Role of Coopetition in Industrial Networks. Journal of Theoretical and Applied Electronic Commerce Research, 19(3), 2343–2359. https://doi.org/10.3390/jtaer19030113. Scopus Published (Q1): H-Index 54
9. Paper 9. Co-Opetition and the Industrial Internet of Things: A Strategic Framework for Operational Efficiency in the Portuguese Ornamental Stone Sector. Journal of Administrative Sciences: https://doi.org/10.3390/admsci14060125. Scopus Published (Q2). H-Index 42
10. Paper 10. Industrial Internet of Things-Driven Coopetition Networks for SMEs. ACCEPTED for oral presentation and publication in ISM 2024- International Conference on Industry 4.0 and Smart Manufacturing (Prague - Czech Republic, 2024). https://doi.org/10.1016/j.procs.2025.01.086. Scopus Published in Procedia Computer Science.
11. Paper 11. Enhancing SME Competitiveness Through Coopetition Networks: A Service-Dominant Logic Approach. Management and Production Engineering Review, 15(3), 1–14. https://doi.org/10.24425/mper.2024.151493; Scopus Published (Q3): H-Index 27
12. Paper 12. Coopetition with the Industrial IoT: A Service-Dominant Logic Approach. Applied System Innovation, 7(3), 47. https://doi.org/10.3390/asi7030047; Scopus Published (Q1): H-Index 35

13. Paper 13. An Innovative Service Blueprint for Enhancing Coopetition Networks. ACCEPTED for oral presentation in the 2024 International Conference on Innovations in Computing Research (Athens) (ICR'24) (pp. 322–333). https://doi.org/10.1007/978-3-031-65522-7_29. Scopus Published in Springer Nature.
14. Paper 14. Engineering Business Solutions: Advancing SME Competitiveness through IIoT-Driven Coopetition. ACCEPTED for oral presentation at 3rd World Conference on Information Systems for Business Management Bangkok, Tailand, (2024). https://doi.org/10.1007/978-981-96-1741-8. Scopus Published in Springer Nature.
15. Paper 15. Navigating the digital shift: a service blueprint for coopetition technology-enabled networks. TELKOMNIKA (Telecommunication Computing Electronics and Control), 22(5), 1138. https://doi.org/10.12928/telkomnika.v22i5.26016. Scopus Published (Q3): H-Index 35
16. Paper 16. Rethinking service blueprint for digital coopetition: A new framework for networked collaboration. Journal of Infrastructure, Policy and Development, 8(9), 7072. https://doi.org/10.24294/jipd.v8i9.7072; Scopus Published (Q2): H-Index 14
17. Paper 17. Enhancing operational scale in SMEs through coopetition: Insights from the Portuguese ornamental stone industry. Journal of Open Innovation: Technology, Market, and Complexity, 10(3), 100363. https://doi.org/10.1016/j.joitmc.2024.100363; Scopus Published (Q1): H-Index 63.
18. Paper 18. Advancing BIM and Sustainability with Coopetition: Evidence from the Portuguese Stone Industry. Journal of Applied System Innovation. https://doi.org/10.3390/asi7040070; Scopus Published (Q1): H-Index 35.
19. Paper 19. Coopetition Networks for SMEs: A Lifecycle Model Grounded in Service-Dominant Logic. Journal Systems. https://doi.org/10.3390/systems12110461. Scopus Published (Q2): H-Index 40.
20. Paper 20. Harnessing Technology to Drive Coopetition and Value Co-Creation: A Service-Dominant Perspective. Administrative Sciences; https://doi.org/10.3390/admsci15020064; Scopus Published (Q2): H-Index 42.
21. Paper 21. Systemic Approaches to Coopetition: Technology and Service Integration in Dynamic Ecosystems Among SMEs. Journal Systems; https://doi.org/10.3390/systems13020097; Scopus Published (Q2): H-Index 40.
22. Paper 22. Enhancing Building Information Modeling Effectiveness, Through Coopetition and the Industrial Internet of Things; Journal of Theoretical and Applied Electronic Commerce Research; https://doi.org/10.3390/jtaer19040152; Scopus Published (Q1): H-Index 54.

9.2 Industry Audience Outreach

Industry-focused conferences and seminars are crucial for disseminating research findings related to CN-EcoTechs. These venues provide opportunities to engage directly with a diverse range of professionals, facilitating discussions that can lead to practical implementation and inform industry strategies. The research team aims to engage with industry stakeholders and policymakers through strategically selected seminars and conferences, thereby maximizing exposure and interaction with key industry figures—details of these events are outlined in Appendix I, Table 9.1.

This chapter offers an exhaustive overview of the communication strategies employed to disseminate DSR findings within the context of CN-EcoTech. It highlights the necessity of effectively articulating research outcomes to ensure they are comprehensible and utilized by academic peers, industry practitioners, and policymakers. The narrative demonstrates how tailored communication strategies can bridge the gap between theoretical research and practical application, thus enhancing the research's impact on real-world practices.

As the thesis nears its conclusion, Chapter 10 will explore the broader implications of these findings, considering the feedback and engagement from the dissemination efforts. It will synthesize key insights, assess the research's effectiveness within and beyond the academic community, and propose future research directions. The chapter will also consider the long-term impacts of implementing CN-EcoTechs, paving the way for continued innovation in integrating DSR findings into practical and policy spheres.

Chapter 10. Conclusions

An opinion should result from thought, not a substitute for it. - Jef Mallett

This thesis examines the dynamics of cooperation networks among small and medium-sized enterprises (SMEs). It focuses on developing and validating a framework to foster long-term collaboration and enhance the competitiveness of SMEs in the digital and global supply chain arenas. Despite the potential of these modern supply chains, SMEs frequently encounter obstacles such as limited financial resources, which impede operational efficiency, scalability, customer satisfaction, and the maintenance of low carbon emissions.

Recognizing these challenges, this research posited coopetition—where SMEs collaborate while remaining competitors—as a strategic solution. These networks are designed to help SMEs navigate the complexities of global and digital markets, leveraging opportunities to improve their competitive stance. However, existing research suggests that coopetition networks primarily composed of SMEs often experience short-term failures.

This observation frames the main Research Problem (RP) of this thesis: What framework for coopetition networks can be effectively implemented to ensure long-term collaboration among SMEs, and how does this framework address the challenges of digital and global supply chains?

To find a solution to this research problem (RP), the thesis employed the Design Science Research (DSR) methodology, grounded in S-D Logic and service ecosystems. The research culminated in the creation of the Coopetition Network for Value Cocreation (CN-VCC) framework, later operationalized as the Coopetition Technology-enabled Service Ecosystem (CN-EcoTech). The Portuguese ornamental stone (OS-PT) sector, integral to the national economy and evolving through BIM-influenced supply chains, served as the empirical setting to validate the framework's effectiveness.

The research progressed through several stages following the DSR methodology. After developing the CN-EcoTech artefact and demonstrating its viability, the first research question (RQ1) was addressed through a Proof-of-Concept (PoC), detailed in Chapter 7. Subsequent research questions focused on assessing CN-EcoTech's impact on operational efficiency (RQ2), scale (RQ3), customer satisfaction (RQ4), and ecological sustainability (RQ5). These aspects were explored through an Experimental Pilot Project, described in Chapter 8. This experimental phase provided essential insights into the practical implications of the CN-EcoTech framework in real-world scenarios, underscoring its potential benefits for SMEs within technology-enabled coopetition networks.

1 Answering RQ1: Evaluating the Effectiveness of the CN-EcoTech

Chapter 7 addressed RQ1 by exploring the integration of the Coopetition Network for Value Cocreation with Industrial IoT technologies (IIoT), resulting in the development of the CN-

EcoTech framework. Utilizing the DSR methodology, the efficacy of CN-EcoTech was assessed through a PoC among three distinct groups of SMEs within the OS-PT sector:

First Group (Independent SMEs): These SMEs operated outside the CN-EcoTech framework and faced significant challenges securing deals, highlighting the need for improved negotiation strategies.

Second Group (Partially Engaged SMEs): While part of CN-EcoTech, these SMEs retained the option to exit. They experienced post-sale disputes, underscoring the need for better management of post-sale relationships.

Third Group (Fully Engaged SMEs): This group fully adopted CN-EcoTech practices and exhibited the most favourable outcomes, using the competition framework to secure deals and sustain positive customer relationships.

This comparative analysis demonstrated varying levels of effectiveness based on the degree of engagement in CN-EcoTech, confirming its potential to significantly enhance cooperation among SMEs. The fully engaged SMEs benefitted from improved deal closure rates and stronger customer relations, indicating that deep integration into the framework can overcome traditional market challenges.

Overall, the successful deployment of CN-EcoTech, supported by the Service Blueprint method and the ISPAR tool, has proven effective in ensuring long-term collaboration among SMEs while addressing the complexities of digital and global supply chains. The findings underscore the practical viability of CN-EcoTech and suggest its potential for broader application beyond the OS-PT sector.

Answering RQ2: Impact of CN-EcoTech on Operational Efficiency

Further validation of CN-EcoTech's impact was achieved through an experimental pilot project, which applied the framework to real-world settings within three OS-PT SMEs. Data collected over two intervals of fifty-four working days provided a detailed comparative analysis of operational outcomes before and after adopting CN-EcoTech. These findings highlighted substantial improvements in operational efficiency, providing a comprehensive answer to RQ2:

Stability in Manufacturing Practices: Although no quantitative improvement was observed in the success rate of processes executed correctly on the first attempt, a slight increase in consistency by 0.66% suggests potential reductions in error rates or the need for rework. It indicates subtle yet positive shifts towards more stable operational practices under the CN-EcoTech framework.

Significant Performance Efficiency Gains: An impressive average increase of 66.1% in performance efficiency among OS-PT SMEs was noted. This improvement is attributed to the synergistic integration of resources, expertise, and capabilities under CN-EcoTech, which has significantly enhanced order fulfilment efficiency and optimized production. These

advancements enhance overall productivity and create a manufacturing environment that is adaptable and responsive to fluctuating market demands.

Improved Raw Material Yield: A notable 20.4% improvement in raw material yield was observed, indicating more efficient material utilization that leads to decreased waste and enhanced production processes. A consistency gain of 1.72% further indicates a reduction in variability in material use, ensuring more predictable and efficient resource utilization.

Labor Productivity Enhancement: Labor productivity saw an immense quantitative boost of 187.4%, reflecting significant enhancements in output or efficiency per labor unit. Despite the minimal consistency gain of 0.77%, this substantial increase underscores the effectiveness of CN-EcoTech in driving productivity optimization through collaboration and competition.

The transition to CN-EcoTech has significantly improved manufacturing efficiency by 68.5%, accompanied by a 1.2% increase in the consistency of these outcomes. This compelling evidence supports the adoption of CN-EcoTech to enhance operational efficiency and foster sustainable growth within the OS-PT SMEs. Through this analysis, RQ2 has been comprehensively addressed, showcasing the transformative potential of CN-EcoTech in enhancing operational efficiency and contributing to broader sustainability goals, particularly resonating with SDG 9 and SDG 12.

Answering RQ3: Impact of CN-EcoTech on Operational Scale

Examining operational scale-related IOs within the CN-EcoTech framework has highlighted significant enhancements in the performance of SMEs in the OS-PT, as detailed below:

Enhanced Conversion Rates: The adoption of CN.P practices resulted in a 13.2% improvement in conversion rates, reflecting an increase in order confirmations and, subsequently, a rise in production volume. This improvement is attributed to more efficient operational processes facilitated by CN-EcoTech.

Increased Stock Availability and Supply Consistency: Stock availability increased by 6.3%, and supply consistency improved by 1.43%. These improvements demonstrate CN.P's effectiveness in aligning raw material supply with customer demand, thereby enhancing its ability to promptly and efficiently fulfil large orders.

Stabilized Production Processes: While the immediate improvement in Machine versus Available (MvA) was modest at 0.4%, there was a noticeable improvement in the stability of production processes.

Optimized Production Capacities: A substantial 14.1% increase in production capacity utilization reflects significant benefits from adopting CN.P. This improvement showcases the enhanced utilization of resources, driven by the collaborative and competitive dynamics inherent in coopetition.

Overall, the transition to CN.P improved the operational scale by 8.5% and enhanced the consistency of operational behaviors, aligning with SDG 9 and SDG 11. These findings confirm CN-EcoTech's substantial and positive impact on the operational Scale of SMEs in the OS-PT sector. The effectiveness of CN.P in amplifying operational scale and capacity while promoting a more predictable and stable performance landscape underscores its potential role in advancing the sector's global competitiveness and sustainability. These results affirmatively answer RQ3, demonstrating how CN-EcoTech supports the expansion of operational scale in a manner that aligns with and contributes to international sustainability objectives.

Answering RQ4: Enhancements in Customer Satisfaction Determinants via CN-EcoTech

The research conducted on Customer Satisfaction Determinants within the CN-EcoTech framework revealed substantial improvements that have reshaped how SMEs in the OS-PT engage and satisfy their customers, providing a clear answer to RQ3:

Increased Value-to-Weight Ratio: This ratio improved by 6.7%, reflecting significant economic benefits, including optimized transportation costs and enhanced delivery performance, which are crucial for reducing the overall cost of product transportation and delivery.

Enhanced Operational Flexibility: A notable 19.4% increase in operational flexibility demonstrates an improved ability to customize and adapt production processes in response to specific customer demands, thereby enhancing operational agility. A 2.93% rise in the consistency of achieving this flexibility underscores a more predictable and adaptable production process.

Reduction in Customer Complaints: A 29.3% decrease in customer complaints indicates enhancements in product quality and overall Customer Satisfaction, highlighting a more reliable and customer-focused operational framework.

Improved On-Time Delivery: A significant 10.5% increase in the on-time delivery ratio demonstrates enhanced production and delivery efficiency, highlighting the operational benefits of CN-EcoTech's collaborative and competitive dynamics.

These improvements collectively resulted in a tangible 9.6% benefit in Customer Satisfaction Determinants from engaging in CN-EcoTech practices. This framework enables SMEs to excel in an increasingly competitive and dynamic business environment, aligning closely with crucial sustainability objectives, notably SDG 9, SDG 11, and SDG 12.

The findings affirmatively answer RQ3, demonstrating how CN-EcoTech catalyzes transformative improvements in customer interactions within the OS-PT sector. These improvements facilitate superior performance in customer engagement and promote the advancement of sustainable industrial practices, underscoring CN-EcoTech's significant potential to transform customer interactions and satisfaction levels across the sector.

Answering RQ5: Impact of CN-EcoTech on Ecological Footprint

The implementation of the CN-EcoTech within the OS-PT has led to substantial ecological improvements, providing a comprehensive answer to RQ5:

Enhanced Energy Utilization: The transition to CN-EcoTechs resulted in a 26.5% improvement in energy utilization. This enhancement reflects the operational and environmental benefits of leveraging shared resources and expertise, significantly reducing overall energy consumption and enhancing environmental sustainability.

Increased Material Utilization Efficiency: Material utilization efficiency improved by 20.4%, indicating a shift towards more sustainable production practices by minimizing waste. Additionally, consistency in this key performance indicator increased by 50.33%, underscoring the role of CN-EcoTechs in optimizing resource use and cementing its value in sustainable industrial practices.

Reduction in CO_2 Emissions: A tangible reduction in CO_2 emissions was observed, with a quantitative gain of 21.8%. This reduction demonstrates the ecological efficiencies achieved through CN-EcoTechs, showing substantial progress in minimizing the environmental impact of production activities.

Final Conclusions

The results from the Experimental Pilot Project, while not accounting for the investment needed to implement CN-EcoTech in the OS-PT sector broadly, suggest that for the SMEs involved, operating within CN.P is an effective strategy to address the challenges posed by BIM-shaped supply chains in the AEC. The positive impacts on operational Efficiency, Scale, Customer Satisfaction, and Ecological Footprint endorse the recommendation of CN-EcoTech to these companies.

It can be concluded that the CN-EcoTech, designed according to S-D Logic foundations, was suitable for addressing the RP stated in this thesis. The DSR methodology enabled robust conclusions about the responses of OS-PT SMEs in various operational contexts, making a significant practical contribution to this research.

By describing and configuring actors and the role of resources in coopetition networks, developing an appropriate artefact in line with the research objectives, and determining the KPIs and IOs before and after implementing the Experimental Pilot Project, this thesis presents a viable solution to the RP outlined in Chapter 1 of the Introduction. The objectives have been successfully met, and this thesis contributes to the advancement of the OS-PT sector, thereby enhancing people's well-being and promoting the planet's sustainability.

The comprehensive evaluation of Ecological Footprint-related IOs underscores the effectiveness of CN-EcoTech in enhancing both ecological sustainability and operational efficiencies. The notable reduction of 0.63 $KgCO_2$-eq per piece produced indicates the significant impact of CN.P

on reducing CO2 emissions. These results position CN-EcoTech as a strategic and sustainable approach for the OS-PT sector, emphasizing its ability to drive meaningful ecological improvements alongside operational enhancements in the competitive OS-PT sector environment. Furthermore, the strong alignment with SDGs 9, 11, 12, and 13 underscores CN-EcoTech's role in advancing sustainability initiatives that contribute to environmental preservation and support the United Nations' global sustainability targets.

Academic Implications

Implementing the CN-EcoTech within the OS-PT sector significantly enriches the existing S-D Logic knowledge body. This research highlights the practical applicability of the DSR methodology in real-world settings, providing a framework for assessing the effectiveness of technological and cooperative strategies across multiple dimensions: Operational Efficiency, Scale, Customer Satisfaction, and Ecological Footprint.

Theoretical Contributions

Foundational Support: Utilizing the theoretical foundations of S-D Logic, this research supports the design and development of CN-EcoTechs. It addresses gaps in coopetition networks by exploring and operationalizing constructs and proposing critical building blocks for the Competition Network for Value Creation framework.

Artefact Development: The CN-EcoTech artefact, grounded in S-D Logic, operationalizes critical concepts such as IO to assess its benefits, demonstrating the framework's capability to bridge theory with practical application.

Research Methodology Enhancements

Pragmatic Approach: By adopting a pragmatic research paradigm, this thesis seamlessly integrates real-world practices with an evolutionary, interactive approach to extract knowledge from experts. It effectively addresses concerns related to requirements validation, ensuring that the findings are both practical and applicable in real-world settings.

Tool and Technique Innovation: The research innovates by utilizing and developing the Service Blueprint tool and employing the ISPAR tool to assess the interests of multiple stakeholders in a coopetition technology-enabled environment.

Operationalization of S-D Logic: The Coopetition Technology-enabled Network for Value Cocreation framework operationalizes S-D Logic in a way that redefines standard business processes, such as order fulfilment, and seamlessly encompasses product and service requirements.

Advancements in Technology Management

Sustainable Coopetition Strategies: The research highlights the role of technology in facilitating sustainable coopetition strategies, offering new insights into how technology can be leveraged to

improve competitive advantage and environmental sustainability through technology-enabled networks.

Technology as an Enabler for Value Cocreation: This thesis's findings enrich strategic discussions on using technology to facilitate value cocreation within competitive industries. They provide a replicable and adaptable model that other sectors can use to harness technological advancements to enhance collaborative innovation and competitiveness.

Practical Implications

The practical implications of this thesis are significant for industry practitioners and policymakers within the OS-PT sector and beyond. By demonstrating the tangible benefits of CN-EcoTechs, this research provides actionable insights that can be applied to enhance business practices and inform policy formulations:

For Industry Practitioners: The demonstrated benefits of CN-EcoTech in terms of Operational Efficiency, Scale, Customer Satisfaction, and reduced Ecological Footprint provide a compelling case for other SMEs to adopt similar frameworks. Industry leaders can use these findings to rethink their strategic approaches, particularly in integrating technology and coopetition into their operational activities to drive innovation and sustainability.

For Policymakers: The alignment of CN-EcoTech outcomes with SDGs suggests that policymakers should consider supporting frameworks that facilitate technology-enabled collaboration networks. Policies could be developed to encourage the adoption of sustainable practices that boost competitive advantage and contribute to broader environmental goals. Such policies could incentivize SMEs, particularly from the OS-PT, to adopt sustainable technologies and participate in CN-EcoTechs.

Challenges and Constraints

While the objectives of this research were achieved, several challenges were encountered that introduced limitations to the study.

Scarcity of Relevant Literature: The literature review highlighted a need for more resources on coopetition networks within S-D Logic, particularly regarding technology-enabled coopetition among SMEs. This scarcity posed significant challenges in designing the framework, necessitating reliance on more general theories and indirect references.

Empirical Implementation Constraints: The practical application of the CN-EcoTech, being empirical, inherently limited the research outcomes. Variations in natural patterns of materials, especially compared to industrial materials, posed challenges in matching during reorder or replacement scenarios. Additionally, the diversity of orders in the empirical test may have influenced the consistency of the results.

Data Collection Across Geographies: Monitoring the entire sequence of events, from order discussions to product delivery, was complex due to the simultaneous occurrence of large

volumes of data. Effective data collection required extensive cooperation from stakeholders at multiple levels, including managing directors, section managers, and operators, who collected data upon request and provided access to their records and databases.

Resource Constraints: Identifying companies willing to participate and securing funding for the Experimental Pilot Project posed significant hurdles. Although the Inovminenal4.0 R&D Project offset some costs, and company participation was secured through confidentiality agreements, these factors still represented substantial difficulties.

Scale of Empirical Testing: The research was conducted over two 54-day periods with only three SMEs. A more significant number of companies and extended testing periods would be necessary to obtain more definitive results. However, the insights gained are believed to be scalable and potentially generalizable to the broader OS-PT sector.

Despite these limitations, the research yielded valuable insights that contribute meaningfully to academic knowledge and practical applications in the OS-PT sector. The cooperation from industry stakeholders and the integration of theoretical concepts into practical settings underscore the relevance and applicability of the findings.

Recommendations for Future Work

This exploratory study has paved the way for more detailed explorations into implementing and scaling CN-EcoTech across the OS-PT sector and potentially beyond. Critical areas for future research include:

Dynamic Cost-Benefit Analysis: Investigate the evolving cost-benefit relationship of implementing CN-EcoTech broadly within the OS-PT sector. This analysis should consider the investment required to extend these coopetition practices across the OS-PT sector, as well as the potential return on investment over time.

Adaptation to Other Sectors: Given the successful application of CN-EcoTech in a sample of OS-PT SMEs, future work should explore how this framework can be adapted and implemented in other SME-dominated sectors. This will test the framework's versatility and effectiveness in different industrial contexts.

This thesis makes a significant contribution to both academic knowledge and practical applications, particularly in the integration of Service-Dominant Logic with technology-enabled coopetition networks. The research acknowledges the limitations and challenges, setting a clear agenda for future investigations that may build on the foundational work presented here. By highlighting these aspects, this discussion provides a balanced view of the implications of deploying CN-EcoTech within the OS-PT sector. It offers a solid foundation for continuous innovation and improvement. Future research based on these recommendations will likely yield further insights and enhancements, potentially broadening the applicability of CN-EcoTech to a broader range of industries and contexts.

List of References

[1] L. Di Bella, A. Katsinis, J. Lagüera-González, L. Odenthal, M. Hell, and B. Lozar, “Annual Report on European SMEs 2022/2023,” 2023.

[2] D. Radicic, G. Pugh, and D. Douglas, “Promoting cooperation in innovation ecosystems: evidence from European traditional manufacturing SMEs,” *Small Bus. Econ.*, vol. 54, no. 1, pp. 257–283, Jan. 2020, doi: 10.1007/s11187-018-0088-3.

[3] T. Kwaak *et al.*, “Survey on the access to finance of enterprises (SAFE),” Blruxels, 2021. doi: 10.2873/840166.

[4] P. Muller *et al.*, *Annual Report on European SMEs*, no. July. 2021.

[5] A. Amaral and P. Peças, “SMEs and Industry 4.0: Two case studies of digitalization for a smoother integration,” *Comput. Ind.*, vol. 125, 2021, doi: 10.1016/j.compind.2020.103333.

[6] C. L. Chen, “Cross-disciplinary innovations by Taiwanese manufacturing SMEs in the context of Industry 4.0,” *J. Manuf. Technol. Manag.*, vol. 31, no. 6, pp. 1145–1168, 2020, doi: 10.1108/JMTM-08-2019-0301.

[7] M. Siddi, “The European Green Deal: Assessing its current state and future implementation,” *FIIA Work. Pap.*, no. May, p. 14, 2020.

[8] L. Cozzi, “CO2 Emissions in 2022,” 2023. doi: 10.1787/12ad1e1a-en.

[9] C. L. Garay-Rondero, J. L. Martinez-Flores, N. R. Smith, S. O. Caballero Morales, and A. Aldrette-Malacara, “Digital supply chain model in Industry 4.0,” *J. Manuf. Technol. Manag.*, vol. 31, no. 5, pp. 887–933, 2020, doi: 10.1108/JMTM-08-2018-0280.

[10] M. Munir, M. S. S. Jajja, K. A. Chatha, and S. Farooq, “Supply chain risk management and operational performance: The enabling role of supply chain integration,” *Int. J. Prod. Econ.*, vol. 227, no. March 2019, p. 107667, 2020, doi: 10.1016/j.ijpe.2020.107667.

[11] M. Negreiro and M. Tambiama, “EU policies – Delivering for citizens Human rights,” 2019.

[12] M. Matzner *et al.*, “Digital Transformation in Service Management,” *J. Serv. Manag. Res.*, vol. 2, no. 2, pp. 3–21, 2018, doi: 10.15358/2511-8676-2018-2-3.

[13] O. Grun, “Manifesto 2030 NEW DEAL,” 2024.

[14] R. D. Raut, S. Kumar, V. S. Narwane, B. B. Gardas, P. Priyadarshinee, and B. E. Narkhede, “Linking big data analytics and operational sustainability practices for sustainable business management,” *J. Clean. Prod.*, vol. 224, pp. 10–24, 2019, doi: 10.1016/j.jclepro.2019.03.181.

[15] U. von der Leyen, “A Union that strives for more. My agenda for Europe : political guidelines for the next European Commission 2019-2024,” *EU Publ.*, p. 24, 2019, [Online]. Available: https://ec.europa.eu/commission/sites/beta-political/files/political-guidelines-next-commission_en.pdf%0Ahttps://op.europa.eu/en/publication-detail/-/publication/43a17056-ebf1-11e9-9c4e-01aa75ed71a1.

[16] J. Ramezani and L. Camarinha-Matos, “Approaches for resilience and antifragility in collaborative business ecosystems,” *Technol. Forecast. Soc. Change*, vol. 151, no. March 2019, p. 119846, 2020, doi: 10.1016/j.techfore.2019.119846.

[17] B. D. Matthies *et al.*, “An ecosystem service-dominant logic? – integrating the ecosystem service approach and the service-dominant logic,” *J. Clean. Prod.*, vol. 124, pp. 51–64, Jun. 2016, doi: 10.1016/j.jclepro.2016.02.109.

[18] European Comission, “Digital transition action plan,” *Urban Agenda EU*, pp. 1–69, 2018.

[19] A. Rouyre, A.-S. Fernandez, and O. Bruyaka, “Big problems require large collective actions: Managing multilateral coopetition in strategic innovation networks,”

Technovation, vol. 132, p. 102968, 2024, doi: https://doi.org/10.1016/j.technovation.2024.102968.

[20] R. Geissbauer, E. Lübben, S. Schrauf, and S. Pillsbury, *Global Digital Operations Study 2018 - Digital Champions*. 2018.

[21] P. Klimas, A. A. Ahmadian, M. Soltani, M. Shahbazi, and A. Hamidizadeh, "Coopetition, Where Do You Come From? Identification, Categorization, and Configuration of Theoretical Roots of Coopetition," *SAGE Open*, vol. 13, no. 1, p. 215824402210850, Jan. 2023, doi: 10.1177/21582440221085003.

[22] R. Bouncken, A. Kumar, J. Connell, A. Bhattacharyya, and K. He, "Coopetition for corporate responsibility and sustainability: does it influence firm performance?," *Int. J. Entrep. Behav. Res.*, vol. 30, no. 1, pp. 128–154, Jan. 2024, doi: 10.1108/IJEBR-05-2023-0556.

[23] S. Manzhynski and F. Figge, "Coopetition for sustainability: Between organizational benefit and societal good," *Bus. Strateg. Environ.*, vol. 29, no. 3, pp. 827–837, Mar. 2020, doi: 10.1002/bse.2400.

[24] European Commission, "Unleashing the full potential of European SMEs," 2020. doi: 10.2775/296379.

[25] J. Crick, "The dark side of coopetition: when collaborating with competitors is harmful for company performance," *J. Bus. Ind. Mark.*, vol. 35, no. 2, pp. 318–337, Sep. 2019, doi: 10.1108/JBIM-01-2019-0057.

[26] A. Tidström, "Managing tensions in coopetition," *Ind. Mark. Manag.*, vol. 43, no. 2, pp. 261–271, 2014, doi: 10.1016/j.indmarman.2013.12.001.

[27] Q. Xie, Y. Gao, N. Xia, S. Zhang, and G. Tao, "Coopetition and organizational performance outcomes: A meta-analysis of the main and moderator effects," *J. Bus. Res.*, vol. 154, no. October 2022, p. 113363, 2023, doi: 10.1016/j.jbusres.2022.113363.

[28] M. Reeves, H. Lotan, J. Legrand, and M. G. Jacobides, "How Business Ecosystems Rise (and Often Fall)," *MIT Sloan Manag. Rev.*, no. July, 2019.

[29] T. Raza-Ullah, M. Bengtsson, and S. Kock, "The coopetition paradox and tension in coopetition at multiple levels," *Ind. Mark. Manag.*, vol. 43, no. 2, pp. 189–198, 2014, doi: 10.1016/j.indmarman.2013.11.001.

[30] J. F. Moore, "Business Ecosystems and the View from the Firm," *Antitrust Bull.*, vol. 51, no. 1, pp. 31–75, 2006, doi: 10.1177/0003603X0605100103.

[31] C. Devece, D. E. Ribeiro-Soriano, and D. Palacios-Marqués, "Coopetition as the new trend in inter-firm alliances: literature review and research patterns," *Rev. Manag. Sci.*, vol. 13, no. 2, pp. 207–226, 2019, doi: 10.1007/s11846-017-0245-0.

[32] M. Abubakre, I. Faik, and M. Mkansi, "Digital entrepreneurship and indigenous value systems: An Ubuntu perspective," *Inf. Syst. J.*, vol. 31, no. 6, pp. 838–862, Nov. 2021, doi: 10.1111/isj.12343.

[33] J. D. Chandler, I. Danatzis, C. Wernicke, M. A. Akaka, and D. Reynolds, "How Does Innovation Emerge in a Service Ecosystem?," *J. Serv. Res.*, vol. 22, no. 1, pp. 75–89, 2019, doi: 10.1177/1094670518797479.

[34] R. Davies, "Industry 4.0. Digitalisation for productivity and growth," 2015. [Online]. Available: http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568337/EPRS_BRI(2015)568337_EN.pdf.

[35] The Economist Intelligence Unit, "Poor collaboration holds back European businesses digital ambitions," 2021. [Online]. Available: https://appian.com/resources/resource-center/google-success/economist-survey-european-businesses-digital-ambitions-success.html.

[36] J. Frazao, "Evolução da Força de Trabalho do Setor dos Recursos Minerais no início da Era Digital," *PhD thesis - ISCTE*, 2019.

[37] J. M. F. Carvalho, J. Meira, C. Marques, S. Machado, L. M. Mergulhão, and J. F. Cancela, "Nature Conservation, Land Use Planning and Exploitation of Ornamental Stones - The Case Study of Cabeça Veada (Portugal)," *Key Eng. Mater.*, vol. 848, pp. 77–86, Jun. 2020, doi: 10.4028/www.scientific.net/KEM.848.77.

[38] J. Carvalho, C. Lopes, A. Mateus, L. Martins, and M. Goulão, "Planning the future exploitation of ornamental stones in Portugal using a weighed multi-dimensional approach," *Resour. Policy*, vol. 59, no. August, pp. 298–317, 2018, doi: 10.1016/j.resourpol.2018.08.001.

[39] J. M. F. Carvalho and J. V. Lisboa, "Ornamental stone potential areas for land use planning: a case study in a limestone massif from Portugal," *Environ. Earth Sci.*, vol. 77, no. 5, p. 206, Mar. 2018, doi: 10.1007/s12665-018-7382-x.

[40] A. Silva, "Improving Industry 4 . 0 Through Service Science," 2018.

[41] A. Silva and A. Pata, "Value Creation in Technology Service Ecosystems - Empirical Case Study," in *Innovations in Industrial Engeneering II*, 2022, pp. 26–36, doi: doi.org/10.1007/978-3-031-09360-9_3.

[42] A. Silva, J. Silva, and I. Almeida, "The role of digital technologies in the innovation of collaborative networks : the case of the ornamental stones in Portugal," *20th Cambridge Int. Manuf. Symp.*, no. September, 2016.

[43] I. Frazao, "Capacidade Dinâmica das Alianças no Cluster dos Recursos Minerais," *PhD Thesis - ISCTE*, 2019.

[44] A. Silva, A. Dionísio, and L. Coelho, "Improving Industry4.0 Through the Service Science," *Int. J. Sci. Basic Appl. Res. ISSN 2307-4531 Vol 52 No 2*, vol. 52, pp. 17–32, 2020.

[45] A. Silva and M. Gil, "Industrial processes optimization in digital marketplace context: A case study in ornamental stone sector," *Results Eng.*, vol. 7, no. April, p. 100152, 2020, doi: 10.1016/j.rineng.2020.100152.

[46] P. U. Wijeratne, C. Gunarathna, R. J. Yang, P. Wu, K. Hampson, and A. Shemery, "BIM enabler for facilities management: a review of 33 cases," *Int. J. Constr. Manag.*, vol. 24, no. 3, pp. 251–260, Feb. 2024, doi: 10.1080/15623599.2023.2222962.

[47] A. Grilo and R. Jardim-Goncalves, "Challenging electronic procurement in the AEC sector: A BIM-based integrated perspective," *Autom. Constr.*, vol. 20, no. 2, pp. 107–114, 2011, doi: 10.1016/j.autcon.2010.09.008.

[48] C. Gragnaniello, G. Mariniello, T. Pastore, and D. Asprone, "BIM-based design and setup of structural health monitoring systems," *Autom. Constr.*, vol. 158, p. 105245, Feb. 2024, doi: 10.1016/j.autcon.2023.105245.

[49] P. Behera, R. Mohanty, and A. Prakash, "Understanding Construction Supply Chain Management," *Prod. Plan. Control*, vol. 2616, no. March, pp. 1332–1350, 2015, doi: 10.1080/09537287.2015.1045953.

[50] S. M. Vieira, A. Silva, J. M. C. Sousa, J. De Brito, and P. L. Gaspar, "Automation in Construction Modelling the service life of rendered facades using fuzzy systems," *Autom. Constr.*, vol. 51, pp. 1–7, 2015, doi: 10.1016/j.autcon.2014.12.011.

[51] A. Silva, "Inovação Tecnológica lean para a Pedra Natural," 2013.

[52] G. Gao, Y.-S. Liu, M. Wang, M. Gu, and J.-H. Yong, "A query expansion method for retrieving online BIM resources based on Industry Foundation Classes," *Autom. Constr.*, vol. 56, pp. 14–25, 2015, doi: 10.1016/j.autcon.2015.04.006.

[53] A. Malleson and D. Watson, "International BIM Report 2016 Views from the countries Survey 2015," 2016. [Online]. Available: https://www.thenbs.com/knowledge/nbs-international-bim-report-2016.

[54] R. Volk, J. Stengel, and F. Schultmann, "Building Information Modeling (BIM) for existing buildings — Literature review and future needs," *Autom. Constr.*, vol. 38, pp. 109–127, 2014, doi: 10.1016/j.autcon.2013.10.023.

[55] I. Almeida and A. Silva, “The circularity endeavour in the Ornamental Stone sector,” in *Reconfiguring global supply chains in the face of continued disruption: towards new design rules and capabilities*, 2022.

[56] Y. Pan and L. Zhang, “Integrating BIM and AI for Smart Construction Management: Current Status and Future Directions,” *Arch. Comput. Methods Eng.*, vol. 30, no. 2, pp. 1081–1110, Mar. 2023, doi: 10.1007/s11831-022-09830-8.

[57] A. Silva and A. Marques Cardoso, “BIM-based Supply Chain in AEC - Threats on the Portuguese Stone sector,” in *Proceedings of the 7th Globalstone Congress, Batalha, 2023; ISBN 978-972-778-327-4*, 2023, [Online]. Available: https://repositorio.lneg.pt/bitstream/10400.9/4150/1/GSC2023_PT Natural Stones-Commercial Names harmonization.pdf.

[58] B. Brende, “The Global Cooperation Barometer 2024.,” Geneva, Switzerland, 2024. [Online]. Available: https://www.weforum.org/publications/the-global-cooperation-bar%0Aometer-2024/.

[59] A. Silva and A. Marques Cardoso, “Technology Paths towards Coopetition Ecosystems - The Portuguese Stone Sector,” in *Proceedings of the 7th Globalstone Congress, Batalha, 2023*, 2023, [Online]. Available: isbn: 978-972-778-327-4.

[60] J. Elo, J. Lumivalo, T. Tuunanen, and S. L. Vargo, “Enabling Value Co-Creation in Partner Collaboration Ecosystems: An Institutional Work Perspective,” *Proc. 57th Hawaii Int. Conf. Syst. Sci.*, no. March, 2024, [Online]. Available: https://hdl.handle.net/10125/106412.

[61] J. F. Moore, “The rise of a new corporate form,” *Wash. Q.*, vol. 21, no. 1, pp. 167–181, 1998, doi: 10.1080/01636609809550301.

[62] B. J. Nalebuff and A. M. Brandenburger, “Co-opetition: Competitive and cooperative business strategies for the digital economy,” *Strateg. Leadersh.*, vol. 25, no. 6, pp. 28–33, Jun. 1997, doi: 10.1108/eb054655.

[63] D. R. Gnyawali and Y. Song, “Pursuit of rigor in research: Illustration from coopetition literature,” *Ind. Mark. Manag.*, vol. 57, pp. 12–22, 2016, doi: 10.1016/j.indmarman.2016.05.004.

[64] D. P. Infante, “Desenvolvimento psicossocial,” *Pediatr. Básica*, pp. 550–552, 1994.

[65] D. R. Gnyawali and T. Ryan Charleton, “Nuances in the Interplay of Competition and Cooperation: Towards a Theory of Coopetition,” *J. Manage.*, vol. 44, no. 7, pp. 2511–2534, 2018, doi: 10.1177/0149206318788945.

[66] M. H. Näsholm and M. Bengtsson, “A conceptual model of individual identifications in the context of coopetition,” *Int. J. Bus. Environ.*, vol. 6, no. 1, p. 11, 2014, doi: 10.1504/IJBE.2014.058021.

[67] C. Ramírez-López *et al.*, “Coopetition: Cooperation among competitors to enhance applied research and drive innovation in elite sport,” *Br. J. Sports Med.*, vol. 55, no. 10, pp. 522–523, 2021, doi: 10.1136/bjsports-2020-102901.

[68] M. Bengtsson and S. Kock, “”Coopetition” in Business Networks—to Cooperate and Compete Simultaneously,” *Ind. Mark. Manag.*, vol. 29, no. 5, pp. 411–426, Sep. 2000, doi: 10.1016/S0019-8501(99)00067-X.

[69] M. Rungtusanatham, F. Salvador, C. Forza, and T. Y. Choi, “Supply-chain linkages and operational performance,” *Int. J. Oper. Prod. Manag.*, vol. 23, no. 9, pp. 1084–1099, Sep. 2003, doi: 10.1108/01443570310491783.

[70] R. B. Bouncken, V. Fredrich, P. Ritala, and S. Kraus, “Coopetition in New Product Development Alliances: Advantages and Tensions for Incremental and Radical Innovation,” *Br. J. Manag.*, vol. 29, no. 3, pp. 391–410, 2018, doi: 10.1111/1467-8551.12213.

[71] G. Dagnino and G. Padula, “Coopetition Strategy. Towards a New Kind of Interfirm Dynamics?”,” *EURAM – Eur. Acad. Manag. Second Annu. Conf. - “Innovative Res. Manag.*, no. May 2002, pp. 9–11, 2002.

[72] M. Bengtsson, S. Kock, E.-L. Lundgren-Henriksson, and M. H. Näsholm, “Coopetition research in theory and practice: Growing new theoretical, empirical, and methodological domains,” *Ind. Mark. Manag.*, vol. 57, pp. 4–11, Aug. 2016, doi: 10.1016/j.indmarman.2016.05.002.

[73] Y. Luo, “A coopetition perspective of global competition,” *J. World Bus.*, vol. 42, no. 2, pp. 129–144, 2007, doi: 10.1016/j.jwb.2006.08.007.

[74] W. Tsai, “Social structure of ‘coopetition’ within a multiunit organization: Coordination, competition, and intraorganizational knowledge sharing,” *Organ. Sci.*, vol. 13, no. 2, pp. 179–190, 2002, doi: 10.1287/orsc.13.2.179.536.

[75] D. R. Gnyawali and B. J. Park, “Co-opetition between giants: Collaboration with competitors for technological innovation,” *Res. Policy*, vol. 40, no. 5, pp. 650–663, 2011, doi: 10.1016/j.respol.2011.01.009.

[76] I. Estrada and J. Dong, “Learning from experience? Technological investments and the impact of coopetition experience on firm profitability,” *Long Range Plann.*, vol. 53, no. 1, p. 101866, 2020, doi: 10.1016/j.lrp.2019.01.003.

[77] D. Mwesiumo, M. Harun, and H. Hogset, “Unravelling the black box between coopetition and firms’ sustainability performance,” *Ind. Mark. Manag.*, vol. 114, pp. 110–124, Oct. 2023, doi: 10.1016/j.indmarman.2023.08.008.

[78] L. Corbo, S. Kraus, B. Vlačić, M. Dabić, A. Caputo, and M. M. Pellegrini, “Coopetition and innovation: A review and research agenda,” *Technovation*, vol. 122, no. September 2022, 2023, doi: 10.1016/j.technovation.2022.102624.

[79] T. Q. T. Nguyen, P. Johnson, and T. Young, “Networking, coopetition and sustainability of tourism destinations,” *J. Hosp. Tour. Manag.*, vol. 50, pp. 400–411, Mar. 2022, doi: 10.1016/j.jhtm.2022.01.003.

[80] O. Gernsheimer, D. K. Kanbach, and J. Gast, “Coopetition research - A systematic literature review on recent accomplishments and trajectories,” *Ind. Mark. Manag.*, vol. 96, no. May, pp. 113–134, 2021, doi: 10.1016/j.indmarman.2021.05.001.

[81] A. Meena, S. Dhir, and S. Sushil, “A review of coopetition and future research agenda,” *J. Bus. Ind. Mark.*, vol. 38, no. 1, pp. 118–136, 2023, doi: 10.1108/JBIM-09-2021-0414.

[82] A. Debnath, A. Bandyopadhyay, J. Roy, and S. Kar, “Game Theory based multi criteria decision making problem under uncertainty: A case study on Indian tea industry,” *J. Bus. Econ. Manag.*, vol. 19, no. 1, pp. 154–175, May 2018, doi: 10.3846/16111699.2017.1401553.

[83] P. T. Spiller, “A Tribute to Oliver Williamson: Regulation: A Transaction Cost Perspective,” *Calif. Manage. Rev.*, vol. 52, no. 2, pp. 147–158, Feb. 2010, doi: 10.1525/cmr.2010.52.2.147.

[84] C. FitzGerald, E. Carter, R. Dixon, and M. Airoldi, “Walking the contractual tightrope: a transaction cost economics perspective on social impact bonds,” *Public Money Manag.*, vol. 39, no. 7, pp. 458–467, Oct. 2019, doi: 10.1080/09540962.2019.1583889.

[85] A. Parkhe, S. Wasserman, and D. A. Ralston, “New Frontiers in Network Theory Development,” *Acad. Manag. Rev.*, vol. 31, no. 3, pp. 560–568, Jul. 2006, doi: 10.5465/amr.2006.21318917.

[86] N. Argyres, L. A. Rios, and B. S. Silverman, “Organizational change and the dynamics of innovation: Formal R&D structure and intrafirm inventor networks,” *Strateg. Manag. J.*, vol. 41, no. 11, pp. 2015–2049, Nov. 2020, doi: 10.1002/smj.3217.

[87] K. Martinus and T. J. Sigler, “Global city clusters: theorizing spatial and non-spatial proximity in inter-urban firm networks,” *Reg. Stud.*, pp. 1–13, May 2017, doi: 10.1080/00343404.2017.1314457.

[88] F. Le Roy, A.-S. Fernandez, and P. Chiambaretto, “From strategizing coopetition to managing coopetition,” in *The Routledge Companion to Coopetition Strategies*, Routledge, 2018, pp. 36–46.

[89] R. B. Bouncken and V. Fredrich, “Business model innovation in alliances: Successful configurations,” *J. Bus. Res.*, vol. 69, no. 9, pp. 3584–3590, Sep. 2016, doi: 10.1016/j.jbusres.2016.01.004.

[90] S. Manzhynski and G. Biedenbach, “The knotted paradox of coopetition for sustainability: Investigating the interplay between core paradox properties,” *Ind. Mark. Manag.*, vol. 110, pp. 31–45, Apr. 2023, doi: 10.1016/j.indmarman.2023.02.013.

[91] M. Chen, C. Lv, X. Wang, L. Li, and P. Yang, “A Critical Review of Studies on Coopetition in Educational Settings,” *Sustain.*, vol. 15, no. 10, pp. 1–18, 2023, doi: 10.3390/su15108370.

[92] J. Navío-Marco, M. Bujidos-Casado, and B. Rodrigo-Moya, “Coopetition as an innovation strategy in the European Union: Analysis of the German case,” *Ind. Mark. Manag.*, vol. 82, pp. 9–14, Oct. 2019, doi: 10.1016/j.indmarman.2019.05.014.

[93] Z. Deng, D. Weng, S. Liu, Y. Tian, M. Xu, and Y. Wu, “A survey of urban visual analytics: Advances and future directions,” *Comput. Vis. Media*, vol. 9, no. 1, pp. 3–39, Mar. 2023, doi: 10.1007/s41095-022-0275-7.

[94] M.-C. Wang and J.-S. Chen, “Driving coopetition strategy to service innovation: the moderating role of coopetition recognition,” *Rev. Manag. Sci.*, vol. 16, no. 5, pp. 1471–1501, Jul. 2022, doi: 10.1007/s11846-021-00488-3.

[95] J. Navío-Marco, R. Ibar-Alonso, and M. Bujidos-Casado, “Interlinkages between coopetition and organisational innovation in Europe,” *J. Bus. Ind. Mark.*, vol. 36, no. 9, pp. 1665–1677, Oct. 2021, doi: 10.1108/JBIM-01-2020-0054.

[96] S. L. Vargo and R. F. Lusch, “Inversions of service-dominant logic,” *Mark. Theory*, vol. 14, no. 3, pp. 239–248, Sep. 2014, doi: 10.1177/1470593114534339.

[97] S. L. Vargo and R. Lusch, “Service-dominant logic 2025,” *Int. J. Res. Mark.*, vol. 34, no. 1, pp. 46–67, Mar. 2017, doi: 10.1016/j.ijresmar.2016.11.001.

[98] E. Jaakkola, V. Kaartemo, J. Siltaloppi, and S. L. Vargo, “Advancing service-dominant logic with systems thinking,” *J. Bus. Res.*, p. 114592, Feb. 2024, doi: 10.1016/j.jbusres.2024.114592.

[99] P. Maglio, K. Cheryl, and J. Spohrer, *Handbook of Service Science*. 2010.

[100] S. L. Vargo and R. F. Lusch, “Evolving to a New Dominant Logic for Marketing,” *J. Mark.*, vol. 68, no. 1, pp. 1–17, Jan. 2004, doi: 10.1509/jmkg.68.1.1.24036.

[101] B. J. Loasby, “The organisation of capabilities,” *J. Econ. Behav. Organ.*, vol. 35, no. 2, pp. 139–160, Apr. 1998, doi: 10.1016/S0167-2681(98)00056-0.

[102] R. Lusch, S. Vargo, and M. O’Brien, “Competing through service: Insights from service-dominant logic,” *J. Retail.*, vol. 83, no. 1, pp. 5–18, 2007, doi: 10.1016/j.jretai.2006.10.002.

[103] M. Akaka, S. Vargo, and R. Lusch, “The Complexity of Context: A Service Ecosystems Approach for International Marketing,” *J. Int. Mark.*, vol. Vol. 21, no. No. 4, 2013, pp. 1–20, Dec. 2013.

[104] C. Greer, R. Lusch, and S. Vargo, “A service perspective. Key managerial insights from service-dominant (S-D) logic.,” *Organ. Dyn.*, vol. 45, no. 1, pp. 28–38, 2016, doi: 10.1016/j.orgdyn.2015.12.004.

[105] R. Lusch, S. Vargo, and A. Gustafsson, “Fostering a trans-disciplinary perspectives of service ecosystems,” *J. Bus. Res.*, vol. 69, no. 8, pp. 2957–2963, Aug. 2016, doi: 10.1016/j.jbusres.2016.02.028.

[106] S. L. Vargo and R. F. Lusch, “It’s all B2B…and beyond: Toward a systems perspective of the market,” *Ind. Mark. Manag.*, vol. 40, no. 2, pp. 181–187, Feb. 2011, doi: 10.1016/j.indmarman.2010.06.026.

[107] B. Edvardsson and B. Tronvoll, “A new conceptualization of service innovation grounded in S-D logic and service systems,” *Int. J. Qual. Serv. Sci.*, vol. 5, no. 1, pp. 19–31, Mar. 2013, doi: https://doi.org/10.1002/sres.2213.

[108] W. Scott, *Institutions and Organizations*. SAGE Publications, Inc, 2001.

[109] J. Siltaloppi, K. Koskela-Huotari, and S. Vargo, "Institutional complexity as a driver for innovation in service ecosystems," *Serv. Sci.*, vol. 8, no. 3, pp. 333–343, 2016, doi: 10.1287/serv.2016.0151.

[110] S. Vargo and R. Lusch, "Institutions and axioms: an extension and update of service-dominant logic," *J. Acad. Mark. Sci.*, vol. 44, no. 1, pp. 5–23, Jan. 2016, doi: 10.1007/s11747-015-0456-3.

[111] B. Edvardsson, M. Kleinaltenkamp, B. Tronvoll, P. McHugh, and C. Windahl, "Institutional logics matter when coordinating resource integration," *Mark. Theory*, vol. 14, no. 3, pp. 291–309, Sep. 2014, doi: 10.1177/1470593114534343.

[112] W. Scott, *Institutions and organizations (4th ed.)*. 2014.

[113] N. N. Hartmann, H. Wieland, and S. L. Vargo, "Converging on a New Theoretical Foundation for Selling," *J. Mark.*, vol. 82, no. 2, pp. 1–18, Mar. 2018, doi: 10.1509/jm.16.0268.

[114] K. Koskela-Huotari, J. Vink, and B. Edvardsson, "The institutional turn in service research: taking stock and moving ahead," *J. Serv. Mark.*, vol. 34, no. 3, pp. 373–387, Apr. 2020, doi: 10.1108/JSM-02-2019-0101.

[115] S. L. Vargo *et al.*, "Emergence in marketing: an institutional and ecosystem framework," *J. Acad. Mark. Sci.*, vol. 51, no. 1, pp. 2–22, 2023, doi: 10.1007/s11747-022-00849-8.

[116] J. Spohrer, "Commentary on 'Value Creation and Cognitive Technologies: Opportunities and Challenges,'" *J. Creat. Value*, vol. 4, no. 2, pp. 199–201, 2018, doi: 10.1177/2394964318809174.

[117] J. Siltaloppi and S. L. Vargo, "Triads: A review and analytical framework," *Mark. Theory*, vol. 17, no. 4, pp. 395–414, 2017, doi: 10.1177/1470593117705694.

[118] M. Akaka, H. Schau, and S. Vargo, "How Practice Diffusion Drives IoT Technology Adoption and Institutionalization of Solutions in Service Ecosystems," in *Proceedings of the Annual Hawaii International Conference on System Sciences*, 2023, vol. 2023-Janua, no. March, pp. 1427–1435, doi: 10.24251/HICSS.2023.178.

[119] S. L. Vargo, J. A. Fehrer, H. Wieland, and A. Nariswari, "The nature and fundamental elements of digital service innovation," *J. Serv. Manag.*, vol. 35, no. 2, pp. 227–252, Mar. 2024, doi: 10.1108/JOSM-02-2023-0052.

[120] J. Crick and D. Crick, "Coopetition and COVID-19: Collaborative business-to-business marketing strategies in a pandemic crisis," *Ind. Mark. Manag.*, vol. 88, no. May, pp. 206–213, Jul. 2020, doi: 10.1016/j.indmarman.2020.05.016.

[121] B. Mandelbrot, "How Long Is the Coast of Britain? Statistical Self-Similarity and Fractional Dimension," *Science (80-.).*, vol. 156, no. 3775, pp. 636–638, May 1967, doi: 10.1126/science.156.3775.636.

[122] A. Pohlmann and V. Kaartemo, "Research trajectories of Service-Dominant Logic: Emergent themes of a unifying paradigm in business and management," *Ind. Mark. Manag.*, vol. 63, pp. 53–68, 2017, doi: 10.1016/j.indmarman.2017.01.001.

[123] J. M. Halley, S. Hartley, A. S. Kallimanis, W. E. Kunin, J. J. Lennon, and S. P. Sgardelis, "Uses and abuses of fractal methodology in ecology," *Ecol. Lett.*, vol. 7, no. 3, pp. 254–271, Feb. 2004, doi: 10.1111/j.1461-0248.2004.00568.x.

[124] I. Scheuring and R. H. Riedi, "Application of multifractals to the analysis of vegetation pattern," *J. Veg. Sci.*, vol. 5, no. 4, pp. 489–496, Aug. 1994, doi: 10.2307/3235975.

[125] M. A. López-Quintela and J. Casado, "Revision of the methodology in enzyme kinetics: A fractal approach," *J. Theor. Biol.*, vol. 139, no. 1, pp. 129–139, Jul. 1989, doi: 10.1016/S0022-5193(89)80062-1.

[126] D. Ristanović and N. T. Milošević, "Fractal analysis: Methodologies for biomedical researchers," *Theor. Biol. Forum*, vol. 105, no. 2, pp. 99–118, 2012.

[127] I. C. Andronache, D. Peptenatu, A.-M. Ciobotaru, A. K. Gruia, and N. M. Gropoşilă, "Using Fractal Analysis in Modeling Trends in the National Economy," *Procedia Environ. Sci.*, vol. 32, pp. 344–351, 2016, doi: 10.1016/j.proenv.2016.03.040.

[128] B. B.Mandelbrot, "The Fractal Geometry of Nature," *W.H. Free. Company, Nov. Iorque*, 1975.

[129] L. Kuhn and R. Woog, "From complexity concepts to creative applications," *World Futur. J. Gen. Evol.*, vol. 63, no. 3–4, pp. 176–193, 2007, doi: 10.1080/02604020601172533.

[130] L. Seuront, *Fractals and Multifractals in Ecology and Aquatic Science*. CRC Press, 2009.

[131] H. F. Jelinek, C. L. Jones, M. D. Warfel, C. Lucas, C. Depardieu, and G. Aurel, "Understanding Fractal Analysis? The Case of Fractal Linguistics," *Complexus*, vol. 3, no. 1–3, pp. 66–73, 2006, doi: 10.1159/000094189.

[132] D. Jarrett and A. Ceric, "Trust is Complicated: looking through a Service Dominant Logic, Complexity Theory Lens," pp. 394–398, 2012.

[133] K. Walley, "Coopetition: An Introduction to the Subject and an Agenda for Research," *Int. Stud. Manag. Organ.*, vol. 37, no. 2, pp. 11–31, 2007, doi: 10.2753/imo0020-8825370201.

[134] J. Crick, "Moderators affecting the relationship between coopetition and company performance," *J. Bus. Ind. Mark.*, vol. 34, no. 2, pp. 518–531, 2019, doi: 10.1108/JBIM-03-2018-0102.

[135] M. Bengtsson and S. Kock, "Coopetition-Quo vadis? Past accomplishments and future challenges," *Ind. Mark. Manag.*, vol. 43, no. 2, pp. 180–188, 2014, [Online]. Available: http://dx.doi.org/10.1016/j.indmarman.2014.02.015.

[136] T. Lindström *et al.*, "Destination networking: Co-opetition in peripheral surroundings," *Ind. Mark. Manag.*, vol. 33, no. 2, pp. 427–448, Jun. 2016, doi: 10.1108/09600030310481997.

[137] D. P. Hannah and K. M. Eisenhardt, "How firms navigate cooperation and competition in nascent ecosystems," *Strateg. Manag. J.*, vol. 39, no. 12, pp. 3163–3192, Dec. 2018, doi: https://doi.org/10.1002/smj.2750.

[138] B. Kogut, "Joint ventures: Theoretical and empirical perspectives," *Strateg. Manag. J.*, vol. 9, no. 4, pp. 319–332, Jul. 1988, doi: 10.1002/smj.4250090403.

[139] A. Lascaux, "Coopetition and trust: What we know, where to go next," *Ind. Mark. Manag.*, vol. 84, no. May, pp. 2–18, 2020, doi: 10.1016/j.indmarman.2019.05.015.

[140] E. Bacon, M. D. Williams, and G. Davies, "Coopetition in innovation ecosystems: A comparative analysis of knowledge transfer configurations," *J. Bus. Res.*, vol. 115, pp. 307–316, Jul. 2020, doi: 10.1016/j.jbusres.2019.11.005.

[141] B. J. R. Park, M. K. Srivastava, and D. R. Gnyawali, "Walking the tight rope of coopetition: Impact of competition and cooperation intensities and balance on firm innovation performance," *Ind. Mark. Manag.*, vol. 43, no. 2, pp. 210–221, 2014, doi: 10.1016/j.indmarman.2013.11.003.

[142] R. B. Bouncken, B. D. Plüschke, R. Pesch, and S. Kraus, "Entrepreneurial orientation in vertical alliances: joint product innovation and learning from allies," *Rev. Manag. Sci.*, vol. 10, no. 2, pp. 381–409, 2016, doi: 10.1007/s11846-014-0150-8.

[143] E. Autio and L. D. W. Thomas, *Innovation Ecosystems: Implications for Innovation Management*. Oxford University Press, 2014.

[144] I. Antai, "A theory of the competing supply chain: Alternatives for development," *Int. Bus. Res.*, vol. 4, no. 1, pp. 74–85, Nov. 2010, doi: 10.5539/ibr.v4n1p74.

[145] A. Akwei, J. Peppard, and P. Hughes, "The Process of Creating Dynamic Capabilities," *Br. J. Manag.*, vol. 44, no. 0, pp. 1–45, 2010, [Online]. Available: https://dspace.lboro.ac.uk/2134/7869.

[146] R. Lusch and S. Vargo, “Service-dominant logic: Continuing the evolution,” *J. Acad. Mark. Sci.*, vol. 36, no. 1, pp. 1–10, 2007, doi: 10.1007/s11747-007-0069-6.

[147] T. J. Pinch and W. E. Bijker, “The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology might Benefit Each Other,” *Soc. Stud. Sci.*, vol. 14, no. 3, pp. 399–441, Aug. 1984, doi: 10.1177/030631284014003004.

[148] T. Dome, “David Ricardo on Public Debt,” *Hist. Polit. Econ.*, vol. 35, no. 3, pp. 570–571, Sep. 2003, doi: 10.1215/00182702-35-3-570.

[149] S. L. Vargo and R. F. Lusch, “The Four Service Marketing Myths: Remnants of a Goods-Based, Manufacturing Model,” *J. Serv. Res.*, vol. 6, no. 4, pp. 324–335, 2004, doi: 10.1177/1094670503262946.

[150] R. F. Lusch and S. L. Vargo, *Service-Dominant Logic*. Cambridge: Cambridge University Press, 2013.

[151] J. Chandler and S. Vargo, “Contextualization and Value-in-Context: How Context Frames Exchange,” *Mark. Theory*, vol. 11, pp. 35–49, Apr. 2011, doi: 10.1177/1470593110393713.

[152] R. Garg, Z. Rahman, and I. Kumar, “Evaluating a model for analyzing methods used for measuring customer experience,” *J. Database Mark. Cust. Strateg. Manag.*, vol. 17, no. 2, pp. 78–90, 2010, doi: 10.1057/dbm.2010.7.

[153] R. Normann and R. Ramirez, “From value chain to value constellation: Designing interactive strategy,” *Harvard Business Review*, vol. 71, no. 4. pp. 65–77, 1993, [Online]. Available: http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=9309166477&site=eds-live.

[154] J. R. McColl-Kennedy, L. Cheung, and L. V. Coote, “Tensions and trade-offs in multi-actor service ecosystems,” *J. Bus. Res.*, vol. 121, pp. 655–666, Dec. 2020, doi: 10.1016/j.jbusres.2020.06.055.

[155] M. Akaka, S. Vargo, and H. Schau, “The context of experience,” *J. Serv. Manag. Vol. 26 No. 2, 2015 pp. 206-223*, vol. 26, no. 2, pp. 206–223, 2015, doi: 10.1108/JOSM-10-2014-0270.

[156] H. A. Simon, “The Science of Design: Creating the Artificial,” *Des. Issues*, vol. 4, no. 1/2, p. 67, 1988, doi: 10.2307/1511391.

[157] W. Scott, *Institutions and Organizations - Ideas, Interests, and Identities*. SAGE Publications, Inc, 2013.

[158] R. F. Lusch and J. R. Brown, “Interdependency, Contracting, and Relational Behavior in Marketing Channels,” *J. Mark.*, vol. 60, no. 4, p. 19, Oct. 1996, doi: 10.2307/1251899.

[159] M. Álvarez Gil, P. Berrone, J. Husillos, and N. Lado, “The Explanatory Power of Trust And Commitment and Stakeholders’ Salience: Their Influence on The Reverse Logistics Programs Performance,” Mar. 2005.

[160] S. Vargo and M. Akaka, “Value Cocreation and Service Systems (Re)Formation: A Service Ecosystems View,” *Serv. Sci.*, vol. 4, no. 3, pp. 207–217, 2012, doi: 10.1287/serv.1120.0019.

[161] A. Rindfleisch and C. Moorman, “Interfirm Cooperation and Customer Orientation,” *J. Mark. Res.*, vol. 40, no. 4, pp. 421–436, Nov. 2003, doi: 10.1509/jmkr.40.4.421.19388.

[162] R. Lusch and S. Vargo, “Service Ecosystems,” in *Service-Dominant Logic*, Cambridge: Cambridge University Press, 2014, pp. 158–176.

[163] S. Vargo and R. Lusch, “The SAGE Handbook of Service-Dominant Logic,” *SAGE Handb. Serv. Log.*, no. January 2018, 2019, doi: 10.4135/9781526470355.

[164] T. Lawrence and R. Suddaby, *Institutions and Institutional Work*. The SAGE Handbook of Organization Studies: Chapter 6, 2006.

[165] J. B. Heide and G. John, “Do Norms Matter in Marketing Relationships?,” *J. Mark.*, vol.

56, no. 2, pp. 32–44, Apr. 1992, doi: 10.1177/002224299205600203.

[166] M. Callon, “An Essay on Framing and Overflowing: Economic Externalities Revisited by Sociology,” *Sociol. Rev.*, vol. 46, no. 1_suppl, pp. 244–269, May 1998, doi: 10.1111/j.1467-954X.1998.tb03477.x.

[167] R. S. Achrol, “Evolution of the Marketing Organization: New Forms for Turbulent Environments,” *J. Mark.*, vol. 55, no. 4, pp. 77–93, Oct. 1991, doi: 10.1177/002224299105500406.

[168] P. Maglio, C. Kieliszewski, J. Spohrer, L. Kelly, L. Patrício, and Y. Sawatani, *Handbook of Service Science, Volume II*, vol. II. 2019.

[169] L. Camarinha-Matos and H. Afsarmanesh, “Collaborative networks: A new scientific discipline,” *Virtual Organ. Syst. Pract.*, pp. 73–80, 2005, doi: 10.1007/0-387-23757-7_6.

[170] J. Holmström and J. Partanen, “Digital manufacturing-driven transformations of service supply chains for complex products,” *Supply Chain Manag.*, vol. 19, no. 4, pp. 421–430, 2014, doi: 10.1108/SCM-10-2013-0387.

[171] M. Tsujimoto, Y. Kajikawa, J. Tomita, and Y. Matsumoto, “A review of the ecosystem concept — Towards coherent ecosystem design,” *Technol. Forecast. Soc. Change*, vol. 136, no. June, pp. 49–58, 2018, doi: 10.1016/j.techfore.2017.06.032.

[172] R. Amit and C. Zott, “Value creation in E-business,” *Strateg. Manag. J.*, vol. 22, no. 6–7, pp. 493–520, Jun. 2001, doi: 10.1002/smj.187.

[173] M. Porter, “The Competitive Advantage of Nations,” *Harvard Bus. Rev. (March–April 1990)*, 1990, [Online]. Available: https://hbr.org/1990/03/the-competitive-advantage-of-nations.

[174] J. Barney, “Firm Reources ad Sustained Competitive Advantege,” *Journal of Management*, vol. 17, no. 1. pp. 99–120, 1991.

[175] J. H. Dyer and H. Singh, “The Relational View: Cooperative Strategy and Sources of Interorganizational Competitive Advantage,” *Acad. Manag. Rev.*, vol. 23, no. 4, pp. 660–679, Oct. 1998, doi: 10.5465/amr.1998.1255632.

[176] J. C. Jarillo, “On Strategic Networks,” *Strateg. Manag. J.*, vol. 9, no. 1, pp. 31–41, Sep. 1988, [Online]. Available: http://www.jstor.org/stable/2486000.

[177] L. Camarinha-matos, R. Fornasiero, and Afsarmanesh Hamideh, “Collaborative Networks as a Core Enabler of Industry 4.0,” vol. 506, no. September, 2017, doi: 10.1007/978-3-319-65151-4.

[178] V. Spanikova, L. Birkman, and C. Besseling, “Business Networks Final report,” no. February, 2014.

[179] J. Mariotti, “The value network,” vol. Executive, 2002.

[180] A. F. Payne, K. Storbacka, and P. Frow, “Managing the co-creation of value,” *J. Acad. Mark. Sci.*, vol. 36, no. 1, pp. 83–96, 2008, doi: 10.1007/s11747-007-0070-0.

[181] M. Kärkkäinen, T. Ala-Risku, and K. Främling, “The product centric approach: A solution to supply network information management problems?,” *Comput. Ind.*, vol. 52, no. 2, pp. 147–159, 2003, doi: 10.1016/S0166-3615(03)00086-1.

[182] M. Peltoniemi, “Cluster, Value Network and Business Ecosystem: Knowledge and Innovation Approach,” *Conf. Pap.*, no. September 2004, pp. 9–10, 2004.

[183] S. L. Vargo and R. F. Lusch, “Advancing Service Science with Service-Dominant Logic,” no. 2008, 2010, doi: 10.1007/978-1-4419-1628-0.

[184] R. Lusch and S. Vargo, *The Service-Dominant Logic of Marketing: Dialog, Debate, and Directions*. 2006.

[185] R. F. Lusch, S. L. Vargo, and M. Tanniru, “Service, value networks and learning,” *J. Acad. Mark. Sci.*, vol. 38, no. 1, pp. 19–31, Feb. 2010, doi: 10.1007/s11747-008-0131-z.

[186] D. Flint and J. Mentzer, *Striving for integrated value chain management given a service-dominant logic for marketing*. 2006.

[187] S. Michel, S. L. Vargo, and R. F. Lusch, "Reconfiguration of the conceptual landscape: A tribute to the service logic of Richard Normann," *J. Acad. Mark. Sci.*, vol. 36, no. 1, pp. 152–155, 2008, doi: 10.1007/s11747-007-0067-8.

[188] R. Lusch and S. Nambisan, "Service Innovation: A Service-Dominant Logic Perspective," *MIS Q.*, vol. 39, no. 1, pp. 155–175, Jan. 2015, doi: 10.25300/MISQ/2015/39.1.07.

[189] W. B. Arthur, *THE NATURE of TECHNOLOGY*. Penguin Books Ltd, Registered Offices: 80 Strand, London WC2R 0RL, England, 2009.

[190] J. Mokyr, "Accounting for the Industrial Revolution," in *The Cambridge Economic History of Modern Britain*, Cambridge University Press, 2004, pp. 1–27.

[191] A. Sklyar, C. Kowalkowski, D. Sörhammar, and B. Tronvoll, "Resource integration through digitalisation: a service ecosystem perspective," *J. Mark. Manag.*, vol. 35, no. 11–12, pp. 974–991, 2019, doi: 10.1080/0267257X.2019.1600572.

[192] S. D. Hunt, "A General Theory of Competition: Resources, Competences, Productivity, Economic Growth," *Thousand Oaks - Sage Publ.*, vol. 16:4, no. 2000, pp. 385–393, 2000.

[193] K. A. Munir and N. Phillips, "The Birth of the 'Kodak Moment': Institutional Entrepreneurship and the Adoption of New Technologies," *Organ. Stud.*, vol. 26, no. 11, pp. 1665–1687, Nov. 2005, doi: 10.1177/0170840605056395.

[194] M. A. Akaka, S. L. Vargo, and R. F. Lusch, "The Complexity of Context: A Service Ecosystems Approach for International Marketing," *J. Int. Mark.*, vol. 21, no. 4, pp. 1–20, Dec. 2013, doi: 10.1509/jim.13.0032.

[195] H. Chesbrough and R. Rosenbloom, "The role of the business model in capturing value from innovation: evidence from Xerox Corporation's technology spin-off companies," *Ind. Corp. Chang.*, vol. 11, no. 3, pp. 529–555, Jun. 2002, doi: 10.1093/icc/11.3.529.

[196] S. Vargo, H. Wieland, and M. Akaka, "Innovation through institutionalization: A service ecosystems perspective," *Ind. Mark. Manag.*, vol. 44, no. 2013, pp. 63–72, 2015, doi: 10.1016/j.indmarman.2014.10.008.

[197] T. B. Lawrence, R. Suddaby, and B. Leca, "Introduction: theorizing and studying institutional work," in *Institutional Work*, Cambridge University Press, 2009, pp. 1–28.

[198] L. Sajtos, M. Kleinaltenkamp, and J. Harrison, "Boundary objects for institutional work across service ecosystems," *J. Serv. Manag.*, vol. 29, no. 4, pp. 615–640, Aug. 2018, doi: 10.1108/JOSM-01-2017-0011.

[199] R. Greenwood and R. E. Meyer, "Influencing Ideas: A Celebration of DiMaggio and Powell (1983)," *J. Manag. Inq.*, vol. 17, no. 4, pp. 258–264, Dec. 2008, doi: 10.1177/1056492608326693.

[200] G. Pedeliento, F. Mangiò, G. Murtas, and D. Andreini, "Market system dynamics (MSD): A process-oriented review of the literature," *AMS Rev.*, vol. 13, no. 3–4, pp. 173–195, 2023, doi: 10.1007/s13162-023-00260-8.

[201] S. L. Vargo, "Conceptual reconciliation for clarity and impact," *AMS Rev.*, vol. 13, no. 3–4, pp. 169–172, 2023, doi: 10.1007/s13162-023-00271-5.

[202] T. Ruokolainen and L. Kutvonen, "Managing interoperability knowledge in open service ecosystems," *Proc. - IEEE Int. Enterp. Distrib. Object Comput. Work. EDOC*, pp. 203–211, 2009, doi: 10.1109/EDOCW.2009.5331993.

[203] T. Ruokolainen, S. Ruohomaa, and L. Kutvonen, "Solving service ecosystem governance," *Proc. - IEEE Int. Enterp. Distrib. Object Comput. Work. EDOC*, pp. 18–25, 2011, doi: 10.1109/EDOCW.2011.43.

[204] D. Ballantyne and R. J. Varey, "Creating value-in-use through marketing interaction: the exchange logic of relating, communicating and knowing," *Mark. Theory*, vol. 6, no. 3, pp. 335–348, Sep. 2006, doi: 10.1177/1470593106066795.

[205] R. Friedland, “The Institutional Logics Perspective: A new approach to Culture, Structure, and Process by,” *M@n@gement*, vol. 15, no. 5, pp. 582–595, 2012.

[206] K. Koskela-Huotari and S. L. Vargo, “Institutions as resource context,” *J. Serv. Theory Pract.*, vol. 26, no. 2, pp. 163–178, Jan. 2016, doi: 10.1108/JSTP-09-2014-0190.

[207] I. Ng, P. P. Maglio, J. Spohrer, and S. Wakenshaw, “The Study of Service: From Systems to Ecosystems to Ecology,” in *The SAGE Handbook of Service-Dominant Logic*, SAGE Publications Ltd, Ed. 1 Oliver’s Yard, 55 City Road London EC1Y 1SP: SAGE Publications Ltd, 2018, pp. 230–240.

[208] R. B. Bouncken, J. Gast, S. Kraus, and M. Bogers, “Coopetition: a systematic review, synthesis, and future research directions,” *Rev. Manag. Sci.*, vol. 9, no. 3, pp. 577–601, Jul. 2015, doi: 10.1007/s11846-015-0168-6.

[209] S. Barile, R. Lusch, J. Reynoso, S. Marialuisa, and J. Spohrer, “Systems, Networks, and Ecosystems in Service Research,” *J. Serv. Manag.*, vol. 34, no. 1, pp. 1–5, 2016, doi: https://doi.org/10.1108/JOSM-09-2015-0268.

[210] W. Alderson, “Marketing Behavior and Executive Action: A Functionalist Approach to Marketing Theory,” *Am. Econ. Rev. Vol. 47, No. 6*, 1957, [Online]. Available: https://www.jstor.org/stable/1810080.

[211] S. P. S. Adi, S. Ghinahana, B. R. Yudianto, and A. J. I. Wibowo, “Institutions, technology and resource integration in the value co-creation process: a study of service-dominant logic in higher education,” *J. Appl. Res. High. Educ.*, 2023, doi: 10.1108/JARHE-03-2023-0104.

[212] R. Beunen and J. J. Patterson, “Analysing institutional change in environmental governance: exploring the concept of ‘institutional work,’” *J. Environ. Plan. Manag.*, vol. 62, no. 1, pp. 12–29, 2019, doi: 10.1080/09640568.2016.1257423.

[213] S. L. Vargo, H. Wieland, and M. O’Brien, “Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline,” *J. Bus. Res.*, vol. 164, p. 113965, Sep. 2023, doi: 10.1016/j.jbusres.2023.113965.

[214] S. B. Friend, A. Malshe, and G. J. Fisher, “What drives customer Re-engagement? The foundational role of the sales-service interplay in episodic value co-creation,” *Ind. Mark. Manag.*, vol. 84, no. July, pp. 271–286, 2020, doi: 10.1016/j.indmarman.2019.07.012.

[215] H. Wieland, N. Hartmann, and S. Vargo, “Business models as service strategy,” *J. Acad. Mark. Sci.*, vol. 45, no. 6, pp. 925–943, Nov. 2017, doi: 10.1007/s11747-017-0531-z.

[216] S. L. Vargo, M. A. Akaka, and H. Wieland, “Rethinking the process of diffusion in innovation: A service-ecosystems and institutional perspective,” *J. Bus. Res.*, vol. 116, no. December 2018, pp. 526–534, 2020, doi: 10.1016/j.jbusres.2020.01.038.

[217] L. Doganova and M. Eyquem-Renault, “What do business models do?,” *Res. Policy*, vol. 38, no. 10, pp. 1559–1570, Dec. 2009, doi: 10.1016/j.respol.2009.08.002.

[218] E. G. Guba, *The paradigm dialog*. 1990.

[219] J. Creswell, *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 2014.

[220] R. B. Johnson and A. J. Onwuegbuzie, “Mixed Methods Research: A Research Paradigm Whose Time Has Come,” *Educ. Res.*, vol. 33, no. 7, pp. 14–26, 2004, doi: 10.3102/0013189X033007014.

[221] N. Denzin and L. Yvonna, *Handbook of Qualitative Research*. 1994.

[222] A. Tashakkori and C. Teddlie, *Sage handbook of mixed methods in social and behavioral research (2nd ed.)*. 2010.

[223] D. Morgan, “Paradigms lost and pragmatism regained: Methodological implications of combining qualitative and quantitative methods,” *J. Mix. Methods Res.*, vol. 1, no. 1, pp. 48–76, 2007, doi: 10.1177/2345678906292462.

[224] D. M. Mertens, *Research and evaluation in education and psychology: Integrating*

diversity with quantitative, qualitative, and mixed methods, (4th ed.). 2014.

[225] T. Meynhardt, D. Chandler, and P. Strathoff, "Systemic principles of value co-creation: Synergetics of value and service ecosystems," *J. Bus. Res.*, vol. 69, no. 8, pp. 2981–2989, 2016, doi: 10.1016/j.jbusres.2016.02.031.

[226] P. Ghauri, G. Kjell, and K. Ivar, *Research Methods in Business Studies. A Practical Guide (4th edition)*. 2010.

[227] K. Peffers, T. Tuunanen, M. A. Rothenberger, and S. Chatterjee, "A Design Science Research Methodology for Information Systems Research," *J. Manag. Inf. Syst.*, vol. 24, no. 3, pp. 45–77, Dec. 2007, doi: 10.2753/MIS0742-1222240302.

[228] V. Patkar, "Research Methodology: Logic, Methods and Cases," *Vikalpa J. Decis. Makers*, vol. 43, no. 3, pp. 175–177, 2018, doi: 10.1177/0256090918796953.

[229] C. Eden and C. Huxham, "Action Research for Management Research," *Br. J. Manag.*, vol. 7, no. 1, pp. 75–86, Mar. 1996, doi: 10.1111/j.1467-8551.1996.tb00107.x.

[230] J. vom Brocke, A. Hevner, and A. Maedche, "Introduction to Design Science Research," no. September, 2020, pp. 1–13.

[231] R. Baskerville, A. Baiyere, S. Gregor, A. Hevner, and M. Rossi, "Design science research contributions: Finding a balance between artifact and theory," *J. Assoc. Inf. Syst.*, vol. 19, no. 5, p. 3, 2018.

[232] J. Venable, J. Pries-Heje, and R. Baskerville, "FEDS: a Framework for Evaluation in Design Science Research," *Eur. J. Inf. Syst.*, vol. 25, no. 1, pp. 77–89, Jan. 2014, doi: 10.1057/ejis.2014.36.

[233] Q. Sun, "Towards a New Agenda for Service Design Research," *Des. J.*, vol. 23, no. 1, pp. 49–70, 2020, doi: 10.1080/14606925.2019.1694808.

[234] C. C. Ragin and L. M. Amoroso, *Constructing Social Research: The Unity and Diversity of Method*. SAGE Publications, 2018.

[235] E. Jaakkola, "Designing conceptual articles: four approaches," *AMS Rev.*, vol. 10, no. 1–2, pp. 18–26, Jun. 2020, doi: 10.1007/s13162-020-00161-0.

[236] A. Hevner, S. March, J. Park, and S. Ram, "Design Science in Information Systems Research," *MIS Q.*, vol. 28, no. 1, p. 75, 2004, doi: 10.2307/25148625.

[237] M. Schermann, T. Böhmann, and H. Krcmar, "Explicating Design Theories with Conceptual Models: Towards a Theoretical Role of Reference Models," in *Wissenschaftstheorie und gestaltungsorientierte Wirtschaftsinformatik*, J. Becker, H. Krcmar, and B. Niehaves, Eds. Heidelberg: Physica-Verlag HD, 2009, pp. 175–194.

[238] S. T. March and G. F. Smith, "Design and natural science research on information technology," *Decis. Support Syst.*, vol. 15, no. 4, pp. 251–266, Dec. 1995, doi: 10.1016/0167-9236(94)00041-2.

[239] L. Patrício, N. F. de Pinho, J. G. Teixeira, and R. P. Fisk, "Service Design for Value Networks: Enabling Value Cocreation Interactions in Healthcare," *Serv. Sci.*, vol. 10, no. 1, pp. 76–97, 2018, doi: 10.1287/serv.2017.0201.

[240] A. Hevner, "A Three Cycle View of Design Science Research," *Scand. J. Inf. Syst.*, vol. 19, Jan. 2007.

[241] M. Mustak and L. Plé, "A critical analysis of service ecosystems research: rethinking its premises to move forward," *J. Serv. Mark.*, vol. 34, no. 3, pp. 399–413, 2020, doi: 10.1108/JSM-02-2019-0084.

[242] C. Legner, T. Pentek, and B. Otto, "Accumulating Design Knowledge with Reference Models: Insights from 12 Years' Research into Data Management," *J. Assoc. Inf. Syst.*, vol. 21, no. 3, pp. 735–770, May 2020, doi: 10.17705/1jais.00618.

[243] A. Hevner and S. Chatterjee, "Design Science Research in Information Systems BT - Design Research in Information Systems: Theory and Practice," A. Hevner and S. Chatterjee, Eds. Boston, MA: Springer US, 2010, pp. 9–22.

[244] K. Razmdoost, L. Alinaghian, J. D. Chandler, and C. Mele, “Service ecosystem boundary and boundary work,” *J. Bus. Res.*, vol. 156, no. November 2022, p. 113489, 2023, doi: 10.1016/j.jbusres.2022.113489.

[245] M. Fernández-Martínez and M. A. Sánchez-Granero, “Fractal dimension for fractal structures,” *Topol. Appl.*, vol. 163, no. 1, pp. 93–111, 2014, doi: 10.1016/j.topol.2013.10.010.

[246] A. Silva, A. Dionisio, and I. Almeida, “Enabling Cyber-Physical Systems for Industry 4.0 operations: A Service Science Perspective,” *Int. J. Innov. Technol. Explor. Eng.*, vol. 9, no. 8, pp. 838–846, Jun. 2020, doi: 10.35940/ijitee.H6804.069820.

[247] T. J. Pinch and W. E. Bijker, “The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology might Benefit Each Other,” *Soc. Stud. Sci.*, vol. 14, no. 3, pp. 399–441, Aug. 1984, doi: 10.1177/030631284014003004.

[248] B. Nguyen and L. Simkin, “The Internet of Things (IoT) and marketing : the state of play , future trends and the implications for marketing,” *J. Mark. Manag.*, vol. 33, no. 1–2, pp. 1–6, 2017, doi: 10.1080/0267257X.2016.1257542.

[249] S. L. Vargo and R. F. Lusch, “Service-dominant logic: continuing the evolution,” *J. Acad. Mark. Sci.*, vol. 36, no. 1, pp. 1–10, Mar. 2008, doi: 10.1007/s11747-007-0069-6.

[250] L. A. Bettencourt, R. F. Lusch, and S. L. Vargo, “A Service Lens on Value Creation: Marketing’s Role in Achieving Strategic Advantage,” *Calif. Manage. Rev.*, vol. 57, no. 1, pp. 44–66, Nov. 2014, doi: 10.1525/cmr.2014.57.1.44.

[251] C. Zott, R. Amit, and L. Massa, “The Business Model: Recent Developments and Future Research,” *J. Manage.*, vol. 37, no. 4, pp. 1019–1042, Jul. 2011, doi: 10.1177/0149206311406265.

[252] U. Bodkhe *et al.*, “Blockchain for Industry 4.0: A comprehensive review,” *IEEE Access*, vol. 8, pp. 79764–79800, 2020, doi: 10.1109/ACCESS.2020.2988579.

[253] S. Hoppe, “OPC Unified Architecture-Interoperability for Industrie 4.0 and the Internet of Things,” 2023. [Online]. Available: https://opcfoundation.org/wp-content/uploads/2023/05/OPC-UA-Interoperability-For-Industrie4-and-IoT-EN.pdf.

[254] R. Breillat, “Industrial Artificial Intelligence, Internet of Things Smart Devices, and Big Data-driven Decision-Making in Digital-Twin-based Cyber-Physical Production Systems,” *Econ. Manag. Financ. Mark.*, vol. 15, no. 1, p. 15120204, 2020, doi: DOI: 10.22381/EMFM15120204.

[255] J. Spohrer, P. P. Maglio, J. Bailey, and D. Gruhl, “Steps toward a science of service systems,” *Computer (Long. Beach. Calif).*, vol. 40, no. 1, pp. 71–77, Jan. 2007, doi: 10.1109/MC.2007.33.

[256] J. Spohrer and S. K. Kwan, “Service Science, Management, Engineering, and Design (SSMED),” *Int. J. Inf. Syst. Serv. Sect.*, vol. 1, no. 3, pp. 1–31, Jul. 2009, doi: 10.4018/jisss.2009070101.

[257] R. Y. Zhong, X. Xu, E. Klotz, and S. T. Newman, “Intelligent Manufacturing in the Context of Industry 4.0: A Review,” *Engineering*, vol. 3, no. 5, pp. 616–630, 2017, doi: 10.1016/J.ENG.2017.05.015.

[258] D. Pakkala, J. Koivusaari, P. Pääkkönen, and J. Spohrer, “An Experimental Case Study on Edge Computing Based Cyber-Physical Digital Service Provisioning with Mobile Robotics,” *Proc. 53rd Hawaii Int. Conf. Syst. Sci.*, pp. 1165–1174, 2020, doi: 10.24251/hicss.2020.145.

[259] O. Anya, B. Moore, C. Kieliszewski, P. Maglio, and L. Anderson, “Understanding the Practice of Discovery in Enterprise Big Data Science: An Agent-based Approach,” *Procedia Manuf.*, vol. 3, no. Ahfe, pp. 882–889, 2015, doi: 10.1016/j.promfg.2015.07.345.

[260] M. A. Akaka and S. L. Vargo, “Technology as an operant resource in service (eco)systems,” *Inf. Syst. E-bus. Manag.*, vol. 12, no. 3, pp. 367–384, Aug. 2014, doi: 10.1007/s10257-013-0220-5.

[261] J. Mokyr, *The Gifts of Athena*. Princeton University Press, 2002.

[262] J. Mokyr, "Knowledge, Technology, and Economic Growth during the Industrial Revolution," in *Productivity, Technology and Economic Growth*, Boston, MA: Springer US, 2000, pp. 253–292.

[263] A. Carù and B. Cova, "Co-creating the collective service experience," *J. Serv. Manag.*, vol. 26, no. 2, pp. 276–294, Apr. 2015, doi: 10.1108/JOSM-07-2014-0170.

[264] M. Barrett, E. Davidson, J. Prabhu, and S. L. Vargo, "Service Innovation in the Digital Age: Key Contributions and Future Directions," *MIS Q.*, vol. 39, no. 1, pp. 135–154, Jan. 2015, doi: 10.25300/MISQ/2015/39:1.03.

[265] M. Kleinaltenkamp, M. J. Kleinaltenkamp, and I. O. Karpen, "Resource entanglement and indeterminacy: Advancing the service-dominant logic through the philosophy of Karen Barad," *Mark. Theory*, Oct. 2023, doi: 10.1177/14705931231207327.

[266] E. Gummesson, R. F. Lusch, and S. L. Vargo, "Transitioning from service management to service-dominant logic: Observations and recommendations," *Int. J. Qual. Serv. Sci.*, vol. 2, no. 1, pp. 8–22, 2010, doi: 10.1108/17566691011026577.

[267] R. Normann, *Reframing Business: When the Map Changes the Landscape*. 2001.

[268] I. Ng and S. Wakenshaw, "The Internet-of-Things: Review and research directions," *Int. J. Res. Mark.*, vol. 34, no. 1, pp. 3–21, Mar. 2017, doi: 10.1016/j.ijresmar.2016.11.003.

[269] A. Yazdinejad, M. Kazemi, R. M. Parizi, A. Dehghantanha, and H. Karimipour, "An ensemble deep learning model for cyber threat hunting in industrial internet of things," *Digit. Commun. Networks*, vol. 9, no. 1, pp. 101–110, Feb. 2023, doi: 10.1016/j.dcan.2022.09.008.

[270] P. Mosch, P. Majocco, and R. Obermaier, "Contrasting value creation strategies of industrial-IoT-platforms – a multiple case study," *Int. J. Prod. Econ.*, vol. 263, p. 108937, 2023, doi: https://doi.org/10.1016/j.ijpe.2023.108937.

[271] G. Latif, G. Ben Brahim, S. E. Abdelhamid, R. Alghazo, G. Alhabib, and K. Alnujaidi, "Learning at Your Fingertips: An Innovative IoT-Based AI-Powered Braille Learning System," *Appl. Syst. Innov.*, vol. 6, no. 5, p. 91, Oct. 2023, doi: 10.3390/asi6050091.

[272] D. G. S. Pivoto, L. F. F. de Almeida, R. da Rosa Righi, J. J. P. C. Rodrigues, A. B. Lugli, and A. M. Alberti, "Cyber-physical systems architectures for industrial internet of things applications in Industry 4.0: A literature review," *J. Manuf. Syst.*, vol. 58, no. August 2020, pp. 176–192, 2021, doi: 10.1016/j.jmsy.2020.11.017.

[273] H. M. O'Brien, "the Internet of Things," *J. Internet Law*, vol. 19, no. 12, pp. 1–20, 2016, [Online]. Available: http://biblio.uptc.edu.co:2048/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=116080288&lang=es&site=eds-live.

[274] G. Leal, W. Guédria, and H. Panetto, "An ontology for interoperability assessment: A systemic approach," *J. Ind. Inf. Integr.*, no. May, 2019, doi: 10.1016/j.jii.2019.07.001.

[275] J. Cardoso, H. Fromm, S. Nickel, G. Satzger, and R. Studer, *Fundamentals of Service Systems*. Cham: Springer International Publishing, 2015.

[276] M. Serror, S. Hack, M. Henze, M. Schuba, and K. Wehrle, "Challenges and Opportunities in Securing the Industrial Internet of Things," *IEEE Trans. Ind. Informatics*, vol. 17, no. 5, pp. 2985–2996, 2021, doi: 10.1109/TII.2020.3023507.

[277] K. Storbacka, R. Brodie, T. Böhmann, P. Maglio, and S. Nenonen, "Actor engagement as a microfoundation for value co-creation," *J. Bus. Res.*, vol. 69, no. 8, pp. 3008–3017, Aug. 2016, doi: 10.1016/j.jbusres.2016.02.034.

[278] H. Demirkan and J. C. Spohrer, "Commentary—Cultivating T-Shaped Professionals in the Era of Digital Transformation," *Serv. Sci.*, vol. 10, no. 1, pp. 98–109, Mar. 2018, doi: 10.1287/serv.2017.0204.

[279] V. Y. Khaustova, A. V. Doronin, and M. S. Doronina, "Cognitive Resources of New Economy," *Probl. Econ.*, vol. 3, no. 49, pp. 124–131, 2021, doi: 10.32983/2222-0712-

2021-3-124-131.

[280] P. Maglio, S. Vargo, N. Caswell, and J. Spohrer, “The service system is the basic abstraction of service science,” *Inf. Syst. E-bus. Manag.*, vol. 7, no. 4 SPEC. ISS., pp. 395–406, 2009, doi: 10.1007/s10257-008-0105-1.

[281] A. Silva and I. Almeida, “Towards INDUSTRY 4 . 0 | a case STUDY in ornamental stone sector,” *Resour. Policy*, vol. 67, no. March, p. 101672, 2020, doi: 10.1016/j.resourpol.2020.101672.

[282] F. G. B. Blanco and H. Chen, “The Implementation of Building Information Modelling in the United Kingdom by the Transport Industry,” *Procedia - Soc. Behav. Sci.*, vol. 138, no. 0, pp. 510–520, 2014, doi: 10.1016/j.sbspro.2014.07.232.

[283] S. Suhardi, R. Doss, and P. Yustianto, “Service Engineering Based on Service Oriented Architecture Methodology,” *Telkomnika*, vol. 13, no. 4, p. 1466, 2015, doi: 10.12928/telkomnika.v13i4.2388.

[284] G. Krishnan, C. Kim, and S. Kota, “Building block method: A bottom-up modular synthesis methodology for distributed compliant mechanisms,” *Mech. Sci.*, vol. 3, no. 1, pp. 15–23, 2012, doi: 10.5194/ms-3-15-2012.

[285] B. Backman, “Building Block Approach,” B. F. B. T.-C. S. Backman Design, Safety and Innovation, Ed. Oxford: Elsevier, 2005, pp. 99–110.

[286] R. Light and J. Moody, “Dynamic building blocks for science: Comment on Kronegger, Ferligoj, and Doreian,” *Qual. Quant.*, vol. 45, no. 5, pp. 1017–1022, 2011, doi: 10.1007/s11135-011-9485-2.

[287] V. Vaishnavi and W. Kuechler, “Design Science Research in Information Systems,” *http://www.desrist.org/design-research-in-information-systems/.*, pp. 1–62, 2021, [Online]. Available: http://www.desrist.org/design-research-in-information-systems/.

[288] P. Bicen, S. Hunt, and S. Madhavaram, “Coopetitive innovation alliance performance: Alliance competence, alliance’s market orientation, and relational governance,” *J. Bus. Res.*, vol. 123, no. October 2020, pp. 23–31, 2021, doi: 10.1016/j.jbusres.2020.09.040.

[289] C. Breidbach and P. Maglio, “Technology-enabled value co-creation: An empirical analysis of actors, resources, and practices,” *Ind. Mark. Manag.*, vol. 56, pp. 73–85, 2016, doi: 10.1016/j.indmarman.2016.03.011.

[290] J. Pries-Heje, R. Baskerville, and J. Venable, “Strategies for design science research evaluation,” *16th Eur. Conf. Inf. Syst. ECIS 2008*, 2008.

[291] D. P. Lacerda, A. Dresch, A. Proença, and J. A. V. A. Júnior, “Design Science Research: A research method to production engineering,” *Gest. e Prod.*, vol. 20, no. 4, pp. 741–761, 2013, doi: 10.1590/S0104-530X2013005000014.

[292] P. P. Maglio and J. Spohrer, “A service science perspective on business model innovation,” *Ind. Mark. Manag.*, vol. 42, no. 5, pp. 665–670, Jul. 2013, doi: 10.1016/j.indmarman.2013.05.007.

[293] N. Ameen, A. Tarhini, A. Reppel, and A. Anand, “Customer experiences in the age of artificial intelligence,” *Comput. Human Behav.*, vol. 114, no. June 2020, p. 106548, 2021, doi: 10.1016/j.chb.2020.106548.

[294] Y. Yin, K. E. Stecke, and D. Li, “The evolution of production systems from Industry 2.0 through Industry 4.0,” *Int. J. Prod. Res.*, vol. 56, no. 1–2, pp. 848–861, 2017, doi: 10.1080/00207543.2017.1403664.

[295] A. Jabbour, C. Jabbour, M. Filho, and D. Roubaud, “Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations,” *Ann. Oper. Res.*, vol. 270, no. 1–2, pp. 273–286, 2018, doi: 10.1007/s10479-018-2772-8.

[296] R. Kumar, A. Gunasekaran, S. Gupta, and S. Kamboj, “Personalized digital marketing recommender engine,” *J. Retail. Consum. Serv.*, no. September 2018, p. 101799, 2019, doi: 10.1016/j.jretconser.2019.03.026.

[297] P. P. Maglio and J. Spohrer, “Fundamentals of service science,” *J. Acad. Mark. Sci.*, vol.

36, no. 1, pp. 18–20, Mar. 2008, doi: 10.1007/s11747-007-0058-9.

[298] A. Silva and M. M. Gil, “Industrial Processes Optimization in Digital Marketplace Context : A Case Study in Ornamental Stone Sector,” *Results Eng.*, 2020, doi: https://doi.org/10.1016/j.rineng.2020.100152.

[299] G. Lampropoulos, K. Siakas, and T. Anastasiadis, “Internet of Things in The Context of Industry 4.0: An Overview,” *Int. J. Entrep. Knowl.*, vol. 7, no. 1, pp. 4–19, 2019, doi: 10.2478/IJEK-2019-0001.

[300] H. Hirsch-Kreinsen, “Digitization of industrial work: development paths and prospects,” *J. Labour Mark. Res.*, vol. 49, no. 1, pp. 1–14, 2016, doi: 10.1007/s12651-016-0200-6.

[301] A. Aldoseri, K. N. Al-Khalifa, and A. M. Hamouda, “Methodological Approach to Assessing the Current State of Organizations for AI-Based Digital Transformation,” *Appl. Syst. Innov.*, vol. 7, no. 1, p. 14, Feb. 2024, doi: 10.3390/asi7010014.

[302] M. Urbaniak, D. Zimon, and P. Madzik, “Expectations of manufacturing companies towards suppliers in terms of implementing improvement activities,” *Cent. Eur. Manag. J.*, Feb. 2024, doi: 10.1108/CEMJ-07-2023-0286.

[303] D. Slavic, U. Marjanovic, N. Medic, N. Simeunovic, and S. Rakic, “The Evaluation of Industry 5.0 Concepts: Social Network Analysis Approach,” *Appl. Sci.*, vol. 14, no. 3, p. 1291, Feb. 2024, doi: 10.3390/app14031291.

[304] K. O. M. Salih, T. A. Rashid, D. Radovanovic, and N. Bacanin, “A Comprehensive Survey on the Internet of Things with the Industrial Marketplace,” *Sensors*, vol. 22, no. 3, p. 730, Jan. 2022, doi: 10.3390/s22030730.

[305] H. Manurung, G. Yudoko, and L. Okdinawati, “A conceptual framework of supply chain resilience towards sustainability through a service-dominant logic perspective,” *Heliyon*, vol. 9, no. 3, p. e13901, Mar. 2023, doi: 10.1016/j.heliyon.2023.e13901.

[306] F. Khanboubi, A. Boulmakoul, and M. Tabaa, “Impact of digital trends using IoT on banking processes,” *Procedia Comput. Sci.*, vol. 151, pp. 77–84, 2019, doi: 10.1016/j.procs.2019.04.014.

[307] A. V. Barenji, Z. Li, and W. M. Wang, “Blockchain Cloud Manufacturing: Shop Floor and Machine Level,” in *Smart SysTech 2018; European Conference on Smart Objects, Systems and Technologies*, 2018, pp. 1–6.

[308] A. Yazdinejad, B. Zolfaghari, A. Dehghantanha, H. Karimipour, G. Srivastava, and R. Parizi, “Accurate threat hunting in industrial internet of things edge devices,” *Digital Communications and Networks*, vol. 9, no. 5. pp. 1123–1130, 2023, doi: 10.1016/j.dcan.2022.09.010.

[309] H. Boyes, B. Hallaq, J. Cunningham, and T. Watson, “The industrial internet of things (IIoT): An analysis framework,” *Comput. Ind.*, vol. 101, no. December 2017, pp. 1–12, 2018, doi: 10.1016/j.compind.2018.04.015.

[310] M. Aliyari and Y. Z. Ayele, “Application of Artificial Neural Networks for Power Load Prediction in Critical Infrastructure: A Comparative Case Study,” *Appl. Syst. Innov.*, vol. 6, no. 6, p. 115, Nov. 2023, doi: 10.3390/asi6060115.

[311] L. Da, E. L. Xu, and L. Li, “Industry 4 . 0 : state of the art and future trends,” *Int. J. Prod. Res.*, vol. 56, no. 8, pp. 2941–2962, 2018.

[312] A. Silva, C. Rabadão, and C. Capela, “Towards Industry 4.0 | A case study of BIM deployment in ornamental stones sector,” *Int. J. Innov. Technol. Explor. Eng.*, vol. 67, p. 24535, 2020.

[313] A. Silva, M. M. Gil, and E. Duarte, “Service Innovation | A Service Blueprinting for Industry 4 . 0,” in *International Journal of Sciences: Basic and Applied Research (IJSBAR) ISSN 2307-4531 Vol 52 No 2 (2020)*, ISSN 2307-., vol. ISSN 2307-, 2020, pp. 33–49.

[314] P. Url, W. Vorraber, and J. Gasser, “Practical insights on augmented reality support for shop-floor tasks,” *Procedia Manuf.*, vol. 39, no. 2019, pp. 4–12, 2019, doi:

10.1016/j.promfg.2020.01.222.

[315] D. Romero, N. Galeano, and A. Molina, “A VIRTUAL BREEDING ENVIRONMENT REFERENCE MODEL AND ITS INSTANTIATION METHODOLOGY,” *IFIP Int. Fed. Inf. Process. Vol. 283*, vol. 283, pp. 15–24, 2008.

[316] M. Akaka, S. Vargo, and R. Lusch, “An Exploration of Networks in Value Cocreation: A Service-Ecosystems View,” in *Special Issue – Toward a Better Understanding of the Role of Value in Markets and Marketing*, vol. 9, S. L. Vargo and R. F. Lusch, Eds. Emerald Group Publishing Limited, 2012, pp. 13–50.

[317] D. Romero *et al.*, “Competency And Profiling Management In Virtual Organization Breeding Environments,” *Int. Fed. Inf. Process. Vol. 224*, vol. 21, no. 2, pp. 181–217, 2010, doi: 10.1080/09537280903441963.

[318] A. Silva, M. M. Gil, and E. Duarte, “Service Innovation | A Service Blueprinting for Industry 4 . 0,” *Int. J. Sci. Basic Appl. Res.*, p. 24535, 2020.

[319] L. Patrício, A. Gustafsson, and R. Fisk, “Upframing Service Design and Innovation for Research Impact,” *J. Serv. Res.*, vol. 21, no. 1, pp. 3–16, Feb. 2018, doi: 10.1177/1094670517746780.

[320] G. L. Shostack, “How to Design a Service,” *Eur. J. Mark.*, vol. 16, no. 1, pp. 49–63, 1982, doi: 10.1108/EUM0000000004799.

[321] J. Kingman-Brundage, “The ABC’s of service system Blueprinting: Designing a winning service strategy,” 1989.

[322] R. Magyari and F. Secomandi, “Service Blueprinting for Better Collaboration in Human-Centric AI: The Design of a Digital Scribe for Orthopedic Consultations,” *Int. J. Des.*, vol. 17, no. 3, pp. 63–77, 2023, doi: 10.57698/v17i3.04.

[323] M. J. Bitner, A. L. Ostrom, and F. N. Morgan, “Service Blueprinting: A Practical Technique for Service Innovation,” *Calif. Manag. Rev. VOL. 50,NO. 3 SPRING 2008 C.*, vol. 50, no. 3, pp. 66–94, 2008, doi: 10.2307/41166446.

[324] S. L. Vargo and R. F. Lusch, “Why ‘service’?,” *J. Acad. Mark. Sci.*, vol. 36, no. 1, pp. 25–38, 2008, doi: 10.1007/s11747-007-0068-7.

[325] J. Spohrer, L. Anderson, N. Pass, and T. Ager, “Service science and service-dominant logic,” in *Otago Forum 2*, vol. 1, no. 2, O. F. 2 (2008), Ed. 2009, pp. 133–156.

[326] L. Breznik and M. Lahovnik, “Renewing the resource base in line with the dynamic capabilities view : a key to sustained competitive advantage in the IT industry,” *J. East Eur. Manag. Stud.*, vol. 19, no. 4, pp. 453–485, 2014, doi: 10.1688/JEEMS-2014-04.

[327] D. Tjosvold, A. S. H. Wong, and N. Y. Feng Chen, “Constructively Managing Conflicts in Organizations,” *Annu. Rev. Organ. Psychol. Organ. Behav.*, vol. 1, no. 1, pp. 545–568, Mar. 2014, doi: 10.1146/annurev-orgpsych-031413-091306.

[328] L. Hüttinger, H. Schiele, and J. Veldman, “The drivers of customer attractiveness , supplier satisfaction and preferred customer status : A literature review,” *Ind. Mark. Manag.*, vol. 41, no. 8, pp. 1194–1205, 2012, doi: 10.1016/j.indmarman.2012.10.004.

[329] J. Spohrer, L. Anderson, N. Pass, T. Ager, and D. Gruhl, “Service science,” *J. Grid Comput.*, vol. 6, no. 3, pp. 313–324, 2008, doi: 10.1007/s10723-007-9096-2.

[330] B. Johnson and A. Onwuegbuzie, “Mixed Methods Research: A Research Paradigm Whose Time Has Come,” *Am. Educ. Res. Assoc.*, vol. 33, pp. 14–26, 2004, doi: 10.3102/0013189X033007014.

[331] M. Uriona Maldonado, M. E. Leusin, T. C. de A. Bernardes, and C. R. Vaz, “Similarities and differences between business process management and lean management,” *Bus. Process Manag. J.*, vol. 26, no. 7, pp. 1807–1831, Apr. 2020, doi: 10.1108/BPMJ-09-2019-0368.

[332] R. Lakshmanan, P. Nyamekye, V.-M. Virolainen, and H. Piili, “The convergence of lean management and additive manufacturing: Case of manufacturing industries,” *Clean. Eng. Technol.*, vol. 13, p. 100620, Apr. 2023, doi: 10.1016/j.clet.2023.100620.

[333] M. a. An and S. L. Han, "Effects of experiential motivation and customer engagement on customer value creation: Analysis of psychological process in the experience-based retail environment," *J. Bus. Res.*, no. February, pp. 1–9, 2020, doi: 10.1016/j.jbusres.2020.02.044.

[334] F. Verones *et al.*, "LC-IMPACT: A regionalized life cycle damage assessment method," *J. Ind. Ecol.*, vol. 24, no. 6, pp. 1201–1219, Dec. 2020, doi: 10.1111/jiec.13018.

[335] R. Axelrod, *The Evolution of Co-operation*, Basic Book. 1982.

[336] A. Giddens, "The Constitution of Society," *Univ. Calif. Press. Berkley, CA*, 1984.

[337] Y. von Friedrichs Grängsjö and E. Gummesson, "Hotel networks and social capital in destination marketing," *Int. J. Serv. Ind. Manag.*, vol. 17, no. 1, pp. 58–75, Jan. 2006, doi: 10.1108/09564230610651589.

[338] P. Ritala and A. Tidström, "Untangling the value-creation and value-appropriation elements of coopetition strategy: A longitudinal analysis on the firm and relational levels," *Scand. J. Manag.*, vol. 30, no. 4, pp. 498–515, 2014, doi: https://doi.org/10.1016/j.scaman.2014.05.002.

[339] E. Bacon, M. D. Williams, and G. Davies, "Coopetition in innovation ecosystems: A comparative analysis of knowledge transfer configurations," *J. Bus. Res.*, vol. 115, no. November, pp. 307–316, 2020, doi: 10.1016/j.jbusres.2019.11.005.

[340] L. Bayne, D. Schepis, and S. Purchase, "A framework for understanding strategic network performance: Exploring efficiency and effectiveness at the network level," *Ind. Mark. Manag.*, vol. 67, no. April 2016, pp. 134–147, Nov. 2017, doi: 10.1016/j.indmarman.2017.07.015.

[341] O. Fjeldstad and A. Sasson, "Membership Matters: On the Value of Being Embedded in Customer Networks," vol. 901, no. September, 2010, doi: 10.1111/j.1467-6486.2009.00901.x.

[342] D. Ford and H. Håkansson, "IMP – some things achieved: much more to do," *Eur. J. Mark.*, vol. 40, no. 3/4, pp. 248–258, Jan. 2006, doi: 10.1108/03090560610648039.

[343] H. Håkansson and I. Snehota, "No Business Is an Island: The Network Concept of Business Strategy," *Scand. J. Manag.*, vol. 22, pp. 187–200, Dec. 1989, doi: 10.1016/0956-5221(89)90026-2.

[344] J. Holmqvist and C. Ruiz, "Service ecosystems, markets and business networks," *TQM J.*, vol. 29, no. 6, pp. 800–810, Oct. 2017, doi: 10.1108/TQM-03-2017-0028.

[345] H. Kotzab and C. Teller, "Value-adding partnerships and co-opetition models in the grocery industry," *Int. J. Phys. Distrib. Logist. Manag.*, vol. 33, no. 3, pp. 268–281, Apr. 2003, doi: 10.1108/09600030310472005.

[346] P. E. Eriksson, "Achieving Suitable Coopetition in Buyer–Supplier Relationships: The Case of AstraZeneca," *J. Business-to-bus. Mark.*, vol. 15, no. 4, pp. 425–454, Nov. 2008, doi: 10.1080/15470620802325674.

[347] P. Ritala, A. Golnam, and A. Wegmann, "Coopetition-based business models: The case of Amazon.com," *Ind. Mark. Manag.*, vol. 43, no. 2, pp. 236–249, 2014, doi: 10.1016/j.indmarman.2013.11.005.

[348] S. Vargo and R. Lusch, "Institutions and axioms: an extension and update of service-dominant logic," *J. Acad. Mark. Sci.*, vol. 44, no. 1, pp. 5–23, Jan. 2016, doi: 10.1007/s11747-015-0456-3.

[349] M. Kleinaltenkamp, D. Corsaro, and R. Sebastiani, "The role of proto-institutions within the change of service ecosystems," *J. Serv. Theory Pract.*, vol. 28, no. 5, pp. 609–635, 2018, doi: 10.1108/JSTP-12-2017-0241.

[350] J. Björkdahl, "Technology cross-fertilization and the business model: The case of integrating ICTs in mechanical engineering products," *Res. Policy 38 1468–1477*, vol. 38, no. 9, pp. 1468–1477, 2009, doi: 10.1016/j.respol.2009.07.006.

[351] B. Edvardsson, B. Tronvoll, and T. Gruber, "Expanding understanding of service

exchange and value co-creation: a social construction approach," *J. Acad. Mark. Sci.*, vol. 39, no. 2, pp. 327–339, Apr. 2011, doi: 10.1007/s11747-010-0200-y.

[352] S. Vargo, M. Akaka, and C. Vaughan, "Conceptualizing Value: A Service-ecosystem View," *J. Creat. Value*, vol. 3, no. 2, pp. 117–124, 2017, doi: 10.1177/2394964317732861.

[353] S. Barile, P. Piciocchi, C. Bassano, J. Spohrer, and M. C. Pietronudo, "Re-defining the role of artificial intelligence (AI) in wiser service systems," *Adv. Intell. Syst. Comput.*, vol. 787, pp. 159–170, 2019, doi: 10.1007/978-3-319-94229-2_16.

[354] C. Enberg, "Enabling knowledge integration in coopetitive R&D projects - The management of conflicting logics," *Int. J. Proj. Manag.*, vol. 30, no. 7, pp. 771–780, 2012, doi: 10.1016/j.ijproman.2012.01.003.

[355] J. Spohrer, A. Giuiusa, H. Demirkan, and D. Ing, "Service Science: Reframing Progress with Universities," *Syst. Res. Behav. Sci.*, vol. 30, no. 5, pp. 561–569, Sep. 2013, doi: 10.1002/sres.2213.

[356] A. Silva, A. Dionísio, and L. Coelho, "Improving Industry 4.0 through service science," *Int. J. Serv. Sci.*, vol. 7, no. 2, p. 58, 2020, doi: 10.1504/IJSSCI.2020.113189.

[357] H. M. Silva *et al.*, "Service blueprint of comprehensive medication management: A mapping for outpatient clinics," *Res. Soc. Adm. Pharm.*, vol. 17, no. 10, pp. 1727–1736, 2021, doi: 10.1016/j.sapharm.2021.01.006.

Appendix I. Tables

Table 3.1. Systemic and Institutional Convergence on Coopetition and Value cocreation.

Systemic View on Coopetition and Value Cocreation	Source
Collaborative efforts among individuals aim to establish win-win value relationships.	(Axelrod, 1982)
The structures created by individuals later limit their own actions.	(Giddens, 1984)
Personal relationships influence inter-firm competition, potentially hindering value creation.	(von Friedrichs Grängsjö & Gummesson, 2006)
An organization's survival is tied to its ability to adhere to social norms and acceptable behaviors.	(Covaleski et al., 1998)
Firm activities often reflect broader social norms and practices, challenging the notion of purely individualistic actions.	(Ritala & Tidström, 2014)
Coopetition necessitates social institutions grounded in cooperative norms to facilitate and enhance value creation among partners.	(Bicen et al., 2021)
The formation of coopetition networks involves creating value and materials with partners, fostering a sense of happiness.	(Raza-Ullah et al., 2014)
Coopetition networks are characterized by multiple, continuous processes.	(Bacon et al., 2020)

Table 3.2. Foundational Assumptions on Networks

Foundational Assumption	Source
Long-term relationships are crucial	(Romero et al., 2010)
Interconnections among participants are essential	(Bayne et al., 2017)
All participants expect mutual benefits	(Fjeldstad & Sasson, 2010)
Building relationships is prioritized	(Luo, 2007)
Participants can influence the network by managing interdependencies with partners, including competitors	(Ford & Håkansson, 2006; Håkansson & Snehota, 1989), (Holmqvist & Ruiz, 2017)

Table 25.3. Systemic and Institutional Convergence on Networks and Service Ecosystems

Systemic View on Networks and Service Ecosystems	Source
Progressive processes enhance the coopetition mindset within	(Gnyawali & Park,

networks, encouraging actors to share resources with the expectation of mutual benefit, thus augmenting the firm's ability to profit from coopetition.	2011; Gnyawali & Ryan Charleton, 2018; Park et al., 2014)
Value networks are dynamic entities that spontaneously sense and respond, consisting of loosely connected social and economic actors. These actors interact through institutions and technology to co-produce service offerings, exchange these offerings, and co-create value.	(R. F. Lusch et al., 2010)
Forming loosely coupled collaborations among services offered by autonomous enterprises introduces various requirements and challenges for the associated service ecosystem.	(Ruokolainen & Kutvonen, 2009)

Table 3.26. Summary of Institutional Convergences on Coopetition, Value Cocreation, Networks, and Service Ecosystems

Institutional convergence on coopetition & value cocreation	**Institutional convergence on networks & service ecosystems**
Individuals collaborate toward creating a win-win value relationship (Axelrod, 1982).	Coopetition networks incorporate multiple ongoing processes (Bacon et al., 2020)
Individuals who make the structures later restrict their actions (Giddens, 1984)	Ongoing processes progressively improve the coopetition mindset in the networks (Gnyawali & Park, 2011), motivating the actors to share their resources in the expectation that others do the same (Park et al., 2014), and enabling the firm's capability to profit from coopetition (Gnyawali & Ryan Charleton, 2018).
Information and social exchange underpin economic exchange and coopetition relations (Kotzab & Teller, 2003)	Value networks are spontaneously sensing and responding spatial and temporal structures of largely loosely coupled value proposing social and economic actors interacting through institutions and technology to co-produce service offerings, exchange service offerings, and co-create value." (R. F. Lusch et al., 2010).
In firms' relationships, personal relationships can also affect inter-firm coopetition inhibiting the creation of value (von Friedrichs Grängsjö, 2003).	Establishing loosely coupled collaborations between services provided by autonomous enterprises poses several requirements and challenges for the surrounding service ecosystem. Furthermore, these authors introduced the concept of a service ecosystem as a "socio-technical, complex adaptive system, characterized by metamodels for domain ontology, and metamodels

	relating such domain ontologies with infrastructure services and service production facilities" (Ruokolainen & Kutvonen, 2009).
The survival of an organization (Moore, 1993) is related to its capacity to conform to social norms and acceptable behaviour (Covaleski et al., 1998). When norms or practices resemble a social fact, the activities of firms may not be as calculating and individualistic as evident (Tidström, 2014). Coopetition requires social institutions based on social and cooperative norms to guide and create value for partners (Bicen et al., 2021). Coopetition network creation is to jointly create value and develop the material with the partner that evokes feelings of happiness. (Raza-Ullah et al., 2014).	

Table 3.5. Key terms and definitions of institutional coopetition Networks for Value Cocreation

Key terms	Definitions and sources
Coopetition	Coopetition is the simultaneous pursuit of cooperation and competition between firms (Bengtsson & Kock, 2000); (…) coopetition is the hybrid activity of simultaneous cooperation and competition among the same firms (Walley, 2007); (…) coopetition is a triad in which collaboration between some firms occurs and affects competition among other firms (Rungtusanatham et al., 2003); (…) coopetition is the simultaneous competition and collaboration within the same relation-ship (Bouncken et al., 2018); (…) coopetition is the hybrid behaviour comprising competition and cooperation has been named coopetition (Dagnino & Padula, 2002); (…) in a coopetition relationship, firms cooperate in the upstream activities and compete in the downstream activities (Walley, 2007); Coopetition is dyadic and paradoxical relationship that emerges when two firms cooperate in some activities (Bengtsson & Kock, 2000); (…) coopetition is the simultaneous cooperative and competitive interactions between actors on any level of analysis (Bengtsson & Kock, 2014); (…) coopetition is the balance between cooperation and competition in a competitive environment (Eriksson, 2008).

Value cocreation	the collaborative process of creating idiosyncratically perceived value through resource integration and service exchange coordinated by shared institutional arrangements Vargo and Lusch (2004a, b), Vargo and Lusch 2008, Vargo and Lusch 2016).
Value networks	interactive combination of information machines and people concentrated in creating value in each node, where the technology facilitates exchange relationships among customers distributed in space and time." (Mariotti, 2002) (R. F. Lusch et al., 2010)
Business models	dynamic assemblages of institutions that, through the performative practices (i.e., actions, constructions) of actors, reciprocally link and influence technological and market innovation and contribute to the viability of these actors and the viability of the service ecosystems of which they are a part. (Ritala et al., 2014)(Hartmann et al., 2018)
Service ecosystems	A relatively self-contained, self-adjusting system of resource-integrating actors connected by shared institutional arrangements and mutual value creation through service exchange (S. Vargo & Lusch, 2016). Shared institutional arrangements govern these service ecosystems. Each progression of service ecosystems is shaped by changes in the specific institutional arrangements at the same time (Kleinaltenkamp et al., 2018)
Institutions	Humanly devised rules, norms, and beliefs enable and constrain action and make social life predictable and meaningful (S. Vargo & Lusch, 2016). Institutions arise when organized actors with sufficient resources (institutional entrepreneurs) see in them an opportunity to realize interests that they value highly (Lawrence & Suddaby, 2006)
Institutional arrangements	Interdependent sets of institutions guide thinking and behaviour by serving as sets of value assumptions, cognitive frames, rules, and routines, among other things (Hartmann et al., 2018). These institutional arrangements consist of regulative, normative and cognitive institutional elements (Scott, 2001)

Table 4.1. Integration of S-D Logic Enhancements into Design Science Research Methodology

S-D Logic Foundations	**S Integration of S-D Logic Enhancements into Design Science Research Methodology**
Theoretical Grounding	S-D Logic offers a theoretical lens that enriches the DSR methodology, focusing on value creation through collaborative efforts (Björkdahl, 2009). It helps in designing artifacts for coopetition and value cocreation within SME networks, ensuring innovative and theoretically solid solutions (Stephen L. Vargo & Lusch, 2014), (Jaakkola, 2020; Storbacka et al., 2016).
Focus on Co-creation	S-D Logic's emphasis on cocreation aligns with DSR's goal of creating artifacts that solve real-world problems (S. Vargo et al., 2015). It informs artifact design to foster

	collaboration and mutual value creation among competing firms within service ecosystems (Stephen L. Vargo et al., 2020).
Institutional Arrangements	S-D Logic's focus on institutional arrangements provides insights into regulatory, normative, and cultural-cognitive elements, aiding in the design of artifacts that are technologically advanced and socially viable, enhancing adoption and impact (Mustak & Plé, 2020).
Iterative Refinement	The acknowledgment of dynamic service ecosystems in S-D Logic resonates with DSR's iterative nature, supporting continuous artifact refinement based on real-world feedback, ensuring long-term relevance and effectiveness (Koskela-Huotari & Vargo, 2016).
Actor-to-Actor Networks	S-D Logic's perspective on actor-to-actor networks helps in understanding the complex relationships within Coopetition Networks for Value Cocreation, informing the design of artifacts that enhance communication, collaboration, and resource sharing among SMEs (Patrício et al., 2018).

Table 4.2. Aligning Ontological Assumptions of DSR with Research Objectives

Ontological Alignments	**Ontological assumptions of DSR and the specific objectives of the research**
Reality as a Constructed Artefact	DSR operates under the ontological assumption that reality can be shaped and constructed through the development of innovative artefacts (Hevner et al., 2004). This view aligns with the objective of creating a technology-enabled ecosystem model, which is essentially an artefact designed to modify the competitive landscape for manufacturing SMEs. The artefact (the model) is not merely a theoretical construct but a practical tool, embodying the S-D Logic principle that value is co-created through interactions within service ecosystems (Hartmann et al., 2018).
Problem-solving through Artefact Creation	The ontology of DSR focuses on understanding reality by solving problems through the creation and evaluation of artefacts. This approach is directly aligned with the research goal, which seeks not just to theorize about coopetition and service ecosystems but to provide a tangible solution that SMEs can implement. The development of a framework for Coopetition Networks for Value Cocreation is an exercise in applying DSR's ontological premise that knowledge and understanding are advanced through the creation of practical solutions to real-world problems.
Dynamic Interaction	DSR posits that artefacts interact dynamically with their

with the Environment	environment, leading to changes in both. This perspective aligns with the research objective, which is predicated on the understanding that introducing a new framework for Coopetition Networks for Value Cocreation into the ecosystem of manufacturing SMEs will not only change the way these enterprises compete but also alter the ecosystem itself. This reflects S-D Logic's view of service ecosystems as dynamic and evolving, where entities co-create value through their interactions.
Iterative Learning and Adaptation	The ontological stance of DSR acknowledges that artefacts are refined through iterative processes of testing, feedback, and adaptation. This iterative process mirrors the research objective's emphasis on developing and evaluating the model, suggesting that the understanding of coopetition in digital and global markets will evolve as Coopetition Networks for Value Cocreation framework are applied and refined. This iterative learning and adaptation process is emblematic of S-D Logic's focus on continuous engagement and evolution within service ecosystems.
Value Creation as an Ontological Outcome	DSR's ontology aligns with the objective of enhancing SME competitiveness by framing value creation not as an abstract concept but as an ontological outcome of artefact design and implementation. This is in harmony with S-D Logic, which posits that value is co-created through the interactions facilitated by artefacts (such as the proposed model) within a service ecosystem.

Table 4.3. Epistemological Contributions of DSR to Understanding Coopetition Networks

Epistemological Contributions	**Epistemological Contributions of Design Science Research to Understanding Coopetition Networks**
Knowledge Through Artefact Creation	DSR posits that knowledge is created through the design, development, and iterative refinement of artefacts, such as the Coopetition Technology-Enabled Ecosystem Model. This approach asserts that practical creation can be a primary source of knowledge, challenging traditional epistemologies.
Bridging Theory and Practice	DSR facilitates a direct link between theoretical constructs and practical application, applying S-D Logic principles and service ecosystem dynamics to solve practical problems and refine theoretical understandings.
Iterative Learning	Characterized by iterative cycles of design, implementation, evaluation, and refinement, DSR views knowledge as evolving, deepening understanding with each cycle and underscoring the dynamic nature of knowledge creation.
Contextual Understanding	DSR emphasizes the role of context in artefact creation and evaluation, offering nuanced insights into how coopetition models function within specific environments, such as among

	manufacturing SMEs.
Validation and Generalization	Through real-world artefact evaluation, DSR provides methods for validating theoretical concepts and generalizing findings, testing S-D Logic concepts within SME settings to validate and generalize the S-D Logic framework.
Integrating Diverse Knowledge Sources	DSR integrates knowledge from multiple disciplines, reflecting the interdisciplinary nature of S-D Logic and service ecosystems, and synthesizes diverse epistemologies to create a comprehensive understanding of coopetition dynamics among SMEs.

Table 6.1. Building Blocks for Coopetition Networks for Value Cocreation

Building Blocks #	**Description**	**Sources**
Actors	Identified as the cornerstone of service interactions, the main actors in Coopetition Networks for Value Cocreation include customers, providers, coopetitors, and competitors. Providers adeptly navigate dual roles of collaboration and competition, embodying the dynamic essence of the network.	(Siltaloppi & Vargo, 2017), (Edvardsson et al., 2011)
Resource Integration	Represents collaborative efforts among actors to merge diverse resources, capabilities, and competencies, aiming to fortify the ecosystem's collective value proposition and showcase the synergy achieved through shared endeavors.	(R. Lusch et al., 2016),(Sklyar et al., 2019), (Mustak & Plé, 2020)
Service Exchange	Acts as the conduct for offering and utilizing integrated resources within Coopetition Networks. This mechanism fosters mutual benefits and amplifies value cocreation among participants, highlighting the reciprocal nature of coopetition networks.	(R. Lusch & Vargo, 2007), (S. Vargo et al., 2017)
Institutions and Institutional Arrangements)	Represents the endogenously generated rules, norms, and cultural-cognitive elements that enable and constrain interactions. These guide the network's governance and operational dynamics, ensuring a balanced interplay between competition and collaboration.	(S. L. Vargo & Lusch, 2017), (Koskela-Huotari & Vargo, 2016)
Nested and Overlapping Service	Reflects the broader context where resource integration and service exchange unfold. Characterized by multiple interconnected layers of coopetition and collaboration, it	(Stephen L. Vargo et al., 2023), (Elo et al., 2024)

Ecosystems	underscores the complexity and richness of the networks in the light of service ecosystems.	
Operand Technologies	Represents the facilitating technologies in Coopetition Networks for Value Cocreation. Providing the necessary tools for resource integration and service exchange, operand technologies promote the operational aspects of coopetition networks, ensuring actors can engage effectively.	(Kleinaltenkamp et al., 2023), (R. Lusch & Nambisan, 2015)
Operant Technologies	Acts as the trigger for coopetition actions in Coopetition Networks for Value Cocreation, spearheading innovation and strategic reconfigurations within the network. It offers advanced capabilities and insights, acting as catalysts for transformation and growth.	(R. Lusch & Nambisan, 2015), (Akaka & Vargo, 2014)

Table 6.2. Providers' Resources in Coopetition Networks for Value Cocreation

Resource Type	**Description**	**Source**
Frontstage Human Resources	Engagement directly with customers, competitors, or authorities plays a vital role in service delivery and customer interaction.	(Leal et al., 2019)
Frontstage Operant Technologies	Include technologies that facilitate cognitive assistance and smart object generation, enhancing digital interaction capabilities.	(R. Lusch & Nambisan, 2015)
Frontstage Operand Technologies	Systems and dialogue interfaces that support service facilitation and communication within the ecosystem.	(Barile et al., 2019)
Backstage Human Resources	Support the provider's operations indirectly, ensuring smooth backend processes.	(Enberg, 2012)
Backstage Operant Technologies	Advanced machinery that boosts manufacturing efficiency and capability.	(R. Lusch & Nambisan, 2015), (Stephen L. Vargo et al., 2024)
Backstage Operand Technologies	Shopfloor technologies enable interconnectivity and intelligence sharing, enhancing operational efficiency.	(Bicen et al., 2021)

Support Partnerships Resources	Collaborations with external entities that enhance the provider's capabilities and resources.	(Kleinaltenkamp et al., 2023)
Technology-Enabled Know-How and Shareable Information Resources	Intellectual properties and collaborative projects that provide competitive advantages and contribute to the knowledge base of the ecosystem.	(Spohrer et al., 2013), (A. Silva et al., 2020)

Table 6.3. Coopetitor' Resources in Coopetition Networks for Value Cocreation

Artefact/Resource Type	**Description**	**Source**
Coopetition-Enabled Artefacts	Specialized technologies that facilitate resource sharing and access among ecosystem members, enhancing interoperability and collaboration.	(Bouncken et al., 2018)
Frontstage Coopetition Human Resources	Personnel who directly engage with customers, authorities, and other coopetitors, embodying operant resources critical for service delivery and ecosystem interaction.	(Akaka & Vargo, 2014)
Frontstage Coopetition Operant Technologies	Advanced cognitive and intelligent technologies that enable coopetition, serving as initiators of interoperable solutions within the network.	(Ritala et al., 2014), (S. L. Vargo & Lusch, 2017)
Frontstage Coopetition Operand Technologies	Software and applications that support coopetition by facilitating communication and service provision within the ecosystem.	(Barile et al., 2019)
Backstage Coopetition Human Resources	Individuals who work behind the scenes to support digital market interactions and coopetition activities, indirectly contributing to the ecosystem's operational efficiency.	(Enberg, 2012)
Backstage Coopetition Operant Technologies	Smart and interoperable machinery that enables seamless production and operational activities within the coopetition framework.	(H. M. Silva et al., 2021)
Backstage Coopetition Operand Technologies	Interconnected and shared technological infrastructures that underpin the operational capabilities necessary for effective coopetition.	(Kleinaltenkamp et al., 2023)

Support Partnership Resources	Collaborations with external entities that augment the coopetition ecosystem's capabilities and resources, facilitating broader ecosystem support and enhancement.	(Kleinaltenkamp et al., 2023)
Technology-Enabled Know-How and Shareable Information	Intellectual assets and collaborative initiatives that provide strategic advantages and foster knowledge sharing within the ecosystem, including patents and cross-fertilization projects.	(Spohrer et al., 2013), (A. Silva et al., 2020)

Table 6.4. Industrial IoT Functionalities for Enhancing Coopetition Networks for Value Cocreation

Requirement	**Description**	**Source**
Operant and Operand Technological Capabilities	The Industrial IoT artifact must adapt seamlessly to the dynamic environments of coopetition networks, supporting continuous innovation and flexibility.	M. A. Akaka & Vargo, 2014
Interoperability Across Dimensions	The artifact should ensure technical interoperability for cross-platform communication, semantic interoperability for meaningful data interpretation, and pragmatic interoperability for actionable insights, fostering a comprehensive understanding and application of shared information.	Stephen L. Vargo et al., 2023
Accessibility and Usability for Network Actors	The design should be human-centered, making the system accessible and usable by a broad range of users to facilitate collaboration and value cocreation across the network.	Ahn et al., 2014
Facilitation of Simultaneous Collaboration Among Competitors	Given the complexities of coopetition, the artifact must not only enable but also enhance collaboration among competitors, supporting them throughout business opportunities from inception to conclusion.	Bicen et al., 2021

Table 6.5. Key Features of Cockpit4.0+

Feature	**Description**	**Relevance to Coopetition**
Systemic	This feature integrates diverse	Ensures seamless

Assemblages	technological components into cohesive, functional units that surpass the capabilities of their individual elements, facilitating the complex interconnectivity required in Coopetition Networks for Value Cocreation.	interactions across various technological and social layers.
Architectural Modules for Transactions and Service	Cockpit4.0+ employs a modular design strategy that allows for the flexible configuration of products and services to meet varied user needs. This supports customization and personalization.	Resonates with S-D Logic's view that service fragmentation and recombination can significantly enhance ecosystem value.
Integration of OPC Unified Architecture (OPC UA)	Cockpit4.0+ incorporates OPC UA to leverage its standardized services that promote compatibility across different technological systems, including sophisticated security protocols like digital certificate signing and encryption.	Crucial for ensuring the integrity and privacy of data exchanges within the network.

Table 6.6. *Systematic Implementation Algorithm for Cockpit4.0+ Features*

Algorithm steps	**Core functionalities**
Initialize System Core Components	• Set up the foundational architecture, including cloud computing, high-speed networking, and basic security protocols. • Implement AI and machine learning modules for data analysis, trend prediction, and actionable intelligence.
Integrate Operant Technological Capabilities	• Develop a modular architecture for seamless integration with existing digital frameworks (ERP, CRM). • Enforce data protection with advanced encryption and secure exchange protocols. • Design an intuitive user interface that ensures accessibility and mobile compatibility.
Incorporate Operand Technological Capabilities	• Install sensors and IoT devices for real-time monitoring (temperature, RFID). • Utilize cloud computing for scalable storage and processing. • Ensure high-speed data transmission with secure networking equipment. • Establish direct connections with major digital marketplaces for enhanced market presence.

Ensure Interoperability Across Levels	• Establish communication pathways for technical interoperability with diverse technological platforms. • Focus on semantic interoperability for meaningful data exchange. • Align operational policies and expectations for pragmatic interoperability.
Implement S-D Logic Foundations	• Integrate Resource Density Mechanisms for dynamic resource recombination. • Employ Digital Materiality Mechanisms to merge software and physical object capabilities.
Deploy OPC Unified Architecture (OPC UA)	• Integrate OPC UA for machine-to-machine and device-to-cloud interoperability. • Implement security measures for data protection (digitally signed certificates, encryption).
Enhance Usability and Accessibility	• Apply human-centred design principles for broad usability. • Create systemic assemblages for interconnected technological component integration. • Develop architectural modules for transaction and service customization.
Facilitate Coopetition Collaboration	• Integrate advanced communication and data-sharing tools. • Implement access control and privacy mechanisms. • Provide APIs for third-party integration and ensure compliance standards. • Incorporate cocreation and innovation platforms. • Establish conflict resolution and governance structures. • Implement trust-building and relationship management features.
Finalize System Testing and Deployment	• Conduct comprehensive system testing, including usability, security, and interoperability tests. • Deploy the system for pilot testing with selected SMEs. • Gather feedback and perform necessary adjustments.
Launch and Monitor	• Officially launch Cockpit4.0+ for broader use. • Continuously monitor system performance and user feedback. • Implement updates and enhancements based on feedback and evolving needs.

Table 27. Summary of Average Responses from the Questionnaire

Cockpit4.0+ Functional	**Disruptive**	**Company's**	**Cybersecurity**	**Usability**	**Average**

acceptance (average)	innovation	usefulness			rating
DL#0 Respondents	4,3	1,2	2,6	4,0	3,0
DL#1 Respondents	4,7	2,3	3,8	4,2	3,8
DL#2 Respondents	4,9	3,1	3,0	4,2	3,8
DL#3 Respondents	5,0	4,6	3,0	4,9	4,4
DL#4 Respondents	4,9	5,0	4,1	5,0	4,8
Average Functional Acceptance	**4,8**	**3,2**	**3,3**	**4,5**	**3,9**

Table 7.1. ISPAR Outcomes for Service Journey Evaluation

Code	ISPAR Outcomes Description
(R)	Successful realization of the proposed value.
(-P)	Proposal not perceived due to communication or comprehension failures.
(-A)	Proposal communicated well but not accepted.
(-D)	Value not realized but no disputes arise.
(-K)	Disputes arise but are resolved.
(K)	Disputes arise and are not resolved.
(W)	Interaction is peaceful but does not result in service or value creation.
(C)	Interaction interpreted as displeasing but not criminal.
(-C)	Interaction interpreted as unlawful.
(J)	Interaction deemed criminal with legal confirmation.

Table 7.2. Provider's Resource Categorization in CN.EcoTechs

Stage	Resource Type	Description
Cyber Front-stage	Frontstage Human Resources	Operant, physical-with-rights resources consisting of staff who engage directly with customers, competitors, or authorities. Facilitates external communications and relationships.
Cyber	Frontstage	Non-physical, initiator-based technologies without

Front-stage	Operant Technologies	rights, such as algorithms powering cognitive assistants and smart object creation tools. Drives digital engagement and fosters innovation.
Cyber Front-stage	Frontstage Operand Technologies	Facilitative, non-physical technologies without rights, like software applications, dialogue interfaces, web libraries, and messaging platforms, supporting seamless digital communication.
Physical Back-stage	Backstage Human Resources	Physical-with-rights, operant human resources involved in behind-the-scenes interactions and collaborations, essential for supporting digital market engagement.
Physical Back-stage	Backstage Operant Technologies	Physical, initiator-based technologies without rights, such as smart production machinery, enhancing operational efficiency and fostering innovation on the shop floor.
Physical Back-stage	Backstage Operand Technologies	Physical shopfloor technologies and intelligent machines, without rights, facilitate interconnectivity and sharing among production resources, optimizing operational backbone.
Support-stage	Support Human Resources	Physical-with-rights, operant resources, including personnel managing production and logistics, crucial for operational execution and maintaining flow of operations.
Support-stage	Support Partnerships Resources	Non-physical-with-rights entities, including public and private collaborators that contribute to strategic and operational objectives, enhancing network synergy.
Support-stage	Technology-Enabled Shareable Information	Non-physical resources without rights, such as patents, technology transfers, and coopetition ecosystem expertise, fuel innovation and facilitate knowledge sharing.

Table 7.3. Coopetitor's Resource Categorization in CN.EcoTechs

Stage	Resources	Purpose
Cyber Front-stage	Digital platforms and technologies that enable direct interactions with customers and other actors within the network. Used for communication, negotiation, and management.	Coopetitors leverage these tools to effectively fulfill their roles within the ecosystem.
Physical Back-stage	Tangible technologies and human resources that indirectly contribute to the service process, including machinery, equipment, and the workforce operating in the background.	These resources underpin the operational aspects of the coopetition network.

Support-stage	A broader array of support mechanisms that aid competitors by facilitating partnerships with external entities and providing access to specialized knowledge and technology.	These resources are crucial in maintaining the network's functionality, allowing competitors to remain agile and innovative.

Table 9.1. Dissemination of the findings in Industry Audience Outreach

Event	Description	Primary Goals
CPMR-Cluster Portugal Mineral Resources	This seminar focuses on the mineral resources sector in Portugal, providing an opportunity to discuss the implications of coopetition frameworks for mineral extraction and processing industries.	- Showcase Research Applications: Demonstrate the practical applications of research findings and their potential to solve real-world problems within the industry. - Facilitate Knowledge Exchange: Engage in knowledge exchange with industry leaders and policymakers to enhance understanding and stimulate the adoption of coopetition-based strategies.
SGP-Sociedade Geológica de Portugal	Engaging with geological experts and professionals at this conference will help highlight how geological data can enhance the efficacy of coopetition strategies in resource management.	- Showcase Research Applications: Demonstrate the practical applications of research findings and their potential to solve real-world problems within the industry. - Facilitate Knowledge Exchange: Engage in knowledge exchange with industry leaders and policymakers to enhance understanding and stimulate the adoption of coopetition-based strategies.
CESMIN-Centro para a Sustentabilidade em Recursos Minerais	At CESMIN, discussions will center on sustainability practices within the mineral resources industry and how coopetition can play a role in achieving sustainability goals.	- Showcase Research Applications: Demonstrate the practical applications of research findings and their potential to solve real-world problems within the industry. - Facilitate Knowledge Exchange: Engage in knowledge exchange with industry leaders and policymakers to enhance understanding and stimulate the adoption of coopetition-based strategies.
OEP-Ordem dos Engenheiros de Portugal	Participation in events organized by the Order of Engineers will focus on the engineering challenges and technological solutions facilitated by coopetition ecosystems, especially in industrial applications.	- Showcase Research Applications: Demonstrate the practical applications of research findings and their potential to solve real-world problems within the industry. - Facilitate Knowledge Exchange: Engage in knowledge exchange with industry leaders and policymakers to enhance understanding and stimulate the adoption of coopetition-based strategies.

OE-Ordem dos Economistas	Engaging with economists will help in understanding and disseminating the economic impacts of implementing coopetition strategies, focusing on economic viability and benefits for SMEs.	- Showcase Research Applications: Demonstrate the practical applications of research findings and their potential to solve real-world problems within the industry. - Facilitate Knowledge Exchange: Engage in knowledge exchange with industry leaders and policymakers to enhance understanding and stimulate the adoption of coopetition-based strategies.
ASSIMAGRA – Associação Portuguesa da Indústria dos Recursos Minerais	Discussions at ASSIMAGRA events will delve into the specific needs of the Portuguese mineral industry, exploring how coopetition can enhance operational efficiencies and market responses.	- Showcase Research Applications: Demonstrate the practical applications of research findings and their potential to solve real-world problems within the industry. - Facilitate Knowledge Exchange: Engage in knowledge exchange with industry leaders and policymakers to enhance understanding and stimulate the adoption of coopetition-based strategies.
ANIET – Associação Nacional da Indústria Extractiva e Transformadora	ANIET seminars will provide a platform to present the findings related to the extractive and transformation industry, focusing on how innovative technologies like IIoT can revolutionize these sectors.	- Showcase Research Applications: Demonstrate the practical applications of research findings and their potential to solve real-world problems within the industry. - Facilitate Knowledge Exchange: Engage in knowledge exchange with industry leaders and policymakers to enhance understanding and stimulate the adoption of coopetition-based strategies.

Appendix II. Figures

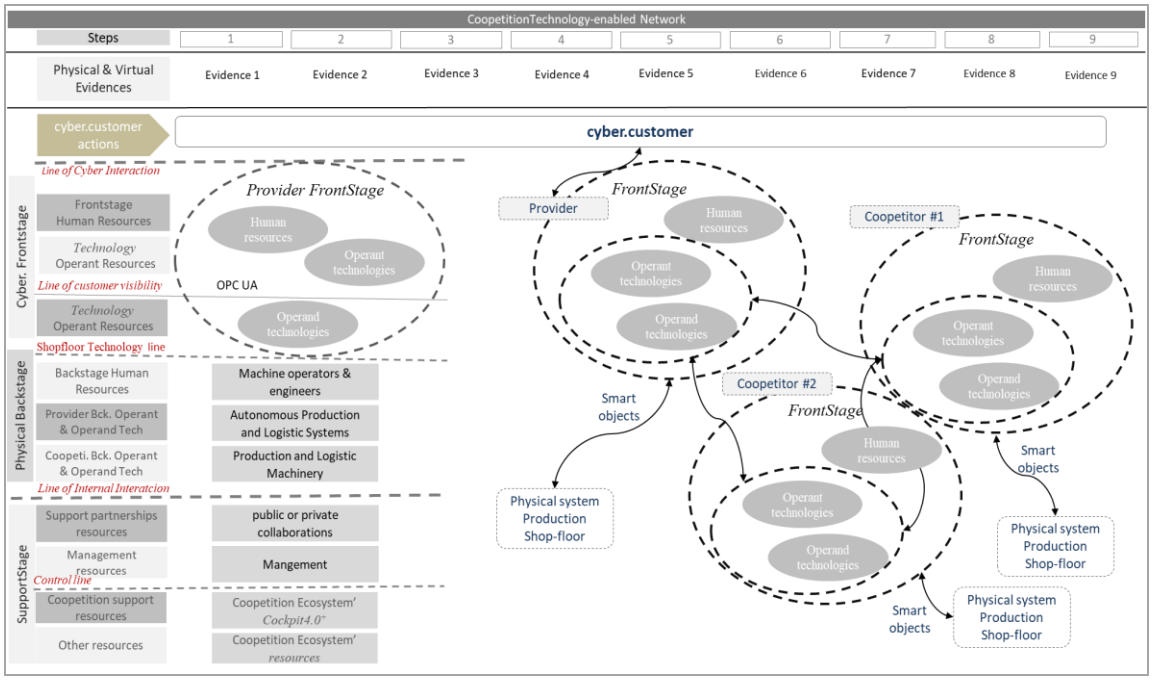


Figure 7.2. Service Blueprint framework for CN.EcoTechs

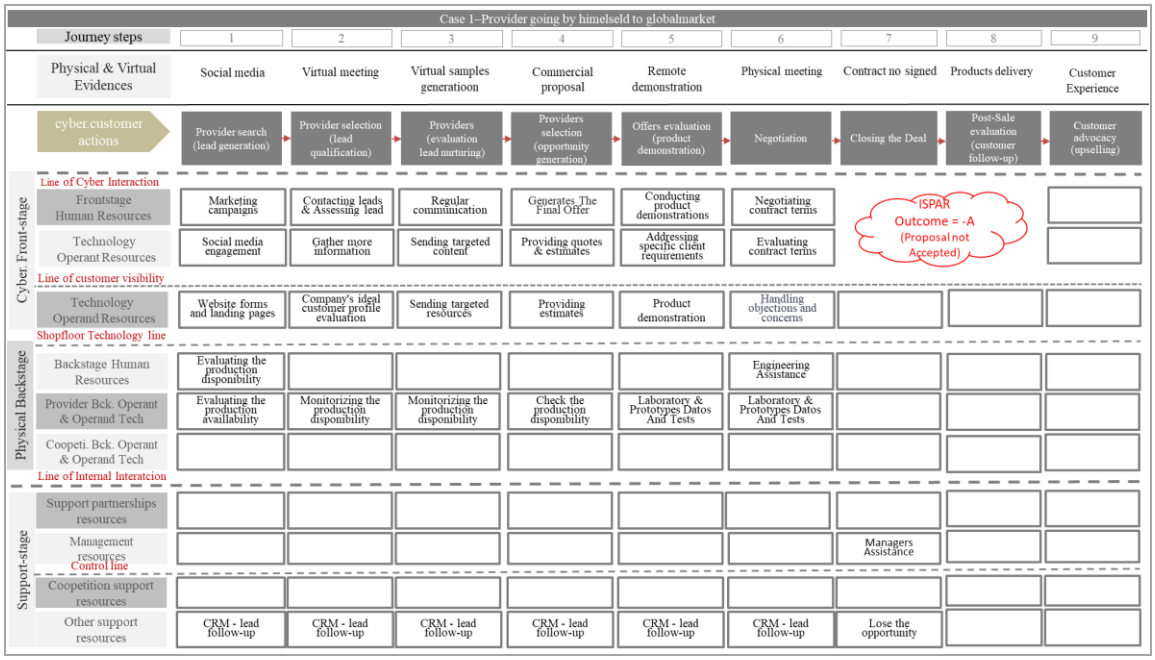


Figure 7.4. Findings from the First Group: SMEs Acting Independently

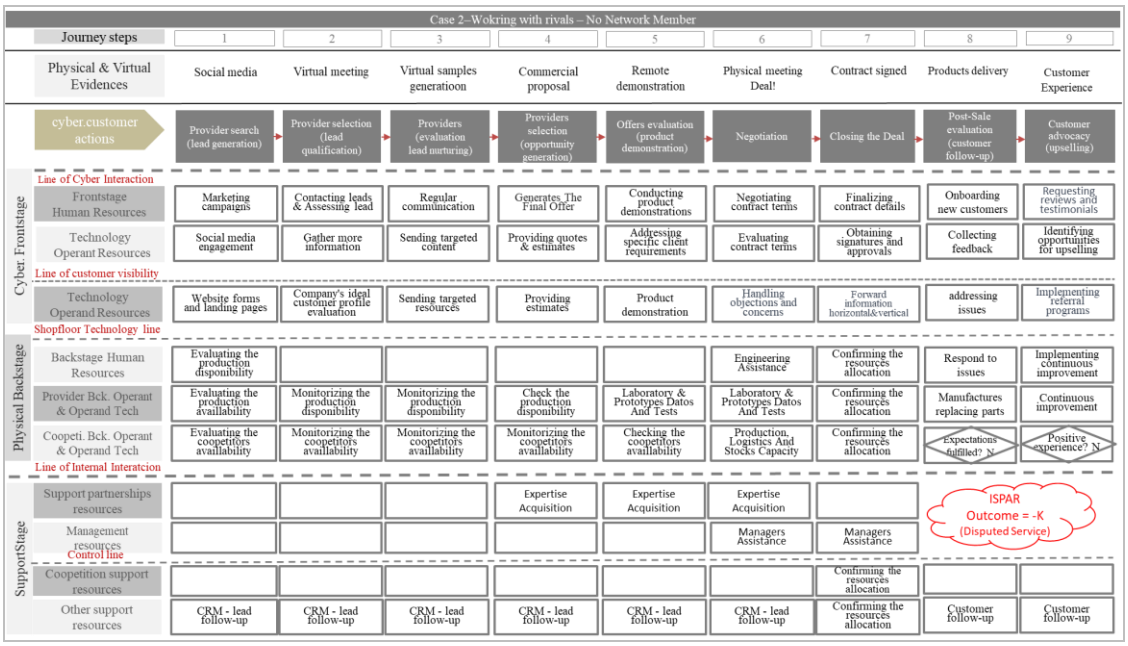


Figure 7.5. Findings from the Second Group: SMEs Acting Partially as CN.EcoTech's members.

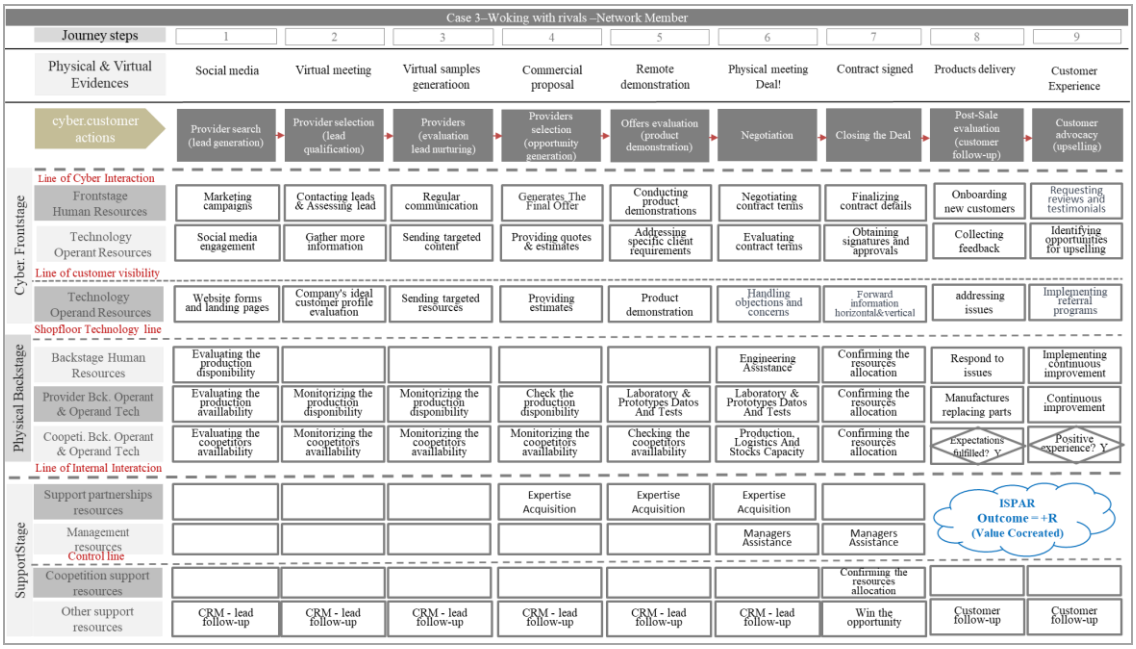


Figure 7.6. Findings from the Third Group: SMEs fully engaged in CN.EcoTech

Appendix III. Scientific Publications

This appendix presents the scientific papers published or accepted for publication that have emerged directly from the research conducted throughout this doctoral thesis. These publications form a vital component of the Design Science Research (DSR) dissemination strategy detailed in Chapter 9. The strategic communication of findings, both within academic circles and across industry and policy domains, has been a key objective of this work.

By focusing on coopetition-driven, technology-enabled networks for SMEs—particularly in the Portuguese ornamental stone sector (OS-PT)—these papers translate the core artefact of this thesis, the CN-EcoTech framework, into actionable insights for both scholars and practitioners. Each paper contributes to one or more dimensions of the framework's evaluation, addressing operational efficiency, scalability, customer satisfaction, and ecological impact. Collectively, they also reflect the iterative learning process that characterizes DSR, reinforcing the practical and theoretical contributions of this research.

The collection spans high-impact journals and major international conferences, ensuring wide dissemination and peer validation. It substantiates the thesis's commitment to bridging theory and practice while also demonstrating the framework's adaptability across contexts and its alignment with key sustainable development goals. A complete list of these publications is provided in the following pages.

Coopetition-Driven Excellence: Enhancing Product Quality and Innovation in Manufacturing SMEs through IoT-Enabled Networks

(*) Agostinho da Silva1[1,2], (**) Antonio J. Marques Cardoso[1]

[1] CISE - Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal
[2] CIGEST - Centre for Research in Management, Lisbon Business School, 1000-002 Lisboa, Portugal
(*) corresponding author: a.silva@zipor.com; (**) ajmcardoso@ieee.org

ABSTRACT

Purpose: This study explores the impact of coopetition—strategic collaboration amidst competition—on product quality standards in Small and Medium Enterprises (SMEs).

Methodology: Using a quantitative approach, the research analyzes improvements on KPIs related to product quality within a group of stone manufacturing SMEs engaged in Internet of Things (IoT)-enabled coopetition networks.

Findings: Results demonstrate a significant 10.8% improvement in product quality standards and a 41,1% increase in quality consistency after adopting coopetition practices. These enhancements highlight the potential of coopetition to boost standard quality in the manufacturing sector.

Research limitations: The study is specific to stone manufacturing SMEs, suggesting a need for further investigation into the long-term viability of coopetition and its applicability across various industries and global markets.

Originality/value: This research quantitatively substantiates the benefits of coopetition in enhancing product quality and consistency, offering a valuable perspective on strategic collaborations through IoT networks. It underscores coopetition's role in driving innovation and maintaining competitive advantage in the rapidly evolving manufacturing landscape, thereby providing a foundation for future studies and practical implementations in diverse industry settings.

Keywords: Coopetition, Stone Industry, SMEs, Quality, Internet of Things

INTRODUCTION

In Small and Medium Enterprises (SMEs), the quest for sustainable growth and a competitive edge in the market is ceaseless (von der Leyen, 2019). Amidst this quest, coopetition—strategically blending collaboration with competition—emerges as a novel paradigm poised to redefine success for SMEs (Xie *et al.*, 2023). This study is about coopetition technology-enabled networks, focusing on their impact on the quality standards of products developed by SMEs (Rouyre, Fernandez and Bruyaka, 2024). Despite the intuitive appeal of coopetition to spur innovation and operational excellence, the literature remains nascent in quantitatively demonstrating its effects, especially concerning product quality within the SMEs (European Commission, 2020). This research gap signals a compelling need for empirical evidence to validate the efficacy of coopetition in enhancing product quality and consistency.

This study uses quantitative methodology to analyze key performance indicators (KPIs) related to product quality. This approach facilitates an assessment of the innovation outcomes stemming from SMEs participation in coopetition networks (Arora and Brintrup, 2021). By bridging the existing research gaps in qualitatively assessing the coopetition impacts, this paper aims not only to contribute to the academic discourse on coopetition but also to provide actionable insights for SMEs contemplating the integration of coopetition into their strategic framework. In doing so, it aspires to pave the way for SMEs to harness the full capabilities of coopetition, fostering a competitive advantage in the rapidly evolving manufacturing sector.

THE ROLE OF THE INTERNET OF THINGS (IOT) IN ENHANCING COOPETITION

The Internet of Things (IoT) stands at the forefront of technological innovations transforming the industrial landscape. By interconnecting a vast array of devices, machinery, and systems through the internet (Latif *et al.*, 2023), IoT enables an unprecedented level of data collection, analysis, and automation. In coopetition, where strategic collaboration meets competition, IoT technologies play a pivotal role in amplifying the benefits and facilitating the processes that define this novel business strategy (Khan, Solvang and Yu, 2024).

IoT technologies may contribute to coopetition in several ways. First, they enhance operational transparency among competing firms by enabling real-time data sharing and communication (Mosch,

Majocco and Obermaier, 2023). This transparency fosters trust and collaboration, allowing SMEs to jointly identify opportunities for improvement, innovation, and efficiency gains without compromising their competitive edge (Büyüközkan and Göçer, 2018). For example, in the manufacturing sector, IoT-enabled machinery can share performance data with all parties in a coopetition network, helping to pinpoint bottlenecks, reduce downtime, and improve product quality standards (Khan, Solvang and Yu, 2024). Second, IoT facilitates a more dynamic and responsive production process. By leveraging IoT sensors and analytics, SMEs can better predict and adapt to market changes, customer preferences, and supply chain disruptions (Tjahjono *et al.*, 2017). This agility is crucial for maintaining high quality and consistency in products, as demonstrated by the significant improvements observed in the study's participating stone manufacturing SMEs. Moreover, IoT technologies support the development of new business models and innovation pathways central to coopetition (Yazdinejad *et al.*, 2023). They enable firms to collaboratively explore new markets, develop complementary products, and integrate services, thereby creating additional value for customers and differentiating themselves in the marketplace (Salih *et al.*, 2022).

METHODOLOGY

The study utilizes a case study methodology to explore the influence of coopetition on product quality in the industrial sector, emphasizing small and medium-sized enterprises (SMEs). At the heart of the analysis are key performance indicators (KPIs) that are directly linked to quality standards, specifically First Time Through (FTT) (Rohac and Januska, 2015), Customer Complaint Ratio (CcR) (Pakdil and Leonard, 2013), and On-Time Delivery Ratio (OtD) (Rohac and Januska, 2015). Through a quantitative examination of these KPIs, the research seeks to evaluate the efficacy of coopetition strategies deployed by SMEs. The aim is to uncover actionable insights that can significantly improve product quality and promote competitive growth within this sector.

First Time Through KPI (KPI_{FTT}) measures the proportion of products meeting quality and compliance standards on the first attempt, highlighting process efficiency and reducing waste (Table 1, Eq. 1). Customer Complaint Ratio (KPI_{CcR}), a vital metric, calculates the frequency of customer complaints, providing insights into product or service quality and customer service effectiveness (Table 1, Eq. 2). On-Time Delivery (KPI_{OtD}) ratio assesses the timeliness of deliveries to customers, reflecting a company's operational efficiency and reliability (Table 1, Eq. 3).

Table 1. Formulation of the Key Performance Indicators

Equation	KPIs	Description	Calculation
Eq.1	KPI_{FTT} (%)	FFT Quantitative KPI	$\sum_1^n\left(\frac{\sum parts\ produced - defective\ parts\ _{(daily)}}{\sum parts\ produced_{(daily)}}\right)\ .\ 100\%$
Eq.2	KPI_{CcR} (%)	MvA Quantitative KPI	$\sum_1^n\left(\frac{\sum total_complained_parts\ _{(daily)}}{\sum parts_delivered)_{(daily)}}\right).\ 100\%$
Eq.3	KPI_{OtD} (%)	PoR Quantitative KPI	$\sum_1^n\left(\frac{parts_delivered_on_time_{(daily)}}{\sum parts_delivered)_{(daily)}}\right)\ .\ 100\%$
Eq.4	$KPI_{(\sigma)}$	Dispersion KPI	$\sqrt[2]{\frac{\sum_1^n[KPI(FTT;CcR;OtD)_{(daily)} - \overline{KPI(FTT;CcR;OtD)_{(daily)}}]^2}{(Observations(FTT;CcR;OtD)_{(test\ period)})}}$

Analyzing these KPIs allows for a nuanced understanding of how coopetition networks influence product quality standards and consistency (Table 1, Eq. 4), offering actionable insights for SMEs. The study further integrates the concept of Innovation Outcomes (IO) (Bouncken and Fredrich, 2012) (Silva, Rabadão and Capela, 2020) to quantify the effects of innovative practices, like joining coopetition networks or adopting new technologies, on operational metrics (Table 2, Eq. 5 - 12).

Table 2. Formulation of the Innovation Outcomes

Equation	IOs	Description	Calculation
Eq.5	$IO_{(QTT)FFT}$	FFT Quantitative gains	$\frac{KPI_{(FTT_COO.N)} - KPI_{(FTT_CBP)})}{KPI_{(FTT_COO.N)}}.100\%$
Eq.7	$IO_{(\sigma)FFT}$	FFT Consistency gains	$\frac{KPI_{(\sigma FTT_COO.N)} - KPI_{(\sigma FTT_CBP)})}{KPI_{(\sigma FTT_COO.N)}}.100\%$
Eq.8	$IO_{(QTT)CcR}$	CcR quantitative gains	$\frac{KPI_{(CcR)CN.P} - KPI_{(CcR)CB.P)}}{KPI_{(CcR)CN.P}}.100\%$
Eq.9	$IO_{(\sigma)\ CcR}$	CcR Consistency gains	$\frac{KPI\sigma_{(CcR)CN.P} - KPI\sigma_{(CcR)CB.P})}{KPI\sigma_{(CcR)CN.P}}.100\%$
Eq.10	$IO_{(QTT)OtD}$	OtD Quantitative gains	$\frac{KPI_{(PoR)CN.P} - KPI_{(PoR)CB.P})}{KPI_{(PoR)CN.P}}.100\%$
Eq.11	$IO_{(\sigma)\ OtD}$	OtD Consistency gains	$\frac{KPI\sigma_{(OtD)CN.P} - KPI\sigma_{(OtD)CB.P}}{KPI\sigma_{(OtD)CB.P}}.100\%$
Eq.12	$IO_{(QTT)Quality}$	Quality Drivers Quantitative gains	$\frac{IO_{(QTT)FTT} + IO_{(QTT)CcR}\ IO_{(QTT)OtD}}{4}.100\%$

Through this methodology, the research aspires to contribute to the discourse on the Internet of Things (IoT), emphasizing the potential of these technologies to redefine industrial capabilities and foster value creation within manufacturing environments.

EMPIRICAL CONTEXT

The selection of the empirical context for this study aligns with the stringent criteria of quantitative research methodologies, as delineated by Johnson & Onwuegbuzie (2004). The decision regarding the specific sector and its companies was made through a pragmatic lens, emphasizing the necessity of data collection while also considering the financial implications of data gathering and analysis (Johnson and Onwuegbuzie, 2004). This approach ensured that the chosen context was feasible and pertinent, facilitating the collection of data that accurately reflects the impact of coopetition networks within the designated environment.

The study zeroes in on the Portuguese ornamental stone sector, exploring the influence of coopetition networks on determinants of quality standards in SMEs, focusing on service innovation (Silva and Pata, 2022). It capitalizes on the capabilities of an Internet of Things (IoT) platform, supported by funding from the European Union, to delve into quality enhancements and the evolving competitive dynamics within the manufacturing SME domain. This case study investigates the transformative potential of IoT in conventional sectors and sheds light on the strategic benefits of fostering competitive dynamics among SMEs.

Population and Sample

The dataset for this study was sourced from the Portuguese Association of the Mineral Resources Industry (ASSIMAGRA) in 2022, focusing on Portugal's Ornamental Stone (OS) sector. This sector plays a crucial role in Portugal's economy, employing over 16,600 people and exporting to 116 countries, making Portugal the eighth largest exporter globally in this market (Almeida and Silva, 2022). The introduction of an IoT system, supported by the European Union, marks a pioneering effort in this sector, enhancing digital connectivity and integrating competing firms into a cohesive coopetition framework (Silva, Rabadão and Capela, 2020).

For this research, three ornamental stone producers were selected to examine the IoT-enabled coopetition network's technological and competitive benefits. The study was conducted in two

phases: an initial assessment of operations and a subsequent evaluation post-IoT implementation. The research began with informal discussions with company directors, leading to formal participation and a confidentiality agreement to protect proprietary information. This agreement provided access to detailed company data, including analytical and financial records, order histories, and management and production process insights.

The research team closely monitored operational activities, ensuring data integrity and security. Data collected from digital machinery and databases underpins the analysis of the IoT-enabled cooperative network's impact, offering a comprehensive evaluation of its benefits for the ornamental stone producers involved.

Data Collection Procedures

This study employs a safe data collection methodology to assess operational efficiencies before and after the implementation of Coopetition Practices (CN.P), juxtaposed with the framework of Current Best Practices (CB.P). The methodology is structured around two 54-day periods, facilitating a detailed comparison between conventional operations and those enhanced by coopetition principles. To ensure confidentiality, participating companies were designated as "A", "B", and "C":

Phase 1 - Current Best Practices (CB.P): This initial phase, spanning from April 17th, 2023, to June 10th, 2023, captured existing operational metrics under the CB.P model. They established a foundational baseline during this period, enabling a subsequent comparison with coopetition practices.

Phase 2 - Coopetition Production Practices (CN.P): Following the baseline assessment, this phase, from September 9th, 2023, to November 14th, 2023, focused on the integration of coopetition. This approach emphasized fostering collaborative and competitive dynamics among the participant companies, using the same duration and methodology as the CB.P phase to ensure a balanced comparison.

Data management protocols were stringently followed, and confidentiality agreements were in place to guarantee the secure and uniform processing of data for comprehensive analysis. This systematic approach is designed to highlight the operational and competitive advantages of embedding

collaboration practices within SMEs, particularly in the Ornamental Stone sector, thereby offering insights into the tangible benefits of such strategic collaborations.

RESULTS AND DISCUSSION

The study's analysis, drawing from data under Current Best Practices (CB.P) and Coopetition Technology-Enabled Networks, reviewed ten performance indicators (KPIs) to assess the impact of coopetition on quality standards. This evaluation, with results detailed in Table 5, contrasts the performance under CB.P and coopetition, providing insights into coopetition's influence on various quality standards dimensions.

Key Performance Indicators (KPIs)

KPI_{FTT} is a metric indicative of operational quality within manufacturing organizations. According to data presented in Table 3, the average daily production was reported at 369.9 parts, with 31.3 of those failing to meet the initial quality criteria. Consequently, the KPI_{FTT} was calculated at 90.9%, demonstrating that, on average, 90.9% of the parts manufactured met the quality standards on their first pass. The same FTT KPI was observed as companies transitioned to adopting Coopetition network practices, as detailed in Table 4. This consistency suggests that integrating coopetition strategies keeps the quality output intact.

Table 3. Data packages collected in Current Best Practices (CB.P)

Data ID	Description	Current Best Practices (CB.P)	Average daily
Data 1	Parts Produced	∑parts_produced(CB.P)	369.9
Data 2	Defective Parts Found	∑defective_parts(CB.P)	31.3
Data 3	Total complained parts	∑ total_complained_parts	15
Data 4	Parts delivered	∑ parts_delivered	339
Data 5	Parts delivered on time	∑ parts_delivered_on_time	240
Data 6	Parts delivered	∑ parts_delivered	339

Table 4. Data packages collected in Coopetition Network Practices (CN.P)

Data ID	Description	Coopetition Networks (CN.P)	Average daily
Data 7	Parts produced	∑parts_produced(CN.P)	454.3
Data 8	Defective parts	∑defective_parts(CN.P)	38.5
Data 9	Total complained parts	∑ total_complained_parts	17
Data 10	Parts delivered	∑ parts_delivered	454
Data 11	Parts delivered on time	∑ parts_delivered_on_time	358
Data 12	Parts delivered	∑ parts_delivered	454

The KPI_{CCR} measures the proportion of customer complaints relative to the total number of products provided within a given timeframe. Under the Current Best Practices, the analysis showed an average of 17 parts rejected daily from 339 dispatched, resulting in a KPI_{CCR} of 6.3%, as outlined in Table 5.

Table 5. KPI assessment in Current Practices (CN.P) and Coopetition Practices (CN.P)

KPIs	**CB.P**	**CN.P**
KPI - First Time Through (%)	KPI_{FTT}: 90.9 % $KPI_{(\sigma)FTT}$: 0.0235	KPI_{FTT}: 90.9 % $KPI_{(\sigma)FTT}$: 0.0169
KPI – Customer Complain Ratio	KPI_{CcR}: 6.3 % $KPI_{(\sigma)CcR}$: 0.03	KPI_{CcR}: 4.4 % $KPI_{(\sigma)\ CcR}$: 0.02
KPI - On-Time Delivery	KPI_{OtD}: 67.1 % $KPI_{(\sigma)OtD}$: 0.05	KPI_{OtD}: 77.5 % $KPI_{(\sigma)OtD}$: 0.03

Transitioning to the Coopetition Production Practices led to an increase in daily production to 454 parts, with rejections holding steady at 17. This escalation in production, while maintaining the number of rejections, highlights the efficiency of scaling up under coopetition. Remarkably, this transition saw the KPI_{CCR} improve to 4.4%, indicating a significant reduction of 1.9% in customer complaints, as demonstrated in Figure 1.

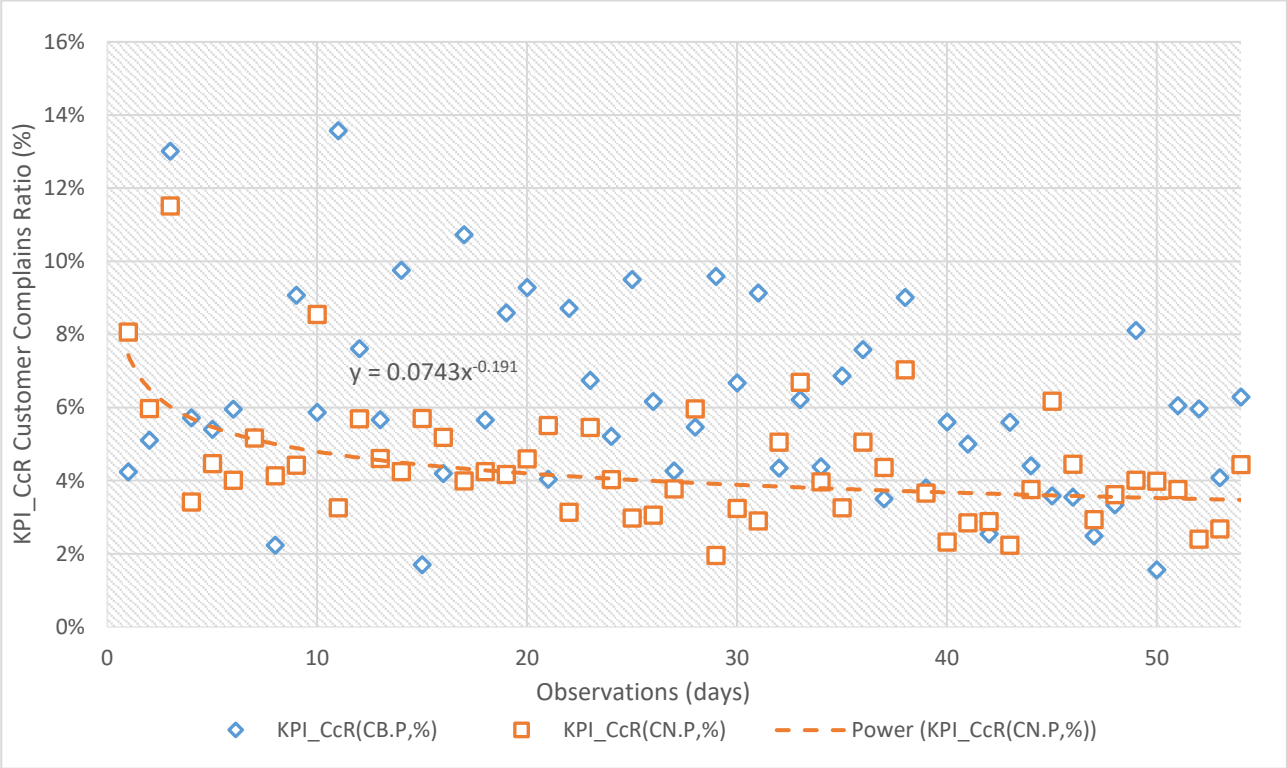


Figure 1. Trend in Customer Complaint Ratio for Stone SMEs Transitioning to Coopetition Networks

Additionally, the variance indicator $KPI(\sigma)_{CcR}$ was recorded at 0.001, signaling a decrease in variability and, thus, a boost in production consistency and stability.

The On-Time Delivery (KPI_{OTD}) measures the percentage of products or services delivered to customers within the agreed-upon delivery timeline. Under the Current Best Practices, analysis shows an on-time delivery of 240 out of 339 parts dispatched daily, resulting in a KPI_{OTD} of 67.1%. This figure is based on data in Table 3. The shift to Coopetition Production Practices markedly enhanced the On-Time Delivery Ratio. With consistent production levels, the number of parts delivered on time rose to an average of 358 parts per day, boosting the KPI_{OTD} to 77.5%. This improvement demonstrates the CN.P strategy's effectiveness in increasing delivery reliability to customers.

Innovation Outcomes (IOs)

Innovation Outcomes (IOs) are crucial for evaluating the concrete benefits derived from participation in cooperative competition, or coopetition, networks, demonstrating marked enhancements in key factors influencing quality standards of the stone SMEs. Table 6 offers a detailed examination of

these benefits, presenting measurable progress and associated reductions in variability across different innovation outcomes.

Table 6. Innovation Outcomes assessment: Transition from CB.P to CN.P

Innovation Outcome (IO)	**Quantitative Gains ($IO_{(QTT)}$)**	**Consistency Gains ($IO_{(\sigma)}$)**
IO - First Time Through (%)	$IO_{(QTT)FFT}$: 0.00 %	$IO_{(\sigma)RMY}$: 28.18%
IO - Cust. Complaint Ratio	$IO_{(QTT)\ CcR}$: 29.3 %	$IO_{(\sigma)CcR}$: 44.9 %
IO – On Time Delivery	$IO_{(QTT)OtD}$: 15.6 %	$IO_{(\sigma)OtD}$: 43.9 %
IO - Quality	$IO_{(QTT)Quality}$: 18,8 %	$IO_{(\sigma)Cust.\ Satisf.\ Det}$: 41,1 %

The analysis highlights explicitly the Customer Complaint Ratio (CCR) within the context of IOs, revealing a direct positive impact on customer satisfaction. This is evidenced by a significant 29.3% reduction in customer rejections of parts and a 44.9% improvement in the uniformity of production processes. Such enhanced consistency underscores the effective streamlining and increased predictability that coopetition networks bring to the manufacturing sector. It underscores the strategic value of embracing a model of collaborative competitiveness, pointing to its ability to refine operational procedures and, by extension, bolster overall customer satisfaction.

The On-Time Delivery Ratio has seen a remarkable increase of 15.6%, indicating significant strides in optimizing production capabilities. This development highlights the advantages of weaving coopetition— the fusion of cooperation and competition— into the fabric of operational strategies. The resulting synergy fosters a highly predictable and efficient operational landscape. Coopetition grants access to a pooled repository of expertise, technological advancements, and capabilities, enhancing individual firms' productivity and elevating the entire network's collective competitiveness.

Further analysis of innovation outcomes reveals a positive impact on KPIs related to quality standards, showcasing an 18.8% improvement as stone SMEs integrate coopetition practices, as depicted in Figure 2. This improvement is amplified by a 41.1% rise in the uniformity of quality enhancements. These findings highlight the significant role of coopetition in expanding operational capacity and scale, supporting a strategic shift towards these hybrid competitive-collaborative networks as a pivotal move to enhance operational capabilities and consolidate market standing.

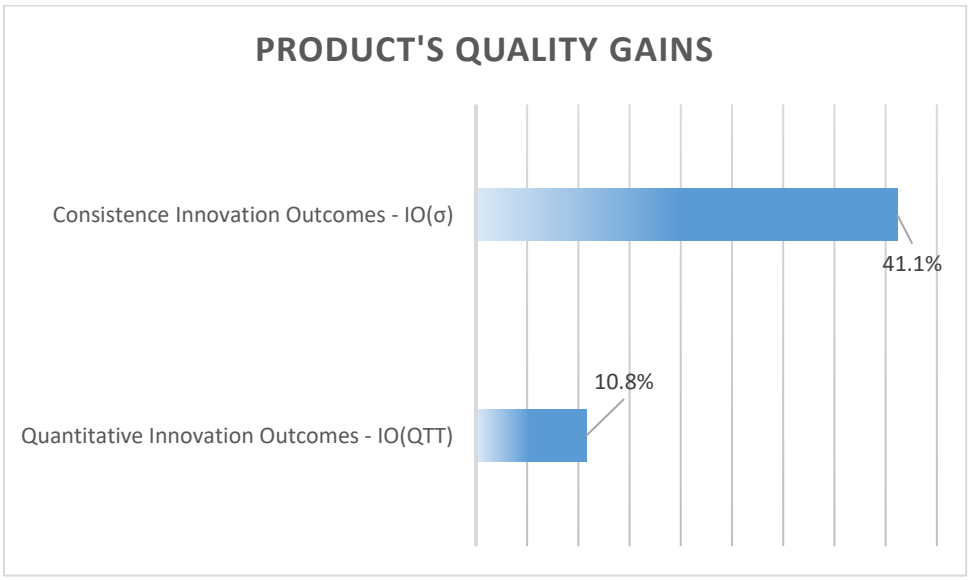


Figure 2. Enhancing Product Quality through the Adoption of Coopetition Network Practices

Figure 3. Product Quality Innovation Outcomes from the transition to coopetition network practices.

This evidence compellingly demonstrates the strategic value of coopetition as a framework that effectively meets customer expectations regarding quality and ensures consistent and predictable performance across various metrics. The insights detailed in Table 6 robustly affirm the substantial advantages of engaging in coopetition networks. These networks foster a unique blend of collaboration and competition, creating an optimal environment for OS SMEs—specifically stone companies—to thrive. Through strategically sharing strengths and resources among peers, stone companies within these networks can significantly enhance the quality of their products, elevate the product's quality, and minimize costs.

CONCLUSION

The study examined the impact of coopetition—a synergistic amalgamation of cooperation and competition—on the quality standards of products within the stone SME sector. An analysis of KPIs from Current Best Practices and Coopetition IoT-Enabled Networks demonstrated that coopetition seems to boost product quality. Key findings, such as improvements in the First Time Through metric, the Customer Complaints Ratio, and the On-Time Delivery Ratio, underscore the substantial benefits that coopetition networks offer to manufacturing processes. Incorporating coopetition into

operational frameworks fosters an environment conducive to enhancing product quality, optimizes production capabilities, streamlines operations, and minimizes costs. This strategic integration positions stone SMEs for increased market competitiveness and sustainable growth, highlighting the pivotal role of coopetition in creating a dynamic and innovative manufacturing landscape.

The conducted study, while insightful, is subject to certain limitations. Its focus on the stone SME sector might restrict the applicability of its conclusions to other industries, which may exhibit different characteristics and competitive dynamics. The emphasis on quantitative metrics to assess quality standards may overlook broader impacts of coopetition, such as its effects on organizational culture, innovation, and employee morale. Furthermore, the study presupposes a stable competitive environment, potentially overlooking industry shifts, technological advancements, or market changes that could influence the effectiveness and sustainability of coopetition strategies over time.

Future research should broaden its scope to assess the impact of coopetition across various industries, enhancing the generalizability of the current study's findings. Longitudinal studies would provide invaluable insights into the long-term effects of coopetition, especially considering evolving technologies and fluctuating market conditions. Moreover, integrating IoT within coopetition networks also presents challenges, including the need for robust cybersecurity measures, data privacy considerations, and the management of technology integration across different firms. Addressing these challenges is essential for harnessing the full potential of IoT in enhancing coopetition strategies.

REFERENCES

Almeida, I. and Silva, A. (2022) 'The circularity endeavour in the Ornamental Stone sector', in Symposium, C. I. M. (ed.) *Reconfiguring global supply chains in the face of continued disruption: towards new design rules and capabilities*. Cambridge International Manufacturing Symposium.

Arora, S. and Brintrup, A. (2021) 'How does the position of firms in the supply chain affect their performance? An empirical study', *Applied Network Science*, 6(1), p. 19. doi: 10.1007/s41109-021-00364-9.

Bouncken, R. and Fredrich, V. (2012) 'Coopetition: Performance Implications and Management Antecedents', *International Journal of Innovation Management*, 16(05), p. 1250028. doi: 10.1142/S1363919612500284.

Büyüközkan, G. and Göçer, F. (2018) 'Digital Supply Chain: Literature review and a proposed framework for future research', *Computers in Industry*. Elsevier B.V., 97, pp. 157–177. doi: 10.1016/j.compind.2018.02.010.

European Commission (2020) *Unleashing the full potential of European SMEs*. doi: 10.2775/296379.

Johnson, R. B. and Onwuegbuzie, A. J. (2004) 'Mixed Methods Research: A Research Paradigm Whose Time Has Come', *Educational Researcher*, 33(7), pp. 14–26. doi: 10.3102/0013189X033007014.

Khan, N., Solvang, W. D. and Yu, H. (2024) '4 . 0 Technologies in Spare Parts Warehousing in the Oil and Gas'.

Latif, G. *et al.* (2023) 'Learning at Your Fingertips: An Innovative IoT-Based AI-Powered Braille Learning System', *Applied System Innovation*, 6(5), p. 91. doi: 10.3390/asi6050091.

von der Leyen, U. (2019) 'A Union that strives for more. My agenda for Europe : political guidelines for the next European Commission 2019-2024', *EU publications*, p. 24. Available at: https://ec.europa.eu/commission/sites/beta-political/files/political-guidelines-next-commission_en.pdf%0Ahttps://op.europa.eu/en/publication-detail/-/publication/43a17056-ebf1-11e9-9c4e-01aa75ed71a1.

Mosch, P., Majocco, P. and Obermaier, R. (2023) 'Contrasting value creation strategies of industrial-IoT-platforms – a multiple case study', *International Journal of Production Economics*, 263, p. 108937. doi: https://doi.org/10.1016/j.ijpe.2023.108937.

Pakdil, F. and Leonard, K. M. (2013) 'Criteria for a lean organisation: development of a lean assessment tool', *International Journal of Production Research*, 52(15), pp. 4587–4607. doi: 10.1080/00207543.2013.879614.

Rohac, T. and Januska, M. (2015) 'Value Stream Mapping Demonstration on Real Case Study', *Procedia Engineering*, 100, pp. 520–529. doi: 10.1016/j.proeng.2015.01.399.

Rouyre, A., Fernandez, A.-S. and Bruyaka, O. (2024) 'Big problems require large collective actions: Managing multilateral coopetition in strategic innovation networks', *Technovation*, 132, p. 102968. doi: https://doi.org/10.1016/j.technovation.2024.102968.

Salih, K. O. M. *et al.* (2022) 'A Comprehensive Survey on the Internet of Things with the Industrial Marketplace', *Sensors*, 22(3), p. 730. doi: 10.3390/s22030730.

Silva, A. and Pata, A. (2022) 'Value Creation in Technology Service Ecosystems - Empirical Case Study', in Machado, J. et al. (eds) *Innovations in Industrial Engeneering II*. Cham: Springer International Publishing, pp. 26–36. doi: doi.org/10.1007/978-3-031-09360-9_3.

Silva, A., Rabadão, C. and Capela, C. (2020) 'Towards Industry 4.0 | A case study of BIM deployment in ornamental stones sector', *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, 67, p. 24535.

Tjahjono, B. *et al.* (2017) 'What does Industry 4.0 mean to Supply Chain?', *Procedia Manufacturing*. Elsevier B.V., 13, pp. 1175–1182. doi: 10.1016/j.promfg.2017.09.191.

Xie, Q. *et al.* (2023) 'Coopetition and organizational performance outcomes: A meta-analysis of the main and moderator effects', *Journal of Business Research*. Elsevier Inc., 154(October 2022), p. 113363. doi: 10.1016/j.jbusres.2022.113363.

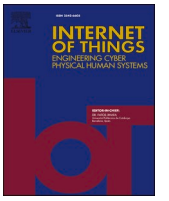
Yazdinejad, A. *et al.* (2023) 'An ensemble deep learning model for cyber threat hunting in industrial internet of things', *Digital Communications and Networks*, 9(1), pp. 101–110. doi: 10.1016/j.dcan.2022.09.008.

Internet of Things 28 (2024) 101408

Contents lists available at ScienceDirect

Internet of Things

journal homepage: www.sciencedirect.com/journal/internet-of-things



Enhancing customer satisfaction through IIoT-Enabled coopetition: Strategic insights and impacts

Agostinho da Silva [a,b,*], Antonio J. Marques Cardoso [a]

[a] CISE - Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal
[b] CIGEST - Business & Economics School, Lisboa, Portugal

ARTICLE INFO

Keywords:
Coopetition
Network
Sme
IIoT
Customer satisfaction

ABSTRACT

This research investigates the significant role of Industrial Internet of Things (IIoT) to enable Coopetition Network Practices (CNPs) in enhancing the performance of Small and Medium Enterprises (SMEs) within the context of global digital supply chains. Employing a quantitative approach, our study reveals that CNPs contribute to a noTable 51.0 % improvement in factors determining customer satisfaction. This underscores the strategic importance of blending competition with collaboration to refine production processes and align with consumer expectations. Additionally, the research presents a remarkable 69.1 % boost in operational consistency and reports substantial progress in manufacturing flexibility and the value-to-weight ratio, witnessing increases of 125.8 % and 33.2 %, respectively. These improvements are pivotal in optimizing production resources, which in turn, have led to a 29.3 % decrease in customer complaints and a 15.6 % rise in on-time delivery rates. Conversely, a slight decline in the consistency of the value-to-weight ratio was observed, pointing to potential areas for future research. The findings decisively show that CNPs offer concrete advantages by enhancing customer satisfaction determinants and operational efficiency in SMEs. The paper advocates for future studies to directly measure customer satisfaction and to formulate actionable guidelines for the effective implementation of coopetition strategies. This proposed research direction aims to provide solutions to the manufacturing sector's emerging challenges, thereby promoting competitive advantage and growth in the digital era.

1. Introduction

In the contemporary global marketplace, customer satisfaction has become a pivotal driver of success, particularly for manufacturing Small and Medium-sized Enterprises (SMEs) [62]. Unlike larger corporations, these SMEs increasingly engage directly with customers, making customer satisfaction an aspirational goal and a strategic imperative [15]. Achieving high levels of customer satisfaction impacts profitability, enhances market positioning, and ensures long-term business sustainability [14].

The correlation between customer satisfaction and repeat business is well-documented; satisfied customers are significantly more likely to return for additional purchases [52]. This repeat patronage is crucial as it reduces the costs of acquiring new customers and fosters enduring customer loyalty [14]. Loyal customers provide a steady revenue stream through frequent and larger purchases and represent a cost-effective source of long-term profitability for SMEs. Furthermore, satisfied customers often act as brand ambassadors,

* Corresponding author.
E-mail addresses: a.silva@zipor.com (A. da Silva), ajmcardoso@ieee.org (A.J.M. Cardoso).

https://doi.org/10.1016/j.iot.2024.101408

Available online 20 October 2024
2542-6605/© 2024 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

recommending products and services to their network, thus generating valuable word-of-mouth promotion [57]. For SMEs, which typically operate with limited advertising budgets compared to their larger counterparts, this organic advocacy can be instrumental in driving growth and expanding their customer base (M. [16]).

1.1. Problem statement

SMEs are often regarded as the backbone of Europe's economy, crucial in job creation, innovation, and wealth generation. These enterprises contribute over 20 % of the EU27′s total value-added and employ more than 35 million people, underscoring their significant economic impact [21]. Historically, SMEs distributed their products directly in local markets, where they could interact closely with customers or indirectly by supplying larger companies that handled distribution to broader markets. However, in the era of globalization, SMEs are compelled to compete on a global scale, facing stiff competition in local and distant markets [20].

Recent studies highlight a pressing challenge: manufacturing SMEs often need help to meet customer satisfaction demands in global markets [41]. This issue is exacerbated by their limited resources and smaller size, which traditionally posed barriers to scaling their operations [50]. To overcome these limitations, there has been growing advocacy for forming manufacturing alliances, enabling SMEs to collaborate and collectively satisfy customer needs [60].

A promising approach to this collaboration is "coopetition"—a strategic fusion of cooperation and competition [42]. This concept is gaining traction for its potential to balance businesses' competitive and collaborative dynamics [9]. Typically, successful coopetition networks revolve around a central, often larger, firm that anchors the collaborative efforts [32]. Leading companies such as Microsoft and Amazon exemplify this model; they dominate their respective networks and achieve significant financial gains, with profitability margins exceeding 29 % [44]. Conversely, smaller firms often rely on these giants to various extents, limiting their independence and strategic flexibility.

While large firms thrive in coopetition networks, the sustainability of such networks without a dominant "keystone" player is questionable, often leading to short-term failures. This dependency presents a unique challenge for manufacturing SMEs. Their inherently competitive nature can hinder the collaborative efforts required for digital growth and sustained customer satisfaction. The Economist Intelligence Unit [51] further emphasizes that European SMEs' reluctance to collaborate stifles their digital aspirations. It indicates a need for strategic frameworks that promote coopetition aligned with SMEs' distinct capabilities and market positions [51]. Given these challenges, how can coopetition be facilitated among manufacturing SMEs, and what are the potential gains in customer satisfaction can be achieved through such collaborations?

1.2. Underlying potential solutions

In addressing the core issue that unmet customer value expectations can lead to dissatisfaction and potential exclusion from the digital marketplace, the Service-Dominant (S-D) Logic literature offers invaluable insights [30]. According to S-D Logic, value does not inherently reside in products or services but is co-created through dynamic interactions between various actors, such as providers and customers [57]. Value materializes through the application of services, being uniquely tailored and perceived by the beneficiary. Thus, firms offer value propositions that customers actualize within their specific contexts through engagement and integration [29].

Understanding value from the S-D Logic perspective compels companies to focus on how they can facilitate value creation rather than merely supplying goods or services. In this vein, emergent and integrated technologies such as the Internet of Things (IoT) are seen as catalysts for a new era in which technology profoundly impacts ecosystems [55]. Empirical research highlights the transformative potential of IoT-based innovations in enabling new service offerings (M. [1]). Furthermore, the progression of the Industrial Internet of Things (IIoT) beyond conventional IoT frameworks signifies a significant leap in operational efficiency and intelligence, fostering global connectivity and facilitating direct device-to-device communication (Abbas [63]).

1.3. Research objective

This research explores how a coopetition network, enabled by IIoT, can enhance innovation outcomes tailored to customer satisfaction. To achieve this, the study is grounded in the S-D Logic and hypothesizes that such a coopetition network, facilitated by IIoT technologies, can significantly improve the ability of SMEs to innovate in ways that meet and exceed customer expectations.

The research will begin by contextualizing coopetition and technological innovation for value creation within the S-D Logic paradigm. The methodology for testing this hypothesis involves implementing an experimental IIoT-enabled coopetition network. It will include selecting empirical fields and companies, defining metrics and key performance indicators (KPIs) to assess innovation outcomes, and establishing data collection and performance analysis procedures.

A thorough quantitative analysis will follow, evaluating the impact of coopetition on customer satisfaction determinants before and after implementing an experimental IIoT-enabled coopetition network. The discussion section will focus on the findings, examining how coopetition practices influence innovation outcomes related to customer satisfaction determinants within participating SMEs. Finally, the Conclusion will summarize the key findings, clearly assessing whether the hypothesis— that an IIoT-enabled coopetition network significantly enhances customer satisfaction— is accepted or refused. The conclusion will also acknowledge the study's limitations and suggest future research directions for understanding and implementing coopetition networks.

2. Service-Dominant (S-D) logic perspective on coopetition

The S-D Logic, introduced by Vargo and Lusch [56], revolutionizes the traditional view of value creation [56]. It shifts the focus from goods to services, emphasizing that value is co-created through interactions between providers and customers rather than being embedded in products. This framework highlights that businesses offer value propositions that customers realise through contextual engagement [29].

Recent expansions of S-D Logic introduce the concept of service ecosystems, where value emerges from dynamic, systemic interactions among various actors [58]. In service ecosystems, technologies like the IoT play a dual role as both tools (operand resources) and active facilitators (operant resources) of value co-creation [25]. IoT and its industrial counterpart, the IIoT, enhance connectivity and operational efficiency [12], creating new service opportunities and fostering intricate networks (A. [63]).

The concept of "coopetition"—combining cooperation and competition—is essential in the S-D Logic framework, especially for SMEs. This approach enables firms to share knowledge and resources while competing, creating a collaborative environment that enhances innovation and value creation [9]. Successful coopetition often hinges on the presence of a central "keystone" player that anchors the network . However, in SME-centric networks, maintaining balance and sustainability without a dominant player presents a significant challenge [44].

S-D Logic advocates for SMEs to focus on their specialized competencies—like knowledge and skills—to facilitate service exchanges and create value collaboratively [37]. This perspective is crucial for SMEs to navigate competitive landscapes by integrating into broader service ecosystems and leveraging coopetition to enhance their offerings and market presence [34].

For SMEs, adopting a value co-creation perspective means recognizing the importance of participating in service ecosystems where coopetition can drive innovation and customer satisfaction. By blending competitive and collaborative strategies, SMEs can access new resources and markets, differentiating themselves through unique service propositions [46]. This integration facilitates their survival and growth in a rapidly evolving economic environment, underscoring the importance of cooperative strategies in sustaining competitive advantage [34].

The governance of service ecosystems through institutional arrangements ensures that despite competitive tensions, mutual value creation remains a focus. These shared norms, rules, and practices orchestrate the cooperative and competitive dynamics, promoting a sustainable and adaptable network [43]. Integrating S-D Logic into coopetition frameworks provides a strategic pathway for SMEs to innovate and enhance customer satisfaction. The theoretical underpinnings of S-D Logic offer a lens to understand how SMEs can leverage coopetition to co-create value and thrive in the digital marketplace. This literature review sets the stage for further exploration into the practical implementation and impact of IIoT-enabled coopetition networks on SMEs' innovation and customer satisfaction outcomes.

3. Value Co-creation through IIoT

Technological advancement, especially within intelligent technologies, has redefined the value creation landscape. Degani (2017) describes technology as "operant," meaning "something that works" or is "engaged in action," reflecting its autonomous capabilities to generate algorithms and undertake initiatives independently [19]. This concept aligns with the rapid evolution of technologies that perform actions without direct human intervention, marking a substantial leap in technological capabilities [10].

3.1. Technological integration in S-D logic

S- Logic places technology at the core of innovation, highlighting its transformative role in revolutionizing service delivery, innovation, and management [13]. S-D Logic explores how technology influences service innovation and value co-creation within ecosystems, serving as both enablers and drivers of innovation (Melissa [2]).

In coopetition, technology-based strategic networks are vital for fostering collaboration among diverse stakeholders [11]. This perspective aligns with S-D Logic's view of technology as both an operand (enabler) and operant (initiator) resource in value creation [8]. Integrating technology with human interactions, value propositions, and shared information paves the way for innovation and value creation [36].

3.2. The role of IoT and IIoT

S-D Logic recognizes emerging technologies like the IoT as ushering in a new era where technology profoundly impacts ecosystems [55]. IoT-based innovations foster new service offerings and enable companies to extend their service portfolios to include advanced options such as remote control and predictive maintenance [40]. This enhances operational efficiency and opens new avenues for value co-creation within coopetition frameworks [45].

The IIoT extends the capabilities of IoT, revolutionizing industrial operations with unprecedented efficiency and intelligence [33]. IIoT enhances global connectivity and enables direct device-to-device communications, significantly improving long-term operational efficiency and adaptability (Abbas [63]). For instance, IIoT frameworks for prognostic health management improve prediction accuracy and operational efficiency in industrial applications [26]. Additionally, the integration of edge computing in IIoT systems optimizes real-time processing and resource sharing, maximizing efficiency and social welfare [33].

4. Methodology

The hypothesis for this research posits that integrating the IIoT within coopetition frameworks empowers SMEs to innovate and co-create value more effectively, resulting in higher levels of customer satisfaction. This hypothesis explores the transformative potential of IIoT-enabled networks in reshaping competitive dynamics among SMEs. By fostering collaboration beyond traditional boundaries, these networks facilitate mutual value creation, allowing firms to leverage shared resources and capabilities to meet better and exceed customer expectations. The study seeks to demonstrate how IIoT technology can catalyze a synergistic environment where cooperation and competition coexist among SMEs, driving substantial enhancements in customer satisfaction determinants. The hypothesis suggests that such a network improves customer satisfaction through enhanced value co-creation determinants.

Given the multifaceted nature of customer satisfaction, which is influenced by production processes, logistics, and overall business activities, a comprehensive and structured case study approach is employed to test this hypothesis. A case study methodology includes the following steps:

1. Identify and establish quantitative metrics to evaluate the impact of the IIoT-enabled coopetition network on key manufacturing-side determinants of customer satisfaction. This involves selecting and developing specific KPIs that measure how the implementation of the IIoT-enabled coopetition network influences crucial aspects of customer satisfaction from a manufacturing perspective.
2. Select a suitable group of SMEs to participate in the experimental pilot IIoT-enabled coopetition network. The selection criteria include their readiness, willingness to engage in collaborative frameworks.
3. Establish the experimental pilot IIoT-enabled coopetition network among the selected SMEs. This process includes establishing the essential IIoT infrastructure to support secure and efficient data sharing, resource integration, and collaborative operations. Key steps involve implementing hardware and software components to ensure each SME can seamlessly connect to a common IIoT artefact. Ensuring robust security protocols are in place for safe and reliable data exchange among the network participants. They are facilitating the integration of shared resources, such as machinery, inventory, and expertise, to optimize collective operational efficiency and enable real-time communication and coordination through the IIoT artefact. It allows SMEs to work together more effectively and respond promptly to dynamic market demands. By connecting each company to this centralized IIoT platform, the pilot network will enhance its ability to coopetition.
4. Gathering data on the impact of the IIoT-enabled coopetition network on the defined customer satisfaction determinants. This step requires utilizing the developed metrics to collect data on KPIs.
5. Conduct a thorough quantitative analysis using the collected data to assess the hypothesis. It involves evaluating the changes in KPIs and exploring how integrating IIoT within the IIoT-enabled coopetition network enhances customer satisfaction determinants.
6. Analyze the results to understand how IIoT-enabled coopetition networks influence the manufacturing-side determinants of customer satisfaction. Examine the interplay between operational improvements and customer satisfaction, providing insights into how coopetition and IIoT technologies drive value co-creation.

Through this case study, the research aims to test the hypothesis and explore the effects of IIoT-enabled coopetition networks on the customer satisfaction determinants of SMEs. By focusing on quantitative metrics and empirical data collection, the study provides a robust framework for assessing the tangible impacts of these coopetition frameworks. This approach ensures that the findings are rooted in concrete, measurable outcomes, offering clear and actionable insights into the advantages of integrating IIoT technologies within coopetition networks.

5. Customer satisfaction determinants: Metrics, KPIs, and innovation outcomes

In the industrial sector, customer satisfaction stems from production processes, logistics, and overall business activities [59]. Under the S-D Logic, satisfaction is not just about delivering products but about how value is co-created through dynamic interactions within the service ecosystem [28]. S-D Logic focuses on how businesses facilitate value co-creation through efficient logistics, customization capabilities, and reliable delivery [5]. Key customer satisfaction drivers include streamlined logistics, ensuring timely, accurate deliveries, and enhancing customer satisfaction by providing seamless and reliable service [7]. Tailoring products to meet specific customer needs fosters engagement and satisfaction by delivering personalized solutions [27]. Consistently meeting deadlines builds trust and reinforces customer confidence in the business's dependability [57].

5.1. Streamlining logistics for better customer satisfaction

Optimizing logistics is essential for enhancing customer satisfaction, particularly by designing and delivering lighter products. Under the S-D Logic framework, customer satisfaction is co-created through the efficiency and effectiveness of service interactions, including how products are transported and delivered [57].

S-D Logic emphasizes value co-creation through seamless interactions within the service ecosystem. Logistics is not merely about moving goods but how these processes enhance the overall customer experience [31]. Lighter products simplify the supply chain, making handling more accessible and reducing logistical complexity. This results in faster, more reliable deliveries, directly contributing to a more satisfying customer experience [4].

For example, consider a machinery component redesigned to be lighter. This lighter component simplifies the loading and

unloading process, reduces the handling time and effort required from logistics partners, and accelerates the delivery process. These improvements lead to quicker turnaround times and faster deliveries, which enhance customer satisfaction by ensuring that products reach them promptly and in good condition. Furthermore, reducing handling complexity minimizes the risk of damage during transportation, ensuring that products arrive intact and meet customer expectations.

Additionally, producing lighter products often leads to a smaller carbon footprint, as less energy is required for transportation. This environmental benefit aligns with the values of eco-conscious consumers who prioritize sustainability [7]. By offering lighter, eco-friendly products, companies can cater to this growing market segment, boosting customer satisfaction and fostering loyalty. This alignment with customer values is crucial to value co-creation in S-D Logic [23].

Companies can use the value-weight ratio (KPIVwR) to evaluate the effectiveness of logistics in contributing to customer satisfaction. This KPI (KPI_{VwR}) is assessed by dividing the product's value by weight, as shown in Eq. (1). This metric provides insights into a product's value relative to its weight [18]. It is particularly relevant in sectors where shipping costs significantly impact the total cost to the customer and the product's perceived value [35].

$$\text{KPIVtW} = \sum_{1}^{54} \left(\frac{total_transport_costs_{(daily)}}{total_value_of_goods_{(daily)}} \right) 100\% \tag{1}$$

Products with a higher KPI_{VwR} indicate a greater value per unit of weight, enhancing customer satisfaction by minimizing shipping costs and improving the overall value proposition. For instance, in the fitness industry, lightweight yet durable gym equipment reduces shipping costs while maintaining high functionality. It lowers customer expenses and enhances their experience by providing superior performance without high shipping fees.

5.2. Enhancing customer satisfaction through customization and flexibility

In today's competitive market, customer satisfaction is deeply influenced by a company's ability to offer customized products (Z. [17]). From the S-D Logic perspective, this customization fosters value co-creation by providing personalized solutions that resonate with individual customer needs [54]. Customization aligns closely with the S-D Logic view, where value is co-created through personalized interactions rather than standardized products. When businesses can tailor their offerings to meet specific customer preferences, they enhance the customer experience, making customers feel valued and understood (Z. [17]). For instance, a gym offering equipment customized to user specifications can deliver a more engaging and satisfying experience than generic, one-size-fits-all products [57]. Customization not only improves customer satisfaction but also streamlines operations. By producing items tailored to each customer's requirements, companies align production more closely with demand, reducing the need for extensive inventories and minimizing waste [24]. This efficiency simplifies logistics and reduces the complications and costs of managing excess stock. For example, a manufacturer that builds gym equipment to order avoids overproduction and the related costs of unsold inventory.

To succeed in customization, companies need high manufacturing flexibility. Manufacturing Flexibility (KPI_{Flex}) measures a company's ability to adapt its production processes to create various products without significant additional costs or delays, as shown in Eq. (2). High KPI_{Flex} allows businesses to quickly switch production lines to accommodate different product variations, which is crucial for responding to shifting customer demands.

$$\text{KPIFLEX} = \sum_{1}^{54} \left(\frac{total_parts_customized_{(daily)}}{total_parts_produced_{(daily)}} \right) 100\% \tag{2}$$

Emphasizing customization and manufacturing flexibility enables businesses to align more closely with customer needs, streamline operations, and enhance value co-creation. This approach improves customer satisfaction and aligns with the S-D Logic view that value is created through interactive, personalized service experiences [38].

5.3. Enhancing customer satisfaction through on-time delivery

In today's fast-paced world, customers expect prompt and reliable delivery of their purchases. Consistently meeting or exceeding these expectations is crucial for enhancing customer satisfaction [47]. From the S-D Logic perspective, on-time delivery is vital to value co-creation, reflecting how well a company fulfils its promises and supports the customer's overall experience [5]. On-time delivery is more than just meeting a deadline; it represents a company's operational and supply chain effectiveness. Reliable delivery reduces customer anxiety and builds trust, making customers feel assured that they will receive their products as expected [24]. For instance, a gym equipment supplier known for punctual deliveries will satisfy existing customers and attract new ones through its reputation for reliability.

Delays can cause significant inconvenience, leading to customer frustration and dissatisfaction. Conversely, consistent on-time delivery reinforces the perception of a company's dependability. Efficient delivery processes indicate streamlined operations, which improve overall performance and reduce costs. This operational excellence becomes a competitive advantage, enhancing customer loyalty and encouraging repeat business.

Companies use the On-time Delivery (KPI_{OtD}) ratio to assess delivery performance, which measures the percentage of orders delivered on or before the promised date (Eq. (3)). A high KPI_{OtD} ratio reflects a company's strong performance in meeting delivery commitments, directly correlating with higher customer satisfaction. Customers value punctual delivery as it meets their expectations

and enhances their overall experience with the company.

$$\text{KPIOtD} = \sum_{1}^{54} \left(\frac{total_parts_delivered_on_time_{(daily)}}{total_parts_delivered_{(daily)}} \right). 100\% \quad (3)$$

Achieving high KPI_{OtD} values consistently builds customer trust. Over time, customers rely on the company's ability to meet its delivery promises, fostering long-term relationships and loyalty. In competitive markets, this reliability becomes a key differentiator. Clear communication about delivery times, supported by a strong KPI_{OtD}, reinforces the company's reputation for dependability and enhances customer confidence.

On-time delivery is integral to the value co-creation [55], as it aligns with the customer's expectations and needs, contributing to a positive service experience. Reliable delivery enhances trust, a cornerstone of long-term customer relationships and loyalty, essential components of value co-creation in S-D Logic [40]. This focus on punctual delivery strengthens the customer experience, fortifies the company's market position, and promotes long-term success [23]. Emphasizing timely delivery through consistently monitoring KPI_{OtD} allows businesses to thrive in a competitive landscape and fosters enduring customer relationships.

5.4. Measuring customer satisfaction through the absence of product complaints

One effective way to gauge customer satisfaction is by monitoring the absence of product complaints [39]. This metric directly reflects how well products meet or exceed customer expectations [53]. Within the S-D Logic framework, a lack of complaints indicates successful value co-creation, showing that products reliably fulfil their intended purposes and satisfy customer needs [6].

The No Complaint Ratio (KPI_{NcR}) measures the percentage of products delivered without generating customer complaints (Eq. (4)). A high KPI_{NcR} signals that products consistently meet quality standards and align with customer expectations. High KPI_{NcR} values indicate that products perform as promised, minimizing customer issues and enhancing satisfaction. Delivering complaint-free products builds trust and fosters long-term customer loyalty, encouraging repeat purchases and positive recommendations.

$$\text{KPINcR} = \sum_{1}^{54} \left(\frac{1 - total_complained_parts_{(daily)}}{total_parts_delivered_{(daily)}} \right) 100\% \quad (4)$$

Monitoring the KPI_{NcR} provides valuable insights into customer satisfaction and product quality. High KPI_{NcR} values reflect products that meet customer needs without issues, aligning with the S-D Logic perspective of value co-creation. By minimizing complaints, companies can enhance customer trust, improve satisfaction, and strengthen their reputation for reliability and quality.

5.5. Innovation outcomes

According to Lusch & Nambisan [34], Innovation Outcomes (IO) evaluate the effects of innovations on KPIs, revealing how these changes enhance operational metrics [34]. This S-D Logic approach highlights the role of innovation in improving competitiveness and sustainability within the digital supply chain [49]. Incorporating the IO concept into this analysis is crucial for assessing how new practices, like joining coopetition networks or integrating new technologies, affect company performance (Eq. (5)).

$$\text{IO} = \frac{KPI_{CN.P} - KPI_{CB.P}}{KPI_{CN.P}}.100\% \quad (5)$$

By incorporating Innovation Outcomes into the analysis, this methodology provides a comprehensive framework to evaluate the impact of coopetition enabled by IIoT on customer satisfaction determinants [22]. These metrics shed light on innovative practices' stability, sustainability, and transformative potential. Embracing the S-D Logic view, this approach underscores how integrating IIoT can drive significant improvements in manufacturing efficiencies and customer satisfaction, ultimately fostering value co-creation in a digital and interconnected world.

6. Empirical context

This investigation is grounded in the systematic principles of quantitative research, focusing on Portugal's Ornamental Stone (OS) sector. The selection of this sector is strategic, aiming to provide a relevant and practical context for studying the dynamics and benefits of IIoT-enabled coopetition networks among SMEs. The OS sector's significant economic role and characteristics make it an exemplary case for understanding how digital technologies and collaborative frameworks can drive customer satisfaction and innovation.

Portugal's status as the second-largest exporter of ornamental stone on a per capita basis underscores its significant impact and competitive edge in the international market [48]. This prominence is a testament to the sector's capacity to compete globally and adapt to changing market demands. According to the Portuguese Association of the Mineral Resources Industry (Assimagra) for 2021, this sector is a significant contributor to the Portuguese economy, employing over 16,600 people and exporting to 116 countries, plays a vital role in generating private sector employment, particularly in Portugal's interior regions, which supports local economies and contributes to regional development, and despite facing various challenges, the sector has demonstrated resilience and steady growth, positioning Portugal as the eighth largest exporter of ornamental stone globally [3].

Focusing on the OS sector in Portugal, this study aims to provide valuable insights into the transformative potential of IIoT-enabled collaboration networks. The sector's significant economic role, global competitiveness, and adaptability make it an ideal context for

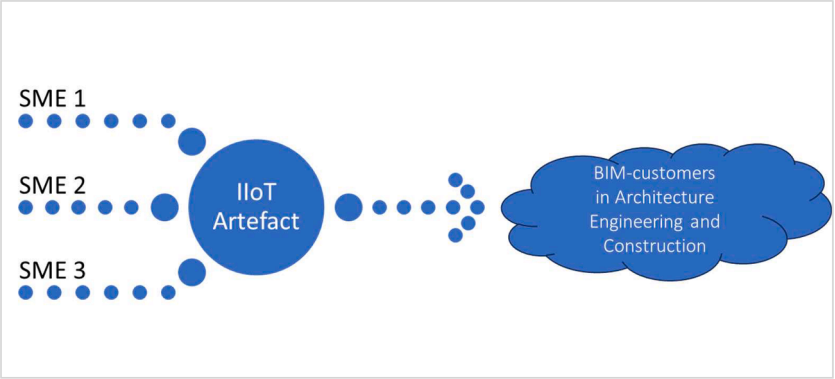


Fig. 1. The IIoT-Enabled coopetition network for ornamental stone SMEs.

exploring how digital and collaborative strategies can drive customer satisfaction and innovation within SMEs. The findings are expected to offer practical implications for SMEs leveraging advanced technologies and collaborative frameworks to enhance their market position and operational capabilities.

6.1. Implementation of an IIoT-enabled coopetition network

Implementing an IIoT-enabled coopetition network in the OS sector significantly advances value enhancement through digital innovation. This initiative, supported by substantial financial backing from the participating companies, has facilitated the development of a pilot IIoT-enabled coopetition network, pivotal for this research.

Building on the foundational work of Silva et al. [49], which demonstrated how IoT systems could connect OS SMEs to the cyber market, an advanced IIoT system has been developed [49]. This new artefact aligns with S-D Logic principles and emphasizes value co-creation within service ecosystems (Melissa [2]). It leverages cutting-edge technological capabilities to revolutionize stone processing, foster a collaborative environment, and ensure: (1) Flexible Network Participation - companies can join or leave the network freely, maintaining their autonomy while actively contributing to the ecosystem. This flexibility supports dynamic collaboration without long-term commitment constraints; (2) Resource Sharing - network members can access and offer resources such as stock and machinery, promoting reciprocal exchanges. This resource sharing optimizes utilization and enhances operational efficiency across the network; (3) Confidential Commercial Opportunities - each member's ongoing business opportunities are kept confidential, preserving competitive integrity and ensuring that sensitive commercial information remains private; (4) BIM Interoperability - the system guarantees compatibility with Building Information Modeling (BIM) systems used by architects, ensuring seamless integration and coordination with external stakeholders in construction and design processes; (5) Secure Communication - utilizes OPC-UA protocols to ensure secure and reliable data exchanges within the network. This secure communication framework protects proprietary information and maintains trust among network participants; and (6) Promoting Value Creation through Coopetition – the IIoT artefact enhances coopetition by integrating the shop floors of competing manufacturers into a unified network, fostering value creation for all stakeholders. By pooling resources and capabilities from rival firms, the system creates an environment where value co-creation is maximized. This collaborative approach ultimately delivers superior services to customers by combining the strengths of each participating company.

For this research, a prototype of the IIoT artefact was deployed with three ornamental stone producers. This pilot project aimed to test the hypothesis that an IIoT-enabled coopetition network enhances customer satisfaction through improved value co-creation determinants. The implementation allowed these SMEs to experience enhanced digital connectivity and collaboration within their operations, demonstrating how IIoT technologies can facilitate seamless integration and cooperative innovation. Fig. 1 illustrates this digital connectivity and the operational synergies achieved through the network.

The approach started with informal discussions with the managing directors of the selected companies, followed by formal invitations to participate in the study. A confidentiality agreement was established to protect the companies' proprietary data, client information, and competitive practices. With the consent of these leaders, the research team gained access to extensive data, including financial documents, order histories, and insights into management and production processes.

To ensure data integrity and confidentiality, the research team monitored operational activities daily, recording quantitative data from digital machinery and databases. This meticulous data collection process provided a solid foundation for analyzing the impact of the IIoT-enabled coopetition network on the participating companies, offering a comprehensive assessment of the network's effects on their operations.

6.2. Data collection

To assess the transition from Current Best Practices (CB.P) to Coopetition Networks Practices (CN.P), this study employs a structured data collection approach across two 54-day periods. This comparative framework enables a detailed analysis of KPIs before

Table 1
Summarized data collected in current best practices (CB.P).

Data ID	Description	Current Best Practices (CB.P)	Average (daily)
Data 1	Total transport costs (€)	total_transport_costs	1724
Data 2	Total value of goods sold €)	total_value_of_goods_sold	8463
Data 3	Total parts customized	total_parts_customized	52
Data 4	Parts produced	total_parts_produced	339
Data 5	Total complained parts	total_complained_parts	15
Data 6	Parts delivered	total_parts_delivered	339
Data 7	Parts delivered on time	total_parts_delivered_on_time	240
Data 8	Parts delivered	total_parts_delivered	339

Table 2
Summarized data collected in coopetition network practices (CN.P).

Data ID	Description	Coop. Network Practices (CN.P)	Average (daily)
Data 1	Total transport costs (€)	total_transport_costs	1376
Data 2	Total value of goods sold €)	total_value_of_goods_sold	10,395
Data 3	Total parts customized	total_parts_customized	157
Data 4	Parts produced	total_parts_produced	454
Data 5	Total complained parts	total_complained_parts	17
Data 6	Parts delivered	total_parts_delivered	454
Data 7	Parts delivered on time	total_parts_delivered_on_time	358
Data 8	Parts delivered	total_parts_delivered	454

Table 3
KPI and IO assessment.

KPIs	CB.P	CN.P	IOs
Value to Weight Ratio	$KPI_{VtW} = 20{,}1\ \%$	$KPI_{VtW} = 13{,}4\ \%$	$IO_{VtW} = 33{,}2\ \%$
Flexibility	$KPI_{Flex} = 15{,}4\ \%$	$KPI_{Flex} = 34{,}8\ \%$	$IO_{Flex} = 125{,}8\ \%$
On-Time Delivery	$KPI_{OtD} = 67{,}1\ \%$	$KPI_{OtD} = 77{,}5\ \%$	$IO_{OtD} = 15{,}6\ \%$
No Complains Ratio	$KPI_{NcR} = 93{,}7\ \%$	$KPI_{NcR} = 95{,}6\ \%$	$IO_{NcR} = 29{,}3\ \%$

and after implementing an IIoT-enabled coopetition network.

From April 17th, 2023, to June 10th, 2023, the first phase focused on documenting the operational metrics under CB.P. During this period, each company operated independently, managing their production and delivery processes without collaboration. This phase aimed to establish a baseline of traditional practices, providing a reference for later comparisons as detailed in Table 3.

The second phase, from September 9th, 2023, to November 14th, 2023, marked the transition to CN.P, where companies engaged in an IIoT-enabled coopetition network. The CN.P represents a strategic approach that blends competition and cooperation among companies. By sharing resources and leveraging IIoT technology, companies can enhance their operational efficiencies and innovate collaboratively. This phase encouraged coopetition, allowing companies to utilize each other's strengths and technological capabilities to co-create value within a secure and adaptable framework. The structured sharing and secure communication practices fostered an environment where companies could innovate and improve collectively, benefiting from the combined advantages of competition and cooperation. During this phase, the following practices were implemented:

1. Companies within the network confidentially shared and accessed each other's available resources, such as stock and machinery. This practice enabled more efficient resource use and fostered mutual support among network members.
2. Each company could join or leave the network anytime, providing flexibility and maintaining autonomy while participating in the collaborative ecosystem.
3. All interactions and data exchanges were conducted through secure OPC-UA protocols [26], ensuring confidentiality and protecting proprietary information.
4. Companies gave and gained access to resources based on a reciprocal model, enhancing cooperation while preserving competitive integrity.
5. The network was designed to integrate seamlessly with Building Information Modeling (BIM) systems used by architects [61], enhancing coordination across different stages of production and delivery.

Adhering to the confidentiality agreement, all data was meticulously stored and handled to ensure privacy and security. This rigorous data management process facilitated a comprehensive and secure analysis, enabling a robust evaluation of the impact of CN.P on operational efficiencies.

By contrasting operational metrics between CB.P and CN.P, from data collected, the study aimed to reveal the tangible benefits of

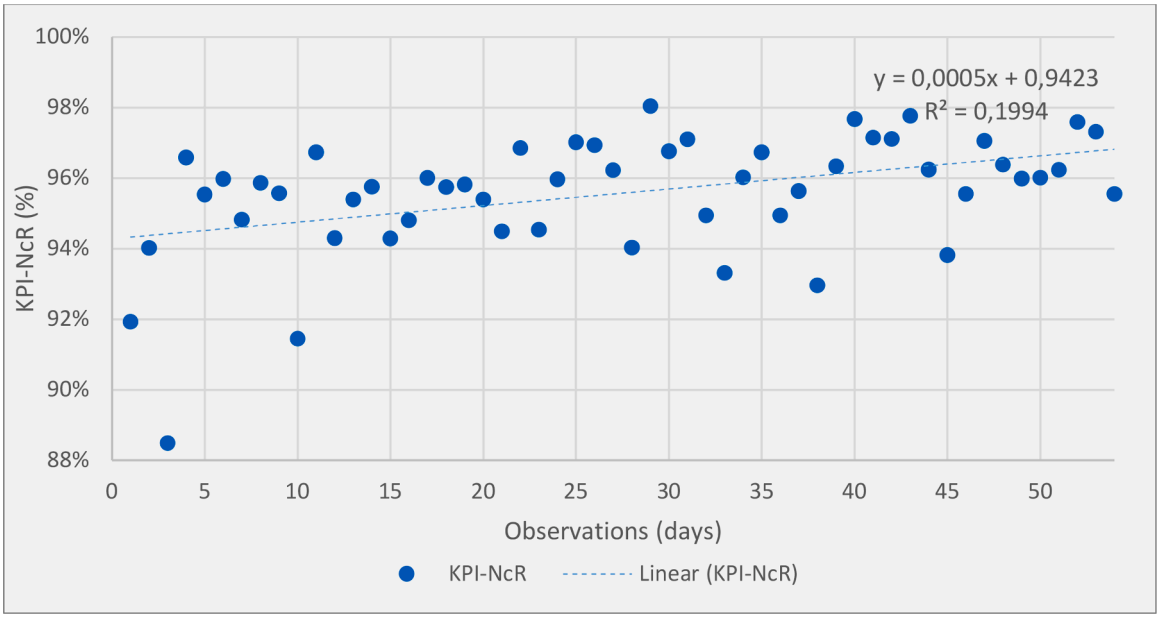


Fig. 2. Trend in KPI_{NcR} Under coopetition networks.

coopetition practices within SMEs.

7. Results and discussion

This section presents a detailed analysis of data collected from CB.P and CN.P. Table 1 captures the baseline metrics under state-of-the-art practices. In contrast, Table 2 outlines the metrics observed after implementing the IIoT-enabled coopetition network. Table 3 synthesizes these findings, offering a comparative analysis that illuminates the multifaceted effects of coopetition on customer satisfaction determinants.

7.1. KPI assessment

Value-to-Weight Ratio (KPI_{VtW}): Under CB.P, as detailed in Table 1, SMEs experienced an average daily transportation cost of €1724 while managing products valued at approximately €8463. This results in a KPI_{VwR} of 20.1 %, which reflects the cost efficiency of transporting these products relative to their value. This percentage indicates how effectively the transportation costs are balanced against the value of the goods being moved, showcasing the SMEs' ability to manage logistics costs efficiently under the CB.P framework. In contrast, Table 2 shows that after implementing the CN.P, the average daily transportation cost decreased to €1373, with the products' value rising to about €10,391. This results in a KPI_{VwR} of 13.4 %, reflecting a significant reduction in the cost per product transported. The decrease in KPI_{VwR} from 20.1 % to 13.4 % under CN.P signifies a marked improvement in transportation cost efficiency. This reduction is attributed to the coopetition strategies, where firms collaboratively optimized their logistics to meet market demands more competitively.

Flexibility (KPI_{FLEX}): Under the CB.P framework, data from SMEs indicated that, on average, 52 parts were customized daily out of a total production of 339 parts. This yields a KPI_{Flex} of 15.4 %, representing the portion of the production that could be customized each day (Table 1). This metric highlights the limited capacity of SMEs to tailor their production to specific customer requirements under traditional operational practices. Transitioning to CN.P brought substantial improvements. The daily average of customized parts increased dramatically to 157, with the total daily production rising to 454 parts. This significant boost in customization was achieved without changing existing work schedules, showcasing the distinct advantages of adopting CN.P practices. Through collaborative efforts on specific production processes, competitors enhanced their ability to effectively address diverse customer demands. As a result, the KPI_{Flex} surged to 38.8 % (Table 2), demonstrating a remarkable improvement in the capability to customize products. This increase underscores how coopetition allows firms to leverage shared resources and collective knowledge, enabling them to respond more agilely to market demands. The rise in KPI_{Flex} from 15.4 % to 38.8 % highlights the transformative impact of coopetition networks in enhancing operational flexibility and meeting customer expectations.

On-Time Delivery (KPI_{OtD}): Under the CB.P framework, data showed that an average of 240 parts out of 339 parts delivered daily were on time. This performance yields a KPI_{OtD} of 67.1 %, reflecting the proportion of timely deliveries under traditional practices (Table 1). Transitioning to the CN.P strategy resulted in a significant improvement in the On-Time Delivery Ratio. The average number of parts delivered on time increased to 358 parts per day. Despite maintaining the same overall production capacity, the KPI_{OtD} rose to 77.5 % (Table 2), demonstrating a marked enhancement in delivery reliability due to coopetition practices. The increase in KPI_{OtD} from

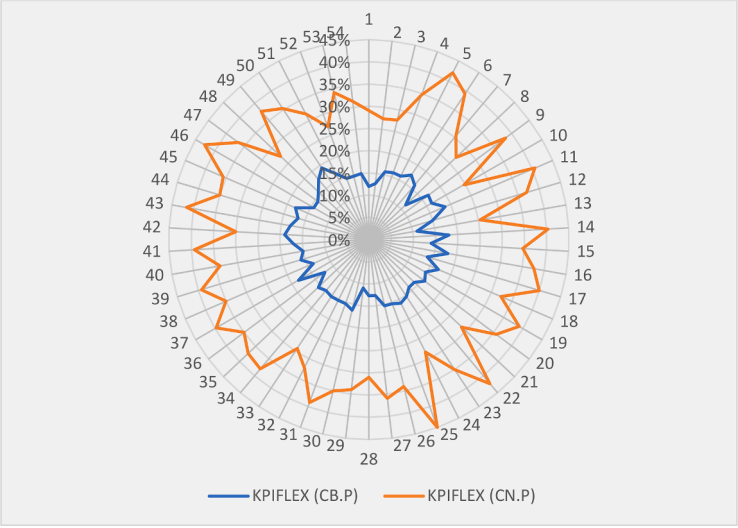


Fig. 3. Quantitative gains in flexibility achieved through coopetition networks.

67.1 % to 77.5 % under the CN.P strategy indicates a substantial improvement in the reliability of deliveries. This enhancement shows how coopetition enables firms to optimize their delivery processes and better meet customer expectations.

No Complaint Ratio (KPI_{NcR}): Data analysis within the CB.P framework, as presented in Table 1, indicates an average daily part without complaints of 324 out of 339 parts dispatched. It translates to a KPI_{NcR} of 73,7 %, as detailed in Table 1. The shift to the CN.P strategy, according to the information in Table 2, led to an increase in the daily average of manufactured parts to 454, with 17 still being rejected. This increase, linked to the heightened production volume, is a typical outcome of scaling up production. Notably, despite the surge in production volume, the KPI_{NcR} improved to 95,6 %, representing a positive shift of 1.9 % in customer complaints across the companies, as illustrated in Fig. 2.

The linear regression analysis of the KPI_{NcR} under the CN.P shows a positive trend, as indicated by the slope of the trend line. It implies that over time, there is a gradual increase in the proportion of products delivered without complaints, reflecting continuous improvement in product quality and customer satisfaction. The slope of 0.0005 suggests a very slight increase in the No Complaint Ratio over time. Specifically, for each unit increase in time or observation number, the KPI_{NcR} increases by 0.05 %. It indicates that, as time progresses, there is a minor but steady improvement in the proportion of products delivered without complaints. Though modest, the upward trend reflects a positive movement towards better quality and customer satisfaction over the studied period. The y-intercept of 0.9423 indicates that the estimated KPI_{NcR} is 94.23 % on the starting day. Moreover, An R^2 value of 0.1994 indicates that the time or observation number explains approximately 19.94 % of the variability in the KPI_{NcR}. In practical terms, this means that the slight upward trend over time is only partially explained by the time progression, implying that other operational or external factors may significantly impact the KPI_{NcR}.

7.2. IO assessment

Innovation Outcomes highlight significant improvements in customer satisfaction determinants and operational efficiencies. Table 3 offers a detailed summary of these enhancements, showcasing quantifiable advancements and reduced variability for each innovation outcome.

Innovation Gains in Flexibility: A notable finding from this study is the increase in Flexibility within the coopetition framework. As shown in Fig. 3, the flexibility in operations surged by 125.8 % after adopting coopetition practices.

This substantial and consistent improvement over the 54 days, denoted as IO_{Flex}, signifies the enhanced ability of firms to customize parts. Coopetition enables companies to delegate the production of components that fall outside their core expertise to other members within the network. This collaborative approach fosters increased production capacity and greater customization capabilities, as firms can leverage their peers' specialized skills and resources. By working together, companies can more effectively meet diverse customer needs and enhance operational flexibility through shared efforts.

Value-to-Weight Ratio Enhancement: Examining the IO_{VtW} among SMEs in coopetition networks, there is an improvement of 33.2 %, highlighting the competitive advantages of coopetition. This enhancement translates to significant reductions in transportation costs per part delivered. Companies can optimize transport and elevate overall delivery performance by aligning their production with other network members. This strategic adaptation helps firms mitigate costs amidst fluctuating market demands and evolving consumer expectations, demonstrating the transformative potential of coopetition within the manufacturing sector.

Improved On-Time Delivery: The KPI_{OtD} experienced an uplift of 15.6 %, reflecting enhanced utilization of existing production capacities under coopetition. This IO_{OtD} progress underscores how the synergy of collaboration and competition cultivates a highly predictable operational environment. Firms in a coopetition network benefit from a collective pool of expertise, capabilities, and

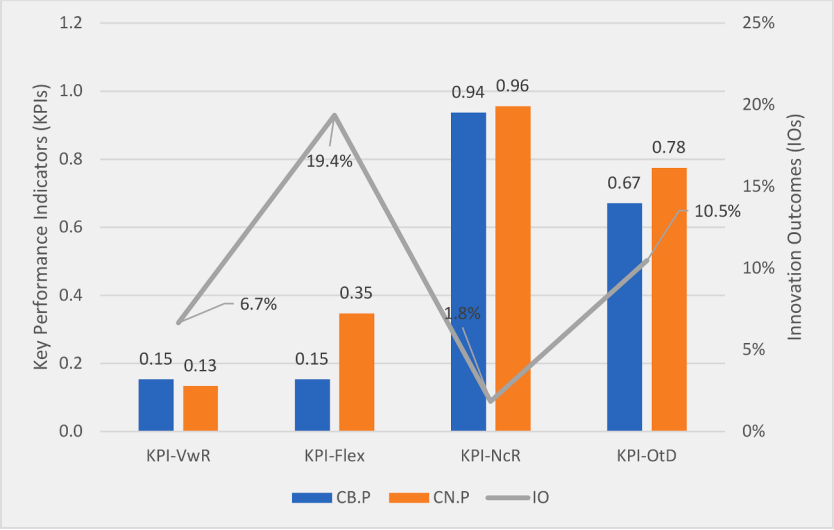


Fig. 4. Customer satisfaction determinants evaluation following the transition to CN.P.

technological innovations, boosting individual and collective market competitiveness. Coopetition practices thus represent a strategic approach to enhancing production output and achieving operational excellence.

Reduction in Customer Complaints: The IONcR analysis indicates a direct improvement in customer satisfaction, with a noTable 29.3 % decrease in the number of parts refused by customers. Such enhancements illustrate the streamlined practices and predictability introduced by coopetition networks, highlighting their strategic importance in fostering customer satisfaction and operational excellence.

Comprehensive Gains in Customer Satisfaction: The average assessment of innovation outcomes demonstrates a substantial impact on customer satisfaction determinants, with a **9.6 %** improvement following the adoption of coopetition network practices as illustrated in Fig. 4.

These results highlight the transformative impact of coopetition on customer satisfaction determinants, advocating for a strategic shift towards collaborative and competitive networks. Coopetition emerges as a powerful approach for SMEs, enabling them to harness collective strengths and navigate the complexities of today's market. By leveraging the combined strengths and resources within these networks, companies can significantly enhance critical determinants of customer satisfaction. The synergy created by blending collaboration with competition fosters an environment ripe for innovation and adaptability to market changes. This dynamic interaction accelerates operational improvements and enhances the ability of SMEs to meet and exceed customer expectations.

8. Conclusions

This research explored the impact of CN.P enabled by the IIoT on customer satisfaction determinants within SMEs in the ornamental stone sector. Grounded in S-D Logic, the study hypothesized that an IIoT-enabled coopetition network significantly enhances customer satisfaction by improving manufacturing flexibility, on-time delivery, and product quality KPIs.

To test this hypothesis, a detailed comparative analysis was conducted between **CB.P** and the innovative CN.P framework. The results confirmed that adopting an IIoT-enabled coopetition network leads to substantial improvements in customer satisfaction determinants. Specifically, the study found significant enhancements in operational flexibility, reduced delivery times, and higher product quality through collaborative efforts facilitated by the IIoT network. Additionally, the research addressed how coopetition can be facilitated among manufacturing SMEs and the potential gains in customer satisfaction achievable through such collaborations. The IIoT-enabled network provided a platform for these firms to integrate their resources effectively, allowing them to meet customer needs more efficiently and consistently. Overall, the study underscores the transformative potential of IIoT-enabled coopetition networks in fostering innovation and operational excellence, thereby significantly boosting customer satisfaction in SMEs.

The insights gained from this research underscore the transformative potential of IIoT-enabled coopetition networks for ornamental stone SMEs. The alignment with S-D Logic principles provides a robust framework for understanding how these networks can foster a more adaptive and resilient business environment.

While this study demonstrates the significant benefits of IIoT-enabled coopetition networks in the ornamental stone sector, several limitations must be acknowledged. The focus on a specific industry and the short-term analysis may limit the broader applicability of the findings. Additionally, the small sample size and some data variability suggest further validation and refinement.

For future research, exploring the long-term impacts of coopetition networks across diverse industries will provide deeper insights into their strategic value. Examining the role of digital transformation and advanced technologies can further enhance the efficacy of these networks. More extensive studies with more varied participants and extended timelines will help generalize the benefits and address the complexities of coopetition practices in dynamic markets.

Declaration of funding statement

Nothing to declare.

CRediT authorship contribution statement

Agostinho da Silva: Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Antonio J. Marques Cardoso:** Writing – review & editing, Writing – original draft, Visualization, Visualization, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

[1] M. Akaka, S. Vargo, Extending the context of service: from encounters to ecosystems, J. Serv. Mark. 29 (6–7) (2015) 453–462, https://doi.org/10.1108/JSM-03-2015-0126.
[2] Akaka, Melissa, Schau, H., & Vargo, S. (2023). How Practice Diffusion Drives IoT Technology Adoption and Institutionalization of Solutions in Service Ecosystems. *Proceedings of the Annual Hawaii International Conference on System Sciences, 2023-Janua*(March), 1427–1435. https://doi.org/10.24251/HICSS.2023.178.
[3] I. Almeida, A. Silva, The circularity endeavour in the Ornamental Stone sector, in: C.I.M. Symposium (Ed.), Reconfiguring Global Supply Chains in the Face of Continued disruption: Towards New Design Rules and Capabilities, Cambridge International Manufacturing Symposium, 2022.
[4] N. Ameen, A. Tarhini, A. Reppel, A. Anand, Customer experiences in the age of artificial intelligence, Comput. Hum. Behav. 114 (June 2020) (2021) 106548, https://doi.org/10.1016/j.chb.2020.106548.
[5] M.a. An, S.L. Han, Effects of experiential motivation and customer engagement on customer value creation: analysis of psychological process in the experience-based retail environment, J. Bus. Res. (2020) 1–9, https://doi.org/10.1016/j.jbusres.2020.02.044. *February*.
[6] C. Antonelli, G. Orsatti, G. Pialli, The effects of the limited exhaustibility of knowledge on firm size and the direction of technological change, J. Technol. Transf. 48 (4) (2023) 1359–1385, https://doi.org/10.1007/s10961-022-09969-3.
[7] B. Babayigit, F. Gürbüz, B. Denizhan, Logistics performance index estimating with artificial intelligence, Int. J. Shipp. Transp. Logist. 16 (3/4) (2023) 360, https://doi.org/10.1504/IJSTL.2023.129876.
[8] S. Barile, P. Piciocchi, C. Bassano, J. Spohrer, M.C. Pietronudo, *Re*-defining the role of artificial intelligence (AI) in wiser service systems, Adv. Intell. Syst. Comput. 787 (2019) 159–170, https://doi.org/10.1007/978-3-319-94229-2_16.
[9] P. Bicen, S. Hunt, S. Madhavaram, Coopetitive innovation alliance performance: alliance competence, alliance's market orientation, and relational governance, J. Bus. Res. 123 (October 2020) (2021) 23–31, https://doi.org/10.1016/j.jbusres.2020.09.040.
[10] U. Bodkhe, S. Tanwar, K. Parekh, P. Khanpara, S. Tyagi, N. Kumar, M. Alazab, Blockchain for Industry 4.0: a comprehensive review, IEEe Access. 8 (2020) 79764–79800, https://doi.org/10.1109/ACCESS.2020.2988579.
[11] R. Bouncken, A. Kumar, J. Connell, A. Bhattacharyya, K. He, Coopetition for corporate responsibility and sustainability: does it influence firm performance? Int. J. Entrep. Behav. Res. 30 (1) (2024) 128–154, https://doi.org/10.1108/IJEBR-05-2023-0556.
[12] H. Boyes, B. Hallaq, J. Cunningham, T. Watson, The industrial internet of things (IIoT): an analysis framework, Comput. Ind. 101 (December 2017) (2018) 1–12, https://doi.org/10.1016/j.compind.2018.04.015.
[13] C. Breidbach, P. Maglio, A service science perspective on the role of ICT in service innovation, ECIS 2015 (2015) 1–9. *May 2015*.
[14] E.V. Bueno, T.B.B. Weber, E.L. Bomfim, H.T. Kato, Measuring customer experience in service: a systematic review, Serv. Ind. J. 39 (11–12) (2019) 779–798, https://doi.org/10.1080/02642069.2018.1561873.
[15] Camarinha-matos, L., Afsarmanesh, H., & Antonelli, D. (2019). Collaborative Networks and Digital Transformation. In L. M. Camarinha-Matos, H. Afsarmanesh, & D. Antonelli (Eds.), *IFIP Advances in Information and Communication Technology* (Vol. 568, Issue October). Springer International Publishing. https://doi.org/10.1007/978-3-030-28464-0.
[16] M. Chen, C. Lv, X. Wang, L. Li, P. Yang, A critical review of studies on coopetition in educational settings, Sustain. (Switzerland) 15 (10) (2023) 1–18, https://doi.org/10.3390/su15108370.
[17] Z. Chen, X. Ming, E. Vareilles, O. Battaia, Modularization of smart product service: a framework integrating smart product service blueprint and weighted complex network, Comput. Ind. 123 (2020) 103302, https://doi.org/10.1016/j.compind.2020.103302.
[18] B. Debnath, A.B.M.M. Bari, M.M. Haq, Jesus de, D.A. Pacheco, M.A. Khan, An integrated stepwise weight assessment ratio analysis and weighted aggregated sum product assessment framework for sustainable supplier selection in the healthcare supply chains, Supply Chain Analytics 1 (2023) 100001, https://doi.org/10.1016/j.sca.2022.100001.
[19] A. Degani, C.V. Goldman, O. Deutsch, O. Tsimhoni, On human–machine relations, Cognition, Technology & Work 19 (2) (2017) 211–231, https://doi.org/10.1007/s10111-017-0417-3.
[20] S. Destefanis, O.W. Maietta, F. Mazzotta, L. Parisi, Firm survival and innovation: direct and indirect effects of knowledge for SMEs, Econ. Innovation and New Technol. (2023) 1–29, https://doi.org/10.1080/10438599.2023.2263371.
[21] Di Bella, L., Katsinis, A., Lagüera-González, J., Odenthal, L., Hell, M., & Lozar, B. (2023). *Annual Report on European SMEs 2022/2023*.
[22] F. Diekert, L. Nøstbakken, A. Richter, Control activities and compliance behavior—Survey evidence from Norway, Mar. Policy. 125 (June 2020) (2021), https://doi.org/10.1016/j.marpol.2020.104381.
[23] Elo, J., Lumivalo, J., Tuunanen, T., & Vargo, S.L. (2024). Enabling Value Co-Creation in Partner Collaboration Ecosystems: an Institutional Work Perspective. *Proceedings of the 57th Hawaii International Conference on System Sciences, March*. https://hdl.handle.net/10125/106412.
[24] A. Francis, A. Thomas, Exploring the relationship between lean construction and environmental sustainability: a review of existing literature to decipher broader dimensions, J. Clean. Prod. 252 (2020), https://doi.org/10.1016/j.jclepro.2019.119913.
[25] N.N. Hartmann, H. Wieland, S.L. Vargo, Converging on a New Theoretical Foundation for Selling, J. Mark. 82 (2) (2018) 1–18, https://doi.org/10.1509/jm.16.0268.

[26] Hoppe, S. (2023). *OPC Unified Architecture-Interoperability for Industrie 4.0 and the Internet of Things*. https://opcfoundation.org/wp-content/uploads/2023/05/OPC-UA-Interoperability-For-Industrie4-and-IoT-EN.pdf.

[27] M. Imschloss, M. Schwemmle, Value creation in post-pandemic retailing: a conceptual framework and implications, J. Bus. Econ. (2023), https://doi.org/10.1007/s11573-023-01189-x.

[28] E. Jaakkola, V. Kaartemo, J. Siltaloppi, S.L. Vargo, Advancing service-dominant logic with systems thinking, J. Bus. Res. 114592 (2024), https://doi.org/10.1016/j.jbusres.2024.114592.

[29] E. Jaakkola, S.L. Vargo, Assessing and enhancing the impact potential of marketing articles, AMS Rev. 11 (3–4) (2021) 407–415, https://doi.org/10.1007/s13162-021-00219-7.

[30] M. Kleinaltenkamp, M.J. Kleinaltenkamp, I.O. Karpen, Resource entanglement and indeterminacy: advancing the service-dominant logic through the philosophy of Karen Barad. Marketing Theory, 2023, https://doi.org/10.1177/14705931231207327.

[31] V.G. Kuppelwieser, P. Klaus, Measuring customer experience quality: the EXQ scale revisited, J. Bus. Res. 126 (December 2018) (2021) 624–633, https://doi.org/10.1016/j.jbusres.2020.01.042.

[32] T. Lindström, P. Polsa, E. Pellegrin-Boucher, F. Le Roy, C. Gurău', R. Filieri, R.B. Bouncken, J. Gast, S. Kraus, M. Bogers, J. Barney, M. Wright, D.J. Ketchen, D. R. Gnyawali, Y. Song, C. Devece, D.E. Ribeiro-Soriano, D. Palacios-Marqués, Y. Grängsjö, S. Kock, Destination networking: co-opetition in peripheral surroundings, Ind. Mark. Manag. 33 (2) (2016) 427–448, https://doi.org/10.1108/09600030310481997.

[33] H. Liu, S. Li, W. Li, W. Sun, A Distributed Resource Sharing Mechanism in Edge-Enabled IIoT Systems, IEEe Internet. Things. J. 11 (8) (2024) 14296–14312, https://doi.org/10.1109/JIOT.2023.3342321.

[34] R. Lusch, S. Nambisan, Service Innovation: a Service-Dominant Logic Perspective, MIS Quarterly 39 (1) (2015) 155–175, https://doi.org/10.25300/MISQ/2015/39.1.07.

[35] A.C. Lyons, K. Vidamour, R. Jain, M. Sutherland, Developing an understanding of lean thinking in process industries, Prod. Plan. Control. 26 (6) (2013) 475–494, https://doi.org/10.1080/09537287.2011.633576.

[36] B.D. Matthies, D. D'Amato, S. Berghäll, T. Ekholm, H.F. Hoen, J. Holopainen, J.E. Korhonen, K. Lähtinen, O. Mattila, A. Toppinen, L. Valsta, L. Wang, R Yousefpour, An ecosystem service-dominant logic? – integrating the ecosystem service approach and the service-dominant logic, J. Clean. Prod. 124 (2016) 51–64, https://doi.org/10.1016/j.jclepro.2016.02.109.

[37] M. Matzner, M. Büttgen, H. Demirkan, J. Spohrer, S. Alter, A. Fritzsche, I.C.L. Ng, J.M. Jonas, V. Martinez, K.M. Möslein, A. Neely, Digital transformation in service management, J. Ser. Manag. Res. 2 (2) (2018) 3–21, https://doi.org/10.15358/2511-8676-2018-2-3.

[38] G. Medberg, C. Grönroos, Value-in-use and service quality: do customers see a difference? J. Serv. Theor. Pract. 30 (4/5) (2020) 507–529, https://doi.org/10.1108/JSTP-09-2019-0207.

[39] A. Meena, S. Dhir, S. Sushil, A review of coopetition and future research agenda, J. Bus. Ind. Mark. 38 (1) (2023) 118–136, https://doi.org/10.1108/JBIM-09-2021-0414.

[40] P. Mosch, P. Majocco, R. Obermaier, Contrasting value creation strategies of industrial-IoT-platforms – a multiple case study, Int. J. Prod. Econ. 263 (2023) 108937, https://doi.org/10.1016/j.ijpe.2023.108937.

[41] P. Muller, D. Shaan, R. Ladher, J. Cannings, E. Murphy, N. Robin, S. Illán, F. Carsa, S. Gorgels, M. Priem, D. Econ, S. Smid, N. Bohn, V. Lefebvre, I. Frizis, Annual report on European SMEs 2020/2021 – Digitalisation of SMEs, in: K. Hope (Ed.), Bedsore Biomech, Publications Office, 2021. https://data.europa.eu/doi/10.2826/56865.

[42] Mwesiumo, D., Harun, M., & Hogset, H. (2023). Unravelling the black box between coopetition and firms' sustainability performance. *Industrial Marketing Management*, 114, 110–124. https://doi.org/10.1016/j.indmarman.2023.08.008.

[43] K. Razmdoost, L. Alinaghian, J.D. Chandler, C. Mele, Service ecosystem boundary and boundary work, J. Bus. Res. 156 (November 2022) (2023) 113489, https://doi.org/10.1016/j.jbusres.2022.113489.

[44] M. Reeves, H. Lotan, J. Legrand, M.G. Jacobides, How Business Ecosystems Rise (and Often Fall), MIT. Sloan. Manage Rev. (2019). *July*.

[45] K.O.M. Salih, T.A. Rashid, D. Radovanovic, N. Bacanin, A Comprehensive Survey on the Internet of Things with the Industrial Marketplace, Sensors 22 (3) (2022) 730, https://doi.org/10.3390/s22030730.

[46] C. Seepana, A. Paulraj, F.A. Huq, The architecture of coopetition: strategic intent, ambidextrous managers, and knowledge sharing, Ind. Mark. Manag. 91 (August) (2020) 100–113, https://doi.org/10.1016/j.indmarman.2020.08.012.

[47] A. Silva, M. Gil, Industrial processes optimization in digital marketplace context: a case study in ornamental stone sector, Results. Eng. 7 (April) (2020) 100152, https://doi.org/10.1016/j.rineng.2020.100152.

[48] Silva, A., & Marques Cardoso, A. (2023). BIM-based Supply Chain in AEC - Threats on the Portuguese Stone sector. In I. 978-972-778-327-4 (Ed.), *Proceedings of the 7th Globalstone Congress*, Batalha, 2023; ISBN 978-972-778-327-4. https://repositorio.lneg.pt/bitstream/10400.9/4150/1/GSC2023 _PT Natural Stones-Commercial Names.harmonization.pdf.

[49] A. Silva, C. Rabadão, C. Capela, Towards Industry 4.0 | A case study of BIM deployment in ornamental stones sector, Int. j. innov. technol. explor. Eng. (IJITEE) 67 (2020) 24535.

[50] M. Štěrbová, V. Stojanovski, G. Weiss, J. Šálka, Innovating in a traditional sector: innovation in forest harvesting in Slovakia and Macedonia, For. Policy. Econ. (June) (2019) 106, https://doi.org/10.1016/j.forpol.2019.101960.

[51] The Economist Intelligence Unit. (2021). Poor collaboration holds back European businesses digital ambitions. In *The Economist Intelligence Unit Limited 2021*. https://appian.com/resources/resource-center/google-success/economist-survey-european-businesses-digital-ambitions-success.html.

[52] R.H. Tsiotsou, A service ecosystem experience-based framework for sport marketing, Serv. Ind. J. 36 (11–12) (2016) 478–509, https://doi.org/10.1080/02642069.2016.1255731.

[53] M. Urbaniak, D. Zimon, P. Madzik, Expectations of manufacturing companies towards suppliers in terms of implementing improvement activities, *Centr. Europ. Manag. J.* (2024), https://doi.org/10.1108/CEMJ-07-2023-0286.

[54] S.L. Vargo, M.A. Akaka, H. Wieland, Rethinking the process of diffusion in innovation: a service-ecosystems and institutional perspective, J. Bus. Res. 116 (December 2018) (2020) 526–534, https://doi.org/10.1016/j.jbusres.2020.01.038.

[55] S.L. Vargo, J.A. Fehrer, H. Wieland, A. Nariswari, The nature and fundamental elements of digital service innovation, J. Serv. Manag. 35 (2) (2024) 227–252, https://doi.org/10.1108/JOSM-02-2023-0052.

[56] S.L. Vargo, R.F. Lusch, Evolving to a New Dominant Logic for Marketing, J. Mark. 68 (1) (2004) 1–17, https://doi.org/10.1509/jmkg.68.1.1.24036.

[57] S.L. Vargo, L. Peters, H. Kjellberg, K. Koskela-Huotari, S. Nenonen, F. Polese, D. Sarno, C. Vaughan, Emergence in marketing: an institutional and ecosystem framework, J. Acad. Mark. Sci. 51 (1) (2023) 2–22, https://doi.org/10.1007/s11747-022-00849-8.

[58] S.L. Vargo, H. Wieland, M O'Brien, Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline, J. Bus. Res. 164 (2023) 113965, https://doi.org/10.1016/j.jbusres.2023.113965.

[59] Vilas-Boas, J., Mirnoori, V., Razy, A., & Silva, A. (2019). Outlining a New Collaborative Business Model as a Result of the Green Building Information Modelling Impact in the AEC Supply Chain. In *Collaborative Networks and Digital Transformation* (pp. 405–417). https://doi.org/10.1007/978-3-030-28464-0_35.

[60] von der Leyen, U. (2019). A Union that Strives For more. My agenda For Europe : Political Guidelines For the Next European Commission 2019-2024. EU Publications, 24. https://ec.europa.eu/commission/sites/beta-political/files/political-guidelines-next-commission_en.pdf%0Ahttps://op.europa.eu/en/publication-detail/-/publication/43a17056-ebf1-11e9-9c4e-01aa75ed71a1.

[61] P.U. Wijeratne, C. Gunarathna, R.J. Yang, P. Wu, K. Hampson, A. Shemery, BIM enabler for facilities management: a review of 33 cases, Int. J.Constr. Manag. 24 (3) (2024) 251–260, https://doi.org/10.1080/15623599.2023.2222962.

[62] Q. Xie, Y. Gao, N. Xia, S. Zhang, G. Tao, Coopetition and organizational performance outcomes: a meta-analysis of the main and moderator effects, J. Bus. Res. 154 (October 2022) (2023) 113363, https://doi.org/10.1016/j.jbusres.2022.113363.

[63] A. Yazdinejad, B. Zolfaghari, A. Dehghantanha, H. Karimipour, G. Srivastava, R. Parizi, Accurate threat hunting in industrial internet of things edge devices, Digit. Commun. Netw. 9 (5) (2023) 1123–1130, https://doi.org/10.1016/j.dcan.2022.09.010. Issue.

The International Journal of Advanced Manufacturing Technology (2024) 135:747–762
https://doi.org/10.1007/s00170-024-14528-1

ORIGINAL ARTICLE

Designing the future of coopetition: An IIoT approach for empowering SME networks

Agostinho da Silva[1,2] · **Antonio J. Marques Cardoso**[1]

Received: 5 March 2024 / Accepted: 19 September 2024 / Published online: 1 October 2024
© The Author(s) 2024

Abstract
In an era where Information and Communication Technologies (ICT) redefine the boundaries of competition and collaboration, the concept of coopetition — simultaneous competition and cooperation — emerges as a strategic imperative for small and medium-sized enterprises (SMEs). This study presents the design and development of an Industrial Internet of Things (IIoT) artefact designed to enable competition among SMEs. Bringing the Service-Dominant Logic (S-D logic) foundations to IIoT, a Design Science Research (DSR) approach was employed. This approach facilitated the integration of design theory with practical problem-solving, creating the Coopetition IIoT-based System. The primary goal of this solution is to augment the dynamics of coopetition networks, with a particular focus on SMEs. The practical evaluation of the Coopetition IIoT-based System is assessed through a prototype evaluation by experts representing twenty-four manufacturing stone SMEs, a crucial sector in the Portuguese economy. The feedback received was highly positive, indicating a positive evaluation rate of 78.9%. This favourable response highlights the Coopetition IIoT-based System's proficiency in fostering simultaneous competition and cooperation throughout the lifecycle of business opportunities in SME networks, thereby underscoring its potential as a facilitator of effective competition. Theoretically, this research enriches the application of S-D logic in coopetition networks and advances state-of-the-art IIoT systems. Practically, the Coopetition IIoT-based System demonstrates significant potential in boosting the competitiveness of SMEs in developed economies. Nonetheless, the ultimate efficacy of such IIoT systems will be best determined through real-world application and evaluation. Future research should concentrate on the real-case deployment and assessment of Coopetition IIoT-based Systems within coopetition networks.

Keywords Coopetition · Value Creation · S-D Logic · IIoT · SMEs

1 Introduction

The proliferation of Information and Communication Technologies (ICT) has been a driving force behind process automation, the widening global market, and job access [5]. In response, business activities are increasingly transitioning towards collaborative, knowledge-intensive services that support manufacturing and innovation [61]. This shift has made service innovation a critical priority for nations, businesses, and citizens [3].

Coopetition, the simultaneous blend of competition and collaboration, has become an important topic in contemporary business literature [55]. It is often seen as a strategic approach for small and medium-sized enterprises (SMEs) to survive or access wider market opportunities [15]. Unlike pure collaboration, coopetition involves firms working together while simultaneously competing, which introduces unique challenges and opportunities that require careful management [8]. However, many coopetition networks still need to achieve their intended lifespan [50]. This indicates that the complex balance between competition and collaboration in such networks is difficult to maintain [13]. Furthermore, a review of the current state-of-the-art reveals a lack of adequate technological solutions that significantly mitigate or address this prevalent challenge for SMEs [43].

✉ Agostinho da Silva
a.silva@zipor.com

Antonio J. Marques Cardoso
ajmarcar@ieee.org

[1] CISE – Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal

[2] CIGEST – Business & Economics School, Lisbon, Portugal

This gap in effective solutions underscores a broader issue: a relatively low understanding of networks in coopetition [38].

In modern business, technologies often labelled as 'disruptive'—such as Artificial Intelligence, the Internet of Things (IoT) [10], and cyber-physical production systems—are rapidly evolving [12]. These technologies are transcending their roles as facilitators of human interactions to become active, independent agents capable of deliberate actions [18]. This evolution marks a significant shift in how businesses operate, integrating more sophisticated forms of human capabilities. Given this backdrop, a pressing question arises for SMEs grappling with the challenges of globalization: How can an IIoT system support coopetition networks among SMEs?

This question underscores the need for specialized technologies tailored to the unique demands of coopetition, particularly for SMEs striving to thrive in a globally competitive environment.

The Industrial Internet of Things (IIoT) refers to the extension and application of the IIoT in industrial settings and sectors [34]. While IoT broadly encompasses the interconnectivity of devices and systems through the Internet, IIoT focuses explicitly on integrating smart technologies within industrial processes, manufacturing, and infrastructure [74].

In the context of IIoT, various physical devices, sensors, machines, and other equipment are equipped with embedded technology and connectivity features, allowing them to collect and exchange data [34]. This data is often analyzed to optimize processes, enhance efficiency, and make informed decisions within industrial environments [53]. Key features and components of the Industrial Internet of Things include sensors and actuators, connectivity, data analytics, cloud computing, cyber-physical systems, and security. IIoT represents a transformative approach to industrial processes by leveraging the power of connectivity and data to pursue enhanced productivity and innovation. IIoT can be crucial in coopetition by facilitating real-time data exchange and collaboration while maintaining competitive edges where necessary [21].

From a review of coopetition made by Abhilasha Meena, Sanjay Dhir, and Sushil Sushil (2023), coopetition is mainly addressed through Game Theory, Resource-Based Theory, Paradox Theory, Transaction Cost Theory, and Network Theory [40]. These approaches often narrow their focus on the allocation and use of resources to gain competitive advantages, thereby relegating value co-creation between rivals to a secondary consideration. This rivalry emphasis can limit coopetition's strategic potential, which ideally balances competition with collaboration to maximize mutual benefits [8].

In contrast, the evolving economic landscape toward service economies calls for a broader perspective, as captured by Vargo and Lusch's [69] concept of Service-Dominant Logic (S-D Logic) (Stephen L. [69]). This theoretical framework represents a paradigm shift from the traditional goods-dominant logic, which prioritizes tangible goods exchange, to a perspective that centres service as the core of economic exchange and value creation. S-D Logic provides a holistic, customer-centric approach that emphasizes actor interaction and the ongoing process of value co-creation in today's dynamic and interconnected world [17]. The IoT emerges as a transformative force within this framework, reshaping traditional manufacturing processes and redefining value chains and ecosystems (Stephen L. [68]). This transformation aligns with S-D Logic principles, which focus on value creation within service ecosystems facilitated by actor-generated institutions and arrangements (Stephen L. [71]).

When viewed through the lens of service ecosystems, IIoT systems are recognized as essential enablers in coopetition networks, promoting a harmonious balance between competition and collaboration (S. L. [63]). IIoT can empower SMEs to compete globally while collaborating on innovation, resource sharing, and market expansion [34].

To leverage this potential, the Design Science Research (DSR) provides a framework for developing artefacts [47]. Consequently, this research is dedicated to designing and demonstrating an IIoT system to empower firms to navigate the nuances of coopetition effectively. The goal is to assist firms in managing the entire spectrum of opportunities within these networks, from their initiation to their eventual outcome, whether successful or otherwise.

Building on the DSR framework, the following sections of this paper are structured to guide the reader through the development and demonstration of the Coopetition IIoT system. The following section addresses the theoretical foundation, exploring how S-D Logic is applied within coopetition networks to establish the underlying principles that support the system's design. This is followed by a discussion of the DSR methodology, which outlines the systematic approach to creating the Coopetition IIoT system, emphasizing the principles and steps that informed its development. The paper then transitions into a comprehensive system description, highlighting the key components and functionalities that enable SMEs to navigate the complexities of coopetition. Finally, the demonstration of the Coopetition IIoT system is presented, showcasing its application and assessing its effectiveness in real-world scenarios with SMEs. The paper concludes by summarizing the key findings, discussing their implications, and suggesting directions for future research, thus encapsulating the overall contribution of this study to the field.

2 The theoretical foundation for IIoT systems in coopetition networks

S-D Logic presents a paradigm shift in understanding value creation, moving away from the traditional goods-centric view, where value is embedded in products, to a service-centric perspective, where value is co-created through interactions among actors (Stephen L. [69]). In S-D Logic, value emerges from the dynamic interactions between actors within service ecosystems (M. A. [1]). These actors—whether individuals, organizations, or other entities involved in exchange—engage in reciprocal service provision, applying their competencies, such as skills, knowledge, and resources, to benefit others [73].

Service ecosystems are complex, adaptive systems characterized by interconnected networks of actors who continuously interact, exchange services, and co-create value [17]. In these ecosystems, value is not predefined or fixed but is continually shaped and reshaped through ongoing interactions [49]. The dynamic nature of these ecosystems means that value emerges due to continuous exchanges, heavily influenced by the specific context in which they occur [17].

Institutions and institutional arrangements play a crucial role in coordinating these interactions. In S-D Logic, institutions refer to the formal and informal rules, norms, and practices that govern the behaviour of actors within the ecosystem (S. L. [63]). Institutional arrangements are the specific configurations of these institutions that facilitate the smooth functioning of the service ecosystem. They provide the necessary structure and stability, enabling actors to effectively engage in value co-creation processes [29].

By establishing the boundaries and guidelines for interaction, institutions ensure that exchanges are meaningful. They also ensure that value is co-created in a way that aligns with the goals and expectations of the involved actors (Stephen L. [65]). These institutional frameworks also support the integration of resources—both operant (such as knowledge and skills) and operand (such as physical goods and technology)—which are essential for the co-creation of value (Stephen L. [68]).

In this context, value is understood as a dynamic and emergent phenomenon that cannot be isolated from the interactions and exchanges within the service ecosystem (Stephen L. [67]). The focus shifts from individual transactions to the ongoing relationships and collaborations that form the foundation of these interactions. As actors engage with one another, they co-create value by integrating their resources in contextually meaningful ways within the ecosystem [64].

Through this lens, S-D Logic emphasizes that value is not produced independently by a single entity but is co-created through the collective efforts of multiple actors within an institutionalized framework [17]. This approach shifts the focus from a linear, producer-to-consumer model to a more holistic view of value creation, where all actors within the ecosystem contribute to and benefit from the value created [64].

The progression within S-D Logic towards focusing on service ecosystems has led to a nuanced understanding of network formation. These networks are seen as arising spontaneously from the interactions of socially and economically motivated actors, with their formation being facilitated by a combination of institutional forces and technological advancements [36]. Characterized by adaptive interactions, these emergent networks are driven by the collective goal of creating value, which is pivotal in ensuring the ongoing viability and sustainability of the ecosystem (Stephen L. [70]). This perspective underscores the dynamic and interconnected nature of modern business environments, where the collaborative and organic development of networks forms the backbone of value creation.

2.1 Operand and operant technology

Digitization involves converting analogue information into digital format [11]. Once digitized, information can be efficiently processed, stored, and transmitted using digital circuits, devices, and networks [74]. This transformation is at the heart of digitalization, which encompasses the integration of ICT with products, systems, solutions, and services along the entire value chain, covering the full spectrum of product and service life cycles (I. [45]). Digitization has given rise to digital networks, fundamentally altering traditional notions of place — where tasks are performed and resources are delivered [23]. In the human service activities domain, digitization has led to the adoption of physical tools and forms, enhancing efficiency and enabling the faster, more consistent replication of services [77].

For S-D logic, technology is a resource with a double role in networks [44]. Emphasizing that value is cocreated through the interaction of operant and operand resources for S-D logic. Operand technology refers to the tangible, physical components. In contrast, operant technology involves the knowledge, skills, and services that enhance and apply these physical components to create value in the service exchange [28]. Both operand and operant aspects are essential for understanding how technology contributes to value creation from a service-dominant perspective [58].

Converging to S-D logic foundations and addressable as operant resources [36], digital technologies represent a non-stop state-of-the-art updating, incorporating new improvements continuously and increasingly embedding the capability to take collaborative actions without humans [35] leading to a hyper-connected society and an increasingly

global economy [7]. These collaborative capabilities make technologies like IIoT crucial to enabling modern networks [19]. Moreover, these collaborative actions happen not only among machines (Silva et al., 2016) but also among providers, customers [77] and rivals (coopetitors) [33], from which value creation is created by multiple actors and determined by the beneficiary [26].

2.2 S-D logic, IIoT, and value co-creation

The term "Internet of Things" was first coined by Kevin Ashton, originally from Procter & Gamble, and later associated with MIT's Auto-ID Center in 1998 [4]. Ashton emphasized that, regardless of the specific business proposition, every object could become a part of the Internet [72]. Over two decades since its inception, the capabilities of IoT have significantly expanded. Today, integrating wireless communication, sensors, and computing power is increasingly commonplace in IoT systems [42].

This advancement enables uniquely identifiable objects to transmit data over the Internet autonomously, often with minimal or no human intervention [19]. Additionally, it marks a significant shift in how objects interact and contribute to the digital ecosystem, laying the groundwork for new avenues of value creation in various sectors, particularly in the context of the IIoT [74].

The IoT and embedded systems era, further reinforced by recent technological advancements [48], finds a significant linkage to ecosystems within the S-D logic literature [63]. In these ecosystems, actors are interconnected through various sensors [27], facilitating the location and identification of these actors and enabling their operation innovatively [43]. Empirical studies have shown that IoT-based developments empower companies to offer novel services [42]. These services range from remote control capabilities to predictive maintenance solutions, among others, expanding what companies can offer [39].

Building upon the IoT's foundation, the IIoT is increasingly recognized for elevating efficiency levels in manufacturing SMEs [34]. It is focused on fostering intelligent, self-regulating, and interconnected processes within industrial value creation, thereby enhancing the manufacturing industry's competitiveness [9]. The IIoT amalgamates a diverse array of previously unconnected technologies through today's nearly universal IP-based networks, repurposing them for innovative applications [62].

However, while technologies like Ethernet enable these 'things' to connect, the practical utility of such connections relies on establishing a standard, meaningful communication protocol [25]. This necessity underscores the importance of connectivity and Interoperability in implementing IIoT solutions, ensuring that the various components within these networks can communicate effectively to realize their full potential [74].

In the context of S-D logic, value co-creation, particularly involving customers, is closely linked with the application of operant and operand technologies [63]. The IIoT epitomizes this idea by merging the global outreach of the Internet with industrial capabilities. This integration allows for the control, coordination, and management of the physical world, encompassing goods, machines, factories, and infrastructure (I. [45]).

Aligned with S-D logic's perspective on operant and operand resources (R. [36]), ICT and service management literature [39] (often reference intelligent artefacts or systems. These can execute specific functions autonomously [31] and respond to user interactions based on predefined property sets of objects. However, some scholars argue that this approach is successful in more straightforward scenarios, but it may lead to a lack of creativity in more complex processes. The "in-box thinking" of smart objects, as noted, can potentially stifle creativity [56, 57], and inhibit the flexibility required for firms to adapt in rapidly changing environments [59].

3 Research methodology

This research adopts the DSR methodology, which is dedicated to creating and evaluating artefacts that solve real-world problems while advancing theoretical and practical knowledge [47]. This study uses DSR to develop an IIoT-based system, a technological solution designed to foster coopetition within SMEs' industrial networks.

Problem Identification and Motivation: The initial phase of this research focuses on identifying the need for an improved IIoT system to support coopetition, a dual process of collaboration and competition among SMEs. The research builds upon the state-of-the-art IIoT system currently employed in the stone manufacturing industry [56, 57], recognized for its ability to link processing plants with the cyber market. Despite its effectiveness, the system shows limitations in promoting coopetition, particularly in interoperability, usability, and accessibility (A. Silva, Rabadão, et al., 2020). These shortcomings inhibit the system's ability to facilitate effective collaboration and competition, which creates a compelling motivation for this study's focus on developing an advanced IIoT artefact that addresses these gaps.

Objectives of the Solution: The primary research objective is to create an artefact that enhances the IIoT system by integrating mechanisms designed to promote coopetition within SME networks. This objective is grounded in S-D Logic (Stephen L. [68]), which highlights the importance of value co-creation through resource integration. The goal is to enable the IIoT system to not only bridge gaps in interoperability, usability, and accessibility but also transform how SMEs collaborate and compete. The resulting artefact, referred to as the Coopetition IIoT-based System, is designed to enhance interactions, foster collaboration, and allow businesses to engage in competitive innovation while co-creating value.

Design and Development: The design and development phase focuses on creating specific mechanisms that address the identified gaps. Guided by DSR principles [47], this phase emphasizes the design of innovative solutions that will foster coopetition by enhancing the system's interoperability, usability, and accessibility: (1) Interoperability mechanisms are developed to ensure seamless interactions between different systems and actors within the network. By enabling the efficient exchange of data and resources across various platforms, the Coopetition IIoT-based System fosters collaboration between competitors while maintaining data integrity and compatibility across different technological infrastructures. (2) Usability and accessibility mechanisms simplify the system's interface, making it intuitive and adaptable for SMEs of varying technological capabilities. Accessibility mechanisms are implemented to ensure that all stakeholders can quickly adopt and engage with the system, thus facilitating broad participation within the coopetition network. The development of these mechanisms draws on operand and operant resources [58], ensuring that the system not only processes data but also supports the co-creation of value by allowing businesses to leverage both physical and intellectual assets in a competitive environment. This ensures that the system can facilitate real-time collaboration and competition within a dynamic industrial network [42].

Demonstration: Following the design and development of the Coopetition IIoT-based System, the prototype is demonstrated in a real-world SME context. The demonstration phase is a critical step in the DSR process as it validates the artefact's ability to achieve its intended purpose within an operational environment. The demonstration highlights the system's capacity to enable value co-creation and foster innovation by seamlessly integrating interoperability, usability, and accessibility mechanisms. It illustrates how the system aligns with the objectives set forth at the beginning of the research, providing real-time solutions for enhancing coopetition.

4 Developing a coopetition IIoT-based system

4.1 IIot interoperability mechanisms for coopetition IIoT-based systems

Realizing the full potential of the IoT hinges on establishing global communication standards that meet a range of complex requirements [24]. Converging to S-D logic literature, achieving this vision involves fostering broad Interoperability, which includes shaping laws, regulations, and social norms to support the institutionalization of service ecosystems (S. [64]). As digital service innovation increasingly relies on integrating institutional and technological dimensions, it is crucial to develop network structures that enable this integration (Stephen L. [68]). Furthermore, in addressing interoperability challenges within ecosystems, Akaka and Vargo (2014) emphasize that IoT systems incorporate resource density and digital materiality mechanisms, further strengthening service mechanisms within these ecosystems (M. [2]).

Anchored on this view, systemic Interoperability is required for IIoT systems like Coopetition IIoT-based Systems, ensuring effective collaboration both within and outside the network [32]. Such collaboration should be designed so that mutual goals are achieved, or the network can be controlled in the event of a failure [51].

In this regard, the operant and operand Coopetition IIoT-based System resources must incorporate systemic Interoperability, encompassing (1) Technical Interoperability — establishing technological facilities for reliable communication pathways [76]; (2) semantic Interoperability — ensuring that the exchanged information and message patterns are meaningful and understood across different systems; and (3) pragmatic Interoperability — achieving alignment with the intentions, expectations, business rules, and organizational policies of collaborating parties [52]. Through such systemic Interoperability, the Coopetition IIoT-based System facilitates actors in accessing and sharing essential information, like expectations, business rules, and organizational policies, enhancing collaboration in the network [22].

4.1.1 Resources density mechanisms

The concept of resource density mechanisms, derived from S-D logic literature, plays an essential role in the evolving landscape of the IIoT, particularly in Coopetition IIoT-based Systems. Michel et al. [41] describe resource density as creating optimal resource combinations through dematerialization mechanisms (R. [36]). This process involves

two key dimensions: (1) Liquification — as defined by Lusch and Vargo (2007) and further elaborated by Vargo and Akaka [66], liquefaction refers to the separation of information from its physical form, enhancing its mobility and utility (Stephen L. [66]). In the context of Coopetition IIoT-based System, this translates to the fluid movement and application of data across different nodes of the network, enabling more agile and responsive decision-making processes; unbundleability—this concept, explored by Normann (2001) and further by [41], involves the disentanglement of traditionally fixed activities, allowing them to be more flexibly managed and executed [41]. In Coopetition IIoT-based System, tasks and operations, previously constrained by time and place, can now be dynamically reconfigured, leading to increased efficiency and adaptability in networks.

These mechanisms, liquification and unbundleability, foster the emergence of new resource densities. As [77] suggest, these new densities can be combined innovatively with other actors' resources to create novel value configurations [77]. Crucially, as Ng and Wakenshaw [45] point out, the resource density mechanism in Coopetition IIoT-based System is not just about the physical resources but also encompasses the subsequent processing and analysis of information (I. [45]). This analytical capability is essential for supporting informed decisions and strategic actions, enabling effective coopetition within networks. Coopetition IIoT-based System, by incorporating these principles, demonstrates a shift towards more fluid, adaptable, and collaborative IIoT environments. The system's ability to fluidly reconfigure resources and information enhances operational efficiency and fosters a cooperative yet competitive ecosystem, essential for driving innovation and value creation in the coopetition domain.

4.1.2 Digital materiality mechanisms

The concept of digital materiality emerges as a critical mechanism for enhancing network functionality and value co-creation in IIoT environments. Digital materiality, as defined by [20], centres around the capabilities of physical objects when augmented by software [20]. More specifically, as [75] elucidate, it involves the manipulation of digital representations of physical objects through embedded software, thereby extending and transforming their functionalities [75]. In the case of the Coopetition IIoT-based System, digital materiality is not just a theoretical construct but a practical enabler. By embedding advanced software capabilities into the system, the Coopetition IIoT-based System transcends traditional physical limitations. This integration allows for more dynamic interactions between the digital and physical components of the system. For instance, real-time sensor data can be processed, analyzed, and used to inform immediate adjustments in machine operations, leading to more efficient and responsive production processes.

Furthermore, this mechanism is crucial in value co-creation within IIoT networks. The enhanced capabilities brought about by digital materiality enable various stakeholders — from manufacturers to end-users — to interact, collaborate, and innovate in ways previously unattainable. For example, the ability to remotely monitor and optimize equipment performance not only improves operational efficiency but also opens new avenues for customer engagement and service innovation. Thus, in a Coopetition IIoT-based System, digital materiality is not merely a feature but a transformative force that redefines the boundaries of what is possible in IIoT environments. It empowers the system to become more than the sum of its physical parts, evolving into an integrated platform where digital intelligence and physical processes coalesce to drive the next wave of industrial innovation.

Building upon these foundational S-D logic concepts, the Coopetition IIoT-based System represents a significant advancement in IIoT. This evolution is exemplified by the transformation of the state-of-the-art "two virtual compartments vehicle", as detailed by Silva, Dionisio, et al. (2020), into a more sophisticated "three-compartment virtual vehicle" (fingerprint4.0+), thereby embedding deeper functionality and versatility into the system [56, 57]. The design of fingerprint4.0+is composed of three distinct compartments, each serving a unique and vital role in the coopetition network:

- **Descriptive Content Compartment —** dedicated to housing the descriptive content of the product specifications. It represents the collaborative effort between the manufacturer and the customer, embodying the essence of co-creation in product development. This compartment ensures that the final product aligns seamlessly with the customer's needs and expectations.
- **Coopetition Information Compartment —** is a novel addition that carries specific information intended for coopetitors. This includes complementary notes, remarks, and other relevant data facilitating a cooperative yet competitive environment. By sharing selected information with coopetitors, this compartment fosters a culture of shared innovation and improvement, enhancing the overall value of the network.
- **Geometric Information Compartment —** The third and final compartment is a critical component in the manufacturing execution process. It contains the product's geometric information, which generates intelligent objects. These objects are then downloaded and employed in manufacturing, ensuring precision and efficiency in production.

Integrating these three compartments in fingerprint4.0^{+} signifies a significant leap forward in IIoT state-of-the-art capabilities (A. Silva, Rabadão, et al., 2020). This enhanced structure streamlines the manufacturing process and reinforces the collaborative and competitive dynamics within the coopetition network. By incorporating these advanced mechanisms into the Coopetition IIoT-based System, the system elevates itself from a mere tool to an intelligent facilitator of collaboration and consequent value creation in the industrial landscape, particularly in industrial coopetition networks.

4.1.3 Embedding interoperability in coopetition IIoT-based systems

Integrating a Service-Oriented Architecture (SOA) in industrial automation systems has been a game-changer since its introduction in 2007 [37]. The Unified Architecture (OPC UA) is at the forefront of this evolution, which offers a scalable, platform-independent solution, fundamentally transforming Interoperability in IIoT systems. As Hoppe [25] noted, OPC UA ingeniously combines the benefits of web services and integrated security within a consistent data model, marking a significant advancement in the field [25].

The Open Platform Communications (OPC) standard, as Lars [30] points out, has been a cornerstone in industrial connectivity, with its adoption spreading across both industrial and non-industrial markets. The transition to a Service-Oriented Architecture with OPC Unified Architecture is fundamental, particularly for systems like Coopetition IIoT-based Systems [30]. This transition aligns with the current technological trends and positions the Coopetition IIoT-based System as a highly interoperable and versatile IIoT system [25].

OPC UA's role in standardizing data connectivity is crucial, as it addresses both horizontal and vertical data communication needs within a network, a point emphasized by [6]. The incorporation of the OPC UA protocol in a Coopetition IIoT-based System enables the system to discover and connect to various OPC UA servers [6], provided the address of the discovery server is known, a functionality underscored by [54]. An illustrative example of horizontal communication is machine-to-machine data exchange on the shop floor [54]. In contrast, vertical communication can be seen in the device-to-cloud data transfer processes. OPC UA is a robust and reliable foundation in both scenarios, facilitating seamless data connectivity and Interoperability within networks [25]. Figure 1 represents this interoperability framework, demonstrating how OPC UA is the backbone for horizontal and vertical communications in Coopetition IIoT-based systems. The figure will illustrate the essential role of OPC UA in ensuring robust, efficient, and secure data exchange across different layers of the IIoT environment in coopetition networks.

The adoption of the OPC UA protocol in a Coopetition IIoT-based System represents a strategic approach to validating and sharing the product's cocreated value proposition. This process is critical not only for ensuring customer satisfaction but also for maintaining transparency and

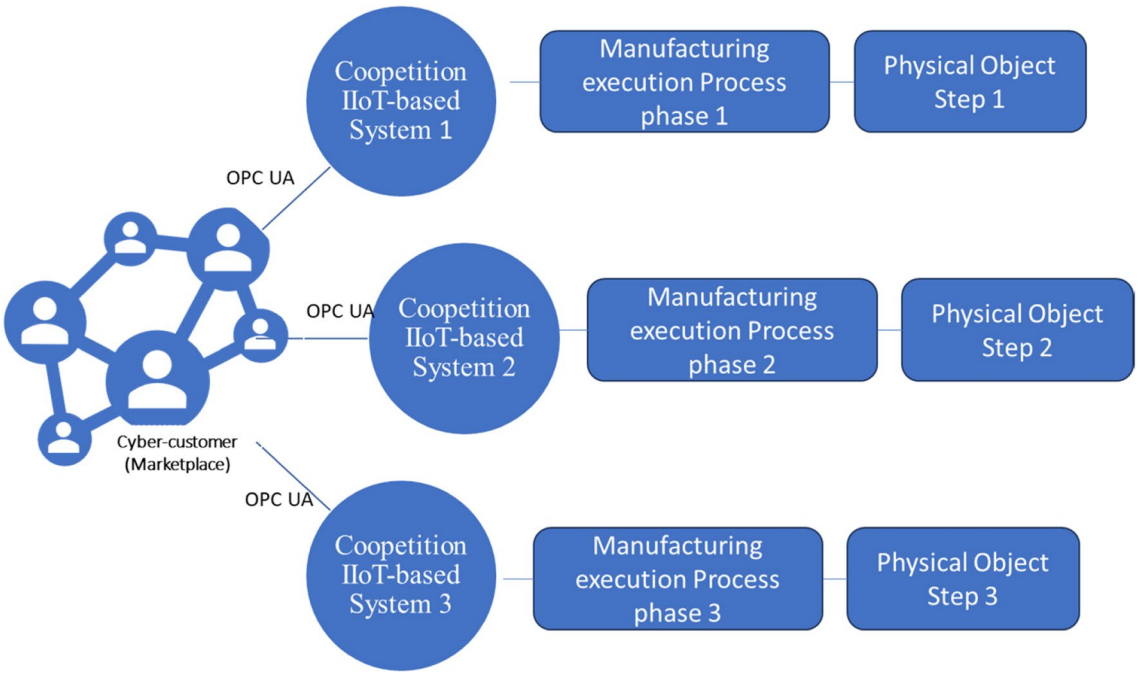


Fig. 1 Embedding interoperability mechanisms in coopetition IIoT-based System through the OPC-UA protocol

collaboration with all actors involved, including competitors, authorities, and manufacturing process providers.

With the OPC UA protocol, the Coopetition IIoT-based System facilitates a comprehensive validation process. Before finalizing the value proposition, the system makes the enhanced fingerprint4.0 + available to customers and coopetitors. Therefore, fingerprint4.0 + includes detailed information on various aspects of the product, such as its ecological footprint, lifecycle, recycling processes, compliance with regulations, and other relevant data [56, 57]. This level of detail and transparency is crucial in today's market, where ecological and regulatory compliance are as important as the product's functional attributes. Moreover, this transparent approach allows all actors involved in the business opportunity — customers, coopetitors, regulatory authorities, and providers of manufacturing processes — to evaluate and confirm the product's value proposition thoroughly. This collaborative validation process ensures that all parties' needs and expectations are met, fostering trust and cooperation in the network.

Upon receiving confirmation from all involved parties, the Coopetition IIoT-based System takes a pivotal action: It generates and forwards the finalized fingerprint4.0 + to each actor. This fingerprint serves as the blueprint from which intelligent objects are derived for the manufacturing shop floor resources. The transition from a validated value proposition to actual manufacturing execution is seamless, thanks to the robust and interoperable framework provided by the OPC UA protocol within the Coopetition IIoT-based System. In summary, integrating the OPC UA protocol in a Coopetition IIoT-based System is a technological enhancement and a facilitator of collaborative and transparent business practices. By enabling comprehensive validation and information sharing, the Coopetition IIoT-based System aligns with contemporary business paradigms where stakeholder engagement, environmental responsibility, and regulatory compliance are integral to the value-creation process.

4.2 IIoT usability and accessibility mechanisms for coopetition IIoT-based systems

As articulated by Stephen L. Vargo, [71], technological environments must be institutional and systemic, emphasizing that value is cocreated through network actors engaged in resource integration and exchange practices (Stephen L. [71]). It underscores the importance of each actor in providing resources that are accessible and integrable to others, as highlighted by Stephen L. Vargo and Lusch (2008), further underpinning the significance of shared rules, norms, and institutions ([64]).

Rooted in this S-D logic institutional and systemic view, the design and functionality of a Coopetition IIoT-based System must prioritize collaboration among competitors, ensuring mutual access to resources right from the initial lead moment of an opportunity through its evolution to its culmination, irrespective of whether it results in a win or loss. This approach requires the implementation of robust usability and accessibility mechanisms. These mechanisms are essential in providing secure and efficient access for service exchange among coopetitors. Such facilitation of interactions is crucial in driving value creation within the network (Stephen L. [68]).

To enhance usability and accessibility in these networks, the S-D logic framework highlights the need for institutional and systemic assemblages [23]. Moreover, it calls for developing architectural modules tailored explicitly for transactions and service exchanges (I. [45]). In practical terms, this translates to Coopetition IIoT-based Systems being equipped with modular, adaptable, and user-friendly interfaces and protocols that facilitate transactional efficiency and nurture the systemic integration of services across the network.

Thus, by embracing the S-D logic perspective, the Coopetition IIoT-based System emerges as a technological system and an enabler of a more connected, collaborative, and value-driven IIoT system. By prioritizing usability and accessibility, the Coopetition IIoT-based System fosters a network of seamlessly exchanging resources and services, leading to a richer, more productive, and sustainable industrial landscape.

4.2.1 Systemic assemblage mechanisms

Systemic assemblages are at the heart of understanding how technological resources, like Coopetition IIoT-based Systems, operate and interact within service ecosystems. Systemic assemblages refer to the collective functioning of objects or devices, which can achieve unattainable outcomes by any single component in isolation [16]. They emphasize the emergent capabilities that arise when diverse elements work in unison, transcending the capabilities of individual components (I. [45]).

In service ecosystems, as discussed by S. Vargo & Lusch [64], systemic assemblages can be perceived as structural configurations comprising both the whole and its sub-components. These assemblages, viewed holistically or in segmented forms, represent the intricate interplay of various societal elements (S. [64]). For analytical purposes, examining these assemblages at different levels of aggregation provides valuable insights into how complex systems function and interact.

When applied to the Coopetition IIoT-based System, the principle of systemic assemblages underlines the importance of viewing its usability and accessibility mechanisms as isolated technological features and as a comprehensive collection of heterogeneous technology components. When working in tandem, these components create a synergy that

enhances the system's overall functionality [42]. This interconnectedness is not confined to within-assemblage interactions but extends to between-assemblage communications, enabling Coopetition IIoT-based Systems to integrate and collaborate seamlessly within the ecosystem.

Thus, understanding and optimizing these systemic assemblages in a Coopetition IIoT-based System is crucial for higher usability and accessibility. By ensuring that each technological component performs its function and effectively interacts with other elements, the Coopetition IIoT-based System becomes more than just a sum of its parts. It evolves into a dynamic, responsive, and integrated system capable of adapting and thriving in the ever-changing landscape of industrial automation and IoT.

4.2.2 Architectural modules for transactions and services

Architectural modules in the context of IIoT systems play a pivotal role in redefining how products adapt and respond to varying contexts. As conceptualized by Ng et al. [46], these modules are central to the product's reconfigurability, enabling more personalization and tailoring to specific user needs (Irene [46]). The argument put forward by these authors is that disintermediation and fragmentation of the physical product are not merely structural changes; they are strategic moves that facilitate value creation within ecosystems.

Coopetition IIoT-based System exemplifies the concept of an architectural software module [77], encompassing both operant and operand functionalities, as detailed by Ng & Wakenshaw [45]. This dual functionality allows the Coopetition IIoT-based System to be more than just a rigid, predefined system,it becomes a dynamic, adaptable entity capable of evolving with the needs of its environment.

From this perspective, the usability and accessibility mechanisms within the Coopetition IIoT-based System can be perceived through the lens of architectural modules. These modules are not static entities; they are dynamic, constantly undergoing processes of decomposition and aggregation. As Storbacka et al. [60] highlight, the design process in such a context carefully balances decomposition and aggregation [60]. The goal is to achieve an architectural framework that not only preserves but also enhances a hierarchy of loosely coupled parts. This approach ensures that each component or module within the Coopetition IIoT-based System can function independently yet harmonize effectively with others, providing a flexible and robust structure for transactions and services. In essence, the architectural modules in the Coopetition IIoT-based System are more than mere technical specifications; they represent a design philosophy that prioritizes adaptability, responsiveness, and user-centricity. By adopting this approach, the Coopetition IIoT-based System positions itself as a tool and a facilitator of innovation and value creation in the ever-evolving landscape of industrial IoT.

4.2.3 Embedding usability and accessibility mechanisms in coopetition IIoT-based systems

To effectively embed usability and accessibility mechanisms in a Coopetition IIoT-based System, the system leverages the capabilities of the OPC UA protocol, renowned for its foundation in the service-oriented architecture paradigm. This choice is strategic, as OPC UA's design inherently supports the needs of complex IIoT systems. Central to this protocol is its information model, which grants access through services that predefine generic standardized services. Such a setup is crucial in ensuring compatibility across all OPC UA implementations, aligning seamlessly with the interoperability goals of a Coopetition IIoT-based System.

A feature of the OPC UA protocol is its robust security framework. When establishing a session, the OPC UA user security protocol mechanisms come into play, offering tailored security features for diverse environments [25]. This protocol includes exchanging digitally signed certificates during the session setup, a critical OPC UA application security protocol component. These certificates authenticate the entities involved and ensure the integrity and confidentiality of communications. Instance certificates identify specific installations, adding another layer of security. Furthermore, OPC UA transport security protocol mechanisms safeguard data integrity and confidentiality [42]. These mechanisms are adept at preventing message tampering and eavesdropping, ensuring that every communication within the network remains secure and reliable (Fig. 2).

In the context of a coopetition network, these OPC UA mechanisms enable multiple Coopetition IIoT-based Systems to function efficiently on behalf of various coopetitors. This network framework facilitates value co-creation across three critical dimensions: the customers, the rivals', and the providers. These dimensions are integral to the coopetition network, ensuring that collaboration among coopetitors persists throughout the business opportunity, from inception to conclusion, whether it results in a win or loss.

Figure 2 visually represents how OPC UA's security protocols are embedded in the Coopetition IIoT-based System, reinforcing the system's capability to support secure and effective coopetition. By leveraging these sophisticated security and interoperability features of OPC UA, the Coopetition IIoT-based System emerges as a powerful tool in facilitating a secure coopetition environment, essential for driving innovation and value creation in today's dynamic business landscapes.

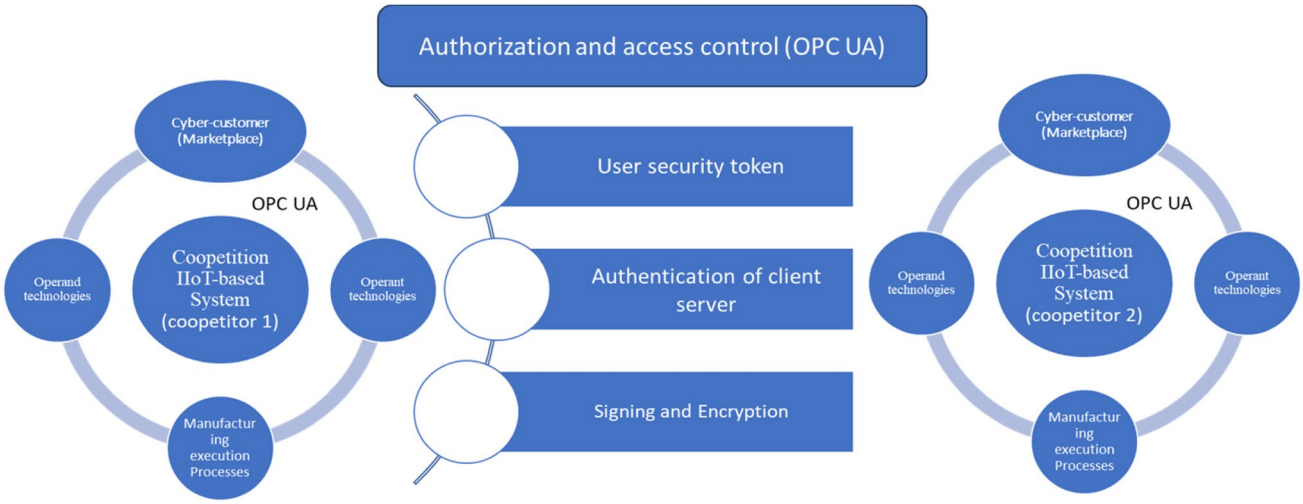


Fig. 2 Embedding usability and accessibility mechanisms in coopetition IIoT-based systems through the OPC-UA protocol

4.3 The prototype — coopetition IIoT-based system

In line with the DSR approach, this section presents a comprehensive overview of the Coopetition IIoT-based System prototype [47]. From the above sections, this IIoT-based system was designed to integrate SMEs within a coopetition network, leveraging advanced technologies to ensure robust Interoperability, security, and scalability across diverse industrial environments. The system's primary goal is to enable SMEs to effectively balance competitive and collaborative activities, thereby enhancing their ability to co-create value while maintaining a competitive edge. Figure 3 visually represents the prototype's interface, providing a clearer understanding of its functionalities.

Key Components of the Coopetition IIoT-based System Prototype can be summarized:

- The foundation of the Coopetition IIoT-based System is an SOA. This architecture facilitates the modular design of services that can be easily integrated and reused across the network, catering to the dynamic needs of the coopetition network. SOA allows services to be adaptable to various business opportunities and collaborative scenarios, ensuring flexibility and responsiveness within the network.
- At the core of the prototype is the OPC UA protocol. OPC UA provides a scalable, platform-independent framework that ensures Interoperability between different systems and devices within the IIoT environment.

Fig. 3 Visual interface of the coopetition IIoT-based system prototype

The protocol supports horizontal communication (e.g., machine-to-machine interactions on the shop floor) and vertical communication (e.g., device-to-cloud data exchanges), making it a critical component for seamless data integration and interaction within the network.
- A standout feature of the prototype is Fingerprint4.0 +, an advanced tool that captures comprehensive information about each product. This includes details such as the product's ecological footprint, lifecycle, recycling processes, and compliance with regulations. This data is made accessible to all actors within the coopetition network, fostering transparency and enabling collaborative validation of the product's value proposition.
- The security of the Coopetition IIoT-based System is reinforced through the robust mechanisms provided by OPC UA. These include digitally signed certificates, instance certificates, and transport security protocols, which ensure the integrity, confidentiality, and authenticity of communications across the network. This security framework is crucial in a coopetition environment, where sensitive information must be protected against unauthorized access and tampering.

This Coopetition IIoT-based System operates within a network of SMEs engaged in coopetition, where multiple systems collaborate to facilitate value co-creation. The prototype's workflow can be structured as follows:

- The system initiates by discovering and connecting to various OPC UA servers within the network. Once established, this connection enables seamless communication between machines, devices, and cloud services, forming the foundation for subsequent interactions.
- Leveraging the OPC UA protocol, the system facilitates data exchange across different layers of the IIoT environment. This includes horizontal communication (e.g., machine-to-machine on the shop floor) and vertical communication (e.g., device-to-cloud), ensuring comprehensive data integration throughout the network.
- Before finalizing a product's value proposition, the system disseminates the enhanced Fingerprint4.0 + to all relevant actors within the network, including customers, coopetitors, and regulatory authorities. This collaborative validation step thoroughly evaluates the product's attributes, ensuring all parties' needs and expectations are met.
- Upon receiving confirmation from all involved parties, the system generates the finalized Fingerprint4.0 + and distributes it to each actor. This fingerprint serves as the blueprint for the manufacturing process, ensuring that production is aligned with the collaboratively validated value proposition.
- Throughout the entire process, OPC UA's security protocols are actively enforced to safeguard all communications within the coopetition network. This ensures that the network operates in a secure environment, protecting sensitive data and maintaining the integrity of the coopetition activities.

In summary, the Coopetition IIoT-based prototype exemplifies a robust, secure, and adaptable system designed to empower SMEs to navigate the complexities of coopetition networks effectively.

5 Coopetition IIoT-based system prototype demonstration

A comprehensive prototype demonstration was conducted to demonstrate the Coopetition IIoT-based System's effectiveness as a coopetition facilitator within SME networks. This demonstration involved a carefully selected group of experts, each representing one of twenty-four manufacturing stone SMEs—a sector crucial to the Portuguese economy. This sector provides over 16,600 direct jobs in Portugal, significantly contributing to employment in inland regions. Despite ongoing challenges, the sector has seen sustained export growth, positioning Portugal as a leading player in the international ornamental stone market (Agostinho [14]).

The prototype demonstration occurred between October 1st, 2023, and November 1st, 2023, culminating in a comprehensive final session on December 11th, 2023. During multiple sessions, the Coopetition IIoT-based System was evaluated by experts. To tailor the demonstration sessions appropriately, each SME's digital maturity level was assessed. The digital maturity levels were categorized as follows:

- DL#0: No digital tools are used.
- DL#1: At least one computerized machine on the manufacturing shop floor.
- DL#2: All machines are computerized.
- DL#3: All machines are computerized and connected to the ERP system.
- DL#4: All machines are connected to the ERP system and can interface with Building Information Modelling (BIM) architects' stations.

This approach ensured a diverse representation across various stages of digital readiness, providing valuable insights into how the Coopetition IIoT-based System's functionalities were perceived by the SMEs involved. The demonstration process included four key actions:

- Introduction: The session began by highlighting the shift towards BIM and the upcoming need for stone companies to adapt to BIM-shaped procurement in the Architecture, Engineering, and Construction (AEC) market. A tangible demonstration of the Coopetition IIoT-based System interface complemented this introduction.
- Explanation: This phase involved a detailed explanation of the Coopetition IIoT-based System's functionalities, focusing on innovation, usefulness, cybersecurity, and usability in facilitating coopetition among rival SMEs. Key features discussed included resource sharing without prior partner knowledge, maintaining commercial confidentiality, and automated resource allocation based on buyer decisions.
- Evaluation: Experts were asked to rate the system on a scale of one to five across several performance metrics:
    - o System Usability: The ease with which SMEs could integrate and utilize the system within their operations.
    - o System Interoperability: The system can seamlessly connect with various devices and platforms across digital maturity levels.
    - o System Cybersecurity: The effectiveness of the system's security protocols in protecting sensitive information during coopetition activities.
    - o System Scalability: The system's ability to adapt and scale as the needs of the SMEs and the complexity of their operations grow.
- Data Collection: Quantitative ratings were collected, anonymized to maintain confidentiality, and documented for analysis.

Table 1 presents the respondents' ratings of the Coopetition IIoT-based System functionalities across different digital maturity levels. The data indicate that DL#0 respondents rated the system's Interoperability low at 1.2, reflecting their limited digital integration. In contrast, DL#4 respondents, representing the most digitally advanced companies, rated Interoperability at a maximum of 5 out of 5, highlighting its importance. Scalability also received high ratings, particularly from DL#4 respondents, who rated it 5. Even DL#0 respondents acknowledged the system's scalability, giving it a score of 4.

Table 1 Respondent's ratings of coopetition IIoT-based system functionalities

Evaluation of the IIoT-based system	Usability	Interoperability	Cybersecurity	Scalability	Average evaluation
DL#0 Respondents	4.3	1.2	2.6	4.0	3.0
DL#1 Respondents	4.7	2.3	3.8	4.2	3.8
DL#2 Respondents	4.9	3.1	3.0	4.2	3.8
DL#3 Respondents	5.0	4.6	3.0	4.9	4.4
DL#4 Respondents	4.9	5.0	4.1	5.0	4.8
Average rating	4.8	3.2	3.3	4.5	3.9

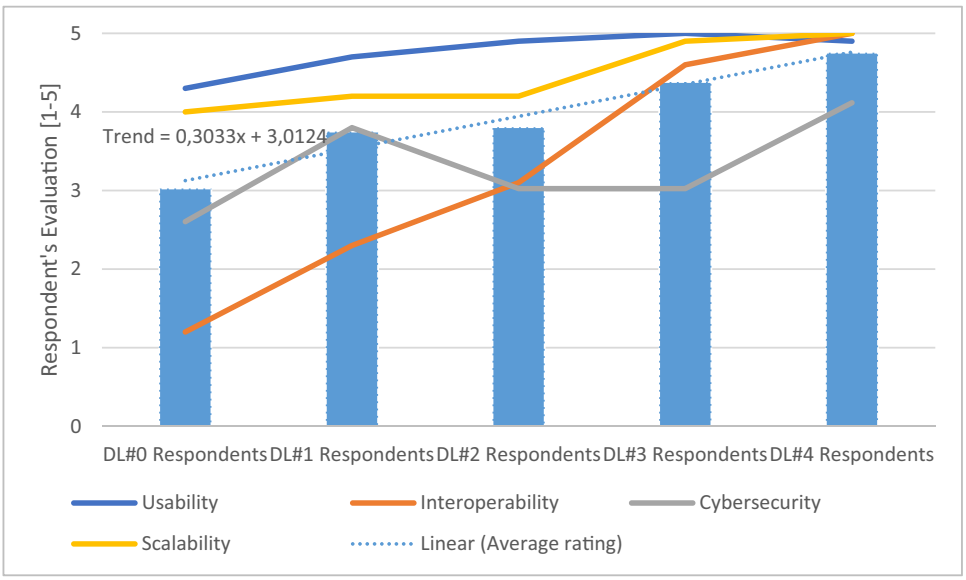


Fig. 4 Evaluation of the coopetition IIoT-based system functionalities

Figure 4 visually represents the evaluation of the Coopetition IIoT-based System functionalities by SME representatives, further illustrating the positive reception and identifying areas for improvement. As digital maturity increases, respondents evaluate the system's functionalities more positively, as indicated by a positive trend with an average increase of 0.3033. This trend likely reflects the greater appreciation of digital technologies' advantages among more digitally advanced companies.

The aggregated evaluation ratings from the demonstration highlighted the perceived innovation of the Coopetition IIoT-based System, with an impressive average score of 3.9 out of 5. This score suggests the prototype's potential functional efficacy within the sector. The system's usefulness was positively correlated with the companies' digital maturity, with the most digitally advanced respondents (DL#4) giving high scores, averaging 4.8 out of 5.

While cybersecurity emerged as an area needing improvement, with an average rating of 3.3 out of 5, the prototype demonstrated significant promise as a tool for enabling coopetition, particularly among SMEs with higher digital levels. The feedback underscored the exceptional value of the system for entities at the forefront of digital integration. However, given the identified cybersecurity concerns, a focused review and enhancement of the system's security features are advisable. Strengthening these aspects will bolster confidence in the prototype and enhance its overall utility and acceptance among SMEs.

The Coopetition IIoT-based System achieved a positive evaluation rate of 78.9%, underscoring its potential as a transformative tool for SMEs. The system's ability to balance competition and collaboration among SMEs was particularly noted as a key strength, making it a promising solution for fostering innovation and value co-creation in the industrial sector. While the feedback was highly encouraging—especially regarding innovation and usefulness for companies at higher digital levels (DL#3 and DL#4)—the moderate rating for cybersecurity suggests the need for enhanced security measures before practical implementation. Addressing these concerns will ensure the system's success and widespread adoption.

6 Conclusions

This research sought to answer how an IIoT system can support coopetition networks among SMEs. In response, the study developed and demonstrated an IIoT system specifically designed to enhance the dynamics of coopetition—where competition and collaboration co-occur—within SME networks. By grounding the system in S-D Logic and employing the DSR methodology, the research aimed to create a framework beyond traditional technological solutions, offering a robust, knowledge-based platform that supports SMEs in navigating the complexities of global markets through a balanced approach to competition and collaboration.

The Coopetition IIoT-based System developed in this study represents a significant advancement toward achieving this goal. The system's design, which aligns closely with S-D Logic principles, underscores the central role of service in economic exchange and value creation, particularly within the industrial sector. By facilitating real-time data exchange, resource sharing, and collaborative decision-making, the system enables SMEs to balance competitive and cooperative activities effectively, thereby maximizing mutual benefits within coopetition networks.

The practical evaluation of the Coopetition IIoT-based System through a prototype demonstration involving experts from the Portuguese manufacturing stone sector resulted in a positive reception, with a positive evaluation rate of 78.9%. This feedback highlights the system's potential to significantly impact how SMEs engage in coopetition. It gives them a powerful tool to manage the entire spectrum of business opportunities—from initiation to conclusion—while maintaining a balance between competition and collaboration.

The study also contributes to the theoretical understanding of service ecosystems and the application of S-D Logic in modern business environments. By illustrating how IIoT can be harnessed to support coopetition networks, this research advances the discourse on integrating disruptive technologies within traditional manufacturing and service processes, offering a more nuanced approach to competition and collaboration among SMEs.

Looking forward, the research emphasizes the importance of further investigations into the practical application and continuous evaluation of the Coopetition IIoT-based System. Such future research is crucial for validating the current findings and exploring the practical challenges and opportunities that IIoT systems present in real-world coopetition networks. By continuing to refine and enhance these technologies, the research community can contribute to SMEs' sustained competitiveness and growth in the global economy.

Author contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Agostinho da Silva, and António Cardoso. The first draft of the manuscript was written by Agostinho da Silva and all authors commented.

Funding Open access funding provided by FCT|FCCN (b-on).

Declarations

Conflict of interest The authors declare no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

1. Akaka MA, Vargo SL, Lusch RF (2013) The complexity of context: a service ecosystems approach for international marketing. J Int Mark 21(4):1–20. https://doi.org/10.1509/jim.13.0032
2. Akaka M, Corsaro D, Kelleher C, Maglio P, Seo Y, Lusch R, Vargo S (2014) The role of symbols in value cocreation. Mark Theory 14(3):311–326. https://doi.org/10.1177/1470593114534344
3. Akaka M, Schau H, Vargo S (2023) How practice diffusion drives IoT technology adoption and institutionalization of solutions in service ecosystems. Proc Ann Hawaii Int Conf Syst Sci 2023(1):1427–1435. https://doi.org/10.24251/HICSS.2023.178
4. Ashton K (2009) That "Internet of things" thing. RFID Journal 22(7):97–114
5. Bai C, Dallasega P, Orzes G, Sarkis J (2020) Industry 4.0 technologies assessment: a sustainability perspective. Int J Prod Econ 229:107776. https://doi.org/10.1016/j.ijpe.2020.107776
6. Bartelt M, Kuhlenk B (2020) Automated production of individualized products for teaching I4.0 concepts. 10th Conf Learning Factories, CLF2020 45:337. https://doi.org/10.1016/j.promfg.2020.04.027
7. Bauer W, Hämmerle M, Schlund S, Vocke C (2015) Transforming to a hyper-connected society and economy – towards an "Industry 4.0. Procedia Manuf 3(1):417–424. https://doi.org/10.1016/j.promfg.2015.07.200
8. Bouncken R, Kumar A, Connell J, Bhattacharyya A, He K (2024) Coopetition for corporate responsibility and sustainability: does it influence firm performance? Int J Entrep Behav Res 30(1):128–154. https://doi.org/10.1108/IJEBR-05-2023-0556
9. Boyes H, Hallaq B, Cunningham J, Watson T (2018) The industrial Internet of things (IIoT): An analysis framework. Comput Industry 101(December 2017):1–12. https://doi.org/10.1016/j.compind.2018.04.015
10. Breillat R (2020) Industrial artificial intelligence, internet of things smart devices, and big data-driven decision-making in digital-twin-based cyber-physical production systems. Econ, ManagFinancial Markets 15(1):15120204. https://doi.org/10.22381/EMFM15120204
11 Chen CL (2020) Cross-disciplinary innovations by Taiwanese manufacturing SMEs in the context of Industry 4.0. J Manuf Technol Manag 31(6):1145–1168. https://doi.org/10.1108/JMTM-08-2019-0301
12 Coelho P, Bessa C, Landeck J, Silva C (2022) Industry 5.0: the arising of a concept. Procedia Comput Sci 217(2022):1137–1144. https://doi.org/10.1016/j.procs.2022.12.312
13. Crick J (2019) The dark side of coopetition: when collaborating with competitors is harmful for company performance. J Business & Ind Mark 35(2):318–337. https://doi.org/10.1108/JBIM-01-2019-0057
14. da Silva A, Cardoso AJM (2024) Coopetition with the industrial IoT: a service-dominant logic approach. Appl Syst Innov 7(3):47. https://doi.org/10.3390/asi7030047
15. Di Bella L, Katsinis A, Lagüera-González J, Odenthal L, Hell M, Lozar B (2023) Annual Report on European SMEs 2022/2023. Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/JRC134336
16. Doganova L, Eyquem-Renault M (2009) What do business models do? Res Policy 38(10):1559–1570. https://doi.org/10.1016/j.respol.2009.08.002
17. Elo J, Lumivalo J, Tuunanen T, Vargo SL (2024) Enabling value co-creation in partner collaboration ecosystems: an institutional work perspective. Proceedings of the 57th Hawaii International Conference on System Sciences, March. https://www.sdlogic.net/pdf/post2018/24_0031.pdf
18 Ergen M (2019) What is artificial intelligence? Technical considerations and future perception. Anatol J Cardiol 22:5–7. https://doi.org/10.14744/AnatolJCardiol.2019.79091
19. Garay-Rondero CL, Martinez-Flores JL, Smith NR, Caballero Morales SO, Aldrette-Malacara A (2020) Digital supply chain model in Industry 4.0. J Manuf Technol Manag 31(5):887–933. https://doi.org/10.1108/JMTM-08-2018-0280
20. Gaskin J, Lyytinen K, Thummadi V, Schutz D, Yoo Y, Weiss A, Berente N (2010) Sequencing design DNA: A set of methodological artifacts for sequencing socio-technical design routines. ICIS 2010 Proceedings. 202
21. Hakimi O, Liu H, Abudayyeh O (2024) Digital twin-enabled smart facility management: a bibliometric review. Front Eng Manag 11(1):32–49. https://doi.org/10.1007/s42524-023-0254-4
22. Haluk D, Spohrer J, Vikas K (2011) Service Systems Implementation. In: B Hefley and W Murphy (eds). https://doi.org/10.1007/978-1-4419-7904-9_17
23. Hietanen J, Andéhn M, Bradshaw A (2018) Against the implicit politics of service-dominant logic. Mark Theory 18(1):101–119. https://doi.org/10.1177/1470593117692023
24 Ho MHW, Chung HFL, Kingshott R, Chiu CC (2020) Customer engagement, consumption and firm performance in a multi-actor service eco-system: the moderating role of resource integration. J Bus Res 121:557. https://doi.org/10.1016/j.jbusres.2020.02.008
25. Hoppe S (2023) OPC unified architecture-interoperability for Industrie 4.0 and the Internet of Things. https://opcfoundation.org/wp-content/uploads/2023/05/OPC-UA-Interoperability-For-Industrie4-and-IoT-EN.pdf
26. Kaartemo V, Akaka M, Vargo S (2017) A service-ecosystem perspective on value creation: implications for international business. Value Creation Int Bus 131–149. https://doi.org/10.1007/978-3-319-39369-8_6
27. Khanboubi F, Boulmakoul A, Tabaa M (2019) Impact of digital trends using IoT on banking processes. Proc Comput Sci 151:77–84. https://doi.org/10.1016/j.procs.2019.04.014
28. Kleinaltenkamp M, Kleinaltenkamp MJ, Karpen IO (2023) Resource entanglement and indeterminacy: advancing the service-dominant logic through the philosophy of Karen Barad. Mark Theory 0(0). https://doi.org/10.1177/14705931231207327
29. Koskela-Huotari K, Vargo SL (2016) Institutions as resource context. J Serv Theory Pract 26(2):163–178. https://doi.org/10.1108/JSTP-09-2014-0190
30. Lars A (2016) German Standardization Roadmap Industry 4.0. In: DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik in DIN und VDE. https://www.dke.de/resource/

blob/2244336/dbbd9c02812f04cc1ab0063647262645/german-standardization-roadmap-industry-4-0-version-5-data.pdf
31. Latif G, Brahim GB, Abdelhamid SE, Alghazo R, Alhabib G, Alnujaidi K (2023) Learning at your fingertips: an innovative IoT-based AI-powered Braille Learning System. Appl Syst Innov 6(5):91. https://doi.org/10.3390/asi6050091
32. Leal G, Guédria W, Panetto H (2019) An ontology for interoperability assessment: a systemic approach. J Industr Inf Integr. https://doi.org/10.1016/j.jii.2019.07.001
33. Lindström T, Polsa P, Pellegrin-Boucher E, Le Roy F, Gurău C, Filieri R, Bouncken RB, Gast J, Kraus S, Bogers M, Barney J, Wright M, Ketchen DJ, Gnyawali DR, Song Y, Devece C, Ribeiro-Soriano DE, Palacios-Marqués D, Grängsjö Y, Kock S (2016) Destination networking: co-opetition in peripheral surroundings. Industr Market Manag 33(2):427–448. https://doi.org/10.1108/09600030310481997
34. Liu H, Li S, Li W, Sun W (2024) A distributed resource sharing mechanism in edge-enabled IIoT systems. IEEE Internet Things J 11(8):14296–14312. https://doi.org/10.1109/JIOT.2023.3342321
35. Lusch RF, Vargo SL, Tanniru M (2010) Service, value networks and learning. J Acad Mark Sci 38(1):19–31. https://doi.org/10.1007/s11747-008-0131-z
36 Lusch R, Nambisan S (2015) Service innovation: a service-dominant logic perspective. MIS Quarterly 39(1):155–175. https://doi.org/10.25300/MISQ/2015/39.1.07
37 Maglio P, Vargo S, Caswell N, Spohrer J (2009) The service system is the basic abstraction of service science. Inf Syst E-Bus Manag 7(4 SPEC. ISS.):395–406. https://doi.org/10.1007/s10257-008-0105-1
38. Manzhynski S, Biedenbach G (2023) The knotted paradox of coopetition for sustainability: Investigating the interplay between core paradox properties. Ind Mark Manage 110:31–45. https://doi.org/10.1016/j.indmarman.2023.02.013
39. Matzner M, Büttgen M, Demirkan H, Spohrer J, Alter S, Fritzsche A, Ng ICL, Jonas JM, Martinez V, Möslein KM, Neely A (2018) Digital transformation in service management. J Service Manag Res 2(2):3–21. https://doi.org/10.15358/2511-8676-2018-2-3
40. Meena A, Dhir S, Sushil S (2023) A review of coopetition and future research agenda. J Business Industrss Marketing 38(1):118–136. https://doi.org/10.1108/JBIM-09-2021-0414
41. Michel S, Vargo SL, Lusch RF (2008) Reconfiguration of the conceptual landscape: a tribute to the service logic of Richard Normann. J Acad Mark Sci 36(1):152–155. https://doi.org/10.1007/s11747-007-0067-8
42. Mosch P, Majocco P, Obermaier R (2023) Contrasting value creation strategies of industrial-IoT-platforms – a multiple case study. Int J Prod Econ 263:108937. https://doi.org/10.1016/j.ijpe.2023.108937
43 Müller JM, Buliga O, Voigt K-I (2018) Fortune favors the prepared: how SMEs approach business model innovations in Industry 4.0. Technol Forecast Social Change 132(September 2017):2–17. https://doi.org/10.1016/j.techfore.2017.12.019
44. Mustak M, Plé L (2020) A critical analysis of service ecosystems research: rethinking its premises to move forward. J Serv Mark 34(3):399–413. https://doi.org/10.1108/JSM-02-2019-0084
45. Ng I, Wakenshaw S (2017) The Internet-of-Things: review and research directions. Int J Res Mark 34(1):3–21. https://doi.org/10.1016/j.ijresmar.2016.11.003
46. Ng I, Scharf K, Pogrebna G, Maull R (2015) Contextual variety, Internet-of-Things and the choice of tailoring over platform: mass customization strategy in supply chain management. Int J Prod Econ 159:76–87. https://doi.org/10.1016/j.ijpe.2014.09.007
47. Peffers K, Tuunanen T, Rothenberger MA, Chatterjee S (2007) A design science research methodology for information systems research. J Manag Inf Syst 24(3):45–77. https://doi.org/10.2753/MIS0742-1222240302
48. Presciuttini A, Portioli-Staudacher A (2024) Applications of IoT and advanced analytics for manufacturing operations: a systematic literature review. Procedia Comput Sci 232:327–336. https://doi.org/10.1016/j.procs.2024.01.032
49. Razmdoost K, Alinaghian L, Chandler JD, Mele C (2023) Service ecosystem boundary and boundary work. J Business Res 156(November 2022):113489. https://doi.org/10.1016/j.jbusres.2022.113489
50. Reeves M, Lotan H, Legrand J, Jacobides MG (2022) Chapter 3 How business ecosystems rise (and often fall). In: Business Ecosystems (July):27–34. De Gruyter. https://doi.org/10.1515/9783110775167-003
51. Rouyre A, Fernandez A-S, Bruyaka O (2024) Big problems require large collective actions: managing multilateral coopetition in strategic innovation networks. Technovation 132:102968. https://doi.org/10.1016/j.technovation.2024.102968
52. Ruokolainen T, Kutvonen L (2009) Managing interoperability knowledge in open service ecosystems. Proc- IEEE Int Enterp Distrib Object Comput Work, EDOC, 203–211. https://doi.org/10.1109/EDOCW.2009.5331993
53. Salih KOM, Rashid TA, Radovanovic D, Bacanin N (2022) A comprehensive survey on the Internet of Things with the industrial marketplace. Sensors 22(3):730. https://doi.org/10.3390/s22030730
54 Schlechtendahl J, Keinert M, Kretschmer F, Lechler A, Verl A (2015) Making existing production systems Industry 4.0-ready. Prod Eng 9(1):143–148. https://doi.org/10.1007/s11740-014-0586-3
55. Seepana C, Paulraj A, Huq FA (2020) The architecture of coopetition: strategic intent, ambidextrous managers, and knowledge sharing. Ind Mark Manage 91(August):100–113. https://doi.org/10.1016/j.indmarman.2020.08.012
56. Silva A, Dionisio A, Almeida I (2020) Enabling cyber-physical systems for Industry 4.0 operations: a service science perspective. Int J Innov Technol Exploring Eng 9(8):838–846. https://doi.org/10.35940/ijitee.H6804.069820
57. Silva A, Rabadão C, Capela C (2020) Towards Industry 4.0 | A case study of BIM deployment in ornamental stones sector. Int J Innov Technol Exploring Eng (IJITEE) 67:24535
58. Sklyar A, Kowalkowski C, Sörhammar D, Tronvoll B (2019) Resource integration through digitalization: a service ecosystem perspective. J Mark Manag 35(11–12):974–991. https://doi.org/10.1080/0267257X.2019.1600572
59 Stock T, Seliger G (2016) Opportunities of sustainable manufacturing in Industry 4.0. Procedia CIRP 40(Icc):536–541. https://doi.org/10.1016/j.procir.2016.01.129
60. Storbacka K, Brodie R, Böhmann T, Maglio P, Nenonen S (2016) Actor engagement as a microfoundation for value co-creation. J Bus Res 69(8):3008–3017. https://doi.org/10.1016/j.jbusres.2016.02.034
61. Svingerova M, Melichar M (2017) Evaluation of Process Risks in Industry 4.0 Environment. 1021–1029. https://doi.org/10.2507/28th.daaam.proceedings.142
62 urRehman MH, Yaqoob I, Salah K, Imran M, Jayaraman PP, Perera C (2019) The role of big data analytics in industrial Internet of Things. Future Gener Comput Syst 99:247–259. https://doi.org/10.1016/j.future.2019.04.020
63. Vargo SL, Lusch R (2017) Service-dominant logic 2025. Int J Res Mark 34(1):46–67. https://doi.org/10.1016/j.ijresmar.2016.11.001
64. Vargo S, Lusch R (2016) Institutions and axioms: an extension and update of service-dominant logic. J Acad Mark Sci 44(1):5–23. https://doi.org/10.1007/s11747-015-0456-3
65. Vargo SL (2023) Conceptual reconciliation for clarity and impact. AMS Review 13(3–4):169–172. https://doi.org/10.1007/s13162-023-00271-5
66. Vargo SL, Akaka MA (2009) Service-dominant logic as a foundation for service science: clarifications. Serv Sci 1(1):32–41. https://doi.org/10.1287/serv.1.1.32

67 Vargo SL, Akaka MA, Wieland H (2020) Rethinking the process of diffusion in innovation: a service-ecosystems and institutional perspective. J Business Res 116(December 2018):526–534. https://doi.org/10.1016/j.jbusres.2020.01.038
68. Vargo SL, Fehrer JA, Wieland H, Nariswari A (2024) The nature and fundamental elements of digital service innovation. J Serv Manag 35(2):227–252. https://doi.org/10.1108/JOSM-02-2023-0052
69. Vargo SL, Lusch RF (2004) Evolving to a new dominant logic for marketing. J Mark 68(1):1–17. https://doi.org/10.1509/jmkg.68.1.1.24036
70. Vargo SL, Lusch RF (2011) It's all B2B…and beyond: toward a systems perspective of the market. Ind Mark Manage 40(2):181–187. https://doi.org/10.1016/j.indmarman.2010.06.026
71. Vargo SL, Wieland H, O'Brien M (2023) Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline. J Bus Res 164:113965. https://doi.org/10.1016/j.jbusres.2023.113965
72. Wang L, Törngren M, Onori M (2015) Current status and advancement of cyber - physical systems in manufacturing. Procedia Manuf XXX, 1–18. https://doi.org/10.1016/j.jmsy.2015.04.008
73. Wieland H, Hartmann N, Vargo S (2017) Business models as service strategy. J Acad Mark Sci 45(6):925–943. https://doi.org/10.1007/s11747-017-0531-z
74. Yazdinejad A, Zolfaghari B, Dehghantanha A, Karimipour H, Srivastava G, Parizi R (2023) Accurate threat hunting in industrial Internet of things edge devices. In Digit Commun Netw 9(5):1123–1130. https://doi.org/10.1016/j.dcan.2022.09.010
75. Yoo Y, Boland RJ, Lyytinen K, Majchrzak A (2012) Organizing for innovation in the digitized world. Organ Sci 23(5):1398–1408. https://doi.org/10.1287/orsc.1120.0771
76. Zatsarinnyy AA, Shabanov AP (2019) Model of a prospective digital platform to consolidate the resources of economic activity in the digital economy. Procedia Computer Sci 150:552–557. https://doi.org/10.1016/j.procs.2019.02.092
77 Zhong RY, Xu X, Klotz E, Newman ST (2017) Intelligent manufacturing in the context of Industry 4.0: a review. Engineering 3(5):616–630. https://doi.org/10.1016/J.ENG.2017.05.015

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

7th Global Stone Congress 2023, Batalha, Portugal, June 18 – 23, 2023

Challenges for Portuguese Stone Companies in Adopting BIM

Agostinho da Silva[1*] Antonio J. Marques Cardoso[2]

(1) CISE: Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal; CIGEST: Centre for Research in Management, Lisboa, Portugal, *a.silva@zipor.com
(2) CISE: Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal

Summary: *This study explores the integration of BIM with sustainability principles in the AEC sector, focusing on the Portuguese ornamental stone (OS) industry. BIM technology's evolution and its various dimensions, from 3D to 8D, offer significant enhancements in project management, cost estimation, and safety. The research identifies three primary concerns for OS companies: efficiency, investment capacity, and customer satisfaction. Efficiency concerns highlight the need for competitive pricing, quick delivery, and sustainable practices. Investment capacity focuses on digital operations and advanced technologies, while customer satisfaction emphasizes real-time collaboration and high-quality, eco-friendly products. The study's limitations include its focus on Portugal and the exclusion of micro-enterprises. Future research should expand geographically, include smaller firms, and explore the integration of emerging technologies like IoT and AI with BIM. Addressing these areas will provide a comprehensive understanding of BIM's role in enhancing the AEC industry's capabilities.*

Key words: *BIM, Sustainability, Efficiency, Investment, Customer Satisfaction*

1. Introduction

In recent years, the architecture, engineering, and construction (AEC) industry has increasingly embraced BIM as a pivotal tool for integrating sustainability principles into construction projects (Hadavi & Alizadehsalehi, 2024). BIM technology fundamentally involves creating a detailed digital representation of a construction project, allowing for comprehensive management throughout its lifecycle (Shao & Cao, 2024).

A common misconception within the AEC community is the conflation of BIM maturity with BIM dimensions (Wijeratne et al., 2024). BIM maturity pertains to the proficiency of supply chain entities in exchanging and utilizing BIM data. In contrast, BIM dimensions refer to the various types of data linked to a model (Abdumutalibovich & Lutfillaevna, 2023). These dimensions enhance the understanding of construction components, encompassing aspects such as work stages, delivery methods, budgeting, and maintenance requirements. Essentially, they foster superior project management and facilitate data-driven optimization.

BIM, initially centered on three core dimensions—length, width, and depth—has evolved to incorporate more sophisticated data dimensions (Johansson & Roupé, 2024). This progression enables a richer and more nuanced representation of construction elements. As BIM continues to advance, the potential for integrating additional dimensions remains boundless, reflecting the technology's dynamic nature (Yilmaz et al., 2023).

Stone has long been a cornerstone of building construction, and the ornamental stone (OS) sector is a critical component of the AEC supply chain (Silva & Pata, 2022). This is particularly true for SMEs in Europe. In Portugal, for instance, the OS sector generates over 16,600 direct jobs and is a significant private employer, especially in inland regions. Despite facing challenges from recent AEC sector crises, the OS industry has shown robust export growth over the past two decades. Portugal is now the eighth-largest exporter of ornamental stone globally and ranks second in per capita international trade.

In a BIM-oriented supply chain (BIM.SC), procurement becomes intricately linked to the design phase. BIM's influence extends to stone elements as it does to all construction materials. By creating detailed information models for each element, BIM enhances the authenticity of the digital model and elevates procurement standards. This raises a critical question: What challenges do stone companies face within BIM-oriented supply chains?

To address this question, it is hypothesized that each BIM dimension interconnects with the AEC supply chain, presenting unique challenges to stakeholders. This research aims to evaluate the specific concerns of OS companies within BIM.SC. The study will proceed through the following methodological steps:

1. Identifying the linkage of each BIM dimension to the AEC supply chain.
2. Conducting a quantitative survey to assess the concerns of Portuguese stone sector companies.
3. Inferring the position and challenges of OS companies within BIM.CS.

By following this structured approach, the research seeks to elucidate the interplay between BIM dimensions and the ornamental stone sector, ultimately contributing to a deeper understanding of how BIM can optimize supply chain integration for this industry.

2. Methodology

To thoroughly investigate the challenges faced by OS companies within BIM.SC, this research adopts a systematic multi-step methodological approach. This approach is structured into three main phases: identification, evaluation, and inference, aligning with the research objectives.

2.1. Identification of BIM Dimension Linkages

Delineate how each BIM dimension connects to different aspects of the AEC supply chain, providing a foundational understanding for the study, by conducting a detailed mapping of BIM dimensions to various components of the AEC supply chain (Hadavi & Alizadehsalehi, 2024). This will highlight how dimensions such as 3D (geometric data), 4D (time scheduling), 5D (cost estimation), and 6D (sustainability) contribute to the efficiency and integration of supply chain activities (Hadavi & Alizadehsalehi, 2024). The mapping process will examine how each dimension enhances project management and supply chain interactions, focusing on the roles these dimensions play in optimizing processes and outcomes (Chowdhury et al., 2024). A comprehensive visual and descriptive representation showing the key linkages between BIM dimensions and AEC supply chain components, demonstrating how these connections enhance project and supply chain efficiency.

2.2. Evaluation of OS Companies' Concerns

Assess the specific concerns and challenges faced by OS companies in relation to BIM.SC, by designing and distribute a structured survey to OS companies in Portugal to collect quantitative data. The survey will focus on understanding the level of BIM adoption, the specific challenges related to BIM integration, and the perceived benefits and barriers (Shao & Cao, 2024). Questions will cover topics such as technology adoption, supply chain coordination, data management, and procurement processes within a BIM context. A detailed quantitative analysis report outlining the primary concerns of OS companies regarding BIM integration, supported by statistical evidence and trends derived from the survey data.

2.3. Inference and Integration into BIM.CS

Integrate the findings, develop a comprehensive understanding of the roles and challenges faced by OS companies within BIM.SC. This synthesis will provide a holistic view of how BIM dimensions impact the OS sector and its interactions with the supply chain. A final report detailing the challenges and opportunities for OS companies in BIM.SCs, complemented by strategic recommendations for better integration and performance within BIM environments.

3. Quantitative Survey

The OS sector is relevant for the Portuguese economy. Since 2011, this sector has demonstrated resilience and growth, with an average annual turnover increase of 5.13%, reflecting a stable and robust industry (Silva et al., 2020). The OS sector encompasses both upstream (raw material extraction) and downstream (processing and finishing) activities. The enhancement of national wealth is closely tied to moving up the value chain, particularly through downstream activities that often involve value-added processing and export of finished stone products.

3.1. Population and Sample

The diversity of the OS sector in Portugal, encompassing various CAE codes, presents challenges for analysis based on official statistical data. To address this, a direct census of OS companies across mainland Portugal was conducted. This census identified 2,551 companies engaged in either upstream or downstream activities, or both, across eighteen districts.

Nearly 70% of the identified companies are micro-enterprises or craft workshops with at least three employees. These entities typically operate in localized markets and do not leverage computerized technologies, making them less likely to benefit from digital transformation in the near term. Given their limited technological engagement, these micro-companies were excluded from the study.

The research focused on the remaining 994 OS companies that have more than three employees and employ at least one computerized machine in their operations. This subset represents companies more likely to be impacted by and to benefit from digital advancements, including BIM technology.

From this identified target population, a sample of 670 companies was selected for the survey, representing 67.4% of the total population. The representativeness of this sample is reinforced by its substantial coverage of the sector's key metrics: The sample accounts for 89.3% of the total turnover of the target population. The

sample represents 95.9% of the total export value. The sample encompasses 88.5% of the direct employment within the target population.

A structured questionnaire was developed to gather data on the challenges and integration of BIM within the OS sector. The questionnaire was designed to capture quantitative data and included questions rated on a five-point Likert scale ranging from "very high" to "very low."

To ensure the reliability and depth of responses, all interviews were conducted face-to-face. This approach facilitated more nuanced understanding and engagement with the respondents.

The survey was conducted over a year, from February 2022 to February 2023, allowing for comprehensive data collection across the diverse geographic and operational spectrum of the OS sector. Responses from the interviews were meticulously recorded and compiled into an Excel database. This database provided a structured format for subsequent data analysis. The collected data was analyzed using various statistical methods to identify trends, correlations, and significant insights related to BIM adoption and the challenges faced by OS companies.

This quantitative survey methodology ensures a comprehensive and representative analysis of the OS sector in Portugal.

3.2. 3D.BIM Concerns Evaluation

Interoperability, or the seamless exchange of data between systems, is critical in the AEC sector. Poor interoperability leads to significant budget overruns, costing the industry billions annually (HM Government, 2015). In a BIM-oriented supply chain, real-time collaboration among BIM users is becoming the standard practice. This shift necessitates that sales and operational teams work closely with BIM tools and operators. Successful 3D.BIM integration requires companies to overhaul their digital operations, adopt advanced technologies, and enhance real-time collaboration. These capabilities are essential for meeting market demands and improving project execution.

To assess the concerns related to 3D.BIM, respondents were asked to evaluate their capabilities in the following areas: Digital Operations (KPI-Digital Operations), (KPI-Advanced Technologies), and (KPI-Skills Admission). The responses to these areas are summarized in Table I below.

Table I. Level of Concerns Related to 3D.BIM

Level of Concerns related to 3D BIM	KPI_Digital_Operations	KPI_Advanced_Technologies	KPI_Skills_Admission	KPI_Real-time_Collaboration	Average
Very high	25,8%	33,9%	29,7%	38,6%	32,0%
High	21,9%	25,7%	26,8%	26,9%	25,3%
Moderate	20,8%	14,3%	18,0%	15,4%	17,1%
Low	17,4%	14,2%	14,6%	12,6%	14,7%
Very low	14,2%	11,9%	10,8%	6,5%	10,9%
High + Very high	47,7%	59,6%	56,5%	65,4%	57,3%

The survey highlights significant concerns about real-time collaboration and advanced technologies as companies integrate 3D.BIM. Addressing these areas is vital for effective BIM adoption. Companies need to focus on digital transformation, technology upgrades, and building a skilled workforce to leverage the benefits of BIM fully.

3.3. 4D.BIM Concerns Evaluation

The fourth dimension of BIM, known as 4D.BIM, incorporates schedule information into the digital modeling process (Johansson et al., 2015). This dimension is crucial for the AEC sector, as one of the primary goals of implementing BIM is to minimize execution time and prevent schedule delays (HM Government, 2013)). By embedding schedule data into BIM objects, users can plan and visualize the progression of construction activities across the entire lifecycle of a building (Wijeratne et al., 2024). This capability is essential for detecting potential conflicts early and managing changes effectively during both construction and maintenance phases.

4D.BIM tools are invaluable for processing on-site information, visualizing the impacts of schedule changes, and keeping stakeholders informed about construction progress and potential risks. These tools can be seamlessly integrated with project management applications, providing significant advantages in optimizing project plans. For builders and manufacturers, 4D.BIM enables the streamlining of construction activities and facilitates better coordination among various teams involved in the project.

A critical aspect of integrating BIM into the supply chain is the ability to respond swiftly to market demands and deliver products efficiently, irrespective of project size. Companies need to ensure quick lead times for both small and large-scale projects to maintain competitive advantage and meet client expectations.

To evaluate concerns specifically related to 4D.BIM, respondents were surveyed on their ability to invest in rapid order responses (KPI-Quick Delivery Time), manage orders of varying sizes (KPI-Scale Capacity), and adhere to established delivery deadlines (KPI-In-Time

Delivery). These key performance indicators (KPIs) provide a comprehensive understanding of the challenges faced by companies in integrating 4D.BIM into their operations.

The analysis of the responses (see Table II) revealed significant levels of concern. A substantial 70.8% of respondents expressed high or very high concern regarding their ability to deliver products quickly. This highlights the critical need for efficient processes and technologies that can support rapid responses to market demands. Similarly, 69.2% of respondents indicated high or very high concern about meeting established delivery deadlines. This underscores the importance of reliable scheduling and the ability to manage timelines effectively in the construction process.

These concerns reflect the industry's emphasis on maintaining stringent delivery schedules and the challenges companies face in achieving these goals. The average level of concern across all categories points to the necessity of addressing these issues to ensure successful 4D.BIM integration.

Table II. Level of Concerns Related to 4D.BIM

Level of Concerns related to 4D BIM	KPI_Quick_Deliver_Time	KPI_Scale_Capacity	KPI_In_Time_Delivery	Average
Very high	42,6%	28,0%	38,7%	36,4%
High	28,1%	25,7%	30,5%	28,1%
Moderate	12,3%	19,9%	12,0%	14,7%
Low	9,3%	16,4%	13,3%	13,0%
Very low	7,6%	10,1%	5,6%	7,8%
High + Very high	70,8%	53,6%	69,2%	64,5%

The results from Table II indicate that timely delivery and rapid order response are critical concerns for OS companies integrating 4D.BIM. Addressing these areas is essential for leveraging the full potential of 4D.BIM tools in optimizing project management and enhancing overall supply chain efficiency.

3.4. 5D.BIM Concerns Evaluation

In the context of BIM.SC, companies increasingly provide their products through open-access web libraries, enhancing cost and taxation transparency within the AEC sector (Abdumutalibovich & Lutfillaevna, 2023). By integrating cost information with the quantities derived from 3D.BIM (spatial data) and 4D.BIM (time data), BIM technology allows for detailed cost estimations and cash-flow projections, effectively replacing traditional spreadsheet-based approaches (Tedonchio et al., 2022). Furthermore, 5D.BIM provides predictive insights into how cost variations in materials, equipment, or labor affect overall project budgets (Yilmaz et al., 2023). This capability enables comprehensive cost management and scenario analysis, allowing stakeholders to anticipate and evaluate the financial impact of various changes.

To assess the concerns related to 5D.BIM integration, respondents evaluated their capabilities in the following key performance areas: Competitive Prices (KPI-Competitive Prices), Innovation and Flexibility (KPI-Innovation and Flexibility), and Zero Defects (KPI-Zero Defects). The findings from these assessments are summarized in Table III below.

Table III. Level of Concerns Related to 5D.BIM

Level of Concerns related to 5D BIM	KPI_Competitive_Price	KPI_Innovation_&_Flexibility	KPI_Zero_Defects	Average
Very high	37,3%	31,6%	29,7%	32,9%
High	30,9%	32,0%	26,8%	29,9%
Moderate	13,2%	17,9%	18,0%	16,4%
Low	10,4%	11,5%	14,6%	12,2%
Very low	8,2%	6,9%	10,8%	8,6%
High + Very high	68,2%	63,7%	56,5%	62,8%

The results from Table III reveal that competitive pricing and the ability to innovate and adapt flexibly are the foremost concerns for companies as they integrate 5D.BIM. Addressing these concerns is crucial for leveraging the full potential of 5D.BIM, which offers comprehensive cost management capabilities and enhances transparency. Companies must focus on maintaining cost competitiveness and fostering innovation to succeed in the dynamic AEC market.

3.5. 6D.BIM Concerns Evaluation

In the realm of BIM, sustainability is represented as the sixth dimension (6D.BIM). This dimension enables BIM platforms to estimate a building's energy consumption and ecological footprint throughout its entire lifecycle, including demolition. In the architecture, AEC sector, sustainability is a crucial factor for global competitiveness (Chowdhury et al., 2024). By integrating sustainability metrics into BIM models, 6D.BIM allows designers to set and meet carbon targets, validate design choices, and compare alternative solutions. Additionally, 6D.BIM supports the incorporation of real-time data collected on-site to measure and verify sustainability during construction, thereby optimizing the selection of high-performance, eco-friendly facilities.

To assess concerns related to 6D.BIM, respondents evaluated their capabilities in the following key performance areas: Low Footprint (KPI-Low Footprint), Green Label (KPI-Green Label), Easy Recycling (KPI-Easy Recycling), and Energy Efficiency Products (KPI-Energy Efficiency Products). The findings from these assessments are summarized in Table IV below.

Table IV. Level of Concerns Related to 6D.BIM

Level of Concerns related to 6D BIM	KPI_Low_Footprint	KPI_Green_Label	KPI_Easy_Recycling	KPI_Energy_Efficiency_Products	Average
Very high	37,0%	31,4%	31,5%	33,3%	33,3%
High	26,1%	27,6%	26,2%	28,5%	27,1%
Moderate	17,2%	19,2%	17,4%	16,6%	17,6%
Low	11,8%	12,5%	14,1%	12,6%	12,8%
Very low	7,9%	9,2%	10,9%	8,9%	9,2%
High + Very high	63,1%	59,0%	57,6%	59,9%	59,9%

The results from Table IV reveals that providing eco-friendly products and ensuring energy-efficient production are the most critical concerns for companies as they integrate 6D.BIM. Addressing these concerns is essential for companies aiming to enhance their sustainability credentials and meet the growing demand for environmentally responsible products. Companies must prioritize investments in sustainable practices and technologies to successfully integrate 6D.BIM and improve their competitive edge in the global market.

3.6. 7D.BIM Concerns Evaluation

The seventh dimension of BIM, known as 7D.BIM, focuses on the operation and maintenance of facilities throughout their lifecycle. This dimension allows facility managers to efficiently track and manage vital asset data, including component status, specifications, maintenance schedules, operation manuals, and warranty dates (Kocziszky & Somosi, 2016). By enabling real-time monitoring and management, 7D.BIM supports optimized asset lifecycle management, including parts replacement and preventive maintenance (Tam et al., 2023).

7D.BIM provides a comprehensive approach to managing the built environment from project inception to demolition, encompassing the specification of maintenance models and the creation of preventive and curative maintenance procedures (Pan & Zhang, 2023). It also facilitates the negotiation of warranty conditions and the provision of low-maintenance products. In a competitive landscape, 7D.BIM allows for the comparison of maintenance levels of rival products through accessible BIM libraries.

To assess concerns related to 7D.BIM integration, respondents evaluated their capabilities in the following areas: Customer Retention (KPI-Customer Retention), Services Incorporation (KPI-Services Incorporation), and Response Time (KPI-Response Time). The findings from these assessments are summarized in Table V below.

Table V. Level of Concerns Related to 7D.BIM

Level of Concerns related to 7D BIM	KPI_Customer_Retention	KPI_Services_Incorporation	KPI_Response_time	Average
Very high	44,9%	38,9%	34,0%	39,3%
High	26,8%	25,6%	27,5%	26,6%
Moderate	14,9%	19,0%	18,0%	17,3%
Low	7,2%	7,9%	12,0%	9,0%
Very low	6,2%	8,7%	8,6%	7,8%
High + Very high	71,7%	64,5%	61,4%	65,9%

The results from Table V indicate that customer retention and the integration of services are the most pressing concerns for companies adopting 7D.BIM. Addressing these concerns is crucial for effective 7D.BIM integration, which enhances asset management and customer satisfaction. Companies should focus on improving their service offerings and response capabilities to leverage the full benefits of 7D.BIM and strengthen their market position.

3.7. 8D.BIM Concerns Evaluation

The eighth dimension of BIM, known as 8D.BIM, focuses on integrating safety information throughout a building's lifecycle, from construction to demolition. This dimension allows designers and project managers to embed safety considerations directly into the BIM model, enabling the creation of detailed safety plans, simulations, and situation analyses well before construction begins. Integrating 8D.BIM within BIM.SC emphasizes the delivery of products that enhance health and safety standards.

To evaluate concerns related to 8D.BIM, respondents assessed their capabilities in the following key performance areas: Healthy Materials (KPI-Healthy Materials), and Safe Products (KPI-Safe Improving). These assessments are summarized in Table VI below.

Table VI. Level of Concerns Related to 8D.BIM

Level of Concerns related to 8D BIM	KPI_Healthy_Materials	KPI_Safe_Improving	Average
Very high	32,1%	36,9%	34,5%
High	32,1%	29,6%	30,9%
Moderate	17,1%	13,9%	15,5%
Low	13,2%	11,1%	12,1%
Very low	5,5%	8,4%	7,0%
High + Very high	64,2%	66,6%	65,4%

Addressing these concerns is essential for the effective integration of 8D.BIM, which enhances safety planning and health standards in construction projects. Companies should prioritize the use of safe, healthy materials and the development of products that meet stringent safety requirements to fully leverage the benefits of 8D.BIM.

4. Discussion

The analysis reveals that the respondents' concerns converge around three primary themes: efficiency, investment capacity, and customer satisfaction. Each of these themes is examined in detail below, supported by KPIs and visualized through (Fig.1, Fig.2 and Fig 3.).

4.1. Convergent Concerns on Efficiency

Respondents highlighted the critical need to enhance manufacturing efficiency across several KPIs, indicating a strong focus on improving operational performance. The KPIs most associated with efficiency are:

KPI_Competitive_Price: 37.3% rated this as highly impactful, and 30.9% rated it as having a high impact, totaling 68.2%.

KPI_Quick_Deliver_Time: 42.6% rated this as highly impactful, and 28.1% rated it as having a high impact, totaling 70.8%.

KPI_Healthy_Materials: 32.1% rated this as highly impactful, and 32.1% rated it as having a high impact, totaling 64.2%.

KPI_Innovation_&_Flexibility: 31.6% rated this as highly impactful, and 32.0% rated it as having a high impact, totaling 63.7%.

KPI_Low_Footprint: 37.0% rated this as highly impactful, and 26.1% rated it as having a high impact, totaling 63.1%.

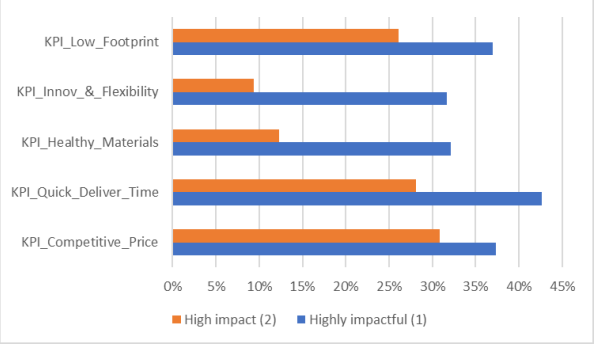


Fig. 1. Convergent Concerns on Efficiency

These results, depicted in Fig. 1, underscore the emphasis on improving aspects that drive competitive pricing, quick delivery, and sustainable, innovative practices. On average, 36.1% of respondents considered these KPIs highly impactful, and 29.3% rated them as having a high impact, leading to a combined impact of 65.4%.

4.2. Convergent Concerns on Investment Capacity

Investment capacity is another critical area where respondents expressed significant concerns. The ability to secure adequate financing and invest in technology and skills is crucial for maintaining competitiveness. Key KPIs in this area include:

KPI_Digital_Operations: 25.8% rated this as highly impactful, and 21.9% as having a high impact, totaling 47.7%.

KPI_Scale_Capacity: 28.0% rated this as highly impactful, and 25.7% as having a high impact, totaling 53.6%.

KPI_Advanced_Technologies: 33.9% rated this as highly impactful, and 25.7% as having a high impact, totaling 59.6%.

KPI_Skills_Admission: 29.7% rated this as highly impactful, and 26.8% as having a high impact, totaling 56.5%.

KPI_Safe_Improving: 36.9% rated this as highly impactful, and 29.6% as having a high impact, totaling 66.6%.

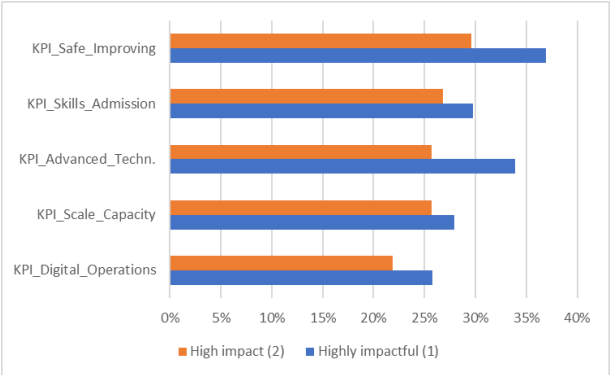


Fig. 2. Convergent Concerns on Investment Capacity

These findings, illustrated in Fig. 2, highlight the significant need for investment in digital operations, scalability, advanced technologies, and skill acquisition. On average, 30.9% of respondents viewed these KPIs as highly impactful, and 25.9% rated them as having a high impact, resulting in a combined impact of 56.8%.

4.3. Convergent Concerns on Customer Satisfaction

Customer satisfaction emerged as a crucial concern, with respondents highlighting the importance of maintaining high service and product standards. The KPIs related to customer satisfaction include:

KPI_Real-time_Collaboration: 38.6% rated this as highly impactful, and 26.9% as having a high impact, totaling 65.4%.

KPI_In_Time_Delivery: 38.7% rated this as highly impactful, and 30.5% as having a high impact, totaling 69.2%.

KPI_Zero_Defects: 29.7% rated this as highly impactful, and 26.8% as having a high impact, totaling 56.5%.

KPI_Green_Label: 31.4% rated this as highly impactful, and 27.6% as having a high impact, totaling 59.0%.

KPI_Customer_Retention: 44.9% rated this as highly impactful, and 26.8% as having a high impact, totaling 71.7%.

KPI_Services_Incorporation: 38.9% rated this as highly impactful, and 25.6% as having a high impact, totaling 64.5%.

KPI_Easy_Recycling: 31.5% rated this as highly impactful, and 26.2% as having a high impact, totaling 57.6%.

KPI_Response_time: 34.0% rated this as highly impactful, and 27.5% as having a high impact, totaling 61.4%.

KPI_Energy_Efficiency_Products: 33.3% rated this as highly impactful, and 28.5% as having a high impact, totaling 61.9%.

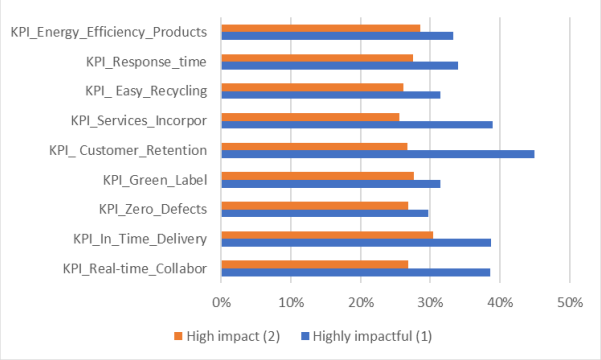


Fig. 3. Convergent Concerns on Customer Satisfaction

These results, visualized in Fig. 3, indicate a strong focus on maintaining real-time collaboration, timely delivery, product quality, and eco-friendly practices to ensure customer satisfaction. On average, 36.5% of respondents considered these KPIs highly impactful, and 26.9% rated them as having a high impact, leading to a combined impact of 63.4%.

Conclusions

The integration of BIM with sustainability principles is becoming increasingly significant in the AEC sector. BIM technology facilitates the creation of detailed digital models of construction projects, offering a thorough understanding of various stages, delivery requirements, budgets, and maintenance needs. Distinguishing between BIM maturity, which pertains to the ability of a supply chain to exchange BIM data effectively, and BIM dimensions, which represent various data types linked to a model, is crucial. These dimensions significantly enhance project management and optimization, and BIM continues to evolve by introducing new dimensions that further enrich its capabilities.

Key Findings

The ornamental stone sector, especially in Portugal, is a vital component of the AEC supply chain. It is a significant employment source, particularly in inland regions, and has demonstrated robust export growth despite recent challenges in the AEC industry. BIM profoundly impacts the procurement and integration of stone elements in construction projects, influencing how these elements are incorporated and managed throughout a project's lifecycle.

The study identifies three primary areas of concern for the Portuguese stone sector, each linked to critical aspects of operational and strategic management.

Efficiency: Competitive pricing, quick delivery time, healthy materials, innovation and flexibility, and low environmental footprint. A substantial portion of respondents highlighted these KPIs as highly impactful, underscoring the necessity for enhanced manufacturing efficiency to remain competitive and meet industry demands.

Investment Capacity: Digital operations, scale capacity, advanced technologies, skills admission, and safe product improvement. Concerns about securing adequate financing and making substantial investments in these areas are paramount. Respondents emphasized the critical need for robust investment to maintain and enhance capabilities within the sector.

Customer Satisfaction: Real-time collaboration, timely delivery, zero defects, green label products, customer retention, service integration, easy recycling, quick response time, and energy-efficient products. Ensuring high customer satisfaction is essential for maintaining a competitive edge. The significant concern expressed by respondents in these areas highlights the importance of addressing these factors to meet customer expectations and sustain market position.

Visualization of Convergent Concerns: The identified concerns are visually summarized in Fig 1, 2, and 3, illustrating the convergence towards efficiency, investment capacity, and customer satisfaction. These Fig. provide a clear depiction of the areas where companies need to focus their efforts to enhance performance and competitiveness.

Limitations: While this study offers valuable insights, it has several limitations: The research is limited to the ornamental stone (OS) sector within mainland Portugal. This geographic and sectoral focus may not fully represent the broader AEC industry or other regions. The exclusion of micro-enterprises from the sample could result in missing variations in concerns, as these

smaller entities might face different challenges compared to larger firms. The use of face-to-face interviews and structured questionnaires may introduce biases related to interviewer influence and respondents' willingness to disclose their concerns fully and accurately.

Future Research Directions: To build on these findings, future research could explore several avenues: Expanding the study to include other regions and countries would enable comparisons and generalizations across the global AEC industry. Including smaller companies in future research can provide a more comprehensive view of the sector's concerns across different company sizes. Tracking changes in concerns over time could offer insights into the effectiveness of strategies and the evolving needs of the sector.

By addressing these limitations and pursuing these future research directions, we can achieve a more comprehensive understanding of the challenges and opportunities within the OS sector and the broader AEC industry.

Acknowledgements: The authors express appreciation to the Inovmineral4.0 Project, for the support they received on their work.

References

Abdumutalibovich, K. A., & Lutfillaevna, B. M. (2023). The Role of Bim Technologies in the Information System of Education. *European Journal of Contemporary Business Law & Technology: Cyber Law, Blockchain, and Legal Innovations*, *1*(2), 9–13. https://doi.org/10.61796/ejcblt.v1i2.87

Chowdhury, M., Hosseini, M. R., Edwards, D. J., Martek, I., & Shuchi, S. (2024). Comprehensive analysis of BIM adoption: From narrow focus to holistic understanding. *Automation in Construction*, *160*, 105301. https://doi.org/10.1016/j.autcon.2024.105301

Hadavi, A., & Alizadehsalehi, S. (2024). From BIM to metaverse for AEC industry. *Automation in Construction*, *160*, 105248. https://doi.org/10.1016/j.autcon.2023.105248

HM Government. (2013). Construction 2025. Industrial Strategy: Government and industry in partnership. *Cabinet Office*, *July*, 1–78. https://doi.org/HM Government.

HM Government. (2015). Digital Built Britain Level 3 Building Information Modelling - Strategic Plan. In *Cabinet Office* (Issue February). http://digital-built-britain.com/DigitalBuiltBritainLevel3BuildingInformationModellingStrategicPlan.pdf

Johansson, M., & Roupé, M. (2024). Real-world applications of BIM and immersive VR in construction. *Automation in Construction*, *158*, 105233. https://doi.org/10.1016/j.autcon.2023.105233

Johansson, M., Roupé, M., & Bosch-Sijtsema, P. (2015). Real-time visualization of building information models (BIM). *Automation in Construction*, *54*, 69–82. https://doi.org/10.1016/j.autcon.2015.03.018

Kocziszky, G., & Somosi, M. V. (2016). Generating Social Innovation with Knowledge Engineering. *Procedia - Social and Behavioral Sciences*, *223*, 167–174. https://doi.org/10.1016/j.sbspro.2016.05.341

Pan, Y., & Zhang, L. (2023). Integrating BIM and AI for Smart Construction Management: Current Status and Future Directions. *Archives of Computational Methods in Engineering*, *30*(2), 1081–1110. https://doi.org/10.1007/s11831-022-09830-8

Shao, S., & Cao, D. (2024). Contagion of BIM Implementation Practices in Interproject Networks: An Empirical Study in China. *Journal of Management in Engineering*, *40*(1). https://doi.org/10.1061/JMENEA.MEENG-5639

Silva, A., Dionísio, A., & Coelho, L. (2020). Methodological Research Design for Industry4 . 0 | A Service Science Approach. *International Journal of Service Sciences*, 24535. https://doi.org/10.1504/IJSSCI.2020.10031018

Silva, A., & Pata, A. (2022). Value Creation in Technology Service Ecosystems - Empirical Case Study. In J. Machado, F. Soares, J. Trojanowska, V. Ivanov, K. Antosz, Y. Ren, V. K. Manupati, & A. Pereira (Eds.), *Innovations in Industrial Engeneering II* (pp. 26–36). Springer International Publishing. https://doi.org/doi.org/10.1007/978-3-031-09360-9_3

Tam, V. W., Zhou, Y., Shen, L., & Le, K. N. (2023). Optimal BIM and LCA integration approach for embodied

environmental impact assessment. *Journal of Cleaner Production*, *385*, 135605. https://doi.org/10.1016/j.jclepro.2022.135605

Tedonchio, C. T., Nadeau, S., Boton, C., & Rivest, L. (2022). Digital mock-ups as support tools for preventing risks related to energy sources in the operation stage of industrial facilities through design. *Results in Engineering*, *16*(August), 100690. https://doi.org/10.1016/j.rineng.2022.100690

Wijeratne, P. U., Gunarathna, C., Yang, R. J., Wu, P., Hampson, K., & Shemery, A. (2024). BIM enabler for facilities management: a review of 33 cases. *International Journal of Construction Management*, *24*(3), 251–260. https://doi.org/10.1080/15623599.2023.2222962

Yilmaz, G., Akcamete, A., & Demirors, O. (2023). BIM-CAREM: Assessing the BIM capabilities of design, construction and facilities management processes in the construction industry. *Computers in Industry*, *147*, 103861. https://doi.org/10.1016/j.compind.2023.103861

Technology Paths towards Coopetition Ecosystems: The Portuguese Stone Sector

Agostinho da Silva[1*] Antonio J. Marques Cardoso[2]

(1) CISE: Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal; CIGEST: Centre for Research in Management, Lisboa, Portugal, *a.silva@zipor.com
(2) CISE: Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal

Summary: *This study examines how digital maturity affects collaboration in the Portuguese Ornamental Stone sector, particularly in the context of Building Information Modeling (BIM) and its impact on procurement practices. A survey covering 67% of the sector classified companies into five levels of digital maturity. The results show a general reluctance to collaborate under current conditions, especially among companies with high digital maturity, often due to past negative experiences. However, when a technology-enabled "commercial secrecy" environment is introduced, the willingness to collaborate increases significantly among digitally advanced companies. The research highlights the crucial role of secure digital environments in promoting collaboration and suggests that technological solutions can help bridge the collaboration gap across different digital maturity levels. These findings are essential for enhancing the competitiveness of the Ornamental Stone sector and adapting to the evolving demands of BIM-based procurement processes.*

Keywords: *Coopetition, BIM, Ornamental Stone, collaboration, Information systems*

1. Introduction

Designing environmentally friendly buildings that provide both high performance and cost savings is of increasing interest in developing sustainable cities. AEC has embraced the BIM technology in this context (Chen et al., 2024). It is possible to cocreate digital twins, shape procurement, and reduce costs, time, and waste. This BIM generalization tends to reshape the AEC supply chain, pushing providers to operate in a global marketplace. In this regard, the AEC providers, like stone companies, must shift their operations towards a digital marketplace shaped by the potential mandatory use of BIM (Johansson & Roupé, 2024).

Mainly SMEs, the Ornamental Stone sector is relevant to the Portuguese economy. Directly employing more than 16,600 people, this sector is one of the foremost private job generators in inland regions, registering sustained export growth, placing Portugal as the eighth country in the International Trade of Ornamental Stone and the second country in the world international trade per capita (Silva & Pata, 2022).

1.1. Problematic

BIM technology transforms the AEC into a digital and global supply chain, where information interoperability between all actors is one of the pillars (Hoppe, 2023). It requires the actors, whether they are customers, suppliers, or others, to interact through technology accessible from any personal or professional system, enabling customers' direct access to the most competitive suppliers (Abdumutalibovich & Lutfillaevna, 2023).

The BIM dimensions are complementary elements of information such as cost, accuracy, sustainability, and compatibility, among other information (Chen et al., 2024). By creating and using these dimensions, one can better understand the planning of the work to the management of the undertaking sustainably (Corry et al., 2015).

The first three BIM dimensions represent the comprehensive model of general construction plans. This dimension represents the model and projects related to architecture, structures, and installations (Kulinan et al., 2024). Through these three dimensions, it is possible to detect divergences, inconsistencies, and failures before proceeding to execution, making this dimension indispensable to avoid errors that could compromise the schedule and the budget (Wong & Zhou, 2015). The fourth BIM dimension represents the planning process to link the construction activities in time schedules with 3D models to develop a real-time graphical simulation of construction progress against time (Chowdhury et al., 2024). This correlation makes it possible for the manager to follow the physical progress of the construction and, with the simple movement of the computer cursor over the schedule, to see the work being calmly and smoothly built as if in a film (Johansson & Roupé, 2024). The fifth BIM dimension represents the cost dimension associated with the model, where each element (solid block) is linked to the cost database (Marinho, 2014). In this regard, the masonry shown in the walls, for example, becomes associated with the

budget and the respective production and execution costs, whether these are labour equipment among other costs (Waqar et al., 2023). The sixth BIM dimension represents sustainability since it can no longer be absent in any project (Tam et al., 2023). It is not a market differential but a requirement. In this way, this dimension of BIM allows several analyses to be carried out focusing on sustainability. The seventh BIM dimension represents the "as built" information with operation approach and maintenance (Chowdhury et al., 2024). The seventh BIM dimension allows extracting specific information on materials, operating manuals, and warranty dates. Through this dimension, one can also carry out a detailed control of equipment warranty, maintenance plans, manufacturers' and suppliers' data, operating costs, and even photos not only of materials and equipment but of everything inside the walls, not visible at a later stage of the work operation (Wagner et al., 2017). The eighth BIM dimension represents the embedded emergency plans and prevents security issues regarding safety and prevention of workplace accidents (Kulinan et al., 2024) . Through the eighth BIM dimension, it is possible to determine risks in the model, encourage the creation of protection suggestions for high-risk profiles and recommend controlling threats in the work area, helping professionals avoid accidents and improving the team's performance (Gragnaniello et al., 2024).

The functionalities resulting from these eight dimensions seem like marketplace enablers (Dallasega et al., 2018). Through the BIM generalization, the supply chain becomes collaborative, leading to global-scale procurement in AEC. The provider's survival will depend on its competitiveness at a global level, requiring a critical dimension of investment capacity.

1.2. Research Problem and Objective

In the evolving landscape of the digital supply chain, contemporary management, business, and supply chain literature underscore the critical need for long-term collaborative alliances among companies, a strategy often referred to as coopetition (Bouncken et al., 2024). This concept involves businesses simultaneously competing and cooperating with each other to achieve mutual benefits (Rouyre et al., 2024).

The European Commission highlights the pressing need for establishing industrial alliances to bolster the success of European manufacturing SMEs within the digital supply chain framework (Di Bella et al., 2023). These alliances are crucial for fostering innovation and maintaining competitive advantage in a rapidly digitalizing economy (Meena et al., 2023).

Furthermore, recent studies on business ecosystems reveal a significant increase in research focused on coopetition (Bicen et al., 2021). Through collaboration, companies can achieve several strategic advantages: (1) they can scale operations to handle projects of any size, (2) they can enhance their competitiveness by concentrating resources on their most efficient and effective products and services, and (3) they can meet market deliverables irrespective of project scale (Corbo et al., 2023).

However, a study by the BCG Henderson Institute, published in the MIT Sloan Management Review, highlights a significant challenge to the sustainability of these collaborative efforts. According to their findings, only 15% of collaborative ventures endure in the long term, with the majority of successful cases involving large corporations such as Microsoft and Amazon (Reeves et al., 2019).

Social sciences literature further explores the difficulties in maintaining rival collaborations (Crick, 2019). Researchers have identified that collaborations often fail due to negative experiences where competitors gain access to critical information or other key assets (Meena et al., 2023). This brings us to the core research question: Can a technology-enabled "secrecy" environment enhance collaboration among competitors in the Portuguese Ornamental Stone sector?

To address this question, this study will conduct a survey targeting a representative sample of Portuguese stone companies. The survey will assess whether technology-enabled "secrecy" environments can improve collaborative efforts compared to the current state-of-the-art practices.

2. Population and Sample

The Portuguese Ornamental Stone sector comprises over 2,500 active companies, as reported by Silva and Pata (2022). These companies are engaged in various stages of the supply chain, either upstream, downstream, or both. However, a significant portion of these companies—around 1,500—are small-scale operations, including micro-companies and craft workshops, typically employing at least three workers and primarily serving local markets (Silva & Pata, 2022).

For this research, the focus is narrowed down to the remaining thousand Ornamental Stone companies that are distributed across eighteen districts in Portugal. This net population serves as the basis for our study.

From this targeted population, we conducted interviews with a sample of 670 companies, representing 67.0% of the net population. Remarkably, this sample accounts for 89.3% of the sector’s total turnover and 95.9% of its exports. These figures underscore the sample's representativeness and the robustness of the insights derived from it.

In 2004, CEVALOR and ASSIMAGRA presented the "Prospective Strategic Study," which emphasized the need for a digital-lean strategic approach for the

Ornamental Stone sector. This strategy, termed the "leanstone booklet" by Silva (2018), outlined a path for the sector's innovative development and competitive enhancement through successive technological advancements (Silva, 2018).

The first phase (2004-2008) involved a partnership between three technological companies, three adopter companies, and two research centers. This collaboration resulted in technologies that allowed OS companies to transform raw materials flexibly, significantly reduce waste, and convert these efficiencies into productivity gains. The adoption of LS#1 technologies enabled companies to handle small orders efficiently, enhancing their responsiveness in both domestic and European markets (Almeida & Silva, 2022).

The second phase (2010-2013) expanded to include four technological companies, twelve adopter companies, and three research centers. LS#2 technologies focused on further enhancing productivity and operational efficiency within the OS sector, facilitating significant improvements in manufacturing processes and outputs (Silva, Gil, et al., 2020).

The third phase (2016-2018) involved two technological companies, two adopter companies, and three research centers. LS#3 technologies enabled OS companies to tackle customized projects regardless of order size. These technologies significantly reduced material waste and energy consumption while minimizing the ecological footprint. They also prepared companies for the transition to Industry 4.0 by integrating advanced manufacturing technologies (Silva, Rabadão, et al., 2020).

The fourth phase (2017-2020) saw collaboration between two technological companies, two adopter companies, and three research centers. LS#4 technologies marked a crucial move towards collaborative and intelligent manufacturing. These technologies, part of the Inovstone4.0 Project (Silva, Rabadão, et al., 2020), promote the co-creation of value with customers, facilitating a more personalized and optimized manufacturing approach across different scales (Almeida & Silva, 2022).

Despite these technological advancements, the Portuguese stone sector, predominantly composed of SMEs, continues to face challenges. These include limited investment capacity and traditional family-based management structures that hinder the development of a collaborative mindset, which is essential for fully leveraging the benefits of the leanstone advancements.

3. Digital Enterprise Levels

The literature on management, digital technologies, and the construction industry emphasizes that the benefits of BIM are highly dependent on the level of connectivity among stakeholders within the AEC value chain (Hadavi & Alizadehsalehi, 2024). To successfully implement and reap the advantages of digital technologies, companies must invest in production technologies and develop skills that enhance efficiency, flexibility, and scalability. This necessitated dividing our sample into stages based on their level of digitalization.

Building on these digital steps, we define the **Digital Level** as the extent to which a company employs digital technologies in its operations. This index was established through face-to-face surveys and on-site visits, evaluating factors such as digital production equipment, the integration of management with production systems, and the use of collaborative tools in digital marketplaces.

For this research, companies were categorized into the following digital levels:

- No Digital Level (ND#0): These companies do not use any computerized systems in their production processes and have not initiated digitization.
- First Digital Level (ND#1): Companies at this level have been using computerized production systems for over a year, representing the initial phase of their digitization journey.
- Second Digital Level (ND#2): These companies depend on digital equipment in production, with at least two computerized machines on the shop floor, indicating a moderate level of digitization.
- Third Digital Level (ND#3): Companies at this level integrate information generated by computerized machines on the shop floor with their management systems, showcasing advanced digitization.
- Fourth Digital Level (ND#4): At the highest level, companies integrate collaborative data generated by computerized shop floor technologies with management systems and utilize real-time information in digital marketplaces, representing complete digitization.

To further clarify the categorization criteria:

- ND#0: Companies without any computerized systems in production, showing no digitization efforts.

- ND#1: Companies that have adopted computerized production systems for over a year, indicating the beginning stages of digitization.
- ND#2: Companies with a reliance on digital equipment, including at least two computerized machines in production, demonstrating moderate digitization.
- ND#3: Companies that integrate shop floor data from computerized machines with management information, indicating an advanced level of digitization.
- ND#4: Companies that use collaborative data from computerized shop floor technologies in conjunction with management systems and apply this real-time information in digital marketplaces, indicating complete digitization.

This categorization provides a comprehensive framework for assessing the digital maturity of companies within the Ornamental Stone sector and allows us to evaluate how varying levels of digital adoption impact their operations and collaboration capabilities.

4. Survey

To gather insights from the respondents, the following questionnaire was administered during face-to-face interviews conducted from February 2022 to February 2023. The results were meticulously recorded and stored in an Excel file for analysis.

Introduction to the First Question:

"Construction projects are evolving from traditional CAD-based processes to being developed using BIM. This transition fundamentally alters how specifications and procurement for Ornamental Stone are handled. To adapt to these market changes and secure orders, it is becoming essential for Ornamental Stone suppliers to digitally engage with architects during the BIM-based design phase, handle orders of varying sizes, and strictly adhere to delivery deadlines. Furthermore, suppliers will increasingly be subject to digital evaluations by all stakeholders involved in the project.

Given this evolving market context and based on your experience, do you foresee participating in future projects in collaboration with other competitors?"

- Possible answers: Yes, No, Maybe

Introduction to the Second Question:

"Imagine a hypothetical scenario where a technology is developed to facilitate collaborative market interactions among suppliers, similar to online banking systems. This technology could:

1. Enable companies to conduct market research collaboratively with competitors.
2. Allow companies to integrate specialized productive resources from partners into their commercial proposals without the partners' prior knowledge.
3. Maintain commercial confidentiality until a buyer's decision is made.
4. Automatically reserve the necessary specialized resources from project partners after the buyer's decision.

Under these new 'commercial secrecy' conditions, would you consider collaborating on projects with other competitors?"

- Possible answers: Yes, No, Maybe

All interviews were conducted face-to-face, ensuring a comprehensive understanding of each respondent's perspective. This direct interaction allowed for in-depth discussions and clarification of any ambiguities in the questions, leading to more accurate and reliable responses.

The responses collected through these interviews were systematically recorded and saved in an Excel file. This method of data storage was chosen to facilitate easy analysis and retrieval of information for subsequent research phases.

5. Results

5.1. State-of-the-Art Environment

Aligned with our research objective, our findings reveal that despite the potential competitive challenges posed by BIM-shaped procurement, Ornamental Stone (OS) companies exhibit significant reluctance to collaborate with their rivals under the current state-of-the-art collaborative environment. This reluctance is particularly acute among the most digitally advanced companies. These companies, having experienced negative outcomes from previous collaborative efforts, are notably wary of engaging in cooperation with competitors.

The data shows a clear variation in willingness to collaborate, depending on the level of digital experience of the companies. Here's a detailed analysis of the collaboration willingness across different digital levels:

Low Digital Experience:

ND#0 (No Digital Level): 28.1% of companies without any computerized production system are willing to collaborate.

ND#1 (First Digital Level): 25.8% of companies using a single computerized system for over a year show a willingness to collaborate.

Moderate Digital Experience:

ND#2 (Second Digital Level): 22.3% of companies relying on at least two computerized machines in their production processes are open to collaboration.

High Digital Experience:

ND#3 (Third Digital Level): Only 14.1% of companies that integrate information from computerized machines on the shop floor with their management systems are willing to collaborate.

ND#4 (Fourth Digital Level): A mere 2.2% of companies that integrate collaborative data from computerized shop floor technologies with management and market information are open to collaboration.

Table I summarizes the collaboration willingness across different digital levels under the current state-of-the-art environment.

Table I. Collaboration Willingness Under the Current State-of-the-Art Environment

State-of-the-art	Yes	No	Maybe
ND#4	2.2%	89.8%	8.0%
ND#3	14.1%	77.1%	8.8%
ND#2	22.3%	56.8%	20.9%
ND#1	25.8%	37.5%	36.7%
ND#0	28.1%	33.2%	38.7%

The results indicate a trend where companies with lower levels of digital integration show a relatively higher willingness to collaborate compared to their more digitally advanced counterparts. Companies at the ND#0 and ND#1 levels are more open to collaboration, with around a quarter of them expressing willingness. However, as companies progress in their digital integration to ND#2, ND#3, and ND#4 levels, their willingness to collaborate decreases significantly.

This trend suggests that companies with greater digital capabilities may perceive higher risks or have had more adverse experiences in past collaborations, making them more cautious about entering new cooperative ventures. These findings highlight a crucial area for further exploration: understanding the specific factors that contribute to the reluctance of digitally advanced companies to collaborate and identifying potential strategies to overcome these barriers.

5.2. Technology-Enabled Collaborative Environment

When considering collaboration under a trustworthy technology that ensures "commercial secrecy" conditions, the responses from companies show a notable shift. The "commercial secrecy" environment includes the following provisions:

1. Companies can explore market opportunities collaboratively with competitors.
2. Competitors' specialized resources can be incorporated into commercial proposals without disclosing this to the competitors themselves.
3. Commercial confidentiality is preserved until a buyer makes a decision.
4. Once a buyer decides, the necessary specialized resources are automatically reserved for the project partners.

For companies with low digital experience, the willingness to collaborate remains relatively stable under these conditions. Specifically, the acceptance rates are:

- ND#0 (No Digital Level): 22.4% of companies without any computerized production systems are willing to collaborate.
- ND#1 (First Digital Level): 28.9% of companies using a single computerized system are open to collaboration.

This stability suggests that while these companies are somewhat open to collaboration, their willingness is not significantly influenced by the introduction of technology-enabled "commercial secrecy" conditions.

In contrast, companies with high digital experience show a significant increase in their willingness to collaborate under the "commercial secrecy" environment:

- ND#3 (Third Digital Level): 65.9% of companies that integrate information from computerized machines with management systems are willing to collaborate.
- ND#4 (Fourth Digital Level): An impressive 90.1% of companies that integrate collaborative data from computerized shop floor technologies with management and market information are open to collaboration.

These results indicate that the most digitally advanced companies, which are typically more reluctant to collaborate under current conditions, become much more amenable to cooperation when assured of commercial confidentiality and secure integration processes.

Table II below provides a detailed breakdown of collaboration willingness under a technology-enabled "commercial secrecy" environment.

Table II. Collaboration Willingness Under a Technology-Enabled "Commercial Secrecy" Environment

Technology-enabled Coopetition	Yes	No	Maybe
ND#4	90.1%	1.8%	8.1%
ND#3	65.9%	15.6%	18.5%
ND#2	46.4%	22.1%	31.5%
ND#1	28.9%	33.2%	37.9%
ND#0	22.4%	32.6%	45.0%

The data clearly demonstrates that the introduction of a technology-enabled "commercial secrecy" environment significantly enhances the willingness to collaborate among companies with higher levels of digital experience. The sharp increase in collaboration readiness among ND#3 and ND#4 companies highlights the importance of secure, confidential, and integrated technological solutions in fostering cooperation.

For companies with lower levels of digital integration, while there is some willingness to collaborate, their responses remain relatively stable regardless of the technological assurances provided. This suggests that other factors, possibly related to resource availability or operational focus, might be influencing their collaboration decisions.

These insights underline the potential of secure, technology-enabled environments to bridge the gap between competitive concerns and the benefits of collaboration, particularly for digitally advanced companies.

6. Discussion

To assess the potential for enhanced collaboration in the Portuguese Ornamental Stone (OS) sector, we interviewed a representative sample that covers 67% of the sector's companies. This sample was categorized into five groups based on their digital maturity levels: ND#0 (No Digital Level) to ND#4 (Fourth Digital Level).

The findings suggest a significant divergence in collaboration willingness based on digital maturity levels when a "commercial secrecy" technology is introduced. Specifically, high-level digital companies show a marked increase in their willingness to collaborate under a technology-enabled "commercial secrecy" environment, while low-level digital companies exhibit minimal change. Table III summarizes the improvement in collaboration willingness from the current state-of-the-art to a technology-enabled collaborative environment.

Table III. Collaboration Improvement from Current State-of-the-Art to Technology-Enabled Collaborative Environment

Collaboration Improvements	ND#0	ND#1	ND#2	ND#3	ND#4
Yes	-5.7%	3.1%	24.1%	51.8%	87.9%
No	-0.6%	-4.3%	-34.7%	-61.5%	-88.0%
Maybe	6.3%	1.2%	10.6%	9.7%	0.1%

As depicted in Fig.1, companies with higher digital maturity (ND#3 and ND#4) are significantly more likely to embrace collaboration in a digitally supported environment. These companies have already integrated advanced digital technologies into their operations, making them more attuned to the benefits and potential impacts of such environments.

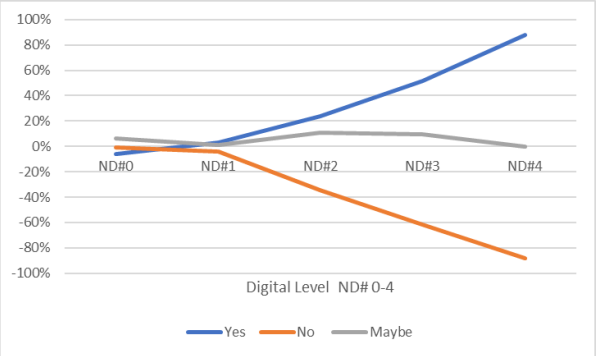


Fig. 1. Digital Level vs. Digitally Supported Collaboration

Graph depicting the relationship between digital maturity levels (ND#0 to ND#4) and willingness to collaborate under a technology-enabled environment.

Companies with lower digital levels (ND#0 and ND#1), possibly due to their limited experience in international markets and digital operations, show less sensitivity to future procurement changes brought by BIM. These companies typically have less exposure to the demands of international markets and the competitive pressures that necessitate collaboration.

Conversely, as companies advance in their digital capabilities, they become more export-oriented and aware of the implications of BIM procurement processes on their operations. For these digitally advanced companies, preserving the confidentiality of differentiating assets is crucial, and the assurance of secure collaborative environments significantly boosts their willingness to collaborate (Fig.2).

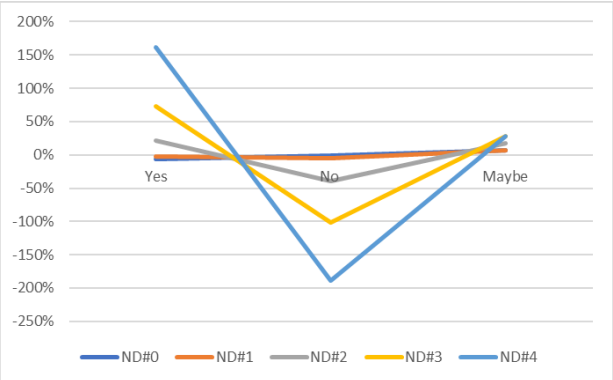


Fig. 2. Collaboration Trend to Mitigate BIM Procurement Challenges

Graph illustrating how the willingness to collaborate increases with digital maturity levels as a strategy to counter BIM procurement challenges.

Strategic Implications of Secure Technology-Enabled Environments

The introduction of a hypothetical technology-enabled secure environment in BIM procurement could foster trust among rivals, leading to improved collaboration and the ability to capitalize on market opportunities. This improvement is particularly pronounced among companies with substantial experience in digital operations. In such a trusting environment, higher digital maturity correlates with a greater likelihood of collaboration, allowing companies to avoid the risks associated with over-indebtedness and competitive disadvantage.

These findings underscore the importance of creating secure and confidential digital environments to enhance collaborative efforts among companies, particularly those with advanced digital capabilities. As the OS sector continues to evolve, leveraging technology to foster secure and productive collaboration will be vital for maintaining competitiveness and responding to the changing dynamics of BIM-based procurement.

Conclusions

The research conducted on the Portuguese Ornamental Stone sector reveals significant insights into the dynamics of collaboration in the context of digital maturity and technological advancements. Here are the key conclusions drawn from our study:

Reluctance to Collaborate Under Current Conditions: Companies show a general reluctance to engage in collaborative efforts under the current state-of-the-art conditions. This hesitancy is most pronounced among digitally advanced companies (ND#3 and ND#4), who have experienced negative outcomes from past collaborations. This highlights a critical barrier to cooperation in an environment that lacks sufficient technological assurances and protections.

Stable Collaboration Willingness Among Low Digital Experience Companies: Companies with lower levels of digital maturity (ND#0 and ND#1) exhibit a relatively stable willingness to collaborate, with minimal improvement even when introduced to technology-enabled "commercial secrecy" conditions. This suggests that other factors, such as limited exposure to international markets or a lack of familiarity with digital tools, may play a more significant role in their collaboration decisions.

Significant Increase in Collaboration Willingness with Technology-Enabled "Commercial Secrecy": For high digital maturity companies (ND#3 and ND#4), the introduction of a technology-enabled "commercial secrecy" environment significantly boosts their willingness to collaborate. This indicates that providing secure, confidential frameworks where sensitive information and resources are protected can overcome their reluctance and foster greater cooperation.

Digital Maturity and Sensitivity to Technological Integration: As companies progress in their digital maturity, they become more attuned to the benefits and necessities of integrating digital technologies into their operations. Digitally advanced companies are more likely to embrace collaboration when assured of secure and seamless digital integration, reflecting their strategic orientation towards efficiency, flexibility, and competitiveness in international markets.

Strategic Importance of Secure Digital Environments: The study underscores the strategic importance of creating secure, technology-enabled environments that ensure commercial confidentiality and facilitate seamless collaboration. Such environments are crucial for encouraging cooperation among digitally advanced companies, helping them to navigate the challenges posed by BIM-based procurement and to capitalize on emerging market opportunities.

Potential for Technology to Bridge Collaboration Gaps: The findings suggest that implementing secure, digitally supported environments can act as a catalyst for bridging the collaboration gap among companies with varying levels of digital maturity. By providing a trustworthy framework for collaboration, technology can mitigate the risks associated with sharing critical information and resources, thereby enhancing overall sector competitiveness.

Recommendations for the OS Sector: To foster greater collaboration and address the barriers identified, the OS sector should invest in developing and adopting technologies that enable secure, confidential, and integrated collaborative environments. This includes promoting digital literacy and capabilities among lower digital maturity companies and providing robust security measures to protect the interests of digitally advanced companies.

In conclusion, the research highlights the Central role of digital maturity and secure technological frameworks in facilitating collaboration within the OS sector. By addressing the identified challenges and leveraging appropriate technologies, the sector can enhance its collaborative efforts, improve competitive positioning,

and effectively respond to the evolving demands of the digital economy and BIM-based procurement processes.

Acknowledgements: The authors express appreciation to the Inovmineral4.0 Project, for the support they received on their work.

References

Abdumutalibovich, K. A., & Lutfillaevna, B. M. (2023). The Role of Bim Technologies in the Information System of Education. *European Journal of Contemporary Business Law & Technology: Cyber Law, Blockchain, and Legal Innovations*, *1*(2), 9–13. https://doi.org/10.61796/ejcblt.v1i2.87

Almeida, I., & Silva, A. (2022). The circularity endeavour in the Ornamental Stone sector. In C. I. M. Symposium (Ed.), *Reconfiguring global supply chains in the face of continued disruption: towards new design rules and capabilities*. Cambridge International Manufacturing Symposium.

Bicen, P., Hunt, S., & Madhavaram, S. (2021). Coopetitive innovation alliance performance: Alliance competence, alliance's market orientation, and relational governance. *Journal of Business Research*, *123*(October 2020), 23–31. https://doi.org/10.1016/j.jbusres.2020.09.040

Bouncken, R., Kumar, A., Connell, J., Bhattacharyya, A., & He, K. (2024). Coopetition for corporate responsibility and sustainability: does it influence firm performance? *International Journal of Entrepreneurial Behavior & Research*, *30*(1), 128–154. https://doi.org/10.1108/IJEBR-05-2023-0556

Chen, Z.-S., Wang, Z.-R., Deveci, M., Ding, W., Pedrycz, W., & Skibniewski, M. J. (2024). Optimization-based probabilistic decision support for assessing building information modelling (BIM) maturity considering multiple objectives. *Information Fusion*, *102*, 102026. https://doi.org/10.1016/j.inffus.2023.102026

Chowdhury, M., Hosseini, M. R., Edwards, D. J., Martek, I., & Shuchi, S. (2024). Comprehensive analysis of BIM adoption: From narrow focus to holistic understanding. *Automation in Construction*, *160*, 105301. https://doi.org/10.1016/j.autcon.2024.105301

Corbo, L., Kraus, S., Vlačić, B., Dabić, M., Caputo, A., & Pellegrini, M. M. (2023). Coopetition and innovation: A review and research agenda. *Technovation*, *122*(September 2022). https://doi.org/10.1016/j.technovation.2022.102624

Corry, E., Pauwels, P., Hu, S., Keane, M., & O'Donnell, J. (2015). A performance assessment ontology for the environmental and energy management of buildings. *Automation in Construction*, *57*, 249–259. https://doi.org/10.1016/j.autcon.2015.05.002

Crick, J. (2019). The dark side of coopetition: when collaborating with competitors is harmful for company performance. *Journal of Business & Industrial Marketing*, *35*(2), 318–337. https://doi.org/10.1108/JBIM-01-2019-0057

Dallasega, P., Rauch, E., & Linder, C. (2018). Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. *Computers in Industry*, *99*(April), 205–225. https://doi.org/10.1016/j.compind.2018.03.039

Di Bella, L., Katsinis, A., Lagüera-González, J., Odenthal, L., Hell, M., & Lozar, B. (2023). *Annual Report on European SMEs 2022/2023*.

Gragnaniello, C., Mariniello, G., Pastore, T., & Asprone, D. (2024). BIM-based design and setup of structural health monitoring systems. *Automation in Construction*, *158*, 105245. https://doi.org/10.1016/j.autcon.2023.105245

Hadavi, A., & Alizadehsalehi, S. (2024). From BIM to metaverse for AEC industry. *Automation in Construction*, *160*, 105248. https://doi.org/10.1016/j.autcon.2023.105248

Hoppe, S. (2023). *OPC Unified Architecture-Interoperability for Industrie 4.0 and the Internet of Things*. https://opcfoundation.org/wp-content/uploads/2023/05/OPC-UA-Interoperability-For-Industrie4-and-IoT-EN.pdf

Johansson, M., & Roupé, M. (2024). Real-world applications of BIM and immersive VR in construction. *Automation in Construction*, *158*, 105233. https://doi.org/10.1016/j.autcon.2023.105233

Kulinan, A. S., Park, M., Aung, P. P. W., Cha, G., & Park, S. (2024). Advancing construction site workforce safety monitoring through BIM and computer vision integration. *Automation in Construction*, *158*, 105227. https://doi.org/10.1016/j.autcon.2023.105227

Marinho, A. J. C. (2014). Aplicação do Building Information Modeling na gestão de projetos de construção. In *Master's thesis - Universidade do Minho*.

Meena, A., Dhir, S., & Sushil, S. (2023). A review of coopetition and future research agenda. *Journal of Business and Industrial Marketing*, *38*(1), 118–136. https://doi.org/10.1108/JBIM-09-2021-0414

Reeves, M., Lotan, H., Legrand, J., & Jacobides, M. G. (2019). How Business Ecosystems Rise (and Often Fall). *MIT Sloan Management Review*, *July*.

Rouyre, A., Fernandez, A.-S., & Bruyaka, O. (2024). Big problems require large collective actions: Managing multilateral coopetition in strategic innovation networks. *Technovation*, *132*, 102968. https://doi.org/https://doi.org/10.1016/j.technovation.2024.102968

Silva, A. (2018). Improving Industry 4 . 0 Through Service Science. In *PhD Thesis - Universidade de Évora*.

Silva, A., Gil, M. M., & Duarte, E. (2020). Service Innovation | A Service Blueprinting for Industry 4 . 0. In *International Journal of Sciences: Basic and Applied Research (IJSBAR) ISSN 2307-4531 Vol 52 No 2 (2020): Vol. ISSN 2307-* (ISSN 2307-, pp. 33–49).

Silva, A., & Pata, A. (2022). Value Creation in Technology Service Ecosystems - Empirical Case Study. In J. Machado, F. Soares, J. Trojanowska, V. Ivanov, K. Antosz, Y. Ren, V. K. Manupati, & A. Pereira (Eds.), *Innovations in Industrial Engeneering II* (pp. 26–36). Springer International Publishing. https://doi.org/doi.org/10.1007/978-3-031-09360-9_3

Silva, A., Rabadão, C., & Capela, C. (2020). Towards Industry 4.0 | A case study of BIM deployment in ornamental stones sector. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, *67*, 24535. https://doi.org/ISSN 2307-4531

Tam, V. W., Zhou, Y., Shen, L., & Le, K. N. (2023). Optimal BIM and LCA integration approach for embodied environmental impact assessment. *Journal of Cleaner Production*, *385*, 135605. https://doi.org/10.1016/j.jclepro.2022.135605

Wagner, T., Herrmann, C., & Thiede, S. (2017). Industry 4.0 Impacts on Lean Production Systems. *Procedia CIRP*, *63*, 125–131. https://doi.org/10.1016/j.procir.2017.02.041

Waqar, A., Qureshi, A. H., & Alaloul, W. S. (2023). Barriers to Building Information Modeling (BIM) Deployment in Small Construction Projects: Malaysian Construction Industry. *Sustainability*, *15*(3), 2477. https://doi.org/10.3390/su15032477

Wong, J. K. W., & Zhou, J. (2015). Enhancing environmental sustainability over building life cycles through green BIM: A review. *Automation in Construction*, *57*, 156–165. https://doi.org/10.1016/j.autcon.2015.06.003

- Earth and Planetary Insights-
Open access peer-reviewed journal of SGEM WORLD SCIENCE (SWS) Scholarly Society, Vienna

Issue 1/2024

CARBON FOOTPRINT REDUCTION ON MANUFACTURING SMES FROM DIGITAL TECHNOLOGIES

Agostinho da Silva[1*], Antonio J. Marques Cardoso[2]

(1) CISE: Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal; CIGEST: Centre for Research in Management, Lisboa, Portugal, *a.silva@zipor.com

(2) (2) CISE – Electromechatronic Systems Research Centre, University of Beira Interior, 6201-001 Covilhã, Portugal

ABSTRACT

This study explores the impact of digital technology adoption on the carbon footprint of SMEs. Utilizing a framework aligned with the ISO Standard 14040 for Life Cycle Assessment, the research evaluates how different levels of digital maturity of the Portuguese Ornamental Stone SMEs influence KPIs related to energy efficiency, production quality, material utilization, and carbon emissions. Companies are categorized by their Digital Rank, ranging from DR#0 (no digitalization) to DR#4 (advanced digital integration). The findings indicate that higher levels of digital maturity are associated with significant environmental and operational benefits. For instance, companies at the DR#4 level achieve a 35.1% reduction in carbon emissions per unit of output compared to those at DR#0. Additionally, these companies show substantial improvements in energy efficiency, producing more units per kWh and enhanced raw material yield, minimizing waste and optimizing resource use. The results underscore the transformative potential of digital technologies in promoting sustainability and operational efficiency. Companies that integrate advanced digital tools not only reduce their environmental impact but also improve their competitiveness and productivity. This research highlights the necessity of a comprehensive approach to digital transformation, encompassing technological investments, organizational change, and process optimization. The study provides actionable insights for policymakers, industry leaders, and SMEs on leveraging digital technologies to achieve sustainability goals. It emphasizes the critical role of digitalization in supporting the global transition to a low-carbon economy. It suggests avenues for future research to explore further integrated digital strategies and their long-term impacts on sustainability.

Keywords: Digital technologies, Decarbonization, Manufacturing SMEs, Ecological Footprint, Stone Industry

INTRODUCTION

Small and medium enterprises (SMEs) are the backbone of the European Union's economy, representing 99.8% of all enterprises in the non-financial business sector across the EU-27 as of 2022 (Di Bella et al., 2023). These 24.3 million SMEs are vital

not only because they provide jobs to over 84.9 million people but also because they supply goods and services to a wide range of customers, from individuals to large organizations (Destefanis et al., 2023). However, despite their smaller individual size, SMEs collectively have a significant environmental impact, contributing notably to global energy-related CO2 emissions. In 2022, these emissions reached a new peak of over 36.8 gigatonnes (Gt), reflecting a 0.9% increase from the previous year (Cozzi, 2023).

In response to the urgent need to combat climate change, there has been a significant surge in investments in digital technologies across various sectors, notably within the Architecture, Engineering, and Construction (AEC) industry. In 2022 alone, these investments reached over EUR 560 billion, driven by the promise of enhancing operational efficiencies and reducing carbon footprints (Yan et al., 2022). Despite these substantial financial commitments, the tangible impact of digital technologies on carbon emission reductions needs to be clarified. Recent studies indicate that the anticipated global reductions in carbon emissions from digital technology adoption have been minimal (Giulia, 2022).

While digital technologies are widely advocated as critical solutions for achieving environmental sustainability (Aldoseri et al., 2024), their direct effectiveness must be thoroughly understood, particularly in reducing carbon footprints within manufacturing SMEs. This gap underscores the need for more focused research to evaluate the real-world impact of digital technologies on carbon footprint reduction in the SME context. Understanding this impact is crucial, as SMEs represent a significant portion of the global economy, and their collective contribution to carbon emissions is substantial. Consequently, this research aims to bridge this gap by providing a detailed empirical analysis of how digital technology adoption affects the carbon footprints of manufacturing SMEs.

The primary objective of this research is to develop and validate a robust empirical framework designed to assess the impact of digital technologies on carbon footprint reduction in manufacturing SMEs. Central to this framework is the concept of DR, which quantifies the extent of a company's adoption of digital technologies. The framework is structured around KPIs that precisely measure improvements in energy efficiency and reductions in carbon emissions.

By evaluating these KPIs across various levels of digital maturity, this study aims to bridge the existing research gap regarding the real-world effectiveness of digital technologies in reducing carbon footprints within the SME sector. The study's findings contributes significantly to global efforts to combat climate change by demonstrating how SMEs can leverage digital technologies to improve their sustainability. These insights will inform policymakers and industry leaders and provide practical guidance for SMEs on optimizing their digital investments to achieve substantial reductions in their carbon footprint. Ultimately, this research will help position manufacturing SMEs as proactive participants in the global transition towards more sustainable and climate-resilient economies.

THEORETICAL BACKGROUND AND RESEARCH METHODOLOGY

The Paris Agreement, adopted by 195 nations in 2015, is a central commitment to the global effort to combat climate change and mitigate its adverse effects (United Nations, 2015). This agreement sets a strategic goal to significantly reduce global greenhouse gas emissions, aiming to cap the rise in global temperatures at two °C above pre-industrial

levels by 2050. Achieving these ambitious targets necessitates innovative approaches across all sectors, including AEC industries, which substantially contribute to global emissions.

The Life Cycle Assessment (LCA) methodology is central to evaluating environmental impacts in the AEC sector, as standardized by ISO 14040:2006 (Tam et al., 2023). This framework provides a structured approach to assessing the environmental impacts associated with all stages of a product's life cycle ensuring consistency and comparability in LCA studies by outlining the systematic procedures for conducting these assessments (Wijeratne et al., 2024).

To address the research gap identified and achieve the study's aim, a comprehensive framework is designed leveraging the principles of LCA and integrating them with the assessment of digital technologies' impact on carbon footprint reduction (Kulinan et al., 2024). This methodology follows a structured approach based on the ISO 14040 standards and encompasses the following key steps:

Description of the Context: This initial phase involves a thorough analysis of the manufacturing SMEs sector within the AEC industry. It includes identifying the current practices, challenges, and opportunities related to digital technology adoption and their environmental implications (Li et al., 2020). Detailed sector-specific factors will be considered, such as the types of digital technologies in use, the scale of operations, and the typical life cycles of products manufactured by these SMEs.

Framework Designing: Building on the contextual analysis, a framework is designed to assess the impact of digital technologies on carbon emissions. This framework will integrate the DR concept, categorizing companies based on their level of digital adoption, from basic to advanced integration. The framework will also outline a set of KPIs aligned with the LCA, providing measurable benchmarks for assessing digital technologies' environmental impacts.

Environmental Impact Assessment: Applying the framework to a representative sample of manufacturing SMEs, detailed assessments to quantify the environmental impacts associated with different levels of digital technology adoption will be conducted. Data will be collected through surveys, on-site evaluations, and digital audits. This data will be used to calculate the carbon emissions at each stage of the product life cycle, enabling a comparison between varying levels of digital integration.

Results Interpretation: The final phase involves interpreting the results to draw meaningful conclusions about the relationship between digital technology adoption and carbon footprint reduction in manufacturing SMEs. This step includes analyzing the KPIs to identify trends and insights and providing recommendations for stakeholders on optimizing digital technology investments to enhance sustainability. The findings will be contextualized within the broader goals of the Paris Agreement, offering strategic guidance for policymakers and industry leaders on leveraging digital technologies for climate action.

By integrating DR assessment into the LCA framework, this research evaluates the direct impacts of digital tools on carbon emissions and explores their broader influence on the efficiency and sustainability of manufacturing processes.

EMPIRICAL CONTEXT, POPULATION, AND SAMPLE

The initial stage in the LCA methodology is defining the purpose and extent of a study, which requires establishing clear boundaries and selecting a representative sample (Verones et al., 2020).

In recent years, the transition to a digital economy, often called Industry 4.0 (I4.0), has gained significant momentum, driven by the proliferation of digital and connectable technologies (Slavic et al., 2024). This transformation has profound implications across various sectors, including AEC. A key component of this digital shift is BIM (Wijeratne et al., 2024). This technology promises to revolutionize the sector by integrating processes and data into a cohesive digital framework to reduce waste and minimize ecological footprints (Hadavi & Alizadehsalehi, 2024).

Despite the rapid advancements and substantial investments in BIM and other digital technologies, their impact on carbon footprint reduction within the AEC sector still needs to be explored. BIM is anticipated to become a mandatory global requirement, aligning procurement models towards low-carbon, zero-waste products (Wijeratne et al., 2024). This anticipated shift underscores the importance of understanding how digital technologies can drive environmental sustainability (Kulinan et al., 2024).

The Portuguese Ornamental Stone sector (OS.Pt) is a compelling case study in this context. Portugal is renowned as a world-class producer of stone products, deeply integrated into the global and competitive AEC supply chain—the OS.Pt comprises numerous SMEs employing over 16,600 people, making it a significant private employer, especially in the country's interior regions (Silva & Pata, 2022).

Traditionally rooted in craftsmanship, the OS.Pt has experienced considerable modernization and growth over the past decades. Since 2004, the sector has seen an average annual growth rate of 5.13% in turnover, generating over a thousand new skilled jobs in the last ten years (Silva, Dionisio, et al., 2020).

The OS.Pt's integration into the AEC supply chain is substantial, with companies typically involved in downstream activities—transforming raw stone materials into finished products for the construction sector. The sector's international presence is robust; in 2019, the OS.Pt exported to 116 countries ranked 9th in global stone trade[1], and positioned Portugal as the second highest per capita in the international stone trade. With exports covering imports by 660% and 45% of these exports going to markets outside Europe, the sector's total turnover reached EUR 1.230 billion, underscoring its economic significance and global reach.

For this research, a representative sample was selected to reflect the diversity of digital maturity levels within the OS.Pt. In 2022, surveys were conducted across 16.2% of the sector's companies, encompassing firms from all eighteen continental districts of Portugal. This sampling approach provides a comprehensive view of the sector, capturing the spectrum of digital adoption and its potential impacts on sustainability practices.

FRAMEWORK DESIGN

It is part of the LCA methodology, a framework designed to assess the environmental impacts of digital technologies on the carbon footprint of SMEs (Tam et al., 2023). This framework is crucial for evaluating how digitalization influences sustainability in the manufacturing sector, particularly within the OS.Pt.

4.1. Digital Rank (DR) Evaluation

To effectively assess the impact of digital technologies, it is essential first to evaluate the digital maturity of each company within the sample. This evaluation was conducted through on-site surveys (in-loco) leading to establishing each company's DR. The

[1] https://www.assimagra.pt/pt/

Digital Rank is categorized into five levels: DR#0: Companies with no digitalization initiatives. DR#1: Companies utilizing a single digital production machine. DR#2: Companies operating with two digital production machines. DR#3: Companies employing at least three digital machines integrated with their Enterprise Resource Planning (ERP) system. DR#4: Companies with more than three digital machines fully integrated collaboratively with the marketplace, aligning with the I4.0 (Ye et al., 2022). This classification allows for a nuanced understanding of how varying levels of digital technology integration affect environmental performance across the sector.

4.2. Energy Efficiency KPI

Energy Efficiency (KPI_{EE}) evaluates how effectively a company utilizes its energy resources to produce goods (Asghari et al., 2024). Energy efficiency is a critical measure of operational performance in the manufacturing sector, as it directly impacts cost control and environmental sustainability (Arowoiya et al., 2024). High energy efficiency signifies that a company can produce more output with less energy, leading to reduced operational costs and lower carbon emissions. KPI_{EE} is a metric for manufacturing companies, especially in energy-intensive sectors like OS.Pt, since it measures how well a company utilizes energy resources relative to its output, it is a key indicator of economic and environmental performance. KPI_{EE} quantifies the amount of output produced per unit of energy consumed, explicitly measuring the number of output units generated per kWh used (Equation 1.). This ratio provides insight into the energy efficiency of a company's production processes (Irfan et al., 2023). A higher KPI_{EE} value indicates greater efficiency, meaning the company produces more output relative to the energy it consumes.

Equation 2. $KPI_{EE} = Average \frac{\sum(O_UNITS)}{\sum(E_CONSUM)}$

Output Units (O_UNITS) refers to the total number of finished products or units produced by the company. It reflects the company's production capacity and operational effectiveness. Accurate measurement of output units is crucial as it serves as the numerator in the efficiency calculation, indicating the volume of production relative to energy usage. Energy Consumption (E_CONSUM) is the total amount of energy consumed by the company over the same period. It includes all forms of energy used in production, such as electricity, gas, and other fuels. Precise energy consumption tracking is essential because it forms the denominator in the KPI_{EE} calculation, influencing the assessment of energy utilization efficiency.
Energy efficiency is particularly important in the OS.Pt due to the energy-intensive nature of stone processing. The sector involves activities such as cutting, polishing, and finishing, which require substantial amounts of energy. Therefore, optimizing energy use can significantly impact operational costs and environmental sustainability.

4.3. First Time Through KPI

The First Time Through (KPI_{FFT}) measures production effectiveness and quality within manufacturing processes. It evaluates production efficiency by assessing the proportion of units produced correctly without requiring any rework (Komkowski et al., 2023). High KPI_{FFT} values indicate that a company's processes are robust and efficient,

producing many defect-free units on the first pass (Ye et al., 2022). This metric is essential for minimizing waste, reducing costs, and enhancing operational efficiency. For sectors like OS.Pt, where precision and quality are critical, achieving high KPI_{FFT} values is essential for maintaining competitive advantage and operational excellence. KPI_{FFT} quantifies the ratio of units that successfully pass the production process without rework to the total number of units produced (Equation 2.). It reflects the company's ability to produce high-quality products consistently and efficiently.

Equation 3. $KPI_{FFT} = Average \frac{\Sigma(FTT_UNITS_k)}{\Sigma(O_UNITS_k)}$

First Time Through Units (FTT_UNITS) represent the count of completed units correctly without needing rework. These units meet all quality and specification requirements on the first pass through the production process. FTT_UNITS is a direct indicator of the efficiency and effectiveness of the production process. Output Units (O_UNITS) refers to the total number of units produced during a specific period. It includes all units, regardless of whether they require rework or meet quality standards on the first pass. The total output provides a comprehensive view of the production volume, allowing for a complete assessment of the process's effectiveness compared to the number of defect-free units.
In the OS.Pt, KPI_{FFT} is particularly significant due to the intricate and precision-dependent nature of stone processing. Processes such as cutting, polishing, and finishing require high accuracy and consistency to meet quality standards without defects. By monitoring and optimizing KPI_{FFT}, companies can enhance their production processes, reduce waste, and improve economic and operational performance.

4.4. Raw-Material Efficiency KPI

Raw-Material Efficiency (KPI_{RMY}) is crucial for assessing how efficiently a company uses its raw materials in production (Silva, Rabadão et al., 2020). This KPI is essential in manufacturing sectors where raw materials constitute a significant portion of the production costs and environmental impact (Wang & Shao, 2023). In essence, KPI_{RMY} measures the material yield—the effectiveness of transforming raw materials into finished products. This KPI is essential for manufacturing companies, especially in sectors like OS.Pt where material costs and waste are significant concerns. It clearly measures how effectively raw materials are converted into finished products, serving as a key indicator of economic and environmental performance. Companies can achieve substantial benefits in cost reduction and sustainability by focusing on improving material efficiency through advanced technologies and process optimization. KPI_{RMY} evaluates the number of output units produced per unit of raw material consumed. It provides a ratio that helps understand how much product is generated from the raw materials used. This ratio directly reflects the material efficiency in the production process (Equation 3.).

Equation 4. $KPI_{RMY} = Average \frac{\Sigma(O_UNITS_k)}{\Sigma(M_CONSUM_k)}$

Raw Material Consumption (M_CONSUM) represents the total quantity of raw materials used during production. It includes all primary materials and additional inputs

required to produce the finished goods. Precise tracking of raw material consumption is critical as it forms the denominator in the KPI_{RMY} calculation, influencing the assessment of material utilization efficiency.
In the OS.Pt, the efficient use of raw materials is particularly vital due to the high cost and environmental impact associated with stone processing. The sector involves cutting, shaping, and polishing, which are material-intensive and generate significant waste. By monitoring and improving KPI_{RMY}, companies can identify opportunities to optimize their material handling and processing operations, fostering economic and environmental benefits.

4.5. Carbon Footprint Emissions KPI

The Carbon Footprint Emissions ($KPI_{CO2\text{-}Eq}$) measures the environmental impact of a company's production processes regarding greenhouse gas emissions (Hoffmann et al., 2024). $KPI_{CO2\text{-}Eq}$ is a vital metric for manufacturing companies, especially in sectors like OS.Pt, where energy use and carbon emissions are significant concerns. It provides a precise measure of the environmental impact per unit of output, helping companies to assess and manage their carbon footprint effectively.
The CO2-eq/kWh value in Europe varies significantly across countries due to the diverse energy mixes used for electricity generation (Cozzi, 2023). Factors influencing these values include the proportion of renewable energy sources, nuclear power, and fossil fuels in the national energy grid. $KPI_{CO2\text{-}Eq}$ quantifies the amount of CO_2 equivalent emissions produced for every 1000 output units. It focuses on emissions derived from public electricity consumption, relating them to the total production output. This measure helps evaluate how efficiently a company uses its energy resources and its impact on climate change. According to the European Environment Agency (EEA)[2] the European average CO2-eq/kWh is approximately 0.233 kg CO2-eq/kWh. This average can be used as a general factor for calculating the carbon footprint in scenarios where specific national data is unavailable (Equation 4.).

Equation 5. $KPI_{CO2\text{-}Eq} = Average \frac{\sum(E_CONSUM)}{\sum(O_UNITS)} x\ 0{,}23314$

The “E_CONSUM” reflects the company’s dependency on energy for its production activities. The “O_UNITS” refers to the total count of finished products or units produced during a given period. The factor 0.23314 represents the average emission intensity of CO_2 from public electricity production, in the OS.Pt sector, which involves energy-intensive processes such as cutting, shaping, and finishing stone products, $KPI_{CO2\text{-}Eq}$ is particularly relevant. The sector's reliance on significant energy inputs means managing and reducing carbon emissions is crucial for environmental sustainability and compliance with regulatory standards. For instance, companies with higher digital integration (DR#3 to DR#4) may implement energy-efficient technologies and automation systems that reduce energy consumption and, consequently, lower CO_2 emissions. These companies are likely to achieve lower $KPI_{CO2\text{-}Eq}$ values than those with less digitalization (DR#0 to DR#1), where older, less efficient equipment may result in higher emissions. By monitoring and optimizing $KPI_{CO2\text{-}Eq}$, companies can identify opportunities to reduce their carbon footprint, improve energy efficiency, and contribute to broader climate action goals.

[2]https://www.eea.europa.eu

ENVIRONMENTAL IMPACT ASSESSMENT

The third stage of the LCA focuses on evaluating the environmental impacts of digital technology adoption among SMEs in the OS.Pt. This stage involves collecting detailed data from companies and analyzing KPIs to understand how varying levels of digital maturity affect their carbon footprint and overall environmental performance. Data collection was conducted through comprehensive on-site surveys, where companies were assessed based on their DR. Each company's operational metrics were evaluated to determine their energy efficiency, rework rates, raw material yield, and CO2 emissions (Table 1).

The analysis revealed distinct variations in performance across the different digital ranks. With no digitalisation initiatives, companies at the DR#0 level could produce 294 units per 1000 kWh of energy consumed. These companies faced high rework rates, with 72.9% of units requiring additional processing, and achieved a raw material yield of 65.7%. Their carbon emissions were the highest among all ranks, at 793 kilograms of CO_2 equivalent (kg CO2-eq) per 1000 units produced. There was a slight improvement for companies at the DR#1 level, which utilize a single digital machine. These firms produced 303 units per 1000 kWh, but their rework rates were higher, with 76.3% of units needing rework. The raw material yield decreased to 63.7%, and CO2 emissions were slightly lower at 769.4 kg CO2-eq per 1000 units.

Significant improvements were observed at the DR#2 level, where companies with two digital machines produced 401 units per 1000 kWh. The rework rate improved, with only 57.1% of units requiring rework, and the raw material yield increased to 69.3%. These companies also substantially reduced CO2 emissions, dropping to 581.4 kg CO2-eq per 1000 units. At the DR#3 level, where companies integrate at least three digital machines with their ERP systems, there was a notable enhancement in performance. These firms produced 589 units per 1000 kWh, significantly reducing rework rates to 19.7%. The raw material yield improved to 77.8%, and CO2 emissions were further reduced to 395.8 kg CO2-eq per 1000 units. Controversially, companies at the DR#4 level, characterized by full digital integration and collaboration with the marketplace, demonstrated the highest levels of efficiency. These companies produced 645 units per 1000 kWh, with only 19.7% of units requiring rework. They achieved the highest raw material yield at 84.9% and the lowest CO2 emissions at 361.5 kg CO2-eq per 1000 units.

These findings, summarized in Table 1, highlight the significant environmental benefits of advancing digital maturity in manufacturing processes.

Table 1. KPIs assessment

Digital Rank	KPI_{EE} (units/1000kWh)	KPI_{FFT} (units/units)	KPI_{RMY} (output/raw_material)	$KPI_{CO2\text{-}Eq}$ (KgCO2-eq/Kunits)
DR#0	29,4	27,1%	65,7%	793,0
DR#1	30,3	23,7%	63,7%	769,4
DR#2	40,1	57,1%	69,3%	581,4
DR#3	58,9	80,3%	77,8%	395,8
DR#4	64,5	81,2%	84,9%	361,5
Average	44,6	53,9%	72,3%	580,2

The assessment indicates a clear correlation between higher digital maturity and enhanced environmental performance. Companies progressing from lower to higher digital ranks exhibit substantial improvements across all KPIs. Energy efficiency, measured by KPI_{EE}, increases significantly, reflecting better utilization of energy resources. Production effectiveness, captured by KPI_{FFT}, shows a dramatic reduction in rework rates, indicating more precise and efficient manufacturing processes. The raw material yield, represented by KPI_{RMY}, improves as digital maturity rises, demonstrating more effective use of raw materials and reduced waste. Lastly, CO_2 emissions, evaluated by $KPI_{CO2\text{-}Eq}$, decrease markedly with higher digital integration, highlighting the role of advanced digital technologies in reducing the carbon footprint of manufacturing activities.

Analytical Insights and Interpretations

This stage of the LCA focuses on analyzing the results to evaluate how effectively the study meets its objectives. The analysis provides insights into how digitalization impacts the environmental performance of SMEs, particularly in the OS.Pt.
The KPI_{EE} shows a positive exponential trend as companies advance in digital maturity. This trend is depicted by the dotted line in Figure 1, which illustrates that higher levels of digital integration lead to substantial improvements in energy efficiency. Companies at DR#4 produce significantly more units per kWh than those at DR#0, indicating that advanced digital technologies enable more efficient energy use.

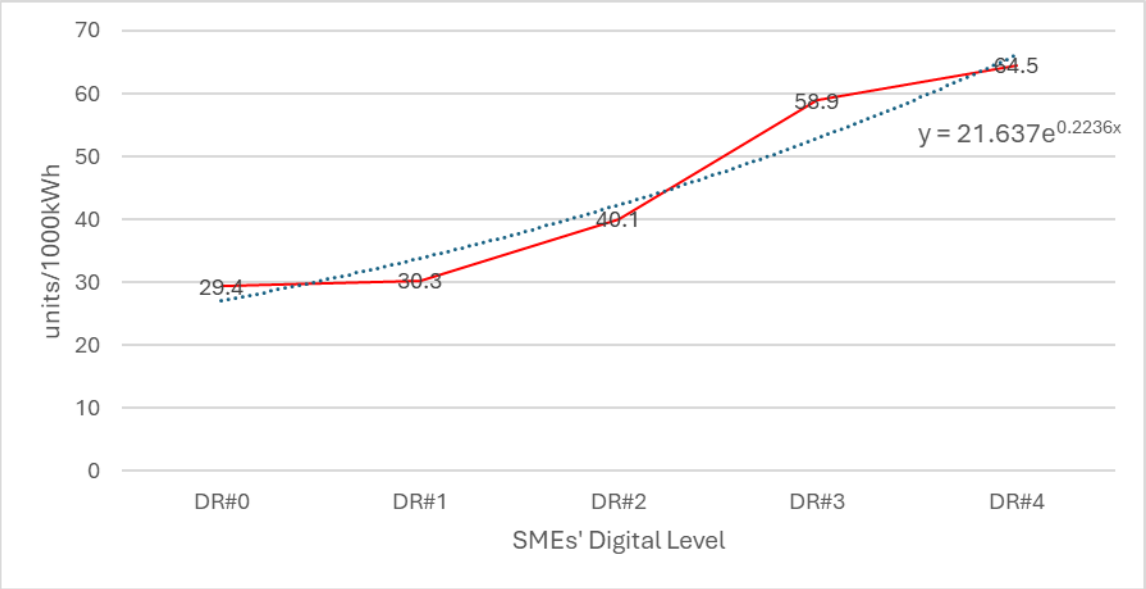


Figure 1. Evolution Trend of Energy Efficiency Across Digital Ranks

This exponential growth in energy efficiency suggests that the benefits of digitalization in reducing energy consumption are amplified as companies invest in more sophisticated technologies. The coefficient value (21.637) of the KPI_{EE} represents the baseline energy efficiency for companies with no digital integration (DR#0). The exponent 0.2236x indicates the growth rate of the KPI_{EE}. A positive exponent means that as a DL increases, the KPI_{EE} increases exponentially.

The KPI_{FFT}, which measures the proportion of units produced without requiring rework, also exhibits a positive trend as companies increase their digital maturity. Unlike the exponential trend observed in energy efficiency, the gains in production effectiveness follow a more linear progression, with an average increase of 16.48% per digital rank. The standard deviation of 0.248 indicates that these gains are consistent across different companies and likely persist over time. This linear improvement in KPI_{FFT} highlights the role of digital technologies in enhancing production quality and reducing defects, thereby minimizing rework and associated costs.

The KPI_{RMY} indicator, which assesses raw material usage efficiency, shows a steady positive trend with increasing digital maturity. Companies that adopt more advanced digital technologies (DR#3 and DR#4) achieve higher material yields, meaning they convert a more significant proportion of raw materials into finished products with less waste. The linear trend gain of 5.05% indicates a consistent reduction in material waste as companies move up the digital ladder. This improvement contributes to carbon footprint reduction and enhances overall productivity and resource efficiency.

The $KPI_{CO2\text{-}Eq}$ indicator measures the carbon emissions per 1000 output units. The data shows an average carbon footprint of 580.2 kg CO2-eq per 1000 pieces across the sample, with a standard deviation of 18.0. This average masks significant differences between digital ranks. Companies at the lowest digital level (DR#0) emit 793 kg CO2-eq per 1000 units, which is 2.19 times higher than the emissions from companies at the highest digital level (DR#4), which emit only 361.5 kg CO2-eq per 1000 units. This stark contrast underscores the potential of digital technologies to reduce carbon emissions drastically and highlights the environmental benefits of advancing digital integration.

By converting energy savings into carbon equivalent reductions, digital technologies play a critical role in lowering the carbon footprint of manufacturing processes. Over five years following investment in digital technologies, the differences between the tiniest and most digitally advanced companies become pronounced. DR#0 companies not only emit more CO_2 but also have higher rates of rework (72.5%) and material waste (34.3%). In contrast, DR#4 companies emit significantly less CO_2 (395.8 kg CO2-eq per 1000 units), have a lower rework rate (19.7%), and waste less raw material (22.2%).

These findings illustrate the transformative impact of digitalization on environmental and operational performance. Companies that invest in and integrate advanced digital technologies can substantially reduce energy consumption, material waste, and carbon emissions while improving production quality and efficiency. The environmental impact assessment confirms that digital technology adoption in the OS.Pt sector leads to significant improvements across all key performance indicators. Companies progressing from lower to higher digital ranks benefit from enhanced energy efficiency, improved production effectiveness, optimized material usage, and reduced carbon emissions. These insights emphasize the importance of digitalization in driving sustainable practices and achieving long-term operational and environmental benefits. As the sector evolves, leveraging advanced digital technologies will be essential for maintaining competitiveness and supporting broader climate action objectives.

CONCLUSION AND FUTURE DIRECTIONS

The primary aim of this research was to evaluate the impact of digital technologies on the carbon footprint reduction of manufacturing SMEs. Using a quantitative

methodology anchored in the ISO Standard 14040 for LCA, a comprehensive framework was designed and applied it to a representative sample of Portuguese stone manufacturing SMEs. The findings from this study provide valuable insights into how different levels of digital technology adoption influence operational and environmental performance, particularly in terms of carbon footprint reduction.

The analysis of KPIs across varying levels of digital maturity reveals two distinct scenarios for potential improvements in carbon footprint and operational efficiency:

Moderate Scenario: An OS.pt SME currently operating with DR#0 that decides to advance to a basic digital maturity level (DR#2) can expect a significant reduction in its carbon footprint of 10.7%. This reduction is supported by a 30.0% decrease in rework rates, reflecting improved production quality and efficiency. Additionally, the OS.pt SME would see a 3.5% gain in raw material yield, indicating more efficient use of resources and reduced waste.

Optimistic Scenario: The potential benefits are even more substantial if the same company opts for a more ambitious investment in digital technologies, reaching an advanced digital maturity level (DR#4). The company could achieve a 35.1% reduction in its carbon footprint. This significant decrease in emissions is accompanied by a 54.1% reduction in rework rates, highlighting the dramatic improvements in production accuracy and defect rates. Moreover, the company would realize a 19.5% increase in raw material yield, demonstrating optimal resource utilization and minimizing waste.

These scenarios illustrate the transformative potential of digital technologies in reducing the environmental impact and enhancing the operational efficiency of manufacturing SMEs. The findings underscore that higher levels of digital integration lead to more significant improvements in energy efficiency, production quality, and material usage, all contributing to substantial reductions in carbon emissions.

The Moderate Scenario offers a practical pathway for companies to begin their digital transformation journey and achieve noticeable environmental and operational gains with relatively modest investments. Conversely, the Optimistic Scenario showcases the significant benefits of comprehensive digital integration, making a compelling case for more substantial investment in digital technologies to maximize sustainability and efficiency.

In conclusion, this research highlights the substantial potential of digital technologies to drive sustainability and efficiency in manufacturing SMEs. As companies navigate their digital transformation journeys, a comprehensive and integrated approach will be essential to realize the full benefits of digitalization. Continued exploration and research in this field will provide deeper insights and support for SMEs aiming to align their operations with sustainable development goals.

Future Research Directions: While this study demonstrates the positive impact of digital technology adoption on carbon footprint reduction, it also suggests that more than simply investing in digital tools may be required to achieve these benefits. The transition to digital operations is complex and requires a multidimensional approach encompassing organizational change, process optimization, and continuous learning. Future research should explore several areas to enhance our understanding of this transition further:

REFERENCES

Aldoseri, A., Al-Khalifa, K. N., & Hamouda, A. M. (2024). Methodological Approach to Assessing the Current State of Organizations for AI-Based Digital Transformation. *Applied System Innovation*, *7*(1), 14. https://doi.org/10.3390/asi7010014

Arowoiya, V. A., Moehler, R. C., & Fang, Y. (2024). Digital twin technology for thermal comfort and energy efficiency in buildings: A state-of-the-art and future directions. *Energy and Built Environment*, *5*(5), 641–656. https://doi.org/10.1016/j.enbenv.2023.05.004

Asghari, M., Fereidoni, S., Fereidooni, L., Nabisi, M., & Kasaeian, A. (2024). Energy efficiency analysis of applying phase change materials and thermal insulation layers in a building. *Energy and Buildings*, *312*, 114211. https://doi.org/10.1016/j.enbuild.2024.114211

Cozzi, L. (2023). CO2 Emissions in 2022. In *INTERNATIONAL ENERGY AGENCY (IEA)*. https://doi.org/10.1787/12ad1e1a-en

Destefanis, S., Maietta, O. W., Mazzotta, F., & Parisi, L. (2023). Firm survival and innovation: direct and indirect effects of knowledge for SMEs. *Economics of Innovation and New Technology*, 1–29. https://doi.org/10.1080/10438599.2023.2263371

Di Bella, L., Katsinis, A., Lagüera-González, J., Odenthal, L., Hell, M., & Lozar, B. (2023). *Annual Report on European SMEs 2022/2023*.

Hadavi, A., & Alizadehsalehi, S. (2024). From BIM to metaverse for AEC industry. *Automation in Construction*, *160*, 105248. https://doi.org/10.1016/j.autcon.2023.105248

Hoffmann, S., Lasarov, W., Reimers, H., & Trabandt, M. (2024). Carbon footprint tracking apps. Does feedback help reduce carbon emissions? *Journal of Cleaner Production*, *434*, 139981. https://doi.org/10.1016/j.jclepro.2023.139981

Irfan, M., Mahapatra, B., & Shahbaz, M. (2023). Energy efficiency in the Indian transportation sector: effect on carbon emissions. *Environment, Development and Sustainability*, *26*(3), 6653–6676. https://doi.org/10.1007/s10668-023-02981-z

Komkowski, T., Antony, J., Garza-Reyes, J. A., Tortorella, G. L., & Pongboonchai-Empl, T. (2023). The integration of Industry 4.0 and Lean Management: a systematic review and constituting elements perspective. *Total Quality Management & Business Excellence*, *34*(7–8), 1052–1069. https://doi.org/10.1080/14783363.2022.2141107

Kulinan, A. S., Park, M., Aung, P. P. W., Cha, G., & Park, S. (2024). Advancing construction site workforce safety monitoring through BIM and computer vision integration. *Automation in Construction*, *158*, 105227. https://doi.org/10.1016/j.autcon.2023.105227

Li, M., Lu, K., Wang, H., & Wang, S. (2020). Integrating BIM with greenhouse-gas emissions in AEC: A scientometric review. *E3S Web of Conferences*, *143*, 0–4. https://doi.org/10.1051/e3sconf/202014301008

Silva, A., Dionisio, A., & Almeida, I. (2020). Enabling Cyber-Physical Systems for Industry 4.0 operations: A Service Science Perspective. *International Journal of Innovative Technology and Exploring Engineering*, *9*(8), 838–846. https://doi.org/10.35940/ijitee.H6804.069820

Silva, A., & Pata, A. (2022). Value Creation in Technology Service Ecosystems - Empirical Case Study. In J. Machado, F. Soares, J. Trojanowska, V. Ivanov, K.

Antosz, Y. Ren, V. K. Manupati, & A. Pereira (Eds.), *Innovations in Industrial Engeneering II* (pp. 26–36). Springer International Publishing. https://doi.org/doi.org/10.1007/978-3-031-09360-9_3

Silva, A., Rabadão, C., & Capela, C. (2020). Towards Industry 4.0 | A case study of BIM deployment in ornamental stones sector. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, *67*, 24535. https://doi.org/ISSN 2307-4531

Slavic, D., Marjanovic, U., Medic, N., Simeunovic, N., & Rakic, S. (2024). The Evaluation of Industry 5.0 Concepts: Social Network Analysis Approach. *Applied Sciences*, *14*(3), 1291. https://doi.org/10.3390/app14031291

Tam, V. W., Zhou, Y., Shen, L., & Le, K. N. (2023). Optimal BIM and LCA integration approach for embodied environmental impact assessment. *Journal of Cleaner Production*, *385*, 135605. https://doi.org/10.1016/j.jclepro.2022.135605

United Nations. (2015). *Conference of the Parties Twenty-first session - ADOPTION OF THE PARIS AGREEMENT: Vol. FCCC/CP/20* (United Nations (ed.); p. 32). United Nations. http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

Verones, F., Hellweg, S., Antón, A., Azevedo, L. B., Chaudhary, A., Cosme, N., Cucurachi, S., de Baan, L., Dong, Y., Fantke, P., Golsteijn, L., Hauschild, M., Heijungs, R., Jolliet, O., Juraske, R., Larsen, H., Laurent, A., Mutel, C. L., Margni, M., … Huijbregts, M. A. J. (2020). LC-IMPACT: A regionalized life cycle damage assessment method. *Journal of Industrial Ecology*, *24*(6), 1201–1219. https://doi.org/10.1111/jiec.13018

Wang, L., & Shao, J. (2023). Digital economy, entrepreneurship and energy efficiency. *Energy*, *269*, 126801. https://doi.org/10.1016/j.energy.2023.126801

Wijeratne, P. U., Gunarathna, C., Yang, R. J., Wu, P., Hampson, K., & Shemery, A. (2024). BIM enabler for facilities management: a review of 33 cases. *International Journal of Construction Management*, *24*(3), 251–260. https://doi.org/10.1080/15623599.2023.2222962

Yan, J., Lu, Q., Tang, J., Chen, L., Hong, J., & Broyd, T. (2022). Digital Tools for Revealing and Reducing Carbon Footprint in Infrastructure, Building, and City Scopes. *Buildings*, *12*(8), 1097. https://doi.org/10.3390/buildings12081097

Ye, X., Lu, Y., & Manoharan, S. (2022). Automated conversion of engineering rules: Towards flexible manufacturing collaboration. *Results in Engineering*, *16*(September), 100680. https://doi.org/10.1016/j.rineng.2022.100680

Design Science for Networks Designing: A Service-Dominant Logic Approach

Agostinho da Silva[1,2] and António Marques Cardoso[1]
[1]CISE - Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal
[2]CIGEST – Centro de Investigação em Gestão

a.silva@zipor.com
ajmcardoso@ieee.org

Abstract: This research explores the dynamics of coopetition among Small and Medium Enterprises (SMEs) during digital transformation, using Design Science Research (DSR) anchored in Service-Dominant (S-D) Logic. It examines the integration challenges of manufacturing SMEs into digital supply chains, highlighting the critical role of coopetition—a blend of competition and collaboration—in driving sustainable growth in this essential sector. Prompted by a consensus on reducing SME vulnerabilities, the study underscores the need for a resilient framework, especially given an 85% attrition rate in digital networks where only a minority, often supported by giants like Amazon and Microsoft, succeeds long-term. The proposed framework focuses on leveraging technology to enhance SMEs' competitiveness, innovation, and growth. This study contributes to academic discourse by suggesting future research directions, such as defining value creation in coopetition networks and assessing the impact of innovative artefacts, but also reveals the potential of coopetition networks as platforms for mutual value creation. This research enriches scholarly discussions on coopetition in the digital age and offers strategic guidance for SMEs navigating digital transformation, aiming to prepare European SMEs for upcoming challenges and opportunities.

Keywords*:* Coopetition, Networks, Small and medium enterprises, Design science research, Service-Dominant logic

1. Introduction

In the digital transformation era, the rapid pace of technological evolution has launched the global economy into a new epoch and fundamentally altered the fabric of business operations (Hernandez *et al.*, 2017). This transformative shift, driven by digital innovation, carries significant repercussions for procurement practices, revolutionizing traditional business methodologies. Within this evolving landscape, Small and Medium Enterprises (SMEs) play an indispensable role; they are the cornerstone of the European economy. European Commission (Di Bella *et al.*, 2023) reported that the EU27 saw over twenty million SMEs operational within the non-financial business sector in 2020, accounting for 99.8% of all businesses and generating upwards of 65% of total employment. This highlights their critical role in bolstering employment and fostering wealth creation, especially within the manufacturing sector—a key component of developed economies (Radicic, Pugh and Douglas, 2020).

However, as SMEs strive to integrate into global digital supply chains, they encounter substantial challenges and opportunities crucial for economic robustness. Scholarly research and policy analysis reveal that optimal integration is achieved within networks that promote cooperation—a synergy of competition and collaboration (Borchert and Bonefeld-Dahl, 2018).

Despite the consensus in business literature and official strategies aimed at mitigating SME vulnerabilities through the generalization of coopetition networks, the BCG Henderson Institute's research, published in the MIT Sloan Management Review (Reeves *et al.*, 2019), reveals concerning trends regarding the "rise and often fall" of these ecosystems. Analysing multiple cases across eleven different sectors, the study uncovered a staggering short-term death rate of over 85%, with less than 15% achieving their long-term goals. The outcomes were categorized as follows: (1) ecosystems that failed at inception, (2) those that quickly gained but then lost market share, (3) ones that saw a gradual decline to non-viability, and (4) a mere 15% that sustained long-term success. In this successful minority, large corporations like Microsoft and Amazon played pivotal roles, securing dominant positions and profit margins exceeding 29%. These thriving ecosystems largely depended on the central, keystone companies, with secondary participants relying more on these leaders than the ecosystem itself.

This study aims to fill a critical void in the existing research on coopetition among SMEs, focusing on the challenges posed by the lack of keystone entities in these networks - a known determinant of network dissolution (Iansiti and Levien, 2004). A question guides this research: How can methodologies be developed to enrich knowledge and fortify coopetition networks among manufacturing SMEs?

Through a comprehensive review of both product-centric and service-centric network theories (Moore, 1998) (Peltoniemi and Vuori, 2004) (Jabbour *et al.*, 2018), alongside empirical insights into the successes and failures of digital networks (Reeves *et al.*, 2019), this paper endeavours to provide an exploration of SMEs' navigation through the intricate dynamics of coopetition technology-enabled networks. Grounded in Design Science Research (Patkar, 2018) and Service-Dominant (S-D) Logic foundations (Vargo and Lusch, 2017), it seeks to establish a structured methodology for designing and validating coopetition networks, thereby informing the development of research proposals.

2. Enhancing Methodologies for Coopetition Networks

As Peffers et al. (2007) defined, a methodology provides a comprehensive framework comprising principles, practices, and procedures meticulously crafted for a specific knowledge domain. It is thoughtfully designed to steer the development and execution of varied research initiatives, representing a disciplined approach anchored in research design logic (Patkar, 2018). Such a structured foundation ensures the diligent application of academic methods, promoting the pursuit of knowledge and fostering scholarly advancement within distinct areas of inquiry.

Coopetition is often addressed through Game Theory (Devece, Ribeiro-Soriano and Palacios-Marqués, 2019), which delineates the strategic decision-making dynamics when enterprises engage in simultaneous cooperation and competition (Dagnino and Padula, 2002). Complementing this, the resource-based view (Barney, Wright and Ketchen, 2001) posits that coopetition facilitates firms' access to and sharing of unique resources, securing a competitive advantage (Crick, 2019). The Dynamic Capabilities Framework broadens this perspective (Prasertsakul, 2013), highlighting firms' capacity to adapt resources in response to the evolving market demands swiftly, a critical aspect in the agile digital ecosystem (Teece, Pisano and Shuen, 1997).

Network theory illuminates the strategic significance of inter-firm relationships and connections, particularly for SMEs (Tsujimoto *et al.*, 2018). It suggests that networks are instrumental in granting access to otherwise inaccessible resources, information, and markets (Granovetter, 1990). Within these networks, keystone firms are indispensable, establishing standards and nurturing an environment conducive to innovation and growth for smaller entities (Iansiti and Levien, 2004). The emphasis on network positioning and the exploitation of social capital underscores the potential for achieving competitive superiority.

The discourse on networks has evolved, revealing a dichotomy between tangible, product-focused views and intangible, service-oriented perspectives (Vargo, 2011). The traditional view of equating value with physical goods is increasingly seen as inadequate for encapsulating the complexities of modern economic exchanges (Vargo, Wieland and Akaka, 2015). This critique has paved the path for the S-D Logic, which revolutionizes the marketing and business strategy landscape by positioning service, not goods, as the essence of economic exchange. S-D Logic community argues that goods serve merely as conduits for service delivery (Edvardsson and Tronvoll, 2013), spotlighting the application of specialized competencies for the benefit of others (Matthies *et al.*, 2016). This paradigm shift redirects focus towards the processes and performances that foster mutual value creation, challenging the conventional goods-centric economic classification (Lusch and Vargo, 2007). It elevates customers to active participants in value co-creation, fundamentally altering traditional consumer behaviour and business strategy perceptions (Joiner and Lusch, 2016; Vargo, Wieland and O'Brien, 2023).

S-D Logic's foundations resonate with a range of theoretical frameworks, including resource-based theory and the dynamic capabilities concept, highlighting its efficacy in elucidating how evolving competencies contribute to value proposition delivery (Akwei, Peppard and Hughes, 2010) (Lindström *et al.*, 2016). Additionally, S-D Logic introduces the notion of service ecosystems, environments where actors create mutual value through service exchange (Bettencourt, Lusch and Vargo, 2014). Drawing inspiration from biological ecosystems, S-D Logic emphasizes the interplay of competitive and cooperative dynamics essential for survival and growth (Peltoniemi and Vuori, 2004) (Vargo and Lusch, 2017).

In the context of SMEs striving for integration into digital supply chains, S-D Logic offers a promising avenue to overcome historical collaboration barriers, thus enhancing digital engagement (Appian, 2021). By adopting a coopetition strategy that harmonizes competition with cooperation, SMEs can more effectively traverse the complexities of digital supply chains, leveraging the foundational principle of mutual value creation to foster innovation, resilience, and growth.

This nuanced approach to understanding and refining coopetition networks among SMEs suggests a departure from the traditional goods versus services dichotomy, advocating for a richer engagement with the intricacies of service exchange and value co-creation. It positions SMEs to unlock innovative pathways for development

and expansion in the digital era, underscoring the transformative potential of embracing service-oriented strategies within coopetition frameworks.

3. Navigating Coopetition in SMEs through DSR

Inspired by Herbert Simon's (1988) vision of a predominantly artificial world, DSR champions a proactive stance towards comprehending and sculpting the constructed environments (Simon, 1988). In addressing the intricate dynamics of SMEs' digital transformation and their engagement in coopetition, Design Science Research (DSR) stands out as a critical methodological approach (Hevner *et al.*, 2004). DSR transcends conventional research paradigms by marrying artefact creation and analytical examination to resolve practical dilemmas and enrich theoretical insights (Peffers *et al.*, 2007).

3.1 DSR's Role in Service Ecosystems and Coopetition Dynamics

DSR's foundational belief is that progress in knowledge is optimally achieved via the design, crafting, and analytical assessment of artefacts aimed at tackling precise challenges (vom Brocke, Hevner and Maedche, 2020). Its application spans various disciplines, such as engineering, computing, and education, highlighting its adaptability and relevance to a broad spectrum of research inquiries. By prioritizing artefact creation - from constructs and models to methods and implementations - DSR offers a concrete research strategy, empowering scholars to address real-world issues while contributing to academic discourse (March and Smith, 1995). The methodology integrates design science and research design principles, advocating for iterative solution development that bridges the existing state with preferred outcomes (Sun, 2020). Within a triadic cycle of relevance, rigour, and design (Hevner, 2007), DSR ensures that research is anchored in tangible problems, leverages existing knowledge, and persistently seeks innovative solutions. This approach solves immediate challenges, stimulates innovation, and enriches scholarly discussions (Peffers *et al.*, 2007).

DSR is especially pertinent in the realms of networks and SME coopetition. Viewing technology as a dynamic asset and business models as established solutions (Peffers *et al.*, 2007), DSR lays the groundwork for discovering novel paths for value co-creation within intricate networks (Arthur, 2009) (Lusch and Vargo, 2013). This perspective is vital for unravelling the complexities of coopetition, where competitive and cooperative interactions coalesce to drive growth and innovation.

3.2 Technological Artifacts and Institutional Integration in DSR

Within DSR, technology surpasses its conventional role, emerging as a crucial ecosystem element enabling actor interactions and guiding market institutions' evolution (March and Smith, 1995). As both artefact and value creation catalysts, this expanded interpretation of technology accentuates DSR's significance in exploring the intricacies of coopetition networks and service ecosystems (Akaka, Vargo and Schau, 2015).

Building on Morgan and Hunt's 1994 framework, institutions are portrayed as composites of organizations and regulatory frameworks, which are crucial in shaping the architectures of business models within ecosystems (Morgan and Hunt, 1994). This view emphasizes the importance of dynamic resources and collaborative value generation, suggesting ecosystem interactions mirror and actively sculpt market institutions (Akaka, Vargo and Schau, 2015). Furthermore, the tangible manifestation of intelligence in tools and artefacts (March and Smith, 1995) underscores technology's critical role in the ongoing dialogue on value creation and DSR, affirming DSR's utility in examining coopetition ecosystems for collaborative innovation (vom Brocke, Hevner and Maedche, 2020).

This view emphasizes the importance of dynamic resources and collaborative value generation, suggesting ecosystem interactions mirror and actively sculpt market institutions (Akaka, Vargo and Schau, 2015). Furthermore, the tangible manifestation of intelligence in tools and artefacts (March and Smith, 1995) underscores technology's critical role in the ongoing dialogue on value creation and DSR, affirming DSR's utility in examining coopetition ecosystems for collaborative innovation (vom Brocke, Hevner and Maedche, 2020).

Moreover, recognizing technology as pivotal artefacts that integrate ecosystems aligns with the institutional perspective on value creation within the DSR framework (Kaartemo, Akaka and Vargo, 2017). This viewpoint highlights a self-regulating system of resource-integrating actors united by shared institutional logic and facilitating mutual value creation through service exchange (Lusch, Vargo and Gustafsson, 2016). Thus, DSR emerges as an appropriate methodology to confront the challenges highlighted (Figure 1).

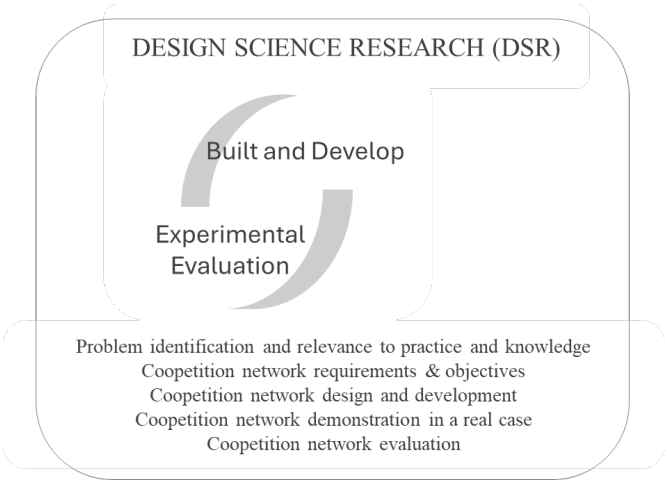


Figure 1: Design Science Research process (adapted from Peffers, 2007)

By spotlighting the critical contribution of manufacturing SMEs to Europe's employment and economic prosperity and underscoring their digital adaptability as essential for survival, the DSR view presents itself as a promising strategy to deepen the understanding and spur innovation within coopetition networks. This structured approach addresses the challenges manufacturing SMEs face in the digital realm. It promotes the development of tangible, inventive solutions to enhance their competitive edge and ensure their long-term viability.

4. Leveraging Design Science Research to Design and Evaluate Coopetition Networks

Drawing from Peffers et al.'s (2007) foundational insights in DSR, and acknowledging the critical role of digital supply chain integration in sustaining manufacturing SMEs as noted by Haleem et al. (2018), this paper introduces a comprehensive framework (Haleem *et al.*, 2018).

This framework is designed to steer academic inquiries within coopetition networks, laying down robust principles and practices. The imperative to consistently exceed customer expectations highlights the risk of providers being rapidly marginalized or excluded from the digital supply chain at the slightest indication of dissatisfaction. This critical requirement resonates with the tenets of Service-Dominant Logic, which posits that value is co-created through persistent service exchanges within ecosystems, fostering innovation as an inherent outcome of these co-creation processes (Akter *et al.*, 2020). The objective is to address the complexities of manufacturing SMEs as they integrate into coopetition networks by (1) Identifying Solutions - exploring knowledge-driven models or constructs to enhance the robustness of manufacturing SME networks. This strategy advocates for a harmonious blend of collaboration and competition, eliminating dependence on any dominant entity; (2) Evaluating Feasibility - conducting thorough assessments of these solutions' practicality and impact within real-world contexts to verify their effectiveness in facilitating manufacturing SMEs' smooth transition into digital supply chains.

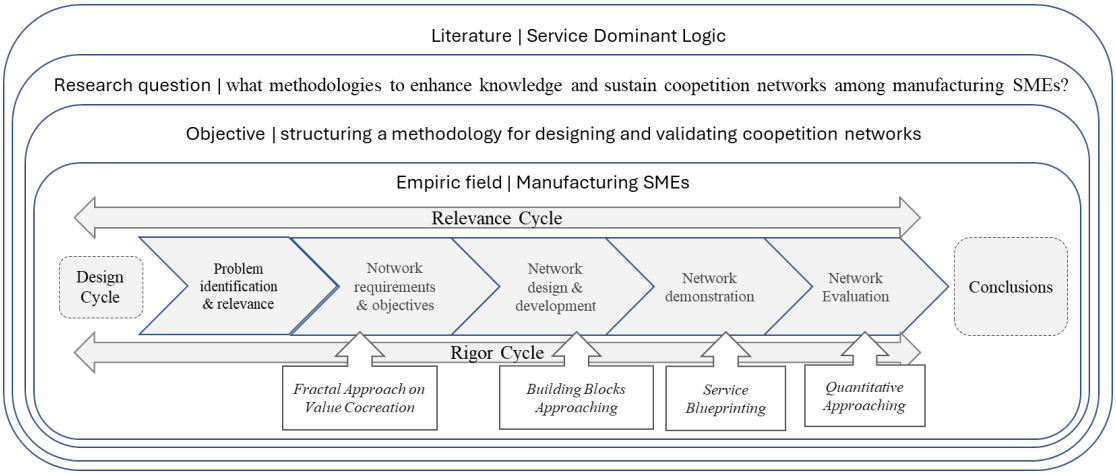


Figure 2: Strategic Framework for Academic Exploration in Coopetition Networks

As represented in Figure 2, the Design Science Research, articulated by Peffers (2007), underscores the importance of engaging in relevance, rigour, and design cycles within research endeavours. This methodological approach demands a comprehensive strategy that includes: (1) defining value creation objectives by pinpointing the necessary advancements within service ecosystems to promote coopetition and value cocreation; (2) tailoring a framework that maximizes value creation opportunities for manufacturing SMEs; (3) validating the framework's applicability and effectiveness by demonstrating practical utility employing case studies focused on manufacturing SMEs; and (4) evaluating impact by assessing the framework's capacity to address and alleviate the digital supply chain vulnerabilities faced by manufacturing SMEs.

This methodical approach aims to systematically cultivate and scrutinise coopetition networks dedicated to value creation, ensuring the strategic development of manufacturing SME resilience and operational efficiency in the digital landscape.

4.1 Research Priority 1

Building upon the methodological insights of Peffers (2007) and the strategic importance of digital supply chain integration identified by Haleem et al. (2018), a structured framework was proposed. This framework is poised to direct the scholarly investigation within coopetition networks, establishing a robust suite of principles and practices. The imperative of surpassing customer expectations underscores the risk providers face of being rapidly sidelined from the digital supply chain due to dissatisfaction. This underscores the alignment with S-D Logic, which posits value as cocreated through persistent service exchanges within ecosystems, fostering innovation as an intrinsic result of these co-creation activities (Gummesson, Mele and Polese, 2014). The objectives are to address the integration challenges of manufacturing SMEs into coopetition networks by (1) identifying solutions - and exploring knowledge-driven models or constructs to enhance the resilience of manufacturing SME networks. It includes fostering a balance of collaboration and competition, independent of a leading entity; and (2) evaluating feasibility - assessing the practicality and impact of these solutions in real-world scenarios, ensuring they effectively support manufacturing SMEs' integration into digital supply chains. These considerations lead to essential research questions aimed at (1) articulating the performative framework for a coopetition network for value creation, (2) delineating the technical requirements for a system that enables competition in SME networks, and (3) identifying the expected improvements for manufacturing SMEs from a Coopetition network.

4.2 Research Priority 2

Peffers (2007) emphasizes the design and development phase as critical for defining the desired functionalities, architecture, and artefact creation. Innovative and valuable artefacts must contribute to research, with resources bridging objectives to design and development encompassing relevant theoretical knowledge (Hevner, 2007). Among the DSR methodology's artefact types, models serve as utilities, elucidating processes and outcomes related to focal constructs (MacInnis, 2011). Key inquiries include the design of coopetition technology-enabled network models for value cocreation and the technological artefacts necessary for enabling coopetition in SME networks. Leveraging S-D logic, a foundational approach includes (1) identifying actors involved in resource integration, (2) detailing resource integration and service exchange processes, (3) understanding institutions and institutional arrangements within ecosystems, and (4) developing a technological system to facilitate Coopetition throughout the service process.

4.3 Research Priority 3

A proof of concept for coopetition networks for value cocreation is paramount (Hevner *et al.*, 2004). It involves demonstrating the coopetition technology-enabled network viability for value creation, particularly its capacity to foster coopetition interactions among manufacturing rivals SMEs. Essential questions include identifying instances where coopetition is enabled by technology within networks. To execute this priority, a proof of concept involves utilizing a technological artefact in manufacturing SMEs, employing service blueprinting to document coopetition interactions, and comparing Coopetition dynamics before and after technology enablement.

4.4 Research Priority 4

This priority focuses on observing and quantifying the artefact's effectiveness in addressing identified problems (Peffers *et al.*, 2007). The evaluation phase is crucial for assessing the benefits of Coopetition networks for value cocreation concerning manufacturing SMEs' digital supply chain vulnerabilities. The goal is to utilize the developed technological artefact in a specific manufacturing SME case, evaluating their operational

improvements when transitioning to coopetition technology-enabled networks. Research questions revolve around the innovation outcomes attributable to a coopetition network. It involves conceptualizing a framework for assessing manufacturing SMEs' performance improvements, benchmarking quantitative KPIs, collecting data from SMEs transitioning to technology-enabled networks, and evaluating the impact on innovation outcomes. Should the coopetition network not yield expected improvements, a redesign will be considered, adhering to DSR guidelines (Peffers *et al.*, 2007).

5. Conclusions

Guided by the research question, "How can methodologies be developed to enrich knowledge and fortify cooperation networks among manufacturing SMEs?", this study systematically addresses the complexities of cooperation in the digital transformation era. Utilizing DSR and the foundational principles of S-D Logic, a comprehensive framework has been developed to enhance the understanding and effectiveness of cooperation networks. These conclusions underscore the necessity for resilient methodologies that foster knowledge enrichment and strengthen the structural and operational aspects of coopetition among SMEs. The proposed framework highlights the indispensable role of technology as both a facilitator and a critical component of these networks, enabling SMEs to achieve competitive advantages, drive innovation, and sustain economic growth.

Furthermore, the research revealed a significant attrition rate within digital networks, indicating a stark survival challenge for SMEs not backed by industry leaders. This finding emphasizes the urgent need for methodologies that promote equitable benefits and ensure the long-term sustainability of coopetition networks.

Looking forward, future research must continue exploring innovative approaches that define value creation, develop and test new artefacts, and assess their practical applications within the ecosystem. Such efforts will advance theoretical understandings and provide actionable strategies for SMEs to navigate and thrive in the evolving digital landscape. Finally, this research contributes to the strategic discourse on cooperation, offering SMEs a pathway to effectively harness the potential of digital transformation and cooperation strategies.

References

Akaka, M., Vargo, S. and Schau, H. (2015) 'The context of experience', *Journal of Service Management Vol. 26 No. 2, 2015 pp. 206-223*, 26(2), pp. 206–223. doi: 10.1108/JOSM-10-2014-0270.

Akter, S. *et al.* (2020) 'Building dynamic service analytics capabilities for the digital marketplace', *Journal of Business Research*. Elsevier, 118(May), pp. 177–188. doi: 10.1016/j.jbusres.2020.06.016.

Akwei, A., Peppard, J. and Hughes, P. (2010) 'The Process of Creating Dynamic Capabilities', *British Journal of Management*, 44(0), pp. 1–45. Available at: https://dspace.lboro.ac.uk/2134/7869.

Appian (2021) *Poor collaboration holds back European businesses digital ambitions*, *The Economist Intelligence Unit*. Available at: https://appian.com/resources/resource-center/google-success/economist-survey-european-businesses-digital-ambitions-success.html.

Arthur, W. B. (2009) *THE NATURE of TECHNOLOGY*. Edited by S. A. Penguin Books (South Africa) (Pty) Ltd, 24 Sturdee Avenue, Rosebank, Johannesburg 2196. Penguin Books Ltd, Registered Offices: 80 Strand, London WC2R 0RL, England. Available at: https://edisciplinas.usp.br/pluginfile.php/4210376/mod_resource/content/1/Brian Arthur-The nature of technology-2009.pdf.

Barney, J., Wright, M. and Ketchen, D. J. (2001) 'The resource-based view of the firm: Ten years after 1991', *Journal of Management*, 27(6), pp. 625–641. doi: 10.1177/014920630102700601.

Di Bella, L. *et al.* (2023) *Annual Report on European SMEs 2022/2023*.

Bettencourt, L. A., Lusch, R. F. and Vargo, S. L. (2014) 'A Service Lens on Value Creation: Marketing's Role in Achieving Strategic Advantage', *California Management Review*, 57(1), pp. 44–66. doi: 10.1525/cmr.2014.57.1.44.

Borchert, M. and Bonefeld-Dahl, C. (2018) 'A Stronger Digital Europe: Our Call to Action Towards 2025', *DigitalEurope*. Available at: https://www.digitaleurope.org/wp/wp-content/uploads/2019/02/DIGITALEUROPE-–-Our-Call-to-Action-for-A-STRONGER-DIGITAL-EUROPE.pdf.

vom Brocke, J., Hevner, A. and Maedche, A. (2020) 'Introduction to Design Science Research', in, pp. 1–13. doi: 10.1007/978-3-030-46781-4_1.

Crick, J. (2019) 'The dark side of coopetition: when collaborating with competitors is harmful for company performance', *Journal of Business & Industrial Marketing*, 35(2), pp. 318–337. doi: 10.1108/JBIM-01-2019-0057.

Dagnino, G. and Padula, G. (2002) 'Coopetition Strategy. Towards a New Kind of Interfirm Dynamics?"', *EURAM – The European Academy of Management Second Annual Conference - "Innovative Research in Management"*, (May 2002), pp. 9–11.

Devece, C., Ribeiro-Soriano, D. E. and Palacios-Marqués, D. (2019) 'Coopetition as the new trend in inter-firm alliances: literature review and research patterns', *Review of Managerial Science*, 13(2), pp. 207–226. doi: 10.1007/s11846-017-0245-0.

Edvardsson, B. and Tronvoll, B. (2013) 'A new conceptualization of service innovation grounded in S-D logic and service systems', *International Journal of Quality and Service Sciences*. Edited by S. Mi Dahlgaard Park, 5(1), pp. 19–31. doi: https://doi.org/10.1002/sres.2213.

Granovetter, M. (1990) '<Granovetter - 1990 - The myth of social network analysis as a special m.pdf>', pp. 13–16.

Gummesson, E., Mele, C. and Polese, F. (2014) 'Service Dominant Logic and Service Science: A Contribute Deriving from Network Theories', *The 2009 Naples Forum on Service*.

Haleem, A. *et al.* (2018) 'Assessing Barriers to Adopting and Implementing Halal Practices in Logistics Operations', *IOP Conference Series: Materials Science and Engineering*, 404, p. 012012. doi: 10.1088/1757-899X/404/1/012012.

Hernandez, J. E. *et al.* (2017) 'Collaboration in a Data-Rich World', *IFIP International Federation for Information Processing 2017*, 506(July 2018), pp. 761–774. doi: 10.1007/978-3-319-65151-4.

Hevner, A. *et al.* (2004) 'Design Science in Information Systems Research', *MIS Quarterly*, 28(1), p. 75. doi: 10.2307/25148625.

Hevner, A. (2007) 'A Three Cycle View of Design Science Research', *Scandinavian Journal of Information Systems*, 19.

Iansiti, M. and Levien, R. (2004) 'The Keystone Advantage: What the New Dynamics of Business Ecosystems Mean for Strategy, Innovation, and Sustainability', *Harvard Business Review*, 20(2), pp. 88–90. Available at: http://journals.aom.org/doi/10.5465/amp.2006.20591015.

Jabbour, A. *et al.* (2018) 'Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations', *Annals of Operations Research*. Springer US, 270(1–2), pp. 273–286. doi: 10.1007/s10479-018-2772-8.

Joiner, K. and Lusch, R. (2016) 'Evolving to a new service-dominant logic for health care', *Innovation and Entrepreneurship in Health*, p. 25. doi: 10.2147/ieh.s93473.

Kaartemo, V., Akaka, M. and Vargo, S. (2017) 'A Service-Ecosystem Perspective on Value Creation: Implications for International Business', *Value Creation in International Business*, pp. 131–149. doi: 10.1007/978-3-319-39369-8_6.

Lindström, T. *et al.* (2016) 'Destination networking: Co-opetition in peripheral surroundings', *Industrial Marketing Management*. Elsevier Inc., 33(2), pp. 427–448. doi: 10.1108/09600030310481997.

Lusch, R. F. and Vargo, S. L. (2013) *Service-Dominant Logic*, *Service Dominant Logic. Premises, perspectives, possibilities*. Cambridge: Cambridge University Press. doi: 10.1017/CBO9781139043120.

Lusch, R. and Vargo, S. (2007) 'Service-dominant logic: Continuing the evolution', *Journal of the Academy of Marketing Science*, 36(1), pp. 1–10. doi: 10.1007/s11747-007-0069-6.

Lusch, R., Vargo, S. and Gustafsson, A. (2016) 'Fostering a trans-disciplinary perspectives of service ecosystems', *Journal of Business Research*. Elsevier Inc., 69(8), pp. 2957–2963. doi: 10.1016/j.jbusres.2016.02.028.

MacInnis, D. J. (2011) 'A Framework for Conceptual Contributions in Marketing', *Journal of Marketing*, 75(4), pp. 136–154. doi: 10.1509/jmkg.75.4.136.

March, S. T. and Smith, G. F. (1995) 'Design and natural science research on information technology', *Decision Support Systems*, 15(4), pp. 251–266. doi: 10.1016/0167-9236(94)00041-2.

Matthies, B. D. *et al.* (2016) 'An ecosystem service-dominant logic? – integrating the ecosystem service approach and the service-dominant logic', *Journal of Cleaner Production*, 124, pp. 51–64. doi: 10.1016/j.jclepro.2016.02.109.

Moore, J. F. (1998) 'The rise of a new corporate form', *Washington Quarterly*, 21(1), pp. 167–181. doi: 10.1080/01636609809550301.

Morgan, R. M. and Hunt, S. D. (1994) 'The Commitment-Trust Theory of Relationship Marketing', *Journal of Marketing*, 58(3), pp. 20–38. doi: 10.1177/002224299405800302.

Patkar, V. (2018) 'Research Methodology: Logic, Methods and Cases', *Vikalpa: The Journal for Decision Makers*, 43(3), pp. 175–177. doi: 10.1177/0256090918796953.

Peffers, K. *et al.* (2007) 'A Design Science Research Methodology for Information Systems Research', *Journal of Management Information Systems*, 24(3), pp. 45–77. doi: 10.2753/MIS0742-1222240302.

Peltoniemi, M. and Vuori, E. (2004) 'Business ecosystem as the new approach to complex adaptive business environments', *Proceedings of eBusiness Research Forum*, pp. 267–281.

Prasertsakul, D. (2013) 'The Role of Dynamic Capabilities in Export Performance of Firms from Emerging Economies', *International Business Research; Vol. 6, No. 8; 2013*, 6(8), pp. 102–113.

Radicic, D., Pugh, G. and Douglas, D. (2020) 'Promoting cooperation in innovation ecosystems: evidence from European traditional manufacturing SMEs', *Small Business Economics*. Small Business Economics, 54(1), pp. 257–283. doi: 10.1007/s11187-018-0088-3.

Reeves, M. *et al.* (2019) 'How Business Ecosystems Rise (and Often Fall)', *MIT Sloan Management Review*. MIT Sloan Management Review, (July).

Simon, H. A. (1988) 'The Science of Design: Creating the Artificial', *Design Issues*, 4(1/2), p. 67. doi: 10.2307/1511391.

Sun, Q. (2020) 'Towards a New Agenda for Service Design Research', *Design Journal*. Routledge, 23(1), pp. 49–70. doi: 10.1080/14606925.2019.1694808.

Teece, D., Pisano, G. and Shuen, A. (1997) 'Dynamic Capabilities and Strategic Management', *Strategic Management Journal*, 18(7), pp. 509–533. doi: 0143-2095/97/070509.

Tsujimoto, M. *et al.* (2018) 'A review of the ecosystem concept — Towards coherent ecosystem design', *Technological Forecasting and Social Change*, 136(June), pp. 49–58. doi: 10.1016/j.techfore.2017.06.032.

Vargo, S. L. (2011) 'Market systems, stakeholders and value propositions: Toward a service-dominant logic-based theory of the market', *European Journal of Marketing*, 45(1), pp. 217–222. doi: 10.1108/03090561111095667.

Vargo, S. L. and Lusch, R. (2017) 'Service-dominant logic 2025', *International Journal of Research in Marketing*. Elsevier B.V., 34(1), pp. 46–67. doi: 10.1016/j.ijresmar.2016.11.001.

Vargo, S. L., Wieland, H. and O'Brien, M. (2023) 'Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline', *Journal of Business Research*, 164, p. 113965. doi: 10.1016/j.jbusres.2023.113965.

Vargo, S., Wieland, H. and Akaka, M. (2015) 'Innovation through institutionalization: A service ecosystems perspective', *Industrial Marketing Management*. Elsevier Inc., 44(2013), pp. 63–72. doi: 10.1016/j.indmarman.2014.10.008.

Journal of
Theoretical and Applied Electronic Commerce Research

MDPI

Article

Value Creation in Technology-Driven Ecosystems: Role of Coopetition in Industrial Networks

Agostinho da Silva [1,2,*] and António J. Marques Cardoso [1]

[1] CISE—Electromechatronic Systems Research Centre, University of Beira Interior, 6201-001 Covilhã, Portugal
[2] CIGEST—Centre for Research in Management, Lisbon Business School, 1000-002 Lisboa, Portugal
* Correspondence: a.silva@zipor.com

Abstract: Coopetition, while offering significant strategic advantages, presents challenges in maintaining long-term collaboration among competitors, often due to a lack of perceived value for the participating actors. This study explores the role of technology in overcoming these challenges by applying the Service-Dominant Logic (S-D Logic) framework to investigate how technology-driven networks can enhance value co-creation among small and medium-sized enterprises (SMEs). The study hypothesizes that transitioning to technology-driven coopetition networks can substantially improve value co-creation. To test this hypothesis, the research critically evaluates existing theoretical approaches to coopetition, identifies gaps in understanding value creation mechanisms, and implements an experimental technology-driven coopetition network leveraging Internet of Things (IoT) technology. The research design is applied explicitly to the Portuguese ornamental stone industry, a significant economic and cultural sector. The findings confirm that technology-driven coopetition networks can enhance value co-creation and improve outputs. These results suggest that integrating technology into coopetition frameworks can provide a viable path to sustaining competitive advantages in SMEs.

Keywords: coopetition; internet of things; value networks; service-dominant logic; value co-creation

check for updates

Citation: da Silva, A.; Cardoso, A.J.M. Value Creation in Technology-Driven Ecosystems: Role of Coopetition in Industrial Networks. *J. Theor. Appl. Electron. Commer. Res.* **2024**, *19*, 2343–2359. https://doi.org/10.3390/jtaer19030113

Academic Editor: Ja-Shen Chen

Received: 2 July 2024
Revised: 19 August 2024
Accepted: 6 September 2024
Published: 7 September 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

In today's globalized market, where resource asymmetry is prevalent, business networks have evolved significantly, giving rise to coopetition—a strategic blend of cooperation and competition among rival firms [1]. Coopetition offers a dual advantage: it enables firms to explore new opportunities while mitigating inherent risks, making it a crucial element in contemporary business strategy [2]. While recognized by both academics and industry leaders as a critical strategy for small and medium-sized enterprises (SMEs) to gain competitiveness in global markets, coopetition also presents significant challenges. These include the risks associated with collaborating with competitors [3] and the frequent premature dissolution of these networks [4]. Such challenges highlight the need for deeper academic exploration into the viability and effectiveness of coopetition.

A critical gap in the current literature is the limited exploration of value creation mechanisms and the role of technology within coopetition networks. Although various theoretical frameworks such as game theory, the resource-based view, paradox theory, transaction cost theory, and network theory have been extensively applied [5,6], there is still a significant lack of understanding about how value is created and distributed among stakeholders [7]. This gap is particularly concerning as unmet expectations regarding value often lead to the early dissolution of these networks [1].

Given technology's critical role in modern business networks, the following question arises: What framework is best suited for technology-driven cooperation networks?

The Service-Dominant Logic (S-D Logic) literature, which shifts the focus from a traditional goods-centric value perspective to a service-oriented approach, emphasizes

value co-creation through service exchange among multiple actors within networks [8]. S-D Logic provides a comprehensive lens for examining value co-creation by focusing on dynamic interactions and encompassing a broad spectrum of actors and resources in service ecosystems [9]. This perspective is particularly relevant as global supply chains become increasingly technology-driven and service innovation gains importance [10].

This study aims to address the question of technology in coopetition by examining it through the lens of S-D Logic, identifying the foundational elements necessary for effective technology-driven coopetition networks. The research design involves identifying key constructs and building blocks, hypothesizing that transitioning to a technology-driven coopetition network enhances value co-creation.

To test this hypothesis, this research critically evaluates mainstream approaches to coopetition, identifies existing gaps—particularly in value creation mechanisms and the role of technology, and experiments with IoT technology as a catalyst for value creation. It will also conduct an experimental technology-driven coopetition network focusing on ornamental stone SMEs, a key sector in the Portuguese economy.

Following this introduction, a literature review will explore the role of technology in value networks. The research design will then outline the plan to address the research question, focusing on the systemic convergence of coopetition, networks, and value co-creation. Based on this convergence, constructs and building blocks for technology-driven coopetition networks will be formulated, leading to an empirical test of the hypothesis.

2. Literature Review

The term "coopetition" was initially coined by Ray Noorda, the founder and CEO of Novell, in the 1980s, gaining theoretical foundation through Nalebuff and Brandenburger's (1997) game theory work [11]. They posited coopetition as a groundbreaking business strategy, advocating for its role in fostering innovation and enhancing the success of both individuals and organizations [12]. This conceptual framework suggests that competition allows rivals to benefit from a unique relationship characterized by simultaneous cooperation and competition, thereby driving competitive advantage and innovation [13]. Since its introduction, the discourse around coopetition has become an essential topic within the literature, emphasizing its relevance and application across various domains [1].

2.1. Approaches to Coopetition

At the core of various strategic approaches to coopetition is their fundamental alignment with innovation, equipping firms to close competitiveness gaps and tackle market challenges and business threats [5]. This orientation underscores coopetition's value in navigating competitive landscapes and highlights its capacity to catalyze transformative growth and resilience [2].

Despite a consensus in the literature on the strategic significance of coopetition for innovation and competitiveness, there still needs to be more consistency in how value-creation mechanisms within coopetition are understood and articulated. Divergent findings across studies [14] underscore the complexity of coopetition's impact on firms.

This variance is further illuminated by a comprehensive review by Abhilasha Meena, Sanjay Dhir, and Sushil Sushil (2023), which points out that although coopetition has been examined through various theoretical lenses [1]. Game theory, for instance, delineates coopetition as a structured analytical framework, elucidating the strategic choices confronting firms in competition [15]. While this view offers a pathway to optimizing mutual and individual gains in coopetition networks [16], real-world challenges such as information asymmetry and trust issues necessitate an adaptation of its models to the complexities of business practice [15]. The resource-based view champions coopetition as a strategy to access and co-develop a broader pool of valuable resources, enhancing firms' innovation potential and market reach [14]. It posits that strategically managing these resources can fortify a firm's competitive edge in a complex, dynamic business landscape [5]. Paradox Theory frames coopetition as a paradoxical relationship where firms

simultaneously collaborate and compete [1]. This perspective encourages firms to leverage these dualities as dynamic capabilities, fostering a nuanced strategy that capitalizes on the synergies of both aspects [17]. Transaction Cost Theory examines coopetition through the prism of economic exchanges, highlighting the balance between reducing transaction costs and safeguarding competitive advantage [7]. This theory accentuates the strategic significance of minimizing opportunism and protecting strategic assets within coopetition arrangements [18]. Network Theory underscores the importance of strategic positioning within networks, enabling firms to access resources and manage competitive dynamics [19]. It advocates for strategically analyzing positioning and relationship management within coopetition networks to optimize stakeholder benefits [20].

These theories collectively provide analytical frameworks for deciphering complex phenomena, offering perspectives through which the operations of organizations, transactions, and market dynamics can be scrutinized. Unlike game theory, which adopts a more strategic and competitive stance, the remainder focuses on value creation, acquisition, and distribution within various contexts. Resource-based [21] and Network Theories [5] specifically delve into how entities exploit resources or networks for value creation and dissemination. Meanwhile, apart from Paradox Theory [22], which navigates through conflicting yet interrelated concepts, these theories underscore the significance of interactions among entities—whether individuals, organizations, or resources—and the impact of these interactions on outcomes.

However, while each theoretical framework offers valuable insights into strategically navigating coopetition, thus allowing firms to tap into its potential for innovation, competitive advantage, and market success, there are noticeable gaps in understanding the value creation mechanisms and the role of technology in coopetition networks.

2.2. Value Creation Mechanisms in Coopetition Networks (Research Gap 1)

The theoretical mainstream frameworks often portray value creation within coopetition networks as a linear and somewhat static process, overly reliant on a firm's internal resources, pre-established market positions, or the outcomes from discrete strategic interactions [6]. This approach tacitly treats value as an intrinsic attribute of goods or services, capable of being transferred from producer to consumer in a unilateral flow [23]. This perspective neglects markets' complexities and fluid nature [24], particularly relevant in coopetition contexts where the lines between competition and collaboration are blurred and constantly evolving [7].

2.3. The Role of Technology in Coopetition Networks (Research Gap 2)

The conventional theoretical mainstream typically needs to fully encapsulate the intricate complexity and interconnectivity of today's technology-infused coopetition networks [5]. In the context of coopetition networks, technology plays a dual role as both an operant [25] and an operand resource [26], fundamentally shaping the dynamics of collaboration and competition among firms. This dual role underscores the intricacy of technology's impact on coopetition networks. Recognizing the significance of operant and operand technology challenges traditional views that overlook the dynamic, networked essence of contemporary economic and social exchanges [16]. It calls for a theoretical recalibration that appreciates the multifaceted role of technology in enhancing the interconnectedness and complexity of coopetition networks, thereby contributing to a richer understanding of value creation and exchange in the digital age [7].

2.4. Approaching Coopetition through Service-Dominant Logic

The exploration of "service" as a cornerstone of economic exchange has deep roots, reaching back to the mid-19th century with intellectual pioneers such as Frederick Bastiat (1848). However, in Lusch and Vargo's seminal work in 2004, a significant paradigm shift occurred, propelling S-D Logic to the forefront of contemporary economic discourse [27]. This innovative perspective elevates operant resources–intangible assets like knowledge

and skills–above tangible goods, or operand resources, traditionally seen as the primary sources of value. S-D Logic redefines goods as mere facilitators of service delivery, emphasizing the role of specialized competencies in serving others [8,28]. This framework positions service and the co-creation of value it entails as central to economic exchange, thereby challenging earlier, more static views of value [26].

Historical economic theories, particularly those espoused by Adam Smith (1776) and David Ricardo (1817), predominantly framed value through labour theory. However, contemporary dialogues have transitioned toward a co-creation perspective, acknowledging the collective contributions of suppliers, partners, allies, and customers to the value creation process [29]. This shift from coproduction to co-creation, and ultimately to value co-creation within service ecosystems, underscores a growing recognition of value's complex nature [30]. Through S-D Logic, the focus on perpetual value derivation and evaluation within service ecosystems portrays these networks as complex adaptive systems [31]. Within these ecosystems, value propositions serve as the conduits for interactions among actors, moving beyond the notion of fixed value deliveries [32]. This approach distinguishes between value-in-exchange and value-in-use, showcasing the dynamic and processual essence of value creation and realization [8]. The alignment of S-D Logic with foundational theories such as the Resource-Based [33], Competencies Core [34], and Corporate Core Competencies theory [35] underscores its broad applicability and relevance to contemporary discussions on value creation.

2.5. The Role of Technology in Value Networks

Historical analyses of networks, drawn from sociology and organizational theory, have primarily focused on the structural aspects of value creation [23]. However, contemporary research calls for a reassessment of these frameworks to align theoretical constructs more closely with their practical applications across various industries and management practices [36]. Pioneers such as Granovetter (1985) and Uzzi (1996) argue that economic activities are intricately tied to network relationships, pushing for a sophisticated comprehension of how cooperation and competition intertwine at different levels [37]. Building on this, Mariotti (2002) introduces the concept of the value network as an ecosystem where information, technology, and human interactions meld to create value throughout its nodes, spotlighting technology's pivotal role in bridging spatial and temporal gaps in exchange processes [38].

The shift toward a service-dominant logic in recent business discourse mirrors a growing consensus on the utility of value networks as frameworks for deconstructing the intricate processes of value creation through services [39]. This paradigm shift accentuates the fluid process of value co-creation, wherein participants within customer service networks amalgamate resources through cooperative endeavors and interactions [40].

In contemporary economic and social ecosystems, the concept of a "network" serves a dual purpose, embodying both the act of networking and the structural composition of the networks themselves. This dual nature emphasizes networks as platforms where various actors, from individuals to organizations, pursue economic and social goals [41]. Within the S-D Logic framework, networks are seen as vast, interconnected systems. In these systems, actors not only bring specialized competencies to the table but also engage in mutual value propositions, underscoring the importance of relationships and collaborative interactions that extend beyond mere transactions of goods and services [28,42].

Technology plays a central role in shaping and evolving these value networks [8]. Historically regarded as a tool to meet societal needs [43], technology is now acknowledged for its dual function as both an enabling tool (operand resource) and a source of knowledge and skills initiation (operant resource) within S-D Logic [44]. This sophisticated perspective views technology as an essential driver of value co-creation, facilitating unprecedented resource integration and innovation [45]. Wieland (2017) highlights the synergy between digital transformation and technological innovation, illustrating how

the fusion of technological progress and service innovation is a powerful force for value creation in contemporary networks [46].

Based on the critical evaluation of value creation mechanisms and the role of technology in coopetition networks, a framework can be formulated to test the hypothesis that transitioning to technology-driven coopetition networks enhances value co-creation.

3. Research Design of a Technology-Driven Framework for Coopetition Networks

The design of empirical research relies heavily on a solid theoretical foundation, guiding the exploration of complex phenomena in fields as varied as medicine, computer science, engineering, management, and economics [47]. Integrative approaches are praised for their ability to dissect individual components and entire complex systems [48], making them ideal for investigating the nuanced nature of coopetition networks [10].

Recent developments in service ecosystems, propelled by S-D Logic, call for a comprehensive approach that integrates S-D Logic with other frameworks [39]. This holistic view shifts focus from firm-centric to service-centric perspectives, emphasizing the need for wide-reaching institutional changes and the important role of coopetition in fostering innovation through mechanisms like knowledge transfer [42,49].

Coopetition is characterized as a driver of multiple innovation processes within ecosystems [39], creating an environment conducive to resource sharing and amplifying the network's innovation capacity [50]. This ecosystemic view suggests that innovation results from and contributes to the dynamic reconfiguration of institutional spaces, focusing on ongoing interaction and co-creation [51]. Therefore, an integrative framework for developing coopetition networks, informed by S-D Logic, might include the following: (1) Understanding the transformation of networks into service ecosystems for value co-creation; (2) Elucidating coopetition's role in enhancing innovation and value within these ecosystems; (3) Bridging identified gaps in coopetition literature using insights from service ecosystems. This approach aligns with S-D Logic's theoretical advancements and provides practical strategies for re-envisioning coopetition, underscoring the endless cycle of innovation and value co-creation in institutional coopetition networks.

3.1. Framing Networks and Ecosystems

Service ecosystems, introduced by Ruokolainen and Kutvonen (2009) as socio-technical and complex adaptive systems, marked a significant advancement in our understanding of network coordination [52]. Defined by sets of metamodels guiding interactions, these ecosystems are noted for their capacity to evolve spontaneously and through strategic planning, necessitating governance principles that align intentions with operational coherence [53]. While the transition from value networks to service ecosystems marked a significant shift in vocabulary, the foundational perspective initially remained anchored in traditional views of value exchange.

This narrative began to transform significantly with Vargo and Lusch's advocacy (2011) for a paradigmatic shift toward service ecosystems within the S-D Logic. They proposed a resource integration framework emphasizing service exchange as a means of value creation, thus connecting people and technology meaningfully [54]. A cornerstone of this evolution is acknowledging institutions and institutional arrangements as vital enablers of value creation. Lusch and Vargo (2014) illustrated how service ecosystems are self-regulating entities composed of resource-integrating actors united by shared institutional logic and objectives of mutual value creation [8]. Referencing Scott (2001), it is noted that institutions provide the frameworks of rules, norms, and beliefs that govern actions, making social interactions predictable and meaningful. According to Koskela-Huotari and Vargo (2016), institutional logic facilitates governance and coordination across the ecosystem through a material-symbolic language, underscoring the transition toward a network-centric view where value is co-created through shared institutional logic and resource integration [55].

By embracing the systemic and adaptive nature of service ecosystems, S-D Logic offers a comprehensive lens through which the intricate dynamics of actors, resources, and institutions in value co-creation processes can be examined [42].

3.2. Framing Coopetition and Value Creation

In business literature, coopetition is recognized for its dual dynamics: cooperation and competition. Raza-Ullah et al. (2014) describe these dynamics as parallel paths where firms collaborate with rivals in specific contexts and compete in others, presenting challenges and opportunities for strategic balance [17]. Moving beyond the concept of separate pathways, some scholars argue for a syncretic, rent-seeking approach [56]. This view posits coopetition as a continuum where firms strive to reconcile the interplay between collaboration and competition, demanding an integrated strategy to manage the inherent tensions [14].

These tensions underline the need for cooperative norms, rules, and other institutions within coopetition networks, aligning with the S-D Logic perspective. S-D Logic suggests that value co-creation thrives within ecosystems governed by shared institutional logics [39], where institutions act as frameworks to enable and regulate collaborative and competitive network actions [8].

According to this view, in such networks, value co-creation arises from service exchanges between actors, including firms, rivals, and customers [8]. This experiential process encourages continual learning and adaptation, guiding entities to refine their actions and interactions in response to changing values and expectations [57]. As with any adaptive system, this dynamic learning environment is crucial for the sustainability and growth of coopetition networks, promoting a cycle of continuous innovation and adaptation [46].

3.3. Systemic Convergence on Coopetition, Networks, and Value Co-Creation

Exploring cooperation networks through the S-D Logic lens becomes essential to understanding institutions' multifaceted role [58]. These institutions are characterized by their regulative, normative, and cultural-cognitive elements [59]. These elements are instrumental in shaping the behavior of network participants, fostering an environment conducive to innovation and value co-creation [60].

Coopetition networks enable firms to enhance their competitive advantage and innovation capacity by acquiring and integrating new resources and capabilities [61]. It aligns with S-D Logic, which views all social and economic actors as resource integrators, with institutions [58], defined as rules, norms, and meanings, playing a crucial role in coordinating interactions for value co-creation within ecosystems [39].

S-D Logic identifies service ecosystems as complex adaptive systems where institutions facilitate and regulate value co-creation actions. These ecosystems are dynamic, with patterns emerging from actor interactions, showcasing the unpredictable nature of resource integration and service provision [62]. Within this context, coopetition networks are seen as avenues for resource integration, creating new, exchangeable resources through service exchanges. The effectiveness of value co-creation depends on coordinated ecosystem governance.

However, coopetition networks face challenges, such as the paradoxical nature that may lead to premature dissolutions. Institutions and institutional arrangements are vital in overcoming these challenges by providing the necessary structure for actor coordination [63], collaboration, and cooperation [39]. Successfully navigating coopetition involves balancing collaboration and competition, with network sustainability relying on proper coordination mechanisms [64]. It demands a transition toward service ecosystems, viewing business opportunities as ongoing service processes where shared institutions have collaboratively managed and supported resource integration and value proposition development [26]. Institutions thus act as both coordination mechanisms and evaluative frameworks to discern the outcomes of collaboration and competition [60]. Adopting this service ecosystem lens provides insights into the processes of value co-creation or

destruction in coopetition networks, illuminating paths for more effective management and sustained operation.

4. Addressing Research Gaps in the Light of S-D Logic

4.1. Value Creation Mechanisms in Coopetition Networks

S-D Logic positions value creation as an inherently dynamic, interactive process that unfolds over time through reciprocal and iterative exchanges among all participants within a network [9]. S-D Logic fundamentally challenges the traditional view by proposing that value is not dormant, waiting to be unlocked from products or services [27]. Instead, it emerges from the co-creative practices of firms, customers, and other stakeholders engaging in mutual and ongoing interactions [54]. This paradigm shift highlights the role of operant resources–such as knowledge, skills, and information–which become the primary means through which value is co-created [45]. From this S-D Logic view, in coopetition scenarios, the interaction between competing firms can lead to novel forms of value creation that were previously unattainable through solitary efforts. By acknowledging and leveraging each other's competencies and resources, competitors in a coopetition framework can jointly explore new market opportunities, innovate in product and service development, and enhance their adaptability to changing market dynamics. This fluid and evolving conceptualization of value creation underscores the necessity for firms engaged in coopetition to foster an environment where open dialogue, shared learning, and collaborative innovation are encouraged [8]. It posits that the competitive advantage in today's complex marketplace no longer lies in merely possessing unique resources but in the ability to dynamically integrate and recombine resources across organizational boundaries to meet consumers' and other stakeholders' ever-changing needs and preferences [65].

4.2. The Role of Technology in Coopetition Networks

S-D Logic profoundly reimagines how value is created and sustained within service ecosystems [64]. It conceptualizes these ecosystems as platforms where value is co-created through the collective efforts and interactions of all actors coordinated by endogenously generated institutions and institutional arrangements [8]. Unlike traditional theories that view markets as battlegrounds for competitive advantage, S-D Logic sees them as forums for collaborative value creation [39], where competition and cooperation coexist and complement each other within a more extensive, more intricate network of relationships [66].

S-D Logic underscores ecosystems' systemic and emergent properties, acknowledging that the value is not a static outcome of individual actions but an emergent property of the network's collective interactions [42]. This perspective invites a deeper exploration of how coopetition–strategic cooperation among competitors–functions within these ecosystems. It opens avenues for understanding how firms can navigate and leverage the complex interplays of competition and collaboration to foster innovation, access new markets, and create superior customer experiences [49].

Furthermore, the S-D Logic perspective illuminates the role of technology as a facilitator and amplifier of these ecosystem dynamics [46]. In an era where digital networks increasingly mediate economic and social interactions, understanding the role of technology in enabling, shaping, and scaling the co-creative processes of service ecosystems becomes crucial [67]. Adopting an S-D Logic approach to study the complexity and interconnectedness of coopetition networks offers a richer, more nuanced understanding of value co-creation in contemporary markets. Through this lens, the strategic interplay of coopetition is seen not just as a tactic for individual firms but as a fundamental principle shaping the evolution of the entire service ecosystem. This service ecosystems perspective helps elucidate the mechanisms through which value is co-created or co-destroyed in coopetition networks, offering insights into how these networks can be more effectively managed and sustained over time.

4.3. Framing Technology-Driven Coopetition Networks

The framework concept provided by Scott (2001) introduces cognitive institutional arrangements as interconnected sets of institutions that underpin the transformation of coopetition networks into arenas of rich, meaningful value co-creation experiences [58]. These arrangements offer governance and evaluation mechanisms, guiding the interactions within nested and overlapping service ecosystems. This perspective emphasizes the importance of dynamic, meaningful interactions among network actors, supported by a robust institutional framework that encourages collaborative innovation and ensures network sustainability [63].

For Lusch & Vargo (2016), networks are envisioned as fluid configurations of institutions, marked by reciprocal connections that facilitate technological and market innovations [60]. This view aligns with Wieland et al. (2017), who argue that institutional innovations play a crucial role in sustaining individual actors and enhancing the resilience of coopetition networks. Such innovations are not merely structural changes but are deeply embedded in the network's cultural and normative fabric, driving evolution and adaptation [46]. To illustrate, consider the case of the renewable energy sector, where firms often coopetition to develop new technologies and standards. Institutional arrangements include shared research initiatives, joint ventures, and common regulatory advocacy groups [8]. These collaborative efforts, guided by shared norms and values, accelerate technological advancements and establish market practices that benefit all participants, demonstrating the transformative potential of institutional coopetition networks.

This enhanced focus on the systemic and institutional underpinnings of technology-driven coopetition networks within the context of S-D Logic invites a deeper examination of how governance structures, shared values, and cultural norms influence value co-creation [31]. By recognizing the significance of these institutional constructs, firms can better navigate the complexities of coopetition, fostering environments that support sustained innovation, resilience, and collective prosperity [9].

Drawing upon S-D logic foundations, systemic constructs for technology-driven coopetition networks can be delineated. These constructs focus on the roles of institutionalization, coordination, and technology in shaping coopetition networks, highlighting the interplay between competing and collaborating entities within service ecosystems.

Construct #1 (systemic and institutional coopetition networks): Underscoring the systemic and dynamic interplay among actors, this construct institutionalizes technology-driven coopetition networks organically from micro-level interactions to broader mezzo-level norms and rules [68]. Coopetition practices, when initiated at the micro-level by individual actors, serve as catalysts for the emergence of new institutions. These emergent institutions facilitate enhanced value creation, setting the foundation for integrated coopetition strategies in technology-driven networks.

Construct#2 (coopetition networks coordination): Anchoring the micro-level where actors engage in complex interactions to co-create value, this construct highlights the shared motivation to optimize these interactions through effective coordination of resource exchanges [31]. The coordination is intricately managed through both specific, actor-generated rules and broader institutional frameworks, ensuring that the outcomes of coopetition align with the collective objectives [57]. Technology-driven coopetition networks coordinate the interactions through strict protocols (actor-generated rules) and regulatory guidelines (institutional frameworks), ensuring competitive advantage and public safety.

Construct#3 (the role of technology in coopetition networks): Acknowledging the technology's dual role, this construct addresses technology as an enabler (operand resource) and initiator (operant resource) of coopetition actions. This dual role of the technology enables novel ways of integrating and utilizing other resources within technology-driven coopetition networks, enhancing innovation and value co-creation [69]. This construct positions technology as a systemic and institutional resource, reshaping the patterns of resource integration and competition dynamics.

The synthesis of these constructs results in a nuanced understanding of the mechanisms, thus driving coopetition within service ecosystems. The institutionalization construct (construct#1) reminds us of the importance of organic, bottom-up processes in shaping the ecosystem's rules and norms in coopetition networks. The coordination construct (construct#2) underscores the necessity for clear, shared protocols for managing complex interactions in coopetition networks. Lastly, construct#3 highlights the crucial role of technology in enabling and propelling coopetition in networks. For practitioners, these constructs offer a roadmap for navigating the complexities of coopetition networks. By understanding and applying these constructs, firms can better position themselves to leverage the benefits of coopetition, from enhanced innovation to access to new markets and resources. The future of competitive advantage lies in mastering these dynamics, where the ability to collaborate strategically with competitors will define success in the rapidly evolving.

5. Experimental Technology-Driven Coopetition Network and Hypothesis Testing

Systemic building blocks form the foundation for developing an effective technology-driven coopetition network, as they encapsulate the essential elements for facilitating value co-creation in service ecosystems. Drawing from constructs, building blocks illustrate how coopetition unfolds strategically, engaging various actors in a dance of collaboration and competition that enriches the service ecosystem.

Figure 1, adapted from [49], succinctly captures the systemic building blocks essential for forming technology-enabled cooperation networks, demonstrating their interconnected roles in facilitating their growth.

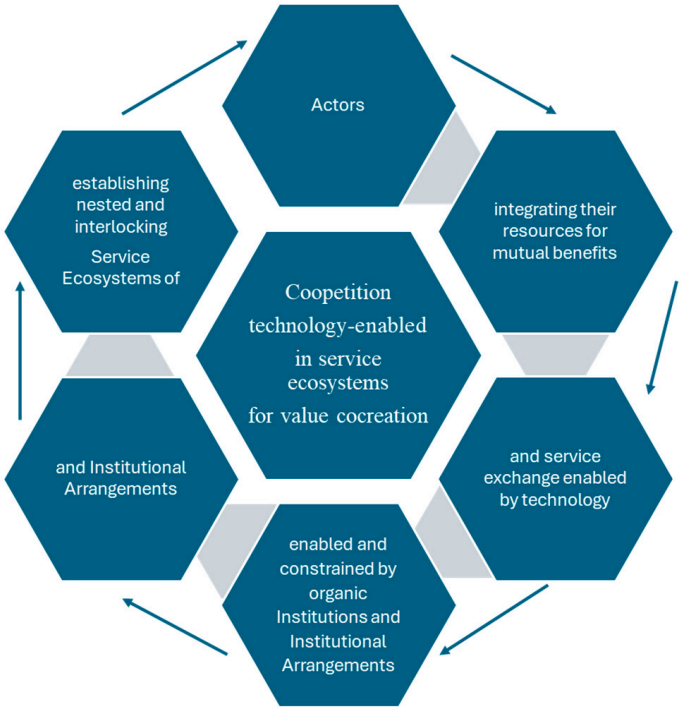


Figure 1. Building blocks for coopetition networks; adapted from Vargo & Lusch (2016).

Building block#1 (Coopetition Actors): Identified as the cornerstone of value co-creation, competition actors include firms, customers, and other stakeholders. These actors adeptly navigate the dual roles of collaboration and competition, embodying the dynamic essence of the technology-driven coopetition network.

Building block#2 (Resource Integration): This represents the collaborative efforts among actors to merge diverse resources, capabilities, and competencies. The goal is to fortify the ecosystem's collective value proposition, showcasing the synergy of shared endeavours in the technology-driven coopetition network.

Building block#3 (Service Exchange): Acting as the conduit for offering and utilizing integrated resources within the technology-driven coopetition network. This mechanism fosters mutual benefits and amplifies value co-creation among participants, highlighting the reciprocal nature of coopetition networks.

Building block#4 (Institutions and Institutional Arrangements): The endogenously generated rules, norms, and cultural-cognitive elements both enable and constrain cooperation actions. This guides the governance and operational dynamics of technology-driven coopetition networks, ensuring a balanced interplay between competition and collaboration.

Building block#5 (Nested Service Ecosystems): Reflects the broader context in which resource integration and service exchange unfold. Characterized by multiple interconnected layers of cooperation and collaboration, it underscores the complexity and richness of the technology-driven coopetition network.

Building block#6 (Operand Technology): Technologies enabling coopetition actions provide resource integration and service exchange tools. These technologies facilitate the operational aspects of coopetition, ensuring actors can engage effectively in the technology-driven coopetition network.

Building block#7 (Operant Technology): The technologies that trigger coopetition actions, spearheading innovation, and strategic reconfigurations within the technology-driven coopetition network. They offer advanced capabilities and insights as catalysts for transformation and growth.

Integrating these building blocks for this research purpose, an experimental technology-driven coopetition network has been implemented, underscoring the critical role of institutional constructs in orchestrating the interactions among coopetition actors, facilitating the integration of resources, and enabling the exchange of services.

5.1. Implementation of the Experimental Technology-Driven Coopetition Network

The experimental network was implemented within the Portuguese ornamental stone sector to evaluate whether transitioning to technology-driven coopetition networks enhances value co-creation.

This sector, integral to Portugal's cultural heritage, has significantly contributed to iconic stone monuments worldwide since the 15th century [70]. Recent reports from the Portuguese Stone Federation highlight its economic importance: the sector exports to 116 countries, ranks ninth globally in the International Stone Trade, and is second in international trade per capita [71]. Predominantly composed of SMEs, the sector's exports surpassed imports by 660%, with a significant portion destined for markets beyond Europe. In 2021, this sector generated a turnover of €1.230 billion, supporting over 16,600 direct jobs, particularly in inland regions [72].

The selection of stone SMEs was based on convenience, with direct invitations sent directly to twenty-two companies identified as having the technological capabilities that reflect the state of the art in the sector. However, due to the costs involved and potential disruptions to their operations, only three companies accepted the invitation to participate in the experimental network.

These companies, representing state-of-the-art practices in the Portuguese stone industry, integrated their machinery with the Building Information Modeling (BIM) systems used by architects, thereby showcasing the sector's advanced technology.

To operationalize the experimental technology-driven coopetition network and test the hypothesis, a secure IoT software application (Figure 2), named Cockpit4.0 V1.0, was developed to connect the shop floors of the participating SMEs.

This integration facilitated the strategic connection of the three SMEs, enabling an evaluation of how coopetition-driven networks can enhance value co-creation.

A comprehensive confidentiality agreement was established with the three companies to safeguard sensitive information related to their operations, clientele, employees, resources, and competitive positioning. This agreement ensured all parties could

collaborate within the coopetition framework without risking their proprietary data or competitive advantage.

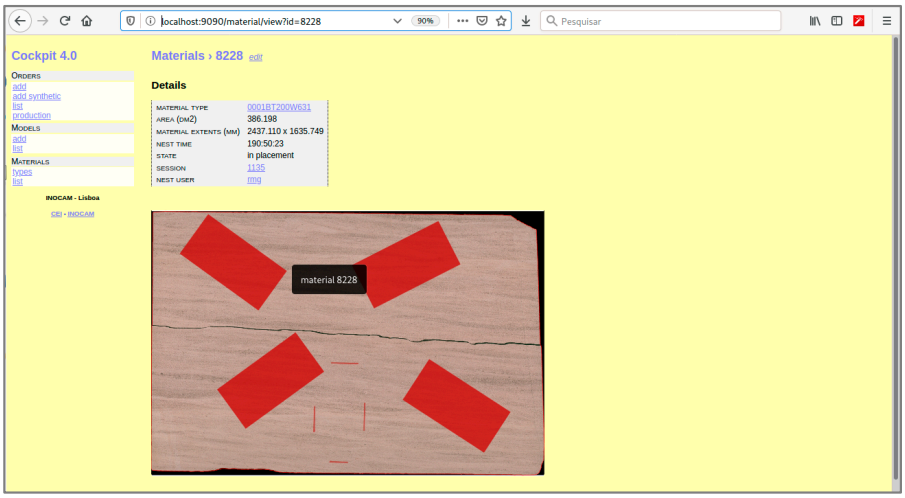


Figure 2. IoT software interface.

5.2. Evaluation Metrics

BIM plays a crucial role in achieving zero waste in construction projects by seamlessly integrating financial data with every component of the digital model [73]. This integration transforms budgeting into a dynamic, detail-oriented process that offers real-time visibility and continuous updates on the financial implications of design decisions and manufacturing changes throughout the project's lifecycle [74]. To meet the stringent requirements of BIM, stone manufacturers must minimize waste and align closely with industry standards. Consequently, the "first time through KPI" (KPI_{FTT}) was selected as a critical performance indicator for this study [75].

KPI_{FTT} measures the percentage of products or services that meet quality and compliance standards without necessitating rework or adjustments. By reflecting operational efficiency, KPI_{FTT} directly contributes to value creation by reducing waste, conserving time, and minimizing the need for additional resources. High KPI_{FTT} rates indicate processes that are efficient and effective in meeting quality standards on the first attempt, thereby significantly enhancing overall operational performance and value generation (Equation (1)).

$$KPI_{FTT}(\%) = \sum_{1}^{n}\left(\frac{\sum \text{parts produced}_{(\text{daily})} - \text{defective parts}_{(\text{daily})}}{\sum \text{parts produced}_{(\text{daily})}}\right) \times 100\% \quad (1)$$

where parts produced means the total number of parts produced daily, defective parts means the total number of parts produced each day that are identified as defective and require rework or cannot be used, and n represents the number of days over which the observation is made.

A data collection strategy was implemented over two fifty-four-day intervals to assess how the technology-driven coopetition network influences the KPI_{FTT}. This approach allowed for a comparative analysis of first time through (FTT) outcomes when transitioning stone SMEs to a technology-driven coopetition network to enhance value co-creation.

5.3. Data Collection, Results, and Discussion

The first 54-day period, conducted in May and June 2023, was focused on capturing state-of-the-art practices (SoAP) at the anonymized companies. This baseline phase documented each company's reliance on internal resources for production and delivery, providing essential reference data for subsequent comparisons.

The second 54-day period, concluding in November and December 2023, assessed the effects of integrating the same three stone firms into the technology-driven coopetition network practices (CTdNP). During this period, the selected stone companies were strategically connected by the IoT system (Figure 3), sharing real-time information about the availability of manufacturing resources and raw material stocks. Table 1 presents a summary of the average data collected.

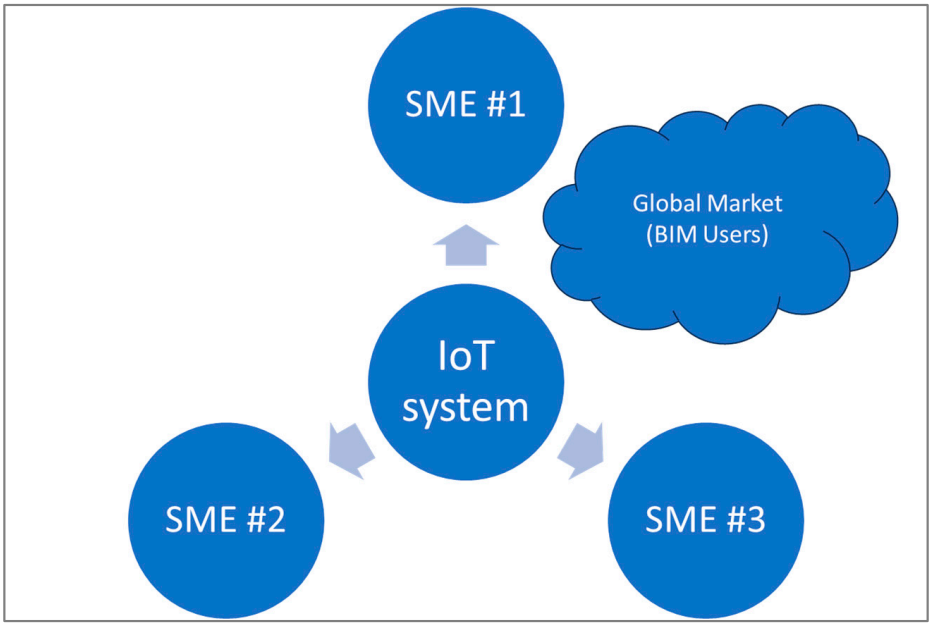


Figure 3. Implementation of the experimental technology-driven coopetition network.

Table 1. Summary of average data collected and KPIFTT assessment.

Data ID	Description	SoAP	CTdNP
Data 1	Parts Produced	369.9	454.3
Data 2	Defective Parts	37.3	38.5
KPI_{FTT}	(%)	90.9%	91.4%

Throughout the study, data management and privacy were maintained in compliance with confidentiality agreements. All data were anonymized and referred to only by company labels. Data collection, recording, and exportation procedures were strictly followed, with results exported to Excel files as detailed in the methodology section. This ensured a secure and consistent approach to data handling, enabling detailed analysis while safeguarding the privacy and proprietary information of the participating companies.

The collected data were used to assess the KPI_{FTT} under both SoAP and CTdNP, as shown in Table 1 and daily illustrated in Figure 4. The comparison provided insights into how the technology-driven coopetition network could improve value co-creation in the Portuguese ornamental stone sector.

Despite a slight increase in KPI_{FTT}, from 90.9% to 91.4%, the analysis reveals a significant rise in total production. Under CTdNP, the total parts produced increased by 22.7% (from 370 to 454), demonstrating an enhanced production capacity within the coopetition network. The marginal improvement in KPI_{FTT} and the increase in output suggest that coopetition practices facilitate better overall efficiency and capacity utilization.

The positive slope (0.0007) in the trend line indicates that, over time, KPI_{FTT} tends to increase under coopetition practices. Although the immediate quantitative improvement in KPI_{FTT} appears small, the consistent upward trend highlights the potential for long-term efficiency gains under CTdNP. The econometric analysis of the trend line suggests a gradual improvement in operational efficiency within the coopetition network over

time. The moderate R^2 value indicates that while time improves KPI_{FTT}, other factors may influence this performance metric.

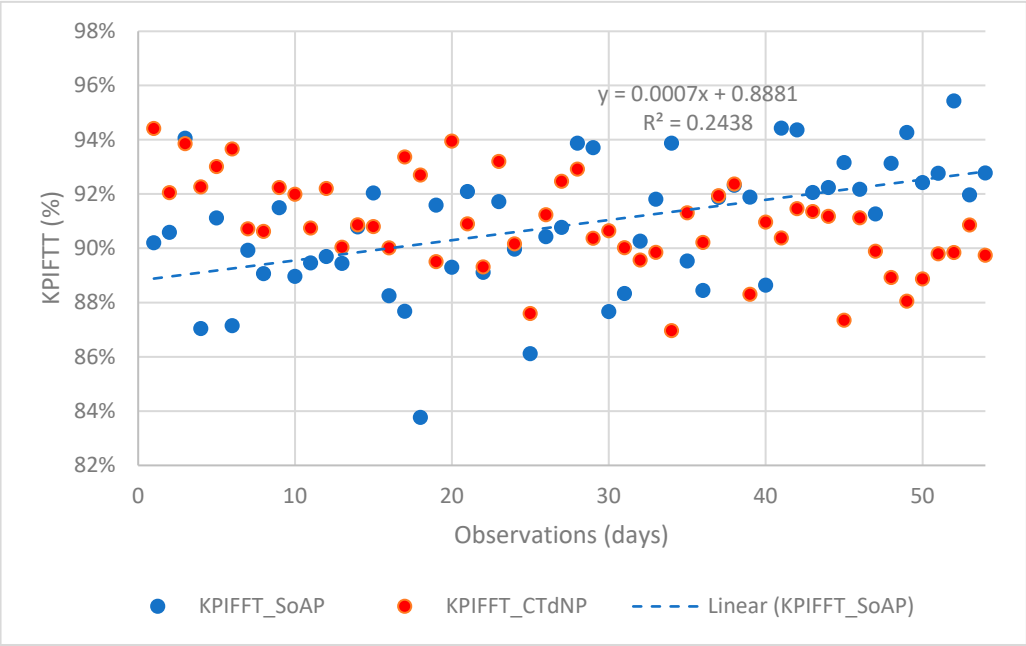


Figure 4. Daily average trend of first time through KPI (KPI_{FTT}).

The increase in daily production under CTdNP, despite a similar KPI_{FTT} being maintained, reflects improved resource utilization and process efficiency. The ability to produce more parts without a proportional increase in defects underscores the benefits of coopetition in leveraging collective capabilities and resources.

The positive trend in KPI_{FTT} over time under CTdNP indicates that coopetition practices can lead to cumulative improvements in operational performance. As companies within the coopetition network continue to refine their processes and leverage shared knowledge and technology, their efficiency in producing defect-free parts on the first attempt improves.

To evaluate whether CTdNP makes a significant difference compared to SoAP, a statistical test was conducted. A paired *t*-test was used to compare means from two related groups. The *t*-test produced a *p*-value of 19.81×10^{-18}, indicating that the observed mean differences are highly unlikely to have occurred by chance. This low *p*-value suggests a statistically significant improvement in on-time delivery performance under CTdNP compared to SoAP.

Under SoAP, the regression model is statistically significant (significance f = 0.001501), indicating a meaningful relationship between non-defective parts and KPI_{FTT}. In contrast, under CTdNP, the regression model is not statistically significant (significance f = 0.712023), suggesting that the relationship between non-defective parts and KPI_{FTT} under coopetition practices is not as impactful. This finding indicates that the performance of KPI_{FTT} under CTdNP requires ongoing monitoring, with necessary adjustments to ensure that the shift from current best practices results in actual performance improvements. To fully realize the potential benefits of technology-driven coopetition, it may be necessary to revisit and refine network practices by enhancing communication, setting more precise goals, and offering better incentives for cooperation.

These results support the hypothesis that transitioning to Coopetition-driven Networks potentially enhances value co-creation in the Portuguese ornamental stone sector. By sharing resources and expertise, companies can improve their first time through results, leading to sustained improvements in quality and efficiency.

While the R^2 value of 0.2438 suggests that time explains a moderate portion of the variation in KPI_{FTT}, it also implies that other variables contribute to performance improvements. Future research could explore these variables, such as specific technological integrations or collaborative strategies within the network.

This empirical evaluation demonstrates that coopetition networks, enhanced by IoT, can boost value creation while maintaining or slightly improving operational efficiency as measured by KPI_{FTT}. The upward trend in KPI_{FTT} indicates potential long-term gains in operational performance, supporting the adoption of coopetition as a strategic approach for SMEs in the ornamental stone sector. Further analysis into other influencing factors could provide deeper insights into maximizing the benefits of such networks.

6. Conclusions

This study aimed to explore the role of technology in coopetition by examining it through the lens of S-D Logic. The objective was to identify the foundational elements necessary for effective technology-driven coopetition networks. The research was designed to identify key constructs and building blocks, hypothesizing that transitioning to a technology-driven coopetition network enhances value co-creation.

To test this hypothesis, the research critically evaluated mainstream approaches to coopetition, identifying existing gaps—particularly in value creation mechanisms—and the role of technology in framing technology-driven coopetition networks. The study then experimented with IoT technology as a catalyst for value creation within an experimental technology-driven coopetition network, focusing on ornamental stone SMEs, a key sector in the Portuguese economy.

The findings confirm that technology-driven coopetition networks can indeed enhance value co-creation among stone SMEs. By integrating their resources and capabilities within a cooperative framework, the participating companies improved their first time through rates and overall output.

However, the study also revealed some limitations. The relationship between non-defective parts and KPI_{FTT} under the experimental technology-driven coopetition network was not as strong as under traditional practices. This suggests that while coopetition can enhance value co-creation, its effectiveness may be contingent upon continuous monitoring and refinement. To fully harness the potential benefits of these networks, it is crucial to enhance communication, set clear goals, and provide strong incentives for cooperation.

Moreover, while the findings indicate that time positively influences KPI_{FTT}, other variables also contribute to performance improvements. Future research should explore these additional variables, particularly examining specific technological integrations and collaborative strategies within coopetition networks. Such studies could provide deeper insights into maximizing the benefits of technology-driven coopetition and offer broader applications in other sectors.

In conclusion, this study supports the hypothesis that transitioning to coopetition technology-driven networks enhances value co-creation in stone SMEs. The findings advocate adopting coopetition as a strategic approach, particularly in sectors where technology integration and resource sharing can lead to significant competitive advantages. However, the study's limitations underscore the need for ongoing research to optimize these networks and fully realize their potential.

Author Contributions: Conceptualization, A.d.S. and A.J.M.C.; methodology, A.d.S.; software, A.d.S.; validation, A.d.S. and A.J.M.C.; formal analysis, A.d.S.; investigation, A.d.S.; resources, A.d.S.; data curation, A.d.S.; writing—original draft preparation, A.d.S.; writing—review and editing, A.d.S.; visualization, A.d.S.; supervision, A.J.M.C.; project administration, A.d.S.; funding acquisition, A.d.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Meena, A.; Dhir, S.; Sushil, S. A review of coopetition and future research agenda. *J. Bus. Ind. Mark.* **2023**, *38*, 118–136. [CrossRef]
2. Rouyre, A.; Fernandez, A.-S.; Bruyaka, O. Big problems require large collective actions: Managing multilateral coopetition in strategic innovation networks. *Technovation* **2024**, *132*, 102968. [CrossRef]
3. Crick, J. The dark side of coopetition: When collaborating with competitors is harmful for company performance. *J. Bus. Ind. Mark.* **2019**, *35*, 318–337. [CrossRef]
4. Reeves, M.; Lotan, H.; Legrand, J.; Jacobides, M.G. How Business Ecosystems Rise (and Often Fall). *MIT Sloan Manag. Rev.* **2019**, 27–34. [CrossRef]
5. Corbo, L.; Kraus, S.; Vlačić, B.; Dabić, M.; Caputo, A.; Pellegrini, M.M. Coopetition and innovation: A review and research agenda. *Technovation* **2023**, *122*, 102624. [CrossRef]
6. Bouncken, R.; Kumar, A.; Connell, J.; Bhattacharyya, A.; He, K. Coopetition for corporate responsibility and sustainability: Does it influence firm performance? *Int. J. Entrep. Behav. Res.* **2023**, *30*, 128–154. [CrossRef]
7. Xie, Q.; Gao, Y.; Xia, N.; Zhang, S.; Tao, G. Coopetition and organizational performance outcomes: A meta-analysis of the main and moderator effects. *J. Bus. Res.* **2023**, *154*, 113363. [CrossRef]
8. Vargo, S.L.; Fehrer, J.A.; Wieland, H.; Nariswari, A. The nature and fundamental elements of digital service innovation. *J. Serv. Manag.* **2023**, *35*, 227–252. [CrossRef]
9. Jaakkola, E.; Kaartemo, V.; Siltaloppi, J.; Vargo, S.L. Advancing service-dominant logic with systems thinking. *J. Bus. Res.* **2024**, *177*, 114592. [CrossRef]
10. da Silva, A.; Cardoso, A.J.M. Co-Opetition and the Industrial Internet of Things: A Strategic Framework for Operational Efficiency in the Portuguese Ornamental Stone Sector. *Adm. Sci. Adm. Sci.* **2024**, *14*, 125. [CrossRef]
11. Nalebuff, B.J.; Brandenburger, A.M. Co-opetition: Competitive and cooperative business strategies for the digital economy. *Strat. Leadersh.* **1997**, *25*, 28–33. [CrossRef]
12. Manzhynski, S.; Biedenbach, G.; Manzhynski, S.; Biedenbach, G. The knotted paradox of coopetition for sustainability: Investigating the interplay between core paradox properties. *Ind. Mark. Manag.* **2023**, *110*, 31–45. [CrossRef]
13. Gnyawali, D.R.; Song, Y. Pursuit of rigor in research: Illustration from coopetition literature. *Ind. Mark. Manag.* **2016**, *57*, 12–22. [CrossRef]
14. Gernsheimer, O.; Kanbach, D.K.; Gast, J. Coopetition research—A systematic literature review on recent accomplishments and trajectories. *Ind. Mark. Manag.* **2021**, *96*, 113–134. [CrossRef]
15. Devece, C.; Ribeiro-Soriano, D.E.; Palacios-Marqués, D. Coopetition as the new trend in inter-firm alliances: Literature review and research patterns. *Rev. Manag. Sci.* **2019**, *13*, 207–226. [CrossRef]
16. Klimas, P.; Ahmadian, A.A.; Soltani, M.; Shahbazi, M.; Hamidizadeh, A. Coopetition, Where Do You Come From? Identification, Categorization, and Configuration of Theoretical Roots of Coopetition. *SAGE Open* **2023**, *13*, 215824402210850. [CrossRef]
17. Raza-Ullah, T.; Bengtsson, M.; Kock, S. The coopetition paradox and tension in coopetition at multiple levels. *Ind. Mark. Manag.* **2014**, *43*, 189–198. [CrossRef]
18. Spiller, P.T. A Tribute to Oliver Williamson: Regulation: A Transaction Cost Perspective. *Calif. Manag. Rev.* **2010**, *52*, 147–158. [CrossRef]
19. Parkhe, A.; Wasserman, S.; Ralston, D.A. New Frontiers in Network Theory Development. *Acad. Manag. Rev.* **2006**, *31*, 560–568. [CrossRef]
20. Burga, R.; Rezania, D. Project accountability: An exploratory case study using actor–network theory. *Int. J. Proj. Manag.* **2017**, *35*, 1024–1036. [CrossRef]
21. Crick, J. Moderators affecting the relationship between coopetition and company performance. *J. Bus. Ind. Mark.* **2019**, *34*, 518–531. [CrossRef]
22. Kleinaltenkamp, M.; Kleinaltenkamp, M.J.; Karpen, I.O. Resource entanglement and indeterminacy: Advancing the service-dominant logic through the philosophy of Karen Barad. *Mark. Theory* **2023**. [CrossRef]
23. Amit, R.; Zott, C. Value creation in E-business. *Strateg. Manag. J.* **2001**, *22*, 493–520. [CrossRef]
24. Vargo, S.L. Conceptual reconciliation for clarity and impact. *AMS Rev.* **2023**, *13*, 169–172. [CrossRef]
25. Vargo, S.; Akaka, M.; Vaughan, C. Conceptualizing Value: A Service-ecosystem View. *J. Creat. Value* **2017**, *3*, 117–124. [CrossRef]
26. Greer, C.R.; Lusch, R.F.; Vargo, S.L. A service perspective. Key managerial insights from service-dominant (S-D) logic. *Organ. Dyn.* **2016**, *45*, 28–38. [CrossRef]
27. Vargo, S.L.; Lusch, R.F. Evolving to a New Dominant Logic for Marketing. *J. Mark.* **2004**, *68*, 1–17. [CrossRef]
28. Lusch, R.F.; Vargo, S.L.; Tanniru, M. Service, value networks and learning. *J. Acad. Mark. Sci.* **2010**, *38*, 19–31. [CrossRef]

29. Normann, R.; Ramírez, R. From value chain to value constellation: Designing interactive strategy. *Harv. Bus. Rev.* **1993**, *71*, 65–77. Available online: http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=9309166477&site=eds-live (accessed on 4 June 2024).
30. Vargo, S.L.; Lusch, R.F. Inversions of service-dominant logic. *Mark. Theory* **2014**, *14*, 239–248. [CrossRef]
31. Elo, J.; Lumivalo, J.; Tuunanen, T.; Vargo, S.L. Enabling Value Co-Creation in Partner Collaboration Ecosystems: An Institutional Work Perspective. In Proceedings of the 57th Hawaii International Conference on System Science and Engineering, Online, 3–6 January 2024. Available online: https://hdl.handle.net/10125/106412 (accessed on 2 June 2024).
32. Siltaloppi, J.; Koskela-Huotari, K.; Vargo, S.L. Institutional complexity as a driver for innovation in service ecosystems. *Serv. Sci.* **2016**, *8*, 333–343. [CrossRef]
33. Bouncken, R.B.; Plüschke, B.D.; Pesch, R.; Kraus, S. Entrepreneurial orientation in vertical alliances: Joint product innovation and learning from allies. *Rev. Manag. Sci.* **2016**, *10*, 381–409. [CrossRef]
34. Autio, E.; Thomas, L.D.W. *Innovation Ecosystems: Implications for Innovation Management*; Oxford University Press: Oxford, UK, 2014.
35. Antai, I. A theory of the competing supply chain: Alternatives for development. *Int. Bus. Res.* **2010**, *4*, 74–85. [CrossRef]
36. Contarinis, S.; Pallikaris, A.; Nakos, B. The value of marine spatial open data infrastructures-potentials of IHO S-100 standard to become the universal marine data model. *J. Mar. Sci. Eng.* **2020**, *8*, 564. [CrossRef]
37. Imschloss, M.; Schwemmle, M. Value creation in post-pandemic retailing: A conceptual framework and implications. *J. Bus. Econ.* **2023**, *94*, 851–889. [CrossRef]
38. Mariotti, J. The value network. *Exec. Excell.* **2002**, *19*, 18.
39. Vargo, S.L.; Lusch, R.F. Service-dominant logic 2025. *Int. J. Res. Mark.* **2017**, *34*, 46–67. [CrossRef]
40. Mustak, M.; Plé, L. A critical analysis of service ecosystems research: Rethinking its premises to move forward. *J. Serv. Mark.* **2020**, *34*, 399–413. [CrossRef]
41. Breidbach, C.F.; Maglio, P.P. Technology-enabled value co-creation: An empirical analysis of actors, resources, and practices. *Ind. Mark. Manag.* **2016**, *56*, 73–85. [CrossRef]
42. Vargo, S.L.; Wieland, H.; O'Brien, M. Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline. *J. Bus. Res.* **2023**, *164*, 113965. [CrossRef]
43. Arthur, W.B. *The Nature of Technology*; Penguin Books Ltd.: London, UK, 2009.
44. Matthies, B.D.; D'Amato, D.; Berghäll, S.; Ekholm, T.; Hoen, H.F.; Holopainen, J.; Korhonen, J.E.; Lähtinen, K.; Mattila, O.; Toppinen, A.; et al. An ecosystem service-dominant logic?—Integrating the ecosystem service approach and the service-dominant logic. *J. Clean. Prod.* **2016**, *124*, 51–64. [CrossRef]
45. Lusch, R.F.; Nambisan, S. Service Innovation: A Service-Dominant Logic Perspective. *MIS Q.* **2015**, *39*, 155–175. [CrossRef]
46. Wieland, H.; Hartmann, N.; Vargo, S. Business models as service strategy. *J. Acad. Mark. Sci.* **2017**, *45*, 925–943. [CrossRef]
47. Jaakkola, E. Designing conceptual articles: Four approaches. *AMS Rev.* **2020**, *10*, 18–26. [CrossRef]
48. da Silva, A.; Dionisio, A.; Almeida, I. Enabling Cyber-Physical Systems for Industry 4.0 operations: A Service Science Perspective. *Int. J. Innov. Technol. Explor. Eng.* **2020**, *9*, 838–846. [CrossRef]
49. Hartmann, N.N.; Wieland, H.; Vargo, S.L. Converging on a New Theoretical Foundation for Selling. *J. Mark.* **2018**, *82*, 1–18. [CrossRef]
50. Gnyawali, D.R.; Ryan Charleton, T. Nuances in the Interplay of Competition and Cooperation: Towards a Theory of Coopetition. *J. Manag.* **2018**, *44*, 2511–2534. [CrossRef]
51. Lusch, R.F.; Vargo, S.L.; Gustafsson, A. Fostering a trans-disciplinary perspectives of service ecosystems. *J. Bus. Res.* **2016**, *69*, 2957–2963. [CrossRef]
52. Ruokolainen, T.; Kutvonen, L. Managing interoperability knowledge in open service ecosystems. In Proceedings of the IEEE International Enterprise Distributed Object Computing Conference (EDOC), Washington, DC, USA, 1–4 September 2009; pp. 203–211. [CrossRef]
53. Ruokolainen, T.; Ruohomaa, S.; Kutvonen, L. Solving service ecosystem governance. In Proceedings of the 21st IEEE International Enterprise Distributed Object Computing Conference (EDOC), Helsinki, Finland, 29 August–2 September 2011; pp. 18–25. [CrossRef]
54. Vargo, S.L.; Lusch, R.F. It's all B2B... and beyond: Toward a systems perspective of the market. *Ind. Mark. Manag.* **2011**, *40*, 181–187. [CrossRef]
55. Koskela-Huotari, K.; Vink, J.; Edvardsson, B. The institutional turn in service research: Taking stock and moving ahead. *J. Serv. Mark.* **2020**, *34*, 373–387. [CrossRef]
56. CSeepana, C.; Paulraj, A.; Huq, F.A. The architecture of coopetition: Strategic intent, ambidextrous managers, and knowledge sharing. *Ind. Mark. Manag.* **2020**, *91*, 100–113. [CrossRef]
57. Akaka, M.; Schau, H.; Vargo, S. How Practice Diffusion Drives IoT Technology Adoption and Institutionalization of Solutions in Service Ecosystems. In Proceedings of the Annual Hawaii International Conference on System Sciences, Big Island, Hawaii, USA, 3–6 January 2023; pp. 1427–1435. [CrossRef]
58. Scott, W. *Institutions and Organizations*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2001.
59. Lawrence, T.; Suddaby, R. Institutions and Institutional Work. In *The SAGE Handbook of Organization Studies: Chapter 6*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2006.

60. Vargo, S.; Lusch, R. Institutions and axioms: An extension and update of service-dominant logic. *J. Acad. Mark. Sci.* **2016**, *44*, 5–23. [CrossRef]
61. Rindfleisch, A.; Moorman, C. Interfirm Cooperation and Customer Orientation. *J. Mark. Res.* **2003**, *40*, 421–436. [CrossRef]
62. Vargo, S.; Lusch, R. *The SAGE Handbook of Service-Dominant Logic*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2018. [CrossRef]
63. Scott, W. *Institutions and Organizations—Ideas, Interests, and Identities*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2013.
64. SBarile, S.; Lusch, R.; Reynoso, J.; Saviano, M.; Spohrer, J. Systems, Networks, and Ecosystems in Service Research. *J. Serv. Manag.* **2016**, *34*, 1–5. [CrossRef]
65. Chandler, J.D.; Danatzis, I.; Wernicke, C.; Akaka, M.A.; Reynolds, D. How Does Innovation Emerge in a Service Ecosystem? *J. Serv. Res.* **2019**, *22*, 75–89. [CrossRef]
66. Uribe, J.; Sytch, M.; Kim, Y.H. When Friends Become Foes: Collaboration as a Catalyst for Conflict. *Adm. Sci. Q.* **2020**, *65*, 751–794. [CrossRef]
67. Di Bella, L.; Katsinis, A.; Lagüera-González, J.; Odenthal, L.; Hell, M.; Lozar, B. *Annual Report on European SMEs 2022/2023*; European Union: Maastricht, The Netherlands, 2023.
68. Razmdoost, K.; Alinaghian, L.; Chandler, J.D.; Mele, C. Service ecosystem boundary and boundary work. *J. Bus. Res.* **2023**, *156*, 113489. [CrossRef]
69. Vargo, S.L.; Peters, L.; Kjellberg, H.; Koskela-Huotari, K.; Nenonen, S.; Polese, F.; Sarno, D.; Vaughan, C. Emergence in marketing: An institutional and ecosystem framework. *J. Acad. Mark. Sci.* **2023**, *51*, 2–22. [CrossRef]
70. Carvalho, J.M.F.; Lisboa, J.V. Ornamental stone potential areas for land use planning: A case study in a limestone massif from Portugal. *Environ. Earth Sci.* **2018**, *77*, 206. [CrossRef]
71. Silva, A.; Marques Cardoso, A. BIM-based Supply Chain in AEC—Threats on the Portuguese Stone sector. In Proceedings of the 7th Globalstone Congress, Batalha, Portugal, 18–23 June 2023; ISBN 978-972-778-327-4. Available online: https://repositorio.lneg.pt/bitstream/10400.9/4150/1/GSC2023_PT%20Natural%20Stones-Commercial%20Names%20harmonization.pdf (accessed on 2 June 2024).
72. Silva, A.; Pata, A. Value Creation in Technology Service Ecosystems—Empirical Case Study. In *Innovations in Industrial Engeneering II*; Springer: Berlin/Heidelberg, Germany, 2022; pp. 26–36. [CrossRef]
73. Chen, Z.-S.; Wang, Z.-R.; Deveci, M.; Ding, W.; Pedrycz, W.; Skibniewski, M.J. Optimization-based probabilistic decision support for assessing building information modelling (BIM) maturity considering multiple objectives. *Inf. Fusion* **2024**, *102*, 102026. [CrossRef]
74. Shao, S.; Cao, D. Contagion of BIM Implementation Practices in Interproject Networks: An Empirical Study in China. *J. Manag. Eng.* **2024**, *40*, 05023009. [CrossRef]
75. Lakshmanan, R.; Nyamekye, P.; Virolainen, V.-M.; Piili, H. The convergence of lean management and additive manufacturing: Case of manufacturing industries. *Clean. Eng. Technol.* **2023**, *13*, 100620. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

administrative sciences

MDPI

Article

Co-Opetition and the Industrial Internet of Things: A Strategic Framework for Operational Efficiency in the Portuguese Ornamental Stone Sector

Agostinho da Silva [1,2,*] and Antonio J. Marques Cardoso [1]

[1] CISE—Electromechatronic Systems Research Centre, University of Beira Interior, 6201-001 Covilhã, Portugal; ajmarcar@ieee.org
[2] CIGEST—Centre for Research in Management, Lisbon Business School, 1000-002 Lisboa, Portugal
* Correspondence: a.silva@zipor.com

Abstract: In our rapidly globalizing and digitizing world, small and medium-sized manufacturing enterprises (SMEs) face significant challenges that compel them to adopt a co-opetition strategy—a blend of competition and collaboration. Despite their potential benefits, the high failure rates and unmet expectations of co-opetition networks highlight a significant gap in the empirical frameworks for establishing and maintaining these networks. This research seeks to address these gaps by developing a framework that enhances value cocreation in the Portuguese ornamental stone sector, integrating the latest developments in the Industrial Internet of Things (IIoT), Service-Dominant Logic (S-D Logic), and service science. Question: How can a framework integrating IIoT, S-D Logic, and service science enhance value cocreation and manage co-opetition among SMEs in the Portuguese ornamental stone sector? Methods: Theoretical insights and practical applications were synthesized to develop and validate a comprehensive co-opetition framework. This framework was tested through an experimental pilot project in the Portuguese ornamental stone sector, leveraging IIoT. Results: The implementation of the framework demonstrated significant operational efficiency, including enhanced performance, reduced production variance, and better resource utilization, indicating that integrating IIoT within co-opetition networks can effectively support SMEs. Conclusions: This study confirms the transformative impact of embedding IIoT in co-opetition networks, offering a replicable and scalable framework for other sectors. This framework addresses the empirical gap and aligns with broader socio-economic goals, setting the stage for further research into its applicability and potential across diverse industrial environments.

Keywords: co-opetition; S-D Logic; service science; IIoT; ornamental stone sector

check for updates

Citation: da Silva, Agostinho, and Antonio J. Marques Cardoso. 2024. Co-Opetition and the Industrial Internet of Things: A Strategic Framework for Operational Efficiency in the Portuguese Ornamental Stone Sector. *Administrative Sciences* 14: 125. https://doi.org/10.3390/admsci14060125

Received: 12 May 2024
Revised: 6 June 2024
Accepted: 11 June 2024
Published: 14 June 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

In the contemporary landscape of rapid globalization and digitization, small and medium-sized manufacturing enterprises (SMEs) face unparalleled challenges (Di Bella et al. 2023). These challenges necessitate adopting a co-opetition strategy among firms (Ramírez-López et al. 2021). Co-opetition is praised for its ability to spur innovation and value creation, which are vital for SMEs grappling with issues related to scale, efficiency (Chen 2020), and limited resources for innovation (Bicen et al. 2021). Despite these theoretical benefits, high failure rates and unmet expectations have emerged in co-opetition networks, highlighting a significant gap in empirical frameworks for establishing and maintaining these networks (Crick 2019). This gap is especially critical considering the essential role of manufacturing SMEs in the economies of developed nations (Muller et al. 2021).

The prevailing academic discourse on co-opetition primarily explores competitive dynamics (Kwon et al. 2020) and the resource-based view (Gernsheimer et al. 2021), focusing on structural strategies and securing unique resources for competitive advantage (Rouyre et al. 2024). However, these perspectives often neglect the value creation and sharing

mechanisms within co-opetition (Xie et al. 2023). Moreover, they need to adequately address the complexities and evolving nature of co-opetition in the digital era, particularly the significant impact of technological advancements on network interactions (Corbo et al. 2023). The high failure rates of co-opetition networks among SMEs (Reeves et al. 2019) and the insufficiency of current empirical models to navigate the challenges posed by technological progress and the need for digital collaboration underscore this critical research gap.

Technological advancements have reshaped the co-opetition landscape, altering network interactions and emphasizing technology's role as a resource within these networks (Bouncken et al. 2024). In this context, the literature on Service-Dominant Logic (S-D Logic) provides an alternative perspective for understanding value cocreation in networks, where technology acts as both a facilitator and a resource in service ecosystems (Vargo et al. 2024). Grounded in S-D Logic, Maglio and Spohrer (2008) pioneered the reevaluation of value cocreation, shifting from isolated, localized processes to a global network that leverages technology (Demirkan and Spohrer 2018). This led to the establishment of service science as a discipline focused on analyzing service systems as abstract entities, exploring the mechanisms of service innovation within economic activities (Yun et al. 2023; Breidbach and Maglio 2015). How can a framework that integrates technology, S-D Logic, and service science enhance value cocreation and manage co-opetition among SMEs in the Portuguese ornamental stone sector?

To address this question, this research study aims to develop and validate a comprehensive framework for co-opetition networks. This framework is designed to enhance value cocreation in the Portuguese ornamental stone (OS-PT) sector, with a focus on improving manufacturing efficiency and contributing to Sustainable Development Goals (SDGs) (UN 2019). By synthesizing theoretical insights with practical applications, the framework aims to establish a new paradigm at the intersection of the Industrial Internet of Things (IIoT) (Liu et al. 2024), S-D Logic, and service science.

The current relevance of the IIoT lies in its ability to revolutionize industrial processes by enabling unprecedented levels of connectivity (Yazdinejad et al. 2023a), real-time data processing, and intelligent automation. These advancements are particularly crucial for industries facing complex digital and global procurement challenges, such as those introduced by Building Information Modelling (BIM) in the Architecture, Engineering, and Construction (AEC) industry (Hadavi and Alizadehsalehi 2024). The OS-PT sector, with its unique combination of traditional craftsmanship and modern technological demands, presents an ideal context for exploring the potential of co-opetition networks for value cocreation (Silva and Cardoso 2023).

Based on insights from IoT-related cases in the literature (Brewster et al. 2017; Dospinescu and Dospinescu 2018), this study hypothesizes that a co-opetition framework integrating the IIoT with S-D Logic and service science principles will enhance value cocreation and effectively manage co-opetition among SMEs in the OS-PT sector.

2. Literature Review

Central to the S-D Logic introduced by Vargo and Lusch (2004) is the notion that service—the application of competencies for the benefit of others—is fundamental to value cocreation with beneficiaries (Lusch and Vargo 2007). This value cocreation process is intricately facilitated and bounded by institutional frameworks and arrangements, which serve as essential mechanisms within ecosystems (Vargo and Lusch 2016). Despite its controversies (Campbell et al. 2013), the adoption of S-D Logic has significantly influenced the dialogue around business models since 2004 (Vargo and Lusch 2004), providing a coherent framework that has seen notable progress and contributions to service-centric business models over the past decade (Vargo and Lusch 2004). Advancements in S-D Logic further articulate value cocreation in service ecosystems (Lusch et al. 2016). Coordinated by institutions and institutional arrangements, this concept transcends beyond mere tangible resources to include intangible assets and institutional structures (Vargo et al. 2024).

In response to the transition towards service-oriented models, Maglio and Spohrer (2008) advocated for a shift from isolated, localized processes to a globally interconnected network facilitated by technology (Maglio and Spohrer 2008), culminating in the establishment of service science with a focus on exploring the concept of service systems (Demirkan and Spohrer 2018). Central to service science is the notion that any interaction between entities inherently represents an opportunity for cocreating value. This perspective has significantly influenced the development of business models, emphasizing the importance of value proposition design and systemic patterns (Maglio et al. 2009).

Central to service science is the service system concept, encompassing configurations of people, technologies, organizations, and shared information. These systems can create and deliver value through service to various stakeholders, including suppliers, users, and other entities (Maglio et al. 2010). Despite slight differences in terminology from S-D Logic, service science shares a similar nature, embodying distinctive and connective roles within ecosystems and networks, facilitating resource reconfiguration and interaction (Cellary et al. 2019).

The discourse within the literature on service science increasingly focuses on networks of service systems, where multiple actors collaborate to cocreate mutual value. This perspective aligns with the S-D Logic view of networks as adaptive ecosystems for value creation and sustainability (Akaka et al. 2023).

S-D Logic and service science communities emerge as natural allies, sharing overlapping research interests, perspectives, and foundational philosophies (Lusch and Nambisan 2015). Both fields advocate for a holistic approach to studying and scaling business activities, transcending the distinction between tangible and intangible assets by integrating knowledge from diverse disciplines (Cellary et al. 2019). Despite some discrepancies in vocabulary, these communities converge on a shared philosophical view that emphasizes the importance of context in the cocreation of value, a complex phenomenon arising from service exchange, resource integration, and value-in-context, thereby providing a robust foundation for the design of empirical models (Pohlmann and Kaartemo 2017).

3. Technology Innovation for Value Creation

Degani et al. (2017) conceptualize technology through the lens of the "operant" adjective, defining it as "something that works" or is "engaged in action". This perspective delineates technology as a resource capable of self-governance, autonomy, and independence from external control, spanning three distinct logics: (1) authority to create and apply its own rules, (2) self-sufficiency without external assistance, and (3) freedom from external influence (Degani et al. 2017). This framework aligns with the emergence of intelligent technologies that can autonomously generate algorithms and undertake initiatives without human intervention, marking a significant leap in technological capabilities (Bodkhe et al. 2020).

The integration of technology as a central resource for innovation is extensively highlighted within service science, underscoring the transformative impact of technological advancements on service provision, revolutionizing how services are delivered, innovated, and managed (Breidbach and Maglio 2015). Parallel to this, S-D Logic explores the influence of technology on service innovation and the cocreation of value within service ecosystems, acknowledging technology's dual role as both an enabler and a driver of innovation (Matthies et al. 2016; Akaka et al. 2023).

Continuing along the same vein, the literature on co-opetition acknowledges the importance of technology-based strategic networks in fostering collective understanding and collaboration among diverse stakeholders (Doganova and Eyquem-Renault 2009; Rusko 2014; Wang and Chen 2022). This viewpoint is in harmony with S-D Logic and service science, which regard technology as a crucial operand (enabler) and operant (initiator) resource in the value creation process (Matzner et al. 2018; Barile et al. 2019). The interplay between operant and operand resources is facilitated through human interaction, technol-

ogy, value propositions, and shared information, laying the groundwork for innovation and value creation (Matthies et al. 2016).

In this context, emergent and embedded technologies like the Internet of Things (IoT) are recognized by S-D Logic (Vargo et al. 2024) and service science (Akaka et al. 2023) as heralding a new era in which technology profoundly influences ecosystems. Empirical evidence underscores the transformative potential of IoT-based innovations in fostering novel service offerings (Akaka et al. 2015).

Companies leveraging IoT capabilities can extend their service portfolio to include remote control options and predictive maintenance solutions (Mosch et al. 2023), advancing operational efficiency and opening new avenues for value cocreation within co-opetition frameworks (Salih et al. 2022). This technological integration catalyzes the development of ecosystems where companies, by harnessing IoT, transcend traditional competitive boundaries (Coelho et al. 2022), facilitating the seamless exchange of resources and collaboration among once-competing entities (Mosch et al. 2023).

The IIoT advancement beyond IoT frameworks marks a significant evolution in industries' operations. According to Yazdinejad et al. (2023b), the IIoT introduces unprecedented efficiency and intelligence, enhancing global connectivity and enabling direct device-to-device communications (Yazdinejad et al. 2023b). It facilitates the development of intelligent artefacts capable of dynamically adapting to user interactions and actively enhancing value-creation processes (Hoppe 2023). Furthermore, the implementation of advanced technological frameworks for prognostic health management, for instance, demonstrates the critical role of the IIoT in improving long-term prediction accuracy and operational efficiency in industrial applications (Li et al. 2024). Additionally, the integration of edge computing within IIoT systems has revolutionized industrial processes by providing flexible data sensing and real-time processing services, ensuring efficient resource sharing and maximizing social welfare in edge-enabled IIoT environments (Liu et al. 2024).

To address the research question, the following hypothesis can be formulated: a co-opetition framework that integrates the IIoT with S-D Logic and service science principles enhances value cocreation and effectively manages co-opetition among SMEs in the OS-PT sector. This integrated framework is expected to improve operational efficiency, fostering a collaborative industrial ecosystem that supports sustainable industrialization and contributes to achieving relevant SDGs.

4. Designing a Co-Opetition-Centric Framework for Value Cocreation

4.1. The Role of Technology in Networks for Value Cocreation

Technology plays a central role in co-opetition networks as an initiator and facilitator of actions among actors (Elo et al. 2024). Providers, driven by the prospect of heightened benefits, may share and integrate their resources with others, including competitors, to partake in service exchanges that enrich resource density and enhance value cocreation (Lusch and Nambisan 2015). This collaborative yet competitive approach necessitates the mutual provision of access to resources, fostering a business model predicated on co-opetition (Seepana et al. 2020).

According to this view, technology stands out as a critical element, acting as both an operant resource by initiating actions and an operand resource by facilitating actions (Akaka et al. 2023). Its integration into the network amplifies resource density, propelling value and developing innovative resources designed to enhance the quality of life for all network actors (Vargo et al. 2024). Technology's unique combination and application in co-opetition networks underlines its essential role in advancing competitive collaboration for mutual and ecosystem-wide benefits (Elo et al. 2024).

4.2. The Role of Entities and Resources in Co-Opetition Networks

Understanding the dynamics of co-opetition networks necessitates identifying the roles played by various actors (service systems) and the resources they leverage for mutual benefit. Drawing from S-D Logic, the essence is recognized that of these networks lies in the service exchange among entities, aimed at reciprocal benefits (Barile et al. 2016). This exchange centers on two primary resource types: operant resources (people and organizations with the capacity to act) and operand resources (tangible assets such as technologies and knowledge). The distinction underscores that service is not merely an offering but the application of competencies for another's benefit (Joiner and Lusch 2016).

With its interdisciplinary approach, service science seeks to unify the concept of resources, asserting that anything named and potentially valuable—be it physical or non-physical—constitutes a resource (Vargo and Akaka 2009). These resources are characterized by their lifecycle (beginning, middle, and end), availability, creation cost, maintenance expense, and the cost of ceasing access or use.

The dynamic interplay of these resources within co-operation networks, spanning individuals, technology, organizations, and shared information, catalyzes actions fundamental to the network's vitality (Vargo et al. 2023a). Actors strategically integrate these resources to foster innovation and create value across various levels within the network (Vargo et al. 2023a).

This perspective suggests that all actors within the network are value cocreators (Silva and Gil 2020). Customers assume the pivotal role of evaluators, assessing offerings based on their experiences, while providers act as facilitators of value cocreation (Elo et al. 2024). Co-opetitors contribute through resource sharing (Bicen et al. 2021), competitors function as independent entities competing for customer attention (Akaka and Vargo 2014), and authorities serve as regulatory bodies ensuring sustainable and equitable interactions within the network (Vargo and Lusch 2016).

Revenue expectations within these networks enabled by technology are shaped by value propositions, which, in turn, are driven by the perceived value and the cocreation process. This cyclical engagement fosters increased resource density, propelling the network towards innovative value propositions and enhanced cocreation opportunities (Ng and Wakenshaw 2017). However, the success of this model hinges on the seamless access to and sharing of resources among entities, with the understanding that value perception is inherently subjective and rooted in individual experiences (Akaka et al. 2013).

Upon joining a co-opetition network, an actor anticipates revenue generation, with the process delineated by S-D Logic's service ecosystem view (Vargo et al. 2023b): initial expectations fuel the creation of value propositions, which in turn generate revenue, spurring further value propositions and enhancing resource density for more significant cocreation opportunities (Vargo et al. 2020). This cycle necessitates mutual access to resources among entities, with the proposition's value uniquely shaped by each beneficiary's experience (Jaakkola et al. 2024).

4.3. Institutionalizing Co-Opetition Networks for Value Cocreation

By adopting S-D Logic's view on service ecosystems, in networks, all actors integrate the resources in value networks (Lusch et al. 2010), understood as architectures of service and information flow frameworks (Zott and Amit 2008) where actors have roles, potential benefits, and sources of revenues, leading to business models (Zott et al. 2011).

Drawing from these foundational concepts, value creation transcends simple bilateral exchanges, necessitating a more comprehensive array of resources and the involvement of multiple actors within an intricate network (Normann and Ramirez 1993). The notion of micro-exchange within these vast ecosystems suggests that customers and providers represent just a fraction of the entire network, including numerous actors engaging in reciprocal resource exchange to create value (Chandler and Vargo 2011). Such complex dynamics require a level of coordination facilitated by endogenously created institutions—comprising rules, norms, symbols, and practices that aid collaboration—and institutional

arrangements (Elo et al. 2024), which are interdependent collections of these institutions, manifesting even at a societal scale (Meynhardt et al. 2016).

In such institutional technology-enabled networks, actors, including competitors, might choose to collaborate for mutual benefits, showcasing the voluntary nature of co-operation even among rivals (Chandler and Vargo 2011; Vargo et al. 2024). The deployment of both operant and operand technologies facilitates this co-operation through resource liquefaction and enhanced resource density, further cementing the institutionalization of networks into fully fledged service ecosystems (Lusch and Nambisan 2015; Jaakkola et al. 2024).

5. Operationalizing Co-Opetition Networks for Value Cocreation

The evolution of the IIoT brings connectivity and enables direct device-to-device communications (Dospinescu and Dospinescu 2018). This development supports creating intelligent systems that dynamically adapt to user interactions, enhancing value creation processes (Yazdinejad et al. 2023b).

5.1. Systemic Interoperability in IIoT-Based Co-Opetition Networkss

Interoperability is fundamental to fostering effective collaboration within networks, facilitating the achievement of mutual goals or enabling the controlled dissolution of co-operation in case of faults (Hoppe 2023). In the context of co-opetition for value cocreation, exchanging information between operand and operant technology resources is crucial (O'Brien 2016). It necessitates that any artefact designed to enable co-opetition within networks embeds mechanisms to address interoperability, especially within IoT- or IIoT-based systems, focusing on semantic and pragmatic issues to ensure network capabilities are fully leveraged (Leal et al. 2019).

As service science highlights, semantic interoperability ensures that the meaning of exchanged information is understood across different systems, while pragmatic interoperability effectively uses this information in operational contexts (Cardoso et al. 2015). Addressing these interoperability dimensions within IIoT artefacts is vital for enabling the seamless integration of diverse technologies and facilitating collaborative environments conducive to co-opetition (Silva et al. 2016).

Akaka and Vargo (2014) highlight the importance of embedded interoperability in digital technologies to connect network resources, emphasizing specific mechanisms necessary to enhance interoperability (Brewster et al. 2017). They underscore the significance of systemic embedded interoperability within digital technologies for connecting network resources and emphasize specific mechanisms for enhancing interoperability (Akaka and Vargo 2014).

Resource density mechanisms: These mechanisms involve the processing and analyzing of information to support decision-making and action-taking processes. By enhancing the density of available resources, IIoT can offer more nuanced insights and foster more informed co-opetition strategies (Ng and Wakenshaw 2017).

Digital materiality mechanisms: This refers to the capacity of software embedded in physical objects to manipulate digital representations, thereby enabling new functionalities and interactions. Digital materiality bridges the gap between the physical and digital realms, opening up new avenues for innovation and collaboration within co-opetition networks (Maglio et al. 2019).

By incorporating these mechanisms, IIoT artefacts can facilitate the dynamic exchange of service information, creating an environment conducive to collaborative and competitive interactions. Enhancing interoperability co-opetition within networks enables quicker responses to necessary adaptations, ultimately harnessing the full potential of value cocreation.

5.2. Systemic Usability and Accessibility in IIoT-Based Co-Opetition Networks

Usability and accessibility within co-opetition networks are paramount, guaranteeing secure service exchange among competitors and leveraging interactions to enhance value creation within the ecosystem (Kahkonen and Lintukangas 2012). As the S-D Logic literature emphasizes, facilitating these aspects necessitates a systemic perspective on assemblages and architectural modules designed for service interaction (Vargo and Lusch 2016). Institutions and institutional arrangements facilitate this coordination (Elo et al. 2024).

The integration of an IIoT system, encompassing both operant (e.g., artificial intelligence or cognitive assistant modules) and operand modules, allows competitors within the network to engage in activities while lacking legal accountability due to the absence of rights and duties (Maglio et al. 2009). Consequently, it cannot be recognized as a service system within service science (Maglio et al. 2019).

To bridge this gap, the system must incorporate human resources capable of operating, interacting, and collaborating with operant and operand technologies. Within this collaborative team, a designated responsible individual serves as the legal and operational representative of the network actors, ensuring accountability and oversight (Ng and Wakenshaw 2017).

Figure 1 illustrates the principles of the IIoT artefact, embedding mechanisms for systemic interoperability, usability, and accessibility to facilitate co-opetition and value cocreation within networks.

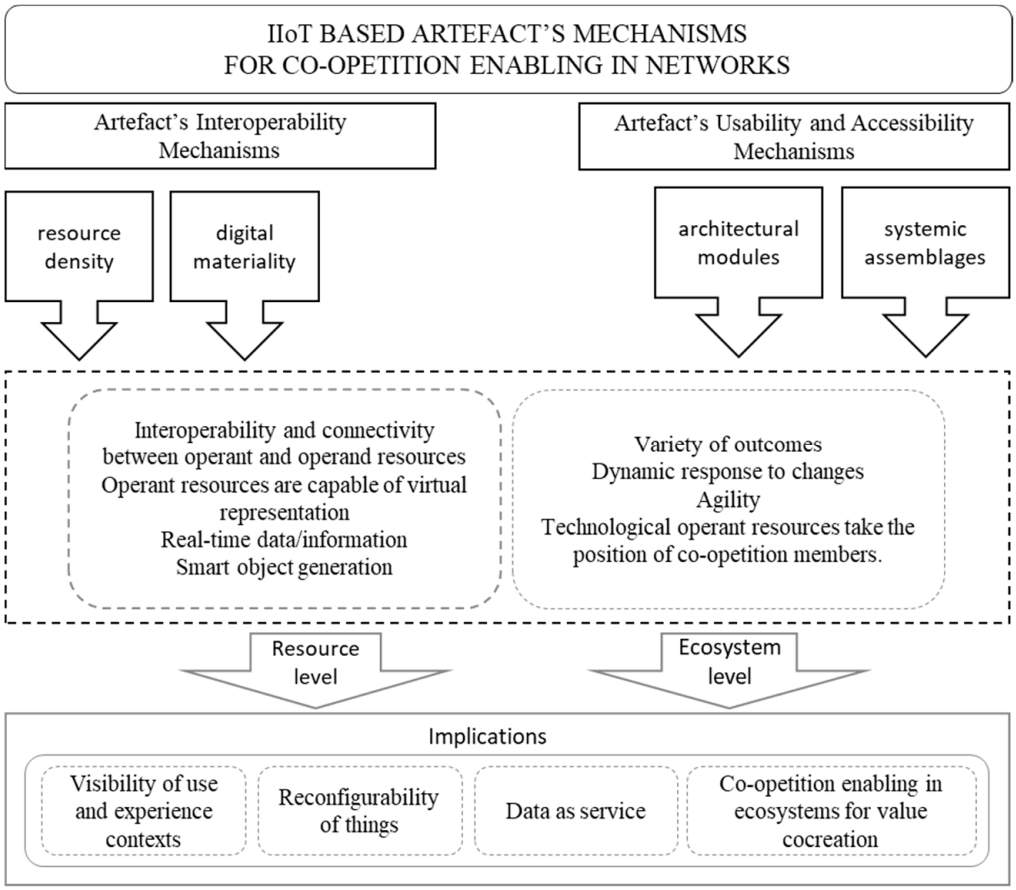


Figure 1. IIoT artifact principles for enabling co-opetition and value cocreation in networks (Ng and Wakenshaw 2017).

This IIoT system categorizes two types of resources critical for its operation: physical and non-physical resources. The category of physical-with-rights resources includes human resources, providing necessary oversight, decision-making capabilities, and legal

accountability in network interactions. Non-physical-with-no-rights resources are operand and operant software that facilitate digital interactions and processes.

By equipping the system with these diverse resource types, co-opetition networks for value cocreation can effectively manage usability and accessibility, fostering secure and productive service exchanges. This approach enhances the potential for value creation within the ecosystem. It addresses the legal and operational challenges of integrating advanced technologies like IoT into co-opetition strategies.

6. Evaluating Co-Opetition Networks for Value Cocreation

An experimental pilot project was conducted within the Portuguese ornamental stone sector to evaluate the effectiveness of the proposed framework. The objective was to assess the impact of the co-opetition network and IIoT artifacts on operational efficiency and value cocreation among SMEs. This case study focused on a representative sample of SMEs in the Portuguese ornamental stone sector, an industry characterized by traditional practices and significant potential for digital transformation.

6.1. The Portuguese Ornamental Stone Sector

The Portuguese ornamental stone sector, integral to Portugal's cultural heritage and a symbol of innovative excellence, has contributed to globally renowned stone monuments since the 15th century (Machado et al. 2021). According to recent statistics, the sector boasts a significant economic impact, exporting to 116 countries, ranking as the ninth largest entity in the global stone trade, and holding second place in per capita international trade (Silva and Pata 2022). The industry's exports exceed its imports by 660%, generating a turnover of EUR 1.230 million and sustaining over 16,600 direct jobs, notably supporting employment in inland regions (Machado et al. 2021). Known for its adaptability and resilience, the OS-PT sector has become a formidable industrial force within the country (Silva and Gil 2020). However, it faces significant challenges due to digital and global procurement processes introduced by BIM within the AEC industry, particularly impacting efficiency (Silva and Cardoso 2023).

Innovative technologies developed under the scope of the Inovstone4.0 R&D Project (Silva et al. 2020) exemplify the practical application of the IIoT in the OS-PT sector. This system has notably transformed the connectivity of OS-PT SMEs with the AEC digital market. Brewster et al. (2017) highlighted the application of IoT technologies in agriculture, demonstrating their potential to drive innovation and efficiency in traditional industries (Brewster et al. 2017). Similarly, Dospinescu and Dospinescu (2018) emphasized the role of information technology in enhancing ethical practices and operational efficiency (Dospinescu and Dospinescu 2018). To effectively support co-opetition among firms, a new IIoT artifact needed to be developed, embedding advanced mechanisms for interoperability, usability, and accessibility to integrate the OS-PT sector into a co-opetition network. Although the technical specifics of this new artifact are beyond the scope of this research, these developments culminated in the creation of Cockpit4.0+. This IIoT-based artifact was engineered to facilitate secure interactions among competing firms within the OS-PT sector.

Consequently, Cockpit4.0+ was utilized to connect three competitor firms in a Co-opetition Network Experimental Pilot Project (CN-EPP). As illustrated in Figure 2, the CN-EPP fostered a collaborative industrial atmosphere among these OS-PT competitor firms, demonstrating the potential of IIoT-based systems to support advanced connectivity and co-operation in an industrial setting.

In the CN-EPP, Cockpit4.0+ supports advanced connectivity and communication strategies. It lays the foundation for an industrial co-opetition ecosystem where rival SMEs can collaborate effectively, driving innovation and enhancing collective market responsiveness.

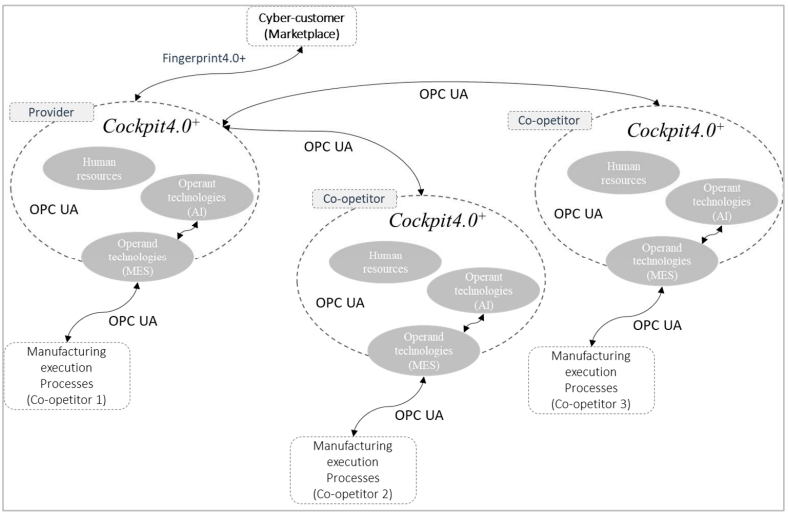


Figure 2. Co-opetition Network Experimental Pilot Project (CN-EPP).

6.2. Company Selection and Evaluation Metrics

The implementation of the CN-EPP involved planning and execution, particularly in the selection and engagement of participant companies from the OS-PT sector.

To begin with, direct and informal communication channels were established with the managing directors of potential participant companies. This approach facilitated a clear understanding of the project's scope and the potential future benefits for OS-PT SMEs.

A comprehensive confidentiality agreement was drafted to protect sensitive information about the companies' operations, clientele, employees, resources, and competitors, ensuring that all participants felt secure in sharing data. After thorough negotiations, three ornamental stone company managers representing the forefront of the sector agreed to participate in the experimental pilot project.

The project was overseen to maintain data integrity and confidentiality. This was achieved through direct, daily monitoring and recording of quantitative data using digital machinery and databases. Such stringent measures ensured that the data collected remained accurate and private, providing reliable insights into the effectiveness and impact of the IIoT implementation.

Drawing on insights from technology management and production literature (Jansen et al. 2004), it is crucial to understand the multifaceted nature of operational efficiency, which relies on production processes, logistics, and overarching business strategies (Serror et al. 2021; Pata and Silva 2022). To evaluate the impact of the co-opetition network for value cocreation in the OS-PT SMEs, two key performance indicators were defined: manufacturing value added and production–output ratio.

Manufacturing value added (KPI_MvA): This KPI represents the economic value added by the manufacturing process, assessing its contribution to overall business value. This measure helps gauge how effectively the manufacturing process adds economic value to the final product (Equation (1)).

$$\text{KPI_MvA } (\%) = \left(\frac{\sum Sold_parts_{(daily)}}{\sum Led_parts_{(daily)}} \right) \cdot 100\% \quad (1)$$

Production–output ratio (KPI_PoR): This KPI quantifies the production volume relative to the resources used, providing insight into operational efficiency. It reflects the ability of the production process to maximize output while minimizing resource input (Equation (2)).

$$\text{KPI_PoR } (\%) = \left(\frac{\sum Parts_produced_{(daily)}}{\sum Manufacturing_capacity)_{(daily)}} \right) \cdot 100\% \quad (2)$$

Once combined, these two KPIs can additionally provide insights into the stability and predictability of the improvements (Equation (3)).

$$\mathrm{KPI}(\sigma)\ (\%) = \sqrt[2]{\frac{\sum_1^n \left[KPI(MvA;PoR)_{(daily)} - \overline{KPI(MvA;PoR)_{(daily)}}\right]^2}{\left(Observations(R;PsO;MvA;PoR)_{(test\ period)}\right)}} \quad (3)$$

For examining the transition from current best practices (CB.Ps) to co-opetition network practices (CN.Ps) enhanced by the CN-EPP, a data collection strategy over two 54-day intervals was implemented, facilitating a comparative analysis of operational outcomes.

Phase 1—CB.Ps (17 April to 10 June 2023): This initial phase captured standard operations at three anonymized companies, designated "A", "B", and "C". It documented their reliance on internal resources for production and delivery, establishing essential baseline data for comparison.

Phase 2—CN.Ps (9 September to 14 November 2023): This phase evaluated the effects of integrating these companies into an IIoT-enhanced CN-EPP, marking a significant operational shift towards shared technologies and resources.

Throughout this study, data privacy and management were maintained under confidentiality agreements. All data were anonymized, referred to only by company labels, and managed according to stringent procedures. Data were recorded and exported to Excel files, ensuring their secure and consistent handling while enabling detailed analysis and preserving the privacy and proprietary information of the participants. This structured approach allowed for directly comparing operational outcomes and upheld data integrity throughout the research process. From these data, the KPIs from the three selected SMEs were assessed under CB.Ps and CN.Ps.

6.3. Insights into Value Addition in Manufacturing

Under CB.Ps, a KPI_MvA of 99.4% was recorded, indicating that most manufacturing operations successfully added value to the final product. Within CN.Ps, despite the scaling of operations, KPI-MvA improved to 99.9%. This enhancement suggests increased efficiency in the production process and reduced variance, as illustrated in Figure 3.

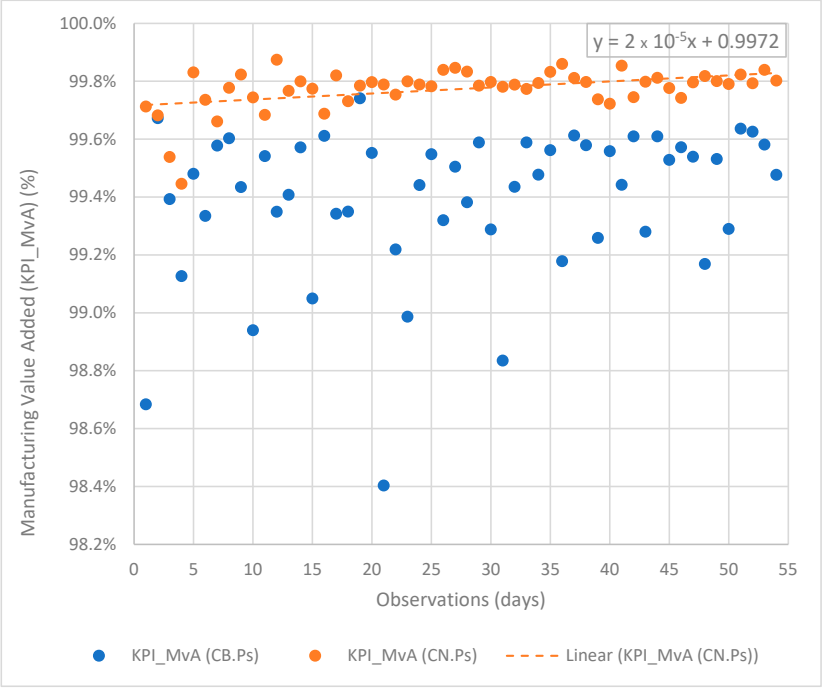


Figure 3. Daily trend in value added (CN.Ps).

This analysis shows that transitioning to CN.Ps not only maintained but slightly enhanced the value added by manufacturing processes despite increased operation volume.

6.4. Insights into Production–Output Ratio

Under CB.Ps, the findings revealed a KPI_PoR of 55.6%, with companies producing an average of 416 parts daily against a capacity of 590. Within CN.Ps, this ratio improved to 69.9%, indicating a substantial increase in production efficiency despite the constant production capacity.

The substantial increase of 14.3% in KPI_PoR under CN.Ps underscores the significant benefits of adopting these co-operative competition practices. This improvement signifies enhanced utilization of production capacities facilitated by the collaborative dynamics of co-opetition.

The gains in the production–output ratio under CN.Ps highlight significant advancements in production efficiency, optimizing resource utilization in manufacturing. The comparative analysis demonstrates the profound impact of adopting co-opetition strategies, which enhance the efficiency of production processes and outputs. In Figure 4, the linear regression trend line for KPI_MvA (CN.Ps) is presented, demonstrating the relationship between the daily observations and the production–output ratio.

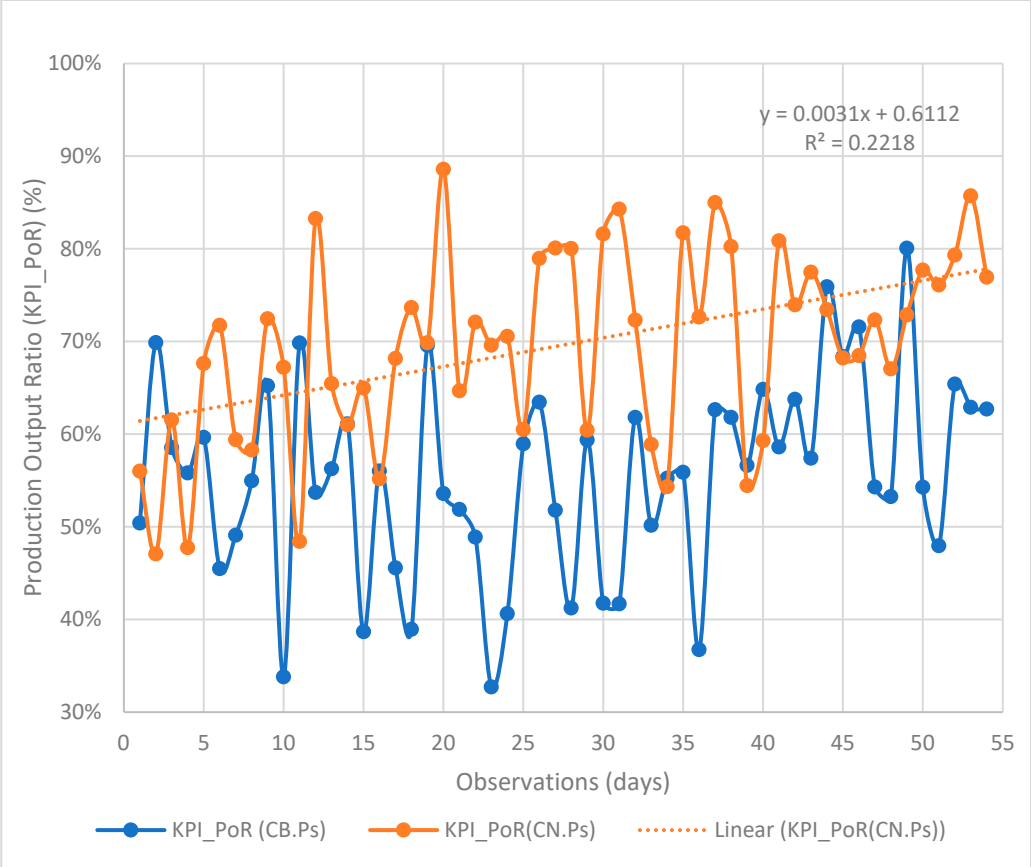


Figure 4. Daily trend in production–output ratio (CN.Ps).

The R-squared value for this regression is 0.2218. The correlation factor is 0.4709, indicating a moderate positive relationship between the variables. Despite this moderate daily growth, this result indicates that co-opetition networks positively contribute to this KPI. This results in an accumulated improvement of 14.1% in the production–output ratio under CN.Ps, highlighting significant benefits and enhanced utilization of production capacities due to collaborative co-opetition dynamics.

7. Discussion

Implementing the CN-EPP demonstrated notable improvements in KPIs for value addition in manufacturing and for the production–output ratio. Under the current best practices, KPI_MvA was recorded at 99.4%, which improved to 99.9% under the co-opetition network practices.

Similarly, KPI_PoR showed a substantial increase from 55.6% under CB.Ps to 69.9% under CN.Ps, highlighting significant production efficiency and resource utilization improvements. This 14.3% increase underscores the benefits of co-opetition, where shared technologies and resources lead to optimized production capacities and enhanced operational outcomes.

Moreover, insights into the stability and predictability of the improvements were assessed through KPI(σ), indicating an improvement of 71.9%, which proves enhanced manufacturing consistency. It indicates enhanced efficiency in the production process and reduced variance, affirming the efficacy of co-opetition strategies in maintaining and even enhancing operational performance despite increased volumes.

The successful application of Cockpit4.0+ within the CN-EPP illustrates the potential for IIoT-based systems to support advanced connectivity and communication strategies, creating an industrial ecosystem where rival SMEs can collaborate effectively. This integration aligns with the sector's inherent resilience and adaptability, supporting broader SDGs related to industry, innovation, and sustainable communities.

These findings confirm the hypothesis that a framework integrating the IIoT, S-D Logic, and service science can enhance value cocreation and effectively manage co-opetition among SMEs within the Portuguese ornamental stone sector.

8. Conclusions

Anchored in S-D Logic and service science principles, this study effectively demonstrates the significant advantages of employing a co-opetition strategy within SMEs by designing and implementing a co-opetition network for value cocreation embedding IIoT-based technologies in the Portuguese ornamental stone sector. Initially, this research study highlighted the pressing challenges SMEs face in adapting to rapid globalization and digitization, emphasizing the need for innovative frameworks that leverage competitive and collaborative dynamics to drive value creation and innovation.

The results from an experimental pilot project in the OS-PT showed that fostering an industrial ecosystem where SMEs engage in both competition and co-operation enabled by the IIoT can significantly improve operational efficiency. These improvements reflect enhanced operational efficiency and suggest reduced production variance and better resource utilization.

The successful application of co-opetition networks in the OS-PT sector has shown that integrating IIoT-based technologies can further enable effective co-opetition. This aligns with the sector's resilience and adaptability and supports broader socio-economic goals, including SDGs related to industry, innovation, and sustainable communities, thus promoting sustainable industrialization and resilience.

In conclusion, this research study provides a comprehensive framework that effectively addresses SMEs' operational challenges in the Portuguese ornamental stone (OS-PT) sector. It also sets a precedent for similar industries dealing with the complexities of digital and global procurement processes. By integrating the IIoT, S-D Logic, and service science, the proposed framework offers a robust solution for enhancing value cocreation and managing co-opetition, thereby contributing to sustainable industrial growth and resilience. The findings confirm the hypothesis that an integrated framework of the IIoT, S-D Logic, and service science significantly improves operational efficiency, reduces production variance, and optimizes resource utilization. The enhanced operational efficiency and optimized resource utilization contribute to SDG 9 (Industry, Innovation, and Infrastructure) by promoting sustainable industrialization and fostering innovation. Additionally, by supporting

employment in inland regions, this framework contributes to SDG 8 (Decent Work and Economic Growth) and SDG 11 (Sustainable Cities and Communities).

While this study effectively demonstrates the significant advantages of employing a co-opetition strategy within SMEs in the Portuguese ornamental stone sector, several limitations must be acknowledged. These include the sector-specific focus, limited sample size, and variability in implementation, which may affect the generalizability of the findings to other industries and contexts.

Despite these limitations, the insights gained and the proposed framework integrating the IIoT, S-D Logic, and service science have the potential for broader applicability. Future research could explore the generalization of this framework across different sectors and geographic regions to validate its effectiveness in enhancing value cocreation and managing co-opetition among SMEs. By conducting comparative studies and pilot implementations in diverse industries, researchers can further refine and adapt the framework, ultimately contributing to a more universal model for industrial collaboration and innovation.

Author Contributions: Both A.d.S. and A.J.M.C. contributed to the conceptualization, methodology, software, and validation of this paper. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data collected are recorded in Excel files and will be provided upon request.

Conflicts of Interest: The authors declare they have no known competing financial interests.

References

Akaka, Melissa, and Stephen L. Vargo. 2014. Technology as an operant resource in service (eco)systems. *Information Systems and E-Business Management* 12: 367–84. [CrossRef]

Akaka, Melissa, Hope Schau, and Stephen Vargo. 2023. How Practice Diffusion Drives IoT Technology Adoption and Institutionalization of Solutions in Service Ecosystems. Paper presented at Annual Hawaii International Conference on System Sciences, Maui, HI, USA, January 3–6; pp. 1427–35. [CrossRef]

Akaka, Melissa, Stephen Vargo, and Hope Schau. 2015. The context of experience. *Journal of Service Management* 26: 206–23. [CrossRef]

Akaka, Melissa, Stephen Vargo, and Robert Lusch. 2013. The Complexity of Context: A Service Ecosystems Approach for International Marketing. *Journal of International Marketing* 21: 1–20. [CrossRef]

Barile, Sergio, Paolo Piciocchi, Clara Bassano, Jim Spohrer, and Maria Cristina Pietronudo. 2019. Re-defining the role of artificial intelligence (AI) in wiser service systems. *Advances in Intelligent Systems and Computing* 787: 159–70. [CrossRef] [PubMed]

Barile, Sergio, Robert Lusch, Javier Reynoso, Marialuisa Saviano, and James Spohrer. 2016. Systems, Networks, and Ecosystems in Service Research. *Journal of Service Management* 34: 1–5. [CrossRef]

Bicen, Pelin, Shelby Hunt, and Sreedhar Madhavaram. 2021. Coopetitive innovation alliance performance: Alliance competence, alliance's market orientation, and relational governance. *Journal of Business Research* 123: 23–31. [CrossRef]

Bodkhe, Umesh, Sudeep Tanwar, Karan Parekh, Pimal Khanpara, Sudhanshu Tyagi, Neeraj Kumar, and Mamoun Alazab. 2020. Blockchain for Industry 4.0: A comprehensive review. *IEEE Access* 8: 79764–800. [CrossRef]

Bouncken, Ricarda, Amit Kumar, Julia Connell, Asit Bhattacharyya, and Kai He. 2024. Coopetition for corporate responsibility and sustainability: Does it influence firm performance? *International Journal of Entrepreneurial Behavior & Research* 30: 128–54. [CrossRef]

Breidbach, Christoph, and Paul Maglio. 2015. A Service Science Perspective on the Role of ICT in Service Innovation. Paper presented at Twenty-Third European Conference on Information Systems (ECIS), Münster, Germany, May 26–29.

Brewster, Christopher, Ioanna Roussaki, Nikos Kalatzis, Kevin Doolin, and Keith Ellis. 2017. IoT in Agriculture: Designing a Europe-Wide Large-Scale Pilot. *IEEE Communications Magazine* 55: 26–33. [CrossRef]

Campbell, Norah, Aidan O'Driscoll, and Michael Saren. 2013. Reconceptualising Resources: A Critique of Service-Dominant Logic. *Journal of Macromarketing* 33: 1–16. [CrossRef]

Cardoso, Jorge, Hansjörg Fromm, Stefan Nickel, Gerhard Satzger, and Rudi Studer. 2015. *Fundamentals of Service Systems*. Edited by Jorge Cardoso, Hansjörg Fromm, Stefan Nickel, Gerhard Satzger, Rudi Studer and Christof Weinhardt. Berlin/Heidelberg: Springer International Publishing. [CrossRef]

Cellary, Wojciech, Louis E.Freund, Stephen K. Kwan, Christine Leitner, and Jim Spohrer. 2019. The Human-Side of Service Engineering: Advancing Technologies Impact on Service Innovation. In *International Conference on Applied Human Factors and Ergonomics*. Cham: Springer International Publishing, pp. 1–30.
Chandler, Jennifer, and Stephen Vargo. 2011. Contextualization and Value-in-Context: How Context Frames Exchange. *Marketing Theory* 11: 35–49. [CrossRef]
Chen, Chun-Liang. 2020. Cross-disciplinary innovations by Taiwanese manufacturing SMEs in the context of Industry 4.0. *Journal of Manufacturing Technology Management* 31: 1145–68. [CrossRef]
Coelho, Pedro, Catarina Bessa, Jorge Landeck, and Cristovão Silva. 2022. Industry 5.0: The Arising of a Concept. *Procedia Computer Science* 217: 1137–1144. [CrossRef]
Corbo, Leonardo, Sascha Kraus, Božidar Vlačić, Marina Dabić, Andrea Caputo, and Massimiliano M. Pellegrini. 2023. Coopetition and innovation: A review and research agenda. *Technovation* 122: 102624. [CrossRef]
Crick, James. 2019. The dark side of coopetition: When collaborating with competitors is harmful for company performance. *Journal of Business & Industrial Marketing* 35: 318–37. [CrossRef]
Degani, Asaf, Claudia V Goldman, Omer Deutsch, and Omer Tsimhoni. 2017. On human–machine relations. *Cognition, Technology & Work* 19: 211–31. [CrossRef]
Demirkan, Haluk, and James C. Spohrer. 2018. Commentary—Cultivating T-Shaped Professionals in the Era of Digital Transformation. *Service Science* 10: 98–109. [CrossRef]
Di Bella, Laura, Anastasis Katsinis, Jaime Lagüera-González, Ludger Odenthal, Markus Hell, and Borut Lozar. 2023. Annual Report on European SMEs 2022/2023. Available online: https://publications.jrc.ec.europa.eu/repository/handle/JRC134336 (accessed on 10 January 2024).
Doganova, Liliana, and Marie Eyquem-Renault. 2009. What do business models do? *Research Policy* 38: 1559–70. [CrossRef]
Dospinescu, Nicoleta, and Octavian Dospinescu. 2018. The Use of Information Technology Toward The Ethics of Food Safety. *Ecoforum* 7. Available online: http://www.ecoforumjournal.ro/index.php/eco/article/view/759 (accessed on 27 January 2024).
Elo, Jenny, Juuli Lumivalo, Tuure Tuunanen, and Stephen L. Vargo. 2024. Enabling Value Co-Creation in Partner Collaboration Ecosystems: An Institutional Work Perspective. Paper presented at 57th Hawaii International Conference on System Sciences, Maui, HI, USA, March; Available online: https://hdl.handle.net/10125/106412 (accessed on 27 January 2024).
Gernsheimer, Oliver, Dominik K. Kanbach, and Johanna Gast. 2021. Coopetition research—A systematic literature review on recent accomplishments and trajectories. *Industrial Marketing Management* 96: 113–34. [CrossRef]
Hadavi, Ahmad, and Sepehr Alizadehsalehi. 2024. From BIM to metaverse for AEC industry. *Automation in Construction* 160: 105248. [CrossRef]
Hoppe, Stefan. 2023. OPC Unified Architecture-Interoperability for Industrie 4.0 and the Internet of Things. Available online: https://opcfoundation.org/wp-content/uploads/2023/05/OPC-UA-Interoperability-For-Industrie4-and-IoT-EN.pdf (accessed on 10 January 2024).
Jaakkola, Elina, Valtteri Kaartemo, Jaakko Siltaloppi, and Stephen L. Vargo. 2024. Advancing service-dominant logic with systems thinking. *Journal of Business Research* 177: 114592. [CrossRef]
Jansen, Benjamin, Pieter C. J. Swinkels, Geert J. A Teeuwen, Babette Van Antwerpen de Fluiter, and Hein A. Fleuren. 2004. Operational planning of a large-scale multi-modal transportation system. *European Journal of Operational Research* 156: 41–53. [CrossRef]
Joiner, Keith, and Robert Lusch. 2016. Evolving to a new service-dominant logic for health care. *Innovation and Entrepreneurship in Health* 3: 25–33. [CrossRef]
Kahkonen, A.-K., and K. Lintukangas. 2012. The underlying potential of supply management in value creation. *Journal of Purchasing & Supply Management* 18: 68–75. [CrossRef]
Kwon, Yona, Dahee Kang, Sinji Kim, and Seungho Choi. 2020. Coopetition in the soc industry: The case of qualcomm incorporated. *Journal of Open Innovation: Technology, Market, and Complexity* 6: 9. [CrossRef]
Leal, Gabriel, Wided Guédria, and Hervé Panetto. 2019. An ontology for interoperability assessment: A systemic approach. *Journal of Industrial Information Integration* 16: 100100. [CrossRef]
Li, Shuaiyong, Chao Zhang, Liang Liu, and Xuyuntao Zhang. 2024. Gated Transient Fluctuation Dual Attention Unit Network for Long-Term Remaining Useful Life Prediction of Rotating Machinery Using IIoT. *IEEE Internet of Things Journal* 11: 18593–604. [CrossRef]
Liu, Huan, Shiyong Li, Wenzhe Li, and Wei Sun. 2024. A Distributed Resource Sharing Mechanism in Edge-Enabled IIoT Systems. *IEEE Internet of Things Journal* 11: 14296–312. [CrossRef]
Lusch, Robert F., and Satish Nambisan. 2015. Service Innovation: A Service-Dominant Logic Perspective. *MIS Quarterly* 39: 155–75. [CrossRef]
Lusch, Robert F., and Stephen Vargo. 2007. Service-dominant logic: Continuing the evolution. *Journal of the Academy of Marketing Science* 36: 1–10. [CrossRef]
Lusch, Robert F., Stephen L. Vargo, and Anders Gustafsson. 2016. Fostering a trans-disciplinary perspectives of service ecosystems. *Journal of Business Research* 69: 2957–63. [CrossRef]
Lusch, Robert F., Stephen L. Vargo, and Mohan Tanniru. 2010. Service, value networks and learning. *Journal of the Academy of Marketing Science* 38: 19–31. [CrossRef]

Machado, Susana, Lia Mergulhão, Bruno Claro Pereira, Pedro Pereira, Jorge Carvalho, José António Anacleto, Carlos Neto de Carvalho, João Belo, Ricardo Paredes, and Andrea Baucon. 2021. Geoconservation in the Cabeço da Ladeira Paleontological Site (Serras de Aire e Candeeiros Nature Park, Portugal): Exquisite Preservation of Animals and Their Behavioral Activities in a Middle Jurassic Carbonate Tidal Flat. *Geosciences* 11: 366. [CrossRef]

Maglio, Paul P., and Jim Spohrer. 2008. Fundamentals of service science. *Journal of the Academy of Marketing Science* 36: 18–20. [CrossRef]

Maglio, Paul P., Cheryl A. Kieliszewski, and James C. Spohrer. 2010. *Handbook of Service Science*. London and Cham: Springer International Publishing. [CrossRef]

Maglio, Paul P., Cheryl A. Kieliszewski, James Spohrer, Kelly Kelly, Lia Patrício, and Yuriko Sawatani. 2019. *Handbook of Service Science, Volume II: Vol. II*. Cham: Springer International Publishing.

Maglio, Paul P., Stephen Vargo, Nathan Caswell, and Jim Spohrer. 2009. The service system is the basic abstraction of service science. *Information Systems and E-Business Management* 7: 395–406. [CrossRef]

Matthies, Brent D., Dalia D'Amato, Sami Berghäll, Tommi Ekholm, Hans F. Hoen, Jani Holopainen, Jaana E. Korhonen, Katja Lähtinen, Osmo Mattila, Anne Toppinen, and et al. 2016. An ecosystem service-dominant logic?—Integrating the ecosystem service approach and the service-dominant logic. *Journal of Cleaner Production* 124: 51–64. [CrossRef]

Matzner, Martin, Marion Büttgen, Haluk Demirkan, Jim Spohrer, Steven Alter, Albrecht Fritzsche, Irene C. L. Ng, Julia M. Jonas, Veronica Martinez, Kathrin M. Möslein, and et al. 2018. Digital Transformation in Service Management. *Journal of Service Management Research* 2: 3–21. [CrossRef]

Meynhardt, Timo, Jennifer D. Chandler, and Pepe Strathoff. 2016. Systemic principles of value co-creation: Synergetics of value and service ecosystems. *Journal of Business Research* 69: 2981–89. [CrossRef]

Mosch, Philipp, Philipp Majocco, and Robert Obermaier. 2023. Contrasting value creation strategies of industrial-IoT-platforms—A multiple case study. *International Journal of Production Economics* 263: 108937. [CrossRef]

Muller, Patrice, Shaan Devnani, Rohit Ladher, James Cannings, Emily Murphy, Nick Robin, Sandra Illán, Francisco Carsa, Stefan Gorgels, Maximilian Priem, and et al. 2021. Annual Report on European SMEs (Issue July). Available online: https://op.europa.eu/en/publication-detail/-/publication/c45665ad-fd9a-11ec-b94a-01aa75ed71a1/language-en (accessed on 27 January 2024).

Ng, Irene C. L., and Susan Y. L. Wakenshaw. 2017. The Internet-of-Things: Review and research directions. *International Journal of Research in Marketing* 34: 3–21. [CrossRef]

Normann, Richard, and Rafael Ramirez. 1993. From Value Chain to Value Constellation: Designing Interactive Strategy. *Harvard Business Review* 71: 65–77. Available online: http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=9309166477&site=eds-live (accessed on 27 January 2024). [PubMed]

O'Brien, H. Michael. 2016. The Internet of Things. *Journal of Internet Law* 19: 1–20. Available online: http://biblio.uptc.edu.co:2048/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=116080288&lang=es&site=eds-live (accessed on 24 January 2024).

Pata, Arminda, and Agostinho Silva. 2022. Implementation of the SMED Methodology in a CNC Drilling Machine to Improve Its Availability. In *Innovations in Industrial Engeneering II*. Edited by J. Machado, F. Soares, J. Trojanowska, S. Yildirim, J. Vojtěšek, P. Rea, B. Gramescu and O. O. Hrybiuk. Cham: Springer International Publishing, pp. 155–63.

Pohlmann, Attila, and Valtteri Kaartemo. 2017. Research trajectories of Service-Dominant Logic: Emergent themes of a unifying paradigm in business and management. *Industrial Marketing Management* 63: 53–68. [CrossRef]

Ramírez-López, Carlos, Kevin Till, Andy Boyd, Mark Bennet, Julien Piscione, Sam Bradley, Pierosario Giuliano, Cedric Leduc, and Ben Jones. 2021. Coopetition: Cooperation among competitors to enhance applied research and drive innovation in elite sport. *British Journal of Sports Medicine* 55: 522–23. [CrossRef] [PubMed]

Reeves, Martin, Hen Lotan, Julien Legrand, and Michael G. Jacobides. 2019. How Business Ecosystems Rise (and Often Fall). *MIT Sloan Management Review* 60: 1–6.

Rouyre, Audrey, Anne-Sophie Fernandez, and Olga Bruyaka. 2024. Big problems require large collective actions: Managing multilateral coopetition in strategic innovation networks. *Technovation* 132: 102968. [CrossRef]

Rusko, Rauno. 2014. Mapping the perspectives of coopetition and technology-based strategic networks: A case of smartphones. *Industrial Marketing Management* 43: 801–12. [CrossRef]

Salih, Kazhan Othman Mohammed, Tarik A. Rashid, Darlibor Radovanovic, and Nebojsa Bacanin. 2022. A Comprehensive Survey on the Internet of Things with the Industrial Marketplace. *Sensors* 22: 730. [CrossRef]

Seepana, Chandrasekararao, Antony Paulraj, and Fahian A. Huq. 2020. The architecture of coopetition: Strategic intent, ambidextrous managers, and knowledge sharing. *Industrial Marketing Management* 91: 100–13. [CrossRef]

Serror, Martin, Sacha Hack, Martin Henze, Marko Schuba, and Klaus Wehrle. 2021. Challenges and Opportunities in Securing the Industrial Internet of Things. *IEEE Transactions on Industrial Informatics* 17: 2985–96. [CrossRef]

Silva, Agostinho da, and A. Marques Cardoso. 2023. BIM-Based Supply Chain in AEC-Threats on the Portuguese Stone sector. Paper presented at 7th Globalstone Congress, Batalha, Portugal, June 18–23; ISBN 978-972-778-327-4. Available online: https://repositorio.lneg.pt/bitstream/10400.9/4150/1/GSC2023_PT%20Natural%20Stones-Commercial%20Names%20harmonization.pdf (accessed on 18 December 2023).

Silva, Agostinho da, and Arminda Pata. 2022. Value Creation in Technology Service Ecosystems-Empirical Case Study. In *Innovations in Industrial Engeneering II*. Edited by José Machado, Filomena Soares, Justyna Trojanowska, Vitalii Ivanov, Katarzyna Antosz, Yi Ren, Vijaya K. Manupati and Alejandro Pereira. Cham: Springer International Publishing, pp. 26–36.

Silva, Agostinho da, and Maria Gil. 2020. Industrial processes optimization in digital marketplace context: A case study in ornamental stone sector. *Results in Engineering* 7: 100152. [CrossRef]
Silva, Agostinho da, Carlos Rabadão, and Carlos Capela. 2020. Towards Industry 4.0 | A case study of BIM deployment in ornamental stones sector. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)* 67: 24535.
Silva, Agostinho da, J.M. Vilas-Boas da Silva, and Isabel Duarte de Almeida. 2016. The role of digital technologies in the innovation of collaborative networks: The case of the ornamental stones in Portugal. Paper presented at 20th Cambridge International Manufacturing Symposium, Cambridge, UK, September 29.
UN. 2019. *The Sustainable Development Goals Report-United Nations*. San Francisco: UN.
Vargo, Stephen L., and Melissa A. Akaka. 2009. Service-Dominant Logic as a Foundation for Service Science: Clarifications. *Service Science* 1: 32–41. [CrossRef]
Vargo, Stephen L., and Robert F. Lusch. 2004. Evolving to a New Dominant Logic for Marketing. *Journal of Marketing* 68: 1–17. [CrossRef]
Vargo, Stephen L., and Robert F. Lusch. 2016. Institutions and axioms: An extension and update of service-dominant logic. *Journal of the Academy of Marketing Science* 44: 5–23. [CrossRef]
Vargo, Stephen L., Heiko Wieland, and Matthew O'Brien. 2023a. Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline. *Journal of Business Research* 164: 113965. [CrossRef]
Vargo, Stephen L., Julia A. Fehrer, Heiko Wieland, and Angeline Nariswari. 2024. The nature and fundamental elements of digital service innovation. *Journal of Service Management* 35: 227–52. [CrossRef]
Vargo, Stephen L., Linda Peters, Hans Kjellberg, Kaisa Koskela-Huotari, Suvi Nenonen, Francesco Polese, Debora Sarno, and Claudia Vaughan. 2023b. Emergence in marketing: An institutional and ecosystem framework. *Journal of the Academy of Marketing Science* 51: 2–22. [CrossRef]
Vargo, Stephen L., Melissa A. Akaka, and Heiko Wieland. 2020. Rethinking the process of diffusion in innovation: A service-ecosystems and institutional perspective. *Journal of Business Research* 116: 526–34. [CrossRef]
Wang, Ming-Chao, and Ja-Shen Chen. 2022. Driving coopetition strategy to service innovation: The moderating role of coopetition recognition. *Review of Managerial Science* 16: 1471–501. [CrossRef]
Xie, Qiuhao, Ying Gao, Nini Xia, Shuibo Zhang, and Guowu Tao. 2023. Coopetition and organizational performance outcomes: A meta-analysis of the main and moderator effects. *Journal of Business Research* 154: 113363. [CrossRef]
Yazdinejad, Abbas, Behrouz Zolfaghari, Ali Dehghantanha, Hadis Karimipour, Gautam Srivastava, and Reza Parizi. 2023a. Accurate threat hunting in industrial internet of things edge devices. *Digital Communications and Networks* 9: 1123–30. [CrossRef]
Yazdinejad, Abbas, Mostafa Kazemi, Reza M. Parizi, Ali Dehghantanha, and Hadis Karimipour. 2023b. An ensemble deep learning model for cyber threat hunting in industrial internet of things. *Digital Communications and Networks* 9: 101–10. [CrossRef]
Yun, JinHyo Joseph, Xiaofei Zhao, Giovanna Del Gaudio, Valentina Della Corte, and Yuri Sadoi. 2023. Leveraging business model innovation through the dynamics of open innovation: A multi-country investigation in the restaurant industry. *European Journal of Innovation Management* 31: 814–31. [CrossRef]
Zott, Christoph, and Raphael Amit. 2008. The fit between product market strategy and business model: Implications for firm performance. *Strategic Management Journal* 29: 1–26. [CrossRef]
Zott, Christoph, Raphael Amit, and Lorenzo Massa. 2011. The Business Model: Recent Developments and Future Research. *Journal of Management* 37: 1019–42. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 253 (2025) 227–236

Procedia Computer Science

www.elsevier.com/locate/procedia

6th International Conference on Industry 4.0 and Smart Manufacturing

Industrial Internet of Things-Driven Coopetition Networks for SMEs

Agostinho da Silva[a,b,*] Antonio J. Marques Cardoso[a]

[a] *CISE - Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal*
[b] *CIGEST – Business & Economics School, Lisboa, Portugal*

(*) a.silva@zipor.com

Abstract

This research explores the dynamics of coopetition networks among small and medium enterprises (SMEs), particularly highlighting the role of technological innovation through the Industrial Internet of Things (IIoT) in enhancing the sustainability and resilience of these networks. Despite extensive studies on SME coopetition networks, a significant research gap exists regarding how IIoT can specifically bolster these networks. This study aims to address this gap by investigating how this technology can facilitate coopetition among SMEs, anchored in the Service-Dominant Logic (S-D Logic) framework that emphasizes a service-centric value cocreation perspective. The research employs a Service Design approach to conduct an in-depth analysis of nine ornamental stone SMEs, examining various stages of customer interaction and documenting the impact of different market approach strategies on business outcomes. Utilizing the Service Blueprint tool, the study identifies a clear divergence in outcomes based on these strategies. Independent companies often fail to close deals, highlighting a critical challenge in achieving market success. Conversely, firms collaborating with rivals secured deals but encountered post-sale disputes, negatively impacting customer satisfaction. Significantly, companies integrated into a coopetition network supported by an IIoT-based system successfully closed deals and maintained harmonious relations with rivals and customers. It illustrates the capacity of IIoT technology to enable effective coopetition in SME networks. Despite its focus on a specific sector and a limited sample size, this study lays the foundation for future research on the scalability of technology-enabled coopetition models and their long-term impacts on SME performance and customer relationships.

© 2025 The Authors. Published by Elsevier B.V.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0)
Peer-review under responsibility of the scientific committee of the 6th International Conference on Industry 4.0 and Smart Manufacturing

Keywords: Coopetition; Service Blueprint; S-D Logic; Industrial Internet of Things; Networks

1877-0509 © 2025 The Authors. Published by Elsevier B.V.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0)
Peer-review under responsibility of the scientific committee of the 6th International Conference on Industry 4.0 and Smart Manufacturing
10.1016/j.procs.2025.01.086

1. Introduction

SMEs are heralded as the economic bedrock of the European Union [1]. To face challenges from the global market, SMEs are increasingly pushed to cooperate with rivals in coopetition networks [2] [3] to leverage scale, access strategic resources, and foster inter-organizational synergies [4]. This strategic blend is crucial for enhancing competitiveness and spurring innovation in the global economic arena [5].

Recent scholarly work has highlighted a pressing need for comprehensive investigations into the role of technological innovations in enhancing the sustainability of coopetition networks over extended periods [6]. Concurrently, research conducted by the BCG Henderson Institute and published in the MIT Sloan Management Review (2019) casts a spotlight on the inherent vulnerabilities of coopetition networks centred around SMEs, particularly emphasizing their struggle to achieve long-term sustainability in the absence of market-leading firms [7]. This scenario underscores a critical research gap: the imperative to devise strategies focusing on technological interventions to reinforce the durability and resilience of these coopetition networks.

S-D Logic provides an essential framework for this exploration, advocating a shift towards a service-centric model of value exchange and co-creation within networks. This paradigm is increasingly vital against evolving global supply chains and the push for service innovation [8] [9]. In this context, the Industrial Internet of Things (IIoT) emerges as a potential game-changer, offering to revolutionize industrial settings through smart technologies that enhance efficiency and facilitate informed decision-making [10]. Its application, particularly in real-time monitoring systems, can significantly uplift SMEs' production processes and collaboration efficiency [11].

Aiming to fill the identified research gap, using a Service Design approach, this study sets forth to (1) Introduce an advanced IIoT solution tailored for the ornamental stone sector; (2) elevate this technological framework to foster effective coopetition among SMEs; (3) apply the Service Blueprint methodology for a proof of concept within a cohort of Portuguese stone SMEs, demonstrating the potential of IIoT to support a resilient coopetition network of nine SMEs.

This investigation aspires to enrich the dialogue surrounding coopetition dynamics, the applicability of S-D Logic, and the integration of IIoT within SME networks. It seeks to provide novel insights into the intricacies of value co-creation and competitive strategy through the lens of coopetition. Practically, it aims to equip SMEs with strategies to navigate and thrive within technology-enabled coopetition networks, thereby enhancing their competitive stance and operational effectiveness.

2. Literature Review

The S-D Logic view of coopetition, particularly its relevance to SMEs, enriches the conversation around the evolution of market dynamics and competition [12]. By embracing the foundational principles introduced by Frederick Bastiat in 1848, which emphasized the notion of "services exchanging for services," S-D Logic provides a framework that transcends the traditional goods-centric model of economic exchange [13]. This perspective was significantly advanced by Vargo and Lusch in 2004, advocating for a marketing paradigm that pivots towards the intangible benefits derived from goods, positioning products as vehicles for service delivery [14]. This shift highlights the importance of the benefits and outcomes that customers experience from using a product rather than the physical product itself [15].

Within this framework, S-D Logic emphasizes the role of specialized competencies - knowledge and skills - applied for the benefit of others, proposing a nuanced understanding of economic exchanges as processes of co-creation [16] It posits that value emerges from the interactions among various actors, leveraging both operant resources (such as people and organizations) and operand resources (including technologies and knowledge) in the service exchange process [17].

This viewpoint is particularly relevant for SMEs. It suggests a strategic approach to navigating competitive landscapes beyond merely offering products. SMEs are encouraged to engage in meaningful service exchanges, applying their unique competencies to create value in collaboration with customers and other stakeholders [18]. This approach aligns with the coopetition model by highlighting the potential for SMEs to simultaneously compete and collaborate within their ecosystems, leveraging shared knowledge and technologies to enhance their value propositions [12].

By adopting a value cocreation perspective, SMEs can better understand the importance of integrating into broader service ecosystems, where coopetition can catalyze innovation and value creation. This integration facilitates access to new resources and markets and enables SMEs to differentiate themselves through their unique services [19]. The emphasis on co-creating value through interactions with various actors within these ecosystems encourages SMEs to

adopt more collaborative and adaptive strategies, ensuring their competitive advantage and sustainability in the rapidly evolving economic landscape.

In a coopetition network environment, the intricate balance between competition and collaboration among actors within the service delivery process introduces a nuanced layer of interaction essential for the vitality of service ecosystems [5]. This blend of cooperation and rivalry underpins the dynamic nature of these ecosystems, as outlined by Vargo and Lusch (2016). Through the lens of service ecosystems [20], a coopetition network is envisioned as an intricate matrix of relationships where providers not only engage directly with consumers but also navigate a complex relationship with competitors [17]. This interaction is characterized by a blend of overt collaboration and subtle competition, fostering a network enriched by the coordinated integration of resources among both providers and competitors [21]. Technological advancements often propel such integration. It is framed within a structure governed by shared norms, rules, expectations, and practices, which orchestrate the collaborative and competitive dynamics within the ecosystem [19].

In the service ecosystem's light, the governance of these networks through such institutional arrangements ensures that, despite inherent competitive tensions, there is a concerted effort of mutual value creation. This is driven by pursuing mutual benefits and fulfilling all participants' expectations [17]. Viewing coopetition networks through the prism of service ecosystems accentuates their nature as dynamic and adaptable systems [22]. It underscores how the interplay between competition and stakeholder collaboration fosters an environment ripe for value co-creation and reciprocal advantages. Manufacturing SMEs can meld their distinctive competencies and resources with those of others, paving the way for a synergistic value creation that surpasses what could be attained in isolation.

To explore how the IIoT can enhance coopetition networks among SMEs, this paper is organized as follows: Section 2 reviews the existing literature on SME coopetition networks and highlights the research gap. Section 3 discusses the theoretical foundations of IIoT [23]. Section 4 outlines the methodology, including our use of the Service Design approach and the Service Blueprint tool. Section 5 presents a proof of concept in the Portuguese ornamental stone sector. Section 6 covers the results and discussion, examining the impact of IIoT on business outcomes and customer satisfaction. Finally, Section 7 concludes the paper by summarizing findings and suggesting directions for future research.

3. Theoretical Underpinnings of Industrial Internet of Things (IIoT)

The journey from the initial concept of the Internet of Things (IoT) to the advanced realm of the Industrial IIoT represents a significant technological evolution. Kevin Ashton, while at Procter & Gamble and later MIT's Auto-ID Center, first introduced the IoT concept in 1998, envisioning a world where all objects could be integrated into the Internet, forming a vast network of interconnected devices [24]. This vision has expanded over the past two decades. IIoT incorporates wireless communication, sensors, and enhanced computing power fundamentally transforming object interactions within the digital ecosystem [25].

This transformative journey is particularly pronounced in IIoT, where the interconnectivity of devices is revolutionizing traditional industrial practices [26]. The IIoT builds upon the foundational principles of IoT, focusing on creating intelligent, self-regulating, and interconnected industrial processes. This advancement elevates the manufacturing sector's competitiveness by amalgamating various technologies into a unified IP-based network, repurposing them for advanced industrial applications [27].

A key aspect of IIoT's functionality is the establishment of standard, meaningful communication protocols, like Ethernet [28], which underscores the importance of interoperability for maximizing operational utility [29]. In this context, the S-D logic becomes particularly relevant. S-D logic, emphasizing value cocreation involving various actors, aligns closely with the interconnected ecosystems facilitated by IIoT technologies [30]. IIoT exemplifies S-D logic by merging the Internet's global reach with industrial capabilities, thus facilitating control, coordination, and management across physical domains, creating a dynamic service environment [31].

Recent IIoT advancements significantly boost operational efficiency and enhance decision-making capabilities through data-driven insights [32] [10]. Arguably serving as a pivotal force for transformation within networks, IIoT embodies the S-D Logic foundations, which prioritizes value creation through collaborative engagement and actor-centric arrangements [33]. A prime example of IIoT's application is its real-time monitoring and improving systems deployment. These systems empower SMEs by optimizing production processes and facilitating more effective collaboration with partners, thus exemplifying the practical benefits of IIoT in enhancing inter-organizational synergy [29].

4. Methodology

This study employs a Service Design approach to analyze coopetition networks among SMEs, utilizing the Service Blueprint as a key tool. Service Design focuses on improving customer experiences by understanding user needs and refining service processes [34]. The Service Blueprint maps out service processes in detail, allowing for the visualization of interactions between customers and service providers, as well as internal organizational functions [35].

Initially proposed by Shostack (1982) and refined by Kingman-Brundage (1989), the Service Blueprint distinguishes between frontstage and back-stage activities through three conceptual lines [36]: the line of interaction, the line of internal interaction, and the line of execution. This framework enables service providers to optimize their delivery by organizing service actions and facilitating a clear understanding of process control [37].

In modern digital and coopetition network contexts, the Service Blueprint must be adapted to include digital interconnectivity and collaborative elements among shop floors, value chains, suppliers, and customers [38]. This adaptation is crucial for supporting sustainable growth and innovation in technology-enabled networks, highlighting strategic decisions for digital transformation while preserving the blueprint's core structure.

Through the lens of S-D Logic, service providers are viewed as co-creators of value, integrating offerings into customers' lives and fostering value co-creation through digital technologies [33]. This paradigm shift emphasizes personalized products and customer-involved production processes [39].

Coopetition, the strategic blend of collaboration and competition, involves providers collaborating while engaging in competitive interactions [5] (Bicen et al., 2021). The digital economy leverages specific technologies to facilitate resource sharing, balancing cooperative benefits with competitive pressures [40]. From an S-D Logic perspective, coopetitors are integral to the network's resource pool, enhancing the capacity for value co-creation and competitive advantage.

5. Proof of concept in the Portuguese Ornamental Stone Sector

The Cockpit4.0 system, a pioneering outcome of the Inovmineral4.0 R&D Project [41], has emerged as a fundamental technological breakthrough in processing ornamental stones. Silva et al. (2020) recognize it as the zenith of innovation in its field, with widespread adoption among Europe's premier stone companies underscoring its industry-leading status[42]. At the core of Cockpit4.0 is the revolutionary fingerprint4.0 feature, a central repository of product specifications crucial for capturing the synergistic value creation between customers and providers [39]. This distinctive feature does more than streamline resource integration; it also enables the development of personalized value propositions for digital customers, converting static data into dynamic, intelligent responses [43]. Through this transformation, Cockpit4.0 redefines customer engagement in the ornamental stone industry, showcasing the power of digital innovation in enhancing product value and customer experience.

Examined from an S-D Logic perspective, Cockpit4.0 transcends being a mere technological solution, evolving into a comprehensive ecosystem of cyber-physical offerings. It harmonizes diverse capabilities, fostering the delivery of context-aware, on-demand services that are responsive to the specific needs of users. Following the methodological insights of Peffers et al. (2007), the Cockpit4.0 framework has undergone a technological evolution, culminating in the development of Cockpit4.0+ [44]. This iteration represents a significant leap in functionality, enhancing the system's capacity to support SMEs in establishing more dynamic and effective coopetition relationships within their networks. By augmenting the foundational strengths of Cockpit4.0, Cockpit4.0+ paves the way for a more integrated and efficient paradigm of value creation among networked SMEs, embodying the essence of collaborative competitiveness in the digital age.

The integration of OPC UA (Object Process Control Unified Architecture), a premier machine-to-machine communication protocol tailored for industrial automation, signifies a pivotal advancement in developing the Cockpit4.0+ system. Designed for standardization and security, OPC UA facilitates seamless data exchange among devices, machines, and systems across the industrial spectrum. This strategic inclusion in Cockpit4.0+ is a cornerstone of the system’s validation process, enhancing its capacity for secure and efficient communication.

The advent of fingerprint4.0+ within Cockpit4.0+ introduces an advanced feature set that caters to customers and coopetitors. This feature extends beyond product specifications to encompass comprehensive information on the ecological footprint, lifecycle, recycling processes, and regulatory compliance. Such enhancements address the growing market imperative for sustainability, regulation adherence, and product functionality. By adopting a

transparent approach, Cockpit4.0+ ensures that all stakeholders - customers, coopetitors, regulatory bodies, and process providers - can thoroughly evaluate and affirm the product's value proposition.
This collaborative validation mechanism, underpinned by transparency, is designed to meet the diverse needs and expectations of the network's participants. It establishes a robust foundation of trust and cooperation, essential for the sustained success and integration of the Cockpit4.0+ system within coopetition networks.

5.1 Population, Resource Uniformity and Variance

The ornamental stone sector, predominantly composed of SMEs, is a cornerstone of the Portuguese economy. According to the Portuguese Stone Federation (2022), it generates over 16,600 direct jobs and is a primary private job creator in inland regions. Despite various challenges, the sector has shown a robust growth trajectory in exports, making Portugal the eighth-largest player in international ornamental stone trade and second in per capita trade.
An examination of the sector reveals uniformity like resources across stone companies, forming the basis of the research population. The primary distinction lies in the scale of resources, observed mainly in terms of company size, with significant variations among enterprises. Similarly, while the customer base remains consistent, their requirements and interactions with the companies differ, influenced by each enterprise's scale and capabilities. This uniformity and variance underline the need to understand the specific resource dimensions in each company, which is crucial for accurately mapping the Service Blueprint and understanding how different actors and resource configurations impact the service process. This understanding also sheds light on value creation within the stone sector, an industry with unique characteristics and challenges.

5.2. Sample Selection Criteria

For this study, companies were intentionally selected from the ornamental stone sector, focusing on those engaged in actual orders and data observed in real-time. The primary selection criterion was the company's status as an SME in stone processing. Additional criteria included the ability to lead and execute orders within the research timeframe, digital maturity, shopfloor operations, and willingness to participate in the study. Consequently, nine companies were chosen, agreeing to collaborate while maintaining commercial confidentiality.
The First Group included ornamental stone companies typically operating independently. A commercial opportunity was tracked for each company, with outcomes initially recorded in Excel and later transferred to service blueprint charts. In the Second Group, companies approach the market independently or in partnership with rivals, depending on the opportunity size. A commercial opportunity involving partnership competition was chosen for each, and outcomes were recorded similarly. In the Third Group, companies agreed to integrate into a coopetition network supported by the Cockpit4.0+ prototype. For each, a commercial opportunity leveraging the coopetition network for real-time resource access was followed, with outcomes documented as before.

5.3. Stone Provider Resource in Coopetition Networks

A comprehensive understanding of resource utilization across service provision stages is paramount in digitally mature ornamental stone companies. Applying the S-D Logic view identified three primary stages of resource allocation: Cyber Frontstage, Physical Backstage, and Support-stage. This tripartite categorization elucidates resource deployment and management, underpinning efficient service delivery and value co-creation.
Cyber Frontstage Resources: (1) Frontstage Human Resources: These are operant, physical-with-rights resources encompassing staff directly engaging with customers, competitors, or authorities, embodying the company's interactive front [45]; (2) Frontstage Operant Technologies: Non-physical, initiator-based technologies without rights, such as algorithms powering cognitive assistants and smart object creation, drive digital engagement and innovation [17]; and (3) Frontstage Operand Technologies: Facilitative, non-physical technologies without rights, including software applications, dialogue interfaces, web libraries, and messaging platforms, support seamless digital communication [25].
Physical Back-stage Resources: (1) Backstage Human Resources - physical-with-rights, operant human resources involved in behind-the-scenes interactions and collaborations, essential for digital market engagement and customer support [46]; (2) Backstage Operant Technologies - physical, initiator-based technologies without rights, such as smart production machinery, enhance operational efficiency and innovation on the shopfloor [19]; and (3) Backstage

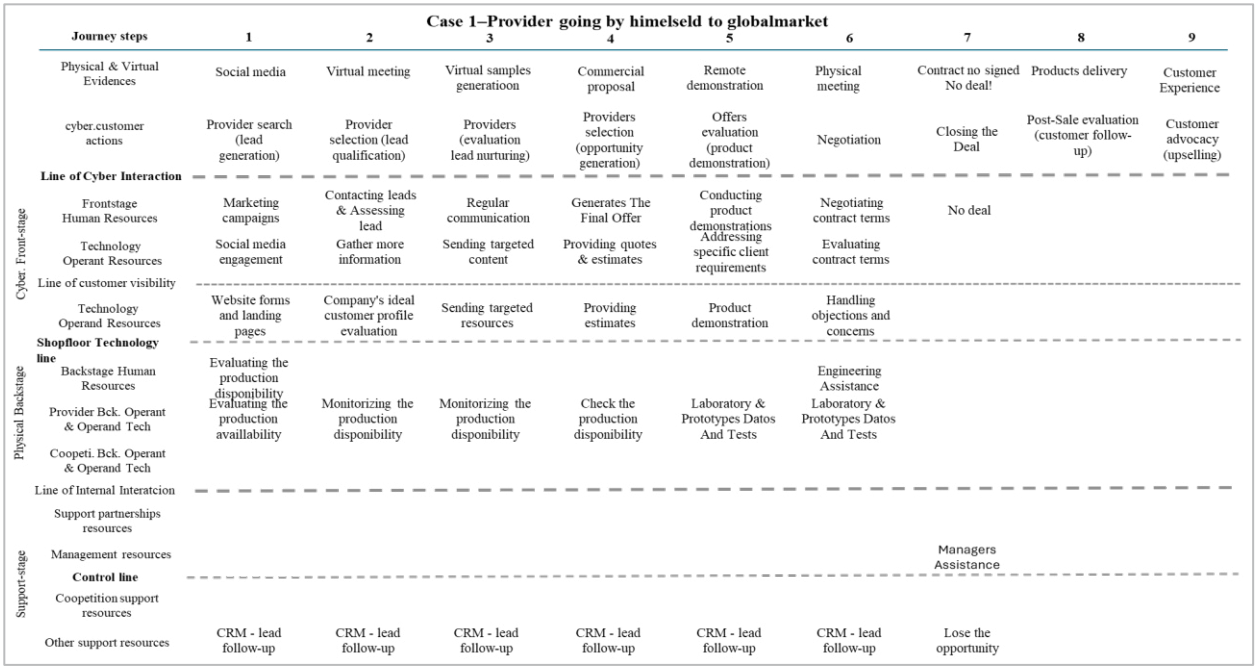
Operand Technologies - physical shopfloor technologies and intelligent machines, categorized as without rights, facilitate interconnectivity and sharing among production resources [5].
Support-stage Resources: (1) Support Human Resources - physical-with-rights, operant resources, including shopfloor personnel managing production and logistics, crucial for operational execution [47]; (2) Support Partnerships Resources - non-physical-with-rights entities, encompassing public and private collaborators that contribute to the company's objectives on various fronts; and, (3) Technology-Enabled Know-How and Shareable Information - non-physical resources without rights, like patents, technology transfers, and cross-fertilization initiatives, alongside coopetition ecosystem expertise, fuel innovation and knowledge sharing.

5.4. Stone Coopetitor Resources in the Coopetition Networks

In the ornamental stone sector, coopetitors are key players within coopetition networks, engaging in mutually sharing and integrating resources to enhance value co-creation and competitive advantage (Raza-Ullah et al., 2014). These networks rely on three categories of resources that support the collaborative process.
Cyber frontstage resources consist of digital platforms and technologies that facilitate direct interactions with customers and other network members. These tools enable communication, negotiation, and management, ensuring that coopetitors effectively fulfil their roles within the ecosystem.
Physical back-stage resources include tangible assets such as machinery, equipment, and human resources that support the service process by handling operational tasks behind the scenes. These elements provide the necessary infrastructure for the network's operations.
Support-stage resources encompass external partnerships, specialized knowledge, and access to advanced technologies. These resources help maintain the network's functionality and allow coopetitors to remain agile and innovative in an evolving industry landscape. By integrating these diverse resources, coopetitors in the ornamental stone sector actively contribute to and enhance the value co-creation process. Their collaborative efforts and resource sharing are crucial to amplifying competitiveness, driving long-term growth, and ensuring the sector's sustainability.

6. Results and Discussion

The study of nine ornamental stone companies unveils insightful patterns across distinct commercial opportunities, categorized into nine stages of customer interaction ranging from the initial provider search to customer advocacy. From June to November 2023, this comprehensive examination captured a wealth of data on each interaction stage, including physical and virtual evidence, the resources deployed, and the resultant outcomes. This data was documented in an Excel file and later articulated through service blueprint charts.
Companies operating autonomously exhibited a recurring outcome at the 'Closing the Deal' stage, consistently resulting in 'no deal'. As illustrated in the Service Blueprint (Figure 1), this outcome signals a systemic inability among these companies to clinch opportunities, highlighting a significant challenge in securing deals when navigating the market solo.

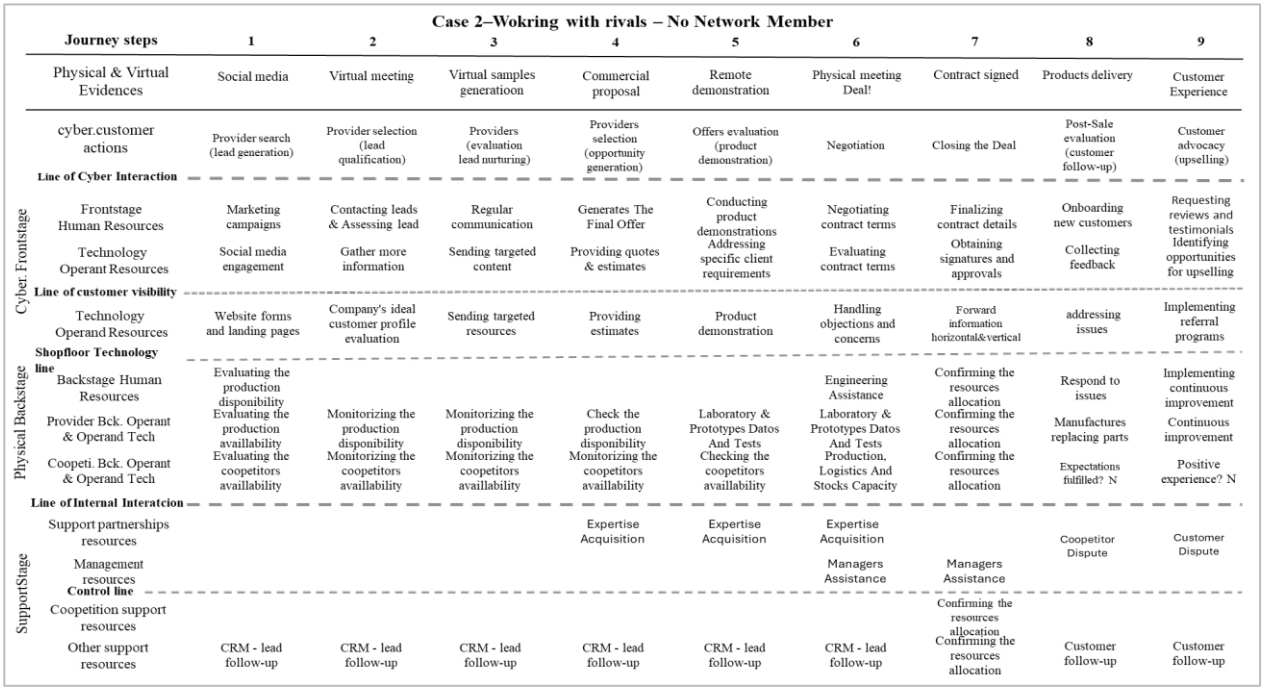


Case 1–Provider going by himelseld to globalmarket

	Journey steps	1	2	3	4	5	6	7	8	9
	Physical & Virtual Evidences	Social media	Virtual meeting	Virtual samples generatioon	Commercial proposal	Remote demonstration	Physical meeting	Contract no signed No deal!	Products delivery	Customer Experience
	cyber.customer actions	Provider search (lead generation)	Provider selection (lead qualification)	Providers (evaluation lead nurturing)	Providers selection (opportunity generation)	Offers evaluation (product demonstration)	Negotiation	Closing the Deal	Post-Sale evaluation (customer follow-up)	Customer advocacy (upselling)
	Line of Cyber Interaction									
Cyber. Front-stage	Frontstage Human Resources	Marketing campaigns	Contacting leads & Assessing lead	Regular communication	Generates The Final Offer	Conducting product demonstrations	Negotiating contract terms	No deal		
Cyber. Front-stage	Technology Operant Resources	Social media engagement	Gather more information	Sending targeted content	Providing quotes & estimates	Addressing specific client requirements	Evaluating contract terms			
Cyber. Front-stage	Line of customer visibility									
Cyber. Front-stage	Technology Operand Resources	Website forms and landing pages	Company's ideal customer profile evaluation	Sending targeted resources	Providing estimates	Product demonstration	Handling objections and concerns			
	Shopfloor Technology line									
Physical Backstage	Backstage Human Resources	Evaluating the production disponibility					Engineering Assistance			
Physical Backstage	Provider Bck. Operant & Operand Tech	Evaluating the production availlability	Monitorizing the production disponibility	Monitorizing the production disponibility	Check the production disponibility	Laboratory & Prototypes Datos And Tests	Laboratory & Prototypes Datos And Tests			
Physical Backstage	Coopeti. Bck. Operant & Operand Tech									
	Line of Internal Interatcion									
Support-stage	Support partnerships resources									
Support-stage	Management resources							Managers Assistance		
Support-stage	**Control line**									
Support-stage	Coopetition support resources									
Support-stage	Other support resources	CRM - lead follow-up	CRM - lead follow-up	CRM - lead follow-up	CRM - lead follow-up	CRM - lead follow-up	CRM - lead follow-up	Lose the opportunity		

Figure 1. Findings from Independent Market Approach (First Group)

The second group, characterized by companies partnering with rivals for more considerable opportunities yet to integrate into the Cockpit4.0+ supported network, demonstrated a distinct pattern. While they succeeded in securing deals, as depicted in the Service Blueprint (Figure 2), the 'Post-Sale Evaluation' stage often led to disputes with partners, negatively impacting the customer experience, as observed in the concluding stage.

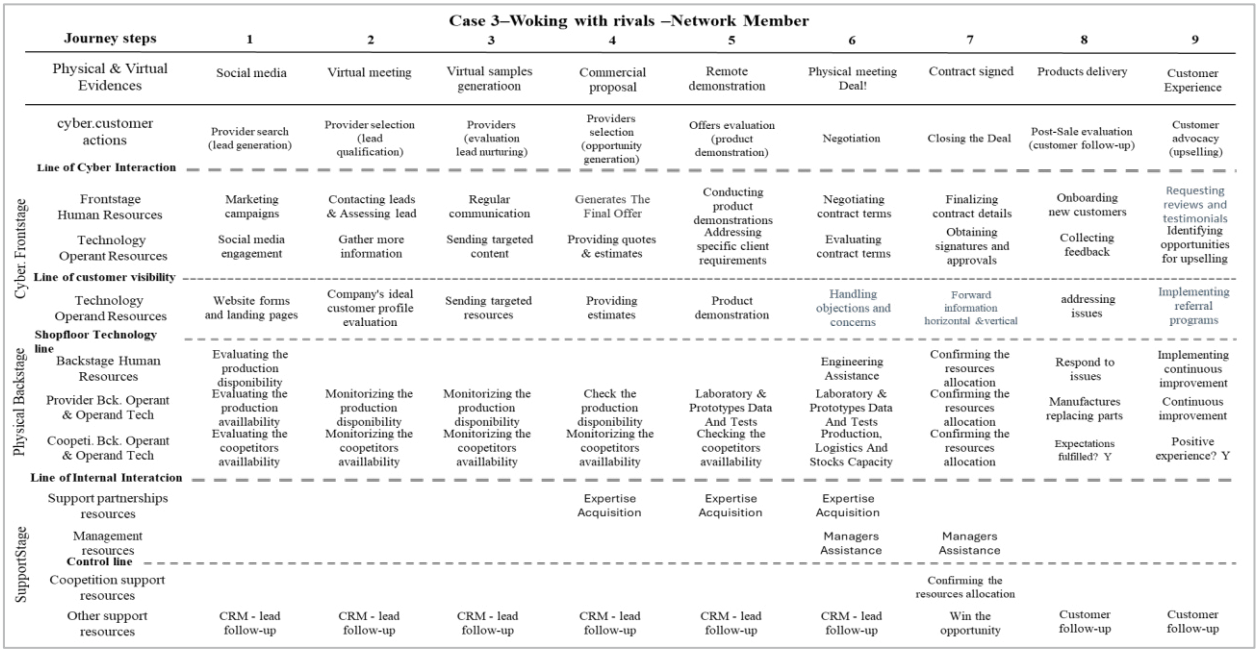


Case 2–Wokring with rivals – No Network Member

	Journey steps	1	2	3	4	5	6	7	8	9
	Physical & Virtual Evidences	Social media	Virtual meeting	Virtual samples generatioon	Commercial proposal	Remote demonstration	Physical meeting Deal!	Contract signed	Products delivery	Customer Experience
	cyber.customer actions	Provider search (lead generation)	Provider selection (lead qualification)	Providers (evaluation lead nurturing)	Providers selection (opportunity generation)	Offers evaluation (product demonstration)	Negotiation	Closing the Deal	Post-Sale evaluation (customer follow-up)	Customer advocacy (upselling)
	Line of Cyber Interaction									
Cyber. Frontstage	Frontstage Human Resources	Marketing campaigns	Contacting leads & Assessing lead	Regular communication	Generates The Final Offer	Conducting product demonstrations	Negotiating contract terms	Finalizing contract details	Onboarding new customers	Requesting reviews and testimonials
Cyber. Frontstage	Technology Operant Resources	Social media engagement	Gather more information	Sending targeted content	Providing quotes & estimates	Addressing specific client requirements	Evaluating contract terms	Obtaining signatures and approvals	Collecting feedback	Identifying opportunities for upselling
Cyber. Frontstage	**Line of customer visibility**									
Cyber. Frontstage	Technology Operand Resources	Website forms and landing pages	Company's ideal customer profile evaluation	Sending targeted resources	Providing estimates	Product demonstration	Handling objections and concerns	Forward information horizontal&vertical	addressing issues	Implementing referral programs
	Shopfloor Technology line									
Physical Backstage	Backstage Human Resources	Evaluating the production disponibility					Engineering Assistance	Confirming the resources allocation	Respond to issues	Implementing continuous improvement
Physical Backstage	Provider Bck. Operant & Operand Tech	Evaluating the production availlability	Monitorizing the production disponibility	Monitorizing the production disponibility	Check the production disponibility	Laboratory & Prototypes Datos And Tests	Laboratory & Prototypes Datos And Tests	Confirming the resources allocation	Manufactures replacing parts	Continuous improvement
Physical Backstage	Coopeti. Bck. Operant & Operand Tech	Evaluating the coopetitors availlability	Monitorizing the coopetitors availlability	Monitorizing the coopetitors availlability	Monitorizing the coopetitors availlability	Checking the coopetitors availlability	Production, Logistics And Stocks Capacity	Confirming the resources allocation	Expectations fulfilled? N	Positive experience? N
	Line of Internal Interatcion									
SupportStage	Support partnerships resources				Expertise Acquisition	Expertise Acquisition	Expertise Acquisition		Coopetitor Dispute	Customer Dispute
SupportStage	Management resources						Managers Assistance	Managers Assistance		
SupportStage	**Control line**									
SupportStage	Coopetition support resources							Confirming the resources allocation		
SupportStage	Other support resources	CRM - lead follow-up	CRM - lead follow-up	CRM - lead follow-up	CRM - lead follow-up	CRM - lead follow-up	CRM - lead follow-up	Confirming the resources allocation	Customer follow-up	Customer follow-up

Figure 2. Findings from Partnership with Rivals (Second Group)

In the third group, companies that embraced integration into the Cockpit4.0+ supported coopetition network showcased the most advantageous outcomes. The Service Blueprint (Figure 3) reveals that these companies not only consistently secured opportunities but also maintained amicable relations with rivals, culminating in a positive customer experience throughout the engagement process.



Case 3–Woking with rivals –Network Member

	Journey steps	1	2	3	4	5	6	7	8	9
	Physical & Virtual Evidences	Social media	Virtual meeting	Virtual samples generatioon	Commercial proposal	Remote demonstration	Physical meeting Deal!	Contract signed	Products delivery	Customer Experience
	cyber.customer actions	Provider search (lead generation)	Provider selection (lead qualification)	Providers (evaluation lead nurturing)	Providers selection (opportunity generation)	Offers evaluation (product demonstration)	Negotiation	Closing the Deal	Post-Sale evaluation (customer follow-up)	Customer advocacy (upselling)
	Line of Cyber Interaction									
Cyber. Frontstage	Frontstage Human Resources	Marketing campaigns	Contacting leads & Assessing lead	Regular communication	Generates The Final Offer	Conducting product demonstrations	Negotiating contract terms	Finalizing contract details	Onboarding new customers	Requesting reviews and testimonials
Cyber. Frontstage	Technology Operant Resources	Social media engagement	Gather more information	Sending targeted content	Providing quotes & estimates	Addressing specific client requirements	Evaluating contract terms	Obtaining signatures and approvals	Collecting feedback	Identifying opportunities for upselling
Cyber. Frontstage	**Line of customer visibility**									
Cyber. Frontstage	Technology Operand Resources	Website forms and landing pages	Company's ideal customer profile evaluation	Sending targeted resources	Providing estimates	Product demonstration	Handling objections and concerns	Forward information horizontal &vertical	addressing issues	Implementing referral programs
	Shopfloor Technology line									
Physical Backstage	Backstage Human Resources	Evaluating the production disponibility					Engineering Assistance	Confirming the resources allocation	Respond to issues	Implementing continuous improvement
Physical Backstage	Provider Bck. Operant & Operand Tech	Evaluating the production availlability	Monitorizing the production disponibility	Monitorizing the production disponibility	Check the production disponibility	Laboratory & Prototypes Data And Tests	Laboratory & Prototypes Data And Tests	Confirming the resources allocation	Manufactures replacing parts	Continuous improvement
Physical Backstage	Coopeti. Bck. Operant & Operand Tech	Evaluating the coopetitors availlability	Monitorizing the coopetitors availlability	Monitorizing the coopetitors availlability	Monitorizing the coopetitors availlability	Checking the coopetitors availlability	Production, Logistics And Stocks Capacity	Confirming the resources allocation	Expectations fulfilled? Y	Positive experience? Y
	Line of Internal Interatcion									
SupportStage	Support partnerships resources				Expertise Acquisition	Expertise Acquisition	Expertise Acquisition			
SupportStage	Management resources						Managers Assistance	Managers Assistance		
	Control line									
SupportStage	Coopetition support resources							Confirming the resources allocation		
SupportStage	Other support resources	CRM - lead follow-up	CRM - lead follow-up	CRM - lead follow-up	CRM - lead follow-up	CRM - lead follow-up	CRM - lead follow-up	Win the opportunity	Customer follow-up	Customer follow-up

Figure 3. Findings from Coopetition Network Integration (Third Group)

The investigation distinctly outlines the challenges and successes across the three groups. Independent operators (First Group) grappled with deal closures, while companies partnering with rivals outside the coopetition network (Second Group) encountered post-sale partner disputes, tarnishing customer satisfaction. Conversely, entities within the coopetition network (Third Group) achieved successful deal closures and fostered positive interactions with rivals and customers. The findings underscore the tangible benefits of coopetition technology in enhancing collaboration effectiveness, deal success rates, and customer satisfaction within the ornamental stone sector. Integrating such technologies propels companies towards more fruitful collaborations and superior customer engagement outcomes.

Conclusions

This study evaluated the efficacy of IIoT-enabled coopetition networks among SMEs in the ornamental stone sector, focusing on the integration and impact of an IIoT-based system. By analyzing nine companies across various customer interaction stages, we identified distinct outcomes based on different market approach strategies. Our findings highlight the critical role of technological innovations in enhancing the coopetition landscape.

Independent companies face significant challenges in closing deals, underscoring the need for supportive frameworks to help SMEs succeed in competitive markets. While partnerships among rivals can initially boost deal closures, they often lead to post-sale disputes that negatively impact customer satisfaction. This underscores the importance of effective relationship management within coopetition networks.

Conversely, integration into IIoT-supported networks, exemplified by the Cockpit4.0+ system, offers a transformative approach. Companies within these networks improved deal closure rates and fostered better relationships with rivals and customers, showcasing IIoT's potential to facilitate successful coopetition.

Integrating IIoT solutions provides SMEs with a promising avenue for enhancing competitiveness and fostering innovation. This approach aligns with Service-Dominant Logic, emphasizing value exchange and co-creation within

networks. Practitioners and policymakers can use these insights to harness coopetition technologies, helping SMEs navigate the complexities of global markets and unlock new growth opportunities.

This study is limited by its focus on a specific sector and a small sample size, which may affect the generalizability of the findings. Future research should explore the scalability of technology-enabled coopetition networks across different industries and larger enterprise settings. Investigating the long-term impacts of these integrations on SME growth, customer relations, and the broader ecosystem would provide valuable insights.

In conclusion, this research enriches the discourse on coopetition dynamics, offering a nuanced understanding of the challenges and opportunities for SMEs in the ornamental stone sector. It underscores IIoT's transformative potential in creating resilient and collaborative networks, enhancing SMEs' strategic positioning and operational effectiveness.

References

[1] P. Muller *et al.*, "Annual report on European SMEs 2020/2021 – Digitalisation of SMEs," B-1049 Brussels, 2021. https://data.europa.eu/doi/10.2826/56865.

[2] L. Di Bella, A. Katsinis, J. Lagüera-González, L. Odenthal, M. Hell, and B. Lozar, "Annual Report on European SMEs 2022/2023," 2023.

[3] L. Corbo, S. Kraus, B. Vlačić, M. Dabić, A. Caputo, and M. M. Pellegrini, "Coopetition and innovation: A review and research agenda," *Technovation*, vol. 122, no. September 2022, p. 102624, Apr. 2023, doi: 10.1016/j.technovation.2022.102624.

[4] A. Meena, S. Dhir, and S. Sushil, "A review of coopetition and future research agenda," *J. Bus. Ind. Mark.*, vol. 38, no. 1, pp. 118–136, 2023, doi: 10.1108/JBIM-09-2021-0414.

[5] P. Bicen, S. Hunt, and S. Madhavaram, "Coopetitive innovation alliance performance: Alliance competence, alliance's market orientation, and relational governance," *J. Bus. Res.*, vol. 123, no. October 2020, pp. 23–31, 2021, doi: 10.1016/j.jbusres.2020.09.040.

[6] O. Gernsheimer, D. K. Kanbach, and J. Gast, "Coopetition research - A systematic literature review on recent accomplishments and trajectories," *Ind. Mark. Manag.*, vol. 96, no. May, pp. 113–134, 2021, doi: 10.1016/j.indmarman.2021.05.001.

[7] M. Reeves, H. Lotan, J. Legrand, and M. G. Jacobides, "How Business Ecosystems Rise (and Often Fall)," in *Business Ecosystems*, no. July, De Gruyter, 2022, pp. 27–34.

[8] E. Jaakkola, V. Kaartemo, J. Siltaloppi, and S. L. Vargo, "Advancing service-dominant logic with systems thinking," *J. Bus. Res.*, p. 114592, Feb. 2024, doi: 10.1016/j.jbusres.2024.114592.

[9] S. L. Vargo, J. A. Fehrer, H. Wieland, and A. Nariswari, "The nature and fundamental elements of digital service innovation," *J. Serv. Manag.*, vol. 35, no. 2, pp. 227–252, Mar. 2024, doi: 10.1108/JOSM-02-2023-0052.

[10] G. Lampropoulos, K. Siakas, and T. Anastasiadis, "Internet of Things in The Context of Industry 4.0: An Overview," *Int. J. Entrep. Knowl.*, vol. 7, no. 1, pp. 4–19, 2019, doi: 10.2478/IJEK-2019-0001.

[11] M. Serror, S. Hack, M. Henze, M. Schuba, and K. Wehrle, "Challenges and Opportunities in Securing the Industrial Internet of Things," *IEEE Trans. Ind. Informatics*, vol. 17, no. 5, pp. 2985–2996, 2021, doi: 10.1109/TII.2020.3023507.

[12] M. A. Akaka and S. L. Vargo, "Technology as an operant resource in service (eco)systems," *Inf. Syst. E-bus. Manag.*, vol. 12, no. 3, pp. 367–384, Aug. 2014, doi: 10.1007/s10257-013-0220-5.

[13] S. Michel, S. L. Vargo, and R. F. Lusch, "Reconfiguration of the conceptual landscape: A tribute to the service logic of Richard Normann," *J. Acad. Mark. Sci.*, vol. 36, no. 1, pp. 152–155, 2008, doi: 10.1007/s11747-007-0067-8.

[14] S. L. Vargo and R. F. Lusch, "Evolving to a New Dominant Logic for Marketing," *J. Mark.*, vol. 68, no. 1, pp. 1–17, Jan. 2004, doi: 10.1509/jmkg.68.1.1.24036.

[15] K. Joiner and R. Lusch, "Evolving to a new service-dominant logic for health care," *Innov. Entrep. Heal.*, p. 25, 2016, doi: 10.2147/ieh.s93473.

[16] H. Demirkan and J. C. Spohrer, "Commentary—Cultivating T-Shaped Professionals in the Era of Digital Transformation," *Serv. Sci.*, vol. 10, no. 1, pp. 98–109, Mar. 2018, doi: 10.1287/serv.2017.0204.

[17] S. L. Vargo and R. Lusch, "Service-dominant logic 2025," *Int. J. Res. Mark.*, vol. 34, no. 1, pp. 46–67, Mar. 2017, doi: 10.1016/j.ijresmar.2016.11.001.

[18] N. N. Hartmann, H. Wieland, and S. L. Vargo, "Converging on a New Theoretical Foundation for Selling," *J. Mark.*, vol. 82, no. 2, pp. 1–18, Mar. 2018, doi: 10.1509/jm.16.0268.

[19] R. Lusch and S. Nambisan, "Service Innovation: A Service-Dominant Logic Perspective," *MIS Q.*, vol. 39, no. 1, pp. 155–175, Jan. 2015, doi: 10.25300/MISQ/2015/39.1.07.

[20] S. Vargo and R. Lusch, "Institutions and axioms: an extension and update of service-dominant logic," *J. Acad. Mark. Sci.*, vol. 44, no. 1, pp. 5–23, Jan. 2016, doi: 10.1007/s11747-015-0456-3.

[21] C. Seepana, A. Paulraj, and F. A. Huq, "The architecture of coopetition: Strategic intent, ambidextrous managers, and knowledge sharing," *Ind. Mark. Manag.*, vol. 91, no. August, pp. 100–113, 2020, doi: 10.1016/j.indmarman.2020.08.012.

[22] K. Razmdoost, L. Alinaghian, J. D. Chandler, and C. Mele, "Service ecosystem boundary and boundary work," *J. Bus. Res.*, vol. 156, no. November 2022, p. 113489, 2023, doi: 10.1016/j.jbusres.2022.113489.

[23] A. Presciuttini and A. Portioli-Staudacher, "Applications of IoT and Advanced Analytics for manufacturing operations: a systematic literature review," *Procedia Comput. Sci.*, vol. 232, pp. 327–336, 2024, doi: 10.1016/j.procs.2024.01.032.

[24] S. Wang, J. Wan, D. Zhang, D. Li, and C. Zhang, "Towards smart factory for Industry 4.0: A self-organized multi-agent system with big data based feedback and coordination," *Comput. Networks 101*, vol. 101, pp. 158–168, 2015, doi: 10.1016/j.comnet.2015.12.017.

[25] C. L. Garay-Rondero, J. L. Martinez-Flores, N. R. Smith, S. O. Caballero Morales, and A. Aldrette-Malacara, "Digital supply chain model in Industry 4.0," *J. Manuf. Technol. Manag.*, vol. 31, no. 5, pp. 887–933, 2020, doi: 10.1108/JMTM-08-2018-0280.

[26] T. Hoske, "Industrial internet of things, industry 4.0," *Control Engineering*, vol. 62, no. 6, pp. 26–35, 2015.

[27] H. Boyes, B. Hallaq, J. Cunningham, and T. Watson, "The industrial internet of things (IIoT): An analysis framework," *Comput. Ind.*, vol. 101, no. December 2017, pp. 1–12, 2018, doi: 10.1016/j.compind.2018.04.015.
[28] M. H. ur Rehman, I. Yaqoob, K. Salah, M. Imran, P. P. Jayaraman, and C. Perera, "The role of big data analytics in industrial Internet of Things," *Futur. Gener. Comput. Syst.*, vol. 99, pp. 247–259, Oct. 2019, doi: 10.1016/j.future.2019.04.020.
[29] S. Hoppe, "OPC Unified Architecture-Interoperability for Industrie 4.0 and the Internet of Things," 2023. [Online]. Available: https://opcfoundation.org/wp-content/uploads/2023/05/OPC-UA-Interoperability-For-Industrie4-and-IoT-EN.pdf.
[30] M. Matzner *et al.*, "Digital Transformation in Service Management," *J. Serv. Manag. Res.*, vol. 2, no. 2, pp. 3–21, 2018, doi: 10.15358/2511-8676-2018-2-3.
[31] I. Ng and S. Wakenshaw, "The Internet-of-Things: Review and research directions," *Int. J. Res. Mark.*, vol. 34, no. 1, pp. 3–21, Mar. 2017, doi: 10.1016/j.ijresmar.2016.11.003.
[32] A. Yazdinejad, B. Zolfaghari, A. Dehghantanha, H. Karimipour, G. Srivastava, and R. Parizi, "Accurate threat hunting in industrial internet of things edge devices," *Digital Communications and Networks*, vol. 9, no. 5. pp. 1123–1130, 2023, doi: 10.1016/j.dcan.2022.09.010.
[33] M. Akaka, H. Schau, and S. Vargo, "How Practice Diffusion Drives IoT Technology Adoption and Institutionalization of Solutions in Service Ecosystems," in *Proceedings of the Annual Hawaii International Conference on System Sciences*, 2023, vol. 2023-Janua, no. March, pp. 1427–1435, doi: 10.24251/HICSS.2023.178.
[34] P. Url, W. Vorraber, and J. Gasser, "Practical insights on augmented reality support for shop-floor tasks," *Procedia Manuf.*, vol. 39, no. 2019, pp. 4–12, 2019, doi: 10.1016/j.promfg.2020.01.222.
[35] Y. H. Wang, C. H. Lee, and A. J. C. Trappey, "Service design blueprint approach incorporating TRIZ and service QFD for a meal ordering system: A case study," *Comput. Ind. Eng.*, vol. 107, pp. 388–400, 2017, doi: 10.1016/j.cie.2017.01.013.
[36] J. Kingman-Brundage, "The ABC's of service system Blueprinting: Designing a winning service strategy," 1989.
[37] J. Pöppel, J. Finsterwalder, and R. A. Laycock, "Developing a film-based service experience blueprinting technique," *J. Bus. Res.*, vol. 85, no. xxxx, pp. 459–466, Apr. 2018, doi: 10.1016/j.jbusres.2017.10.024.
[38] A. Silva, M. M. Gil, and E. Duarte, "Service Innovation | A Service Blueprinting for Industry 4 . 0," *Int. J. Sci. Basic Appl. Res.*, p. 24535, 2020.
[39] A. Silva, A. Dionisio, and I. Almeida, "Enabling Cyber-Physical Systems for Industry 4.0 operations: A Service Science Perspective," *Int. J. Innov. Technol. Explor. Eng.*, vol. 9, no. 8, pp. 838–846, Jun. 2020, doi: 10.35940/ijitee.H6804.069820.
[40] A. Rouyre, A.-S. Fernandez, and O. Bruyaka, "Big problems require large collective actions: Managing multilateral coopetition in strategic innovation networks," *Technovation*, vol. 132, p. 102968, 2024, doi: https://doi.org/10.1016/j.technovation.2024.102968.
[41] A. Silva, C. Rabadão, and C. Capela, "Towards Industry 4.0 | A case study of BIM deployment in ornamental stones sector," *Int. J. Innov. Technol. Explor. Eng.*, vol. 67, p. 24535, 2020.
[42] A. Silva, M. M. Gil, and E. Duarte, "Service Innovation | A Service Blueprinting for Industry 4 . 0," in *International Journal of Sciences: Basic and Applied Research (IJSBAR) ISSN 2307-4531 Vol 52 No 2 (2020)*, ISSN 2307-., vol. ISSN 2307-, 2020, pp. 33–49.
[43] H. Lasi, P. Fettke, H.-G. Kemper, T. Feld, and M. Hoffmann, "Industry 4.0," *Bus. Inf. Syst. Eng.*, vol. 6, no. 4, pp. 239–242, 2014, doi: 10.1007/s12599-014-0334-4.
[44] K. Peffers, T. Tuunanen, M. A. Rothenberger, and S. Chatterjee, "A Design Science Research Methodology for Information Systems Research," *J. Manag. Inf. Syst.*, vol. 24, no. 3, pp. 45–77, Dec. 2007, doi: 10.2753/MIS0742-1222240302.
[45] G. Leal, W. Guédria, and H. Panetto, "An ontology for interoperability assessment: A systemic approach," *J. Ind. Inf. Integr.*, no. May, 2019, doi: 10.1016/j.jii.2019.07.001.
[46] C. Enberg, "Enabling knowledge integration in coopetitive R&D projects - The management of conflicting logics," *Int. J. Proj. Manag.*, vol. 30, no. 7, pp. 771–780, 2012, doi: 10.1016/j.ijproman.2012.01.003.
[47] J. C. Spohrer and L. E. Freund, "Advances in the human side of service engineering," *Adv. Hum. Side Serv. Eng.*, vol. 00, no. 0, pp. 1–475, 2012, doi: 10.1201/b12315.

Management and Production Engineering Review
Volume 15 • Number 3 • September 2024 • pp. 1–14
DOI: 10.24425/mper.2024.151493

Enhancing SME Competitiveness Through Coopetition Networks: A Service-Dominant Logic Approach

Agostinho da Silva[1], Antonio J. Marques Cardoso[2]

[1] *CISE – Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal; CIGEST – Centre for Research in Management, Lisbon Business School, Lisboa, Portugal*
[2] *CISE – Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal*

Received: 24 February 2024
Accepted: 13 June 2024

Abstract
In the era of rapid globalization and digital transformation, small and medium-sized enterprises (SMEs) in the manufacturing sector encounter significant challenges in scaling operations, enhancing operational efficiency, and fostering innovation. This study focuses on manufacturing SMEs, where coopetition – a strategic blend of competition and cooperation – addresses these challenges. Despite its potential to drive innovation and value creation, coopetition networks often struggle to succeed, particularly under the pressures of advancing technology and the need for digital collaboration. To address these issues, this research develops a comprehensive framework that integrates Service-Dominant (S-D) Logic with technology-enabled coopetition networks. Utilizing the Design Science methodology, the study presents a framework that underscores the crucial role of technology in fostering value co-creation within SME networks. This framework is designed to enable sustainable and effective engagement in coopetition, significantly mitigating the risk of network failure by aligning technological innovation with coopetition principles. The proposed framework was evaluated through a targeted survey of managers from SMEs in the Portuguese stone manufacturing sector. The survey results confirmed the practical applicability and potential to promote robust and sustainable coopetition strategies. By integrating theoretical insights with practical applications, this research offers a roadmap for SMEs to effectively manage the complexities of coopetition within the digital supply chain environment.

Keywords
slowa Coopetition, Networks, S-D logic, Service Science, Internet of Things.

Introduction

SMEs face unprecedented challenges in today's rapidly globalizing and digitizing world (Di Bella et al., 2023). To navigate these complexities, SMEs are increasingly adopting coopetition strategies – a blend of competition and collaboration among firms (Rouyre et al., 2024). This strategy is praised for its potential to drive innovation and value creation, which are essential for SMEs struggling with issues of scale, efficiency (Ramírez-López et al., 2021), and limited resources for innovation (Bicen et al., 2021).

However, despite the theoretical advantages, many coopetition networks fail to meet their objectives, leading to high failure rates and unmet expectations (Crick, 2019). This issue highlights a critical research gap in developing robust empirical frameworks for establishing and maintaining effective coopetition networks, particularly among manufacturing SMEs that play a vital role in the economies of developed nations (Muller et al., 2021).

Current academic discourse on coopetition focuses primarily on competitive dynamics (Meena et al., 2023) and the resource-based view, which emphasizes structural strategies and securing unique resources to gain competitive advantages (Maletič et al., 2020). These perspectives often overlook the mechanisms of value creation and sharing in coopetition (Xie et al., 2023), and they fall short of addressing the complexities and evolving nature of coopetition in the digital age. The significant impact of technological advancements on network interactions further complicates the coopeti-

***Corresponding author**: Agostinho da Silva – CISE – Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal, phone: (+351) 275 319 700, e-mail: agostinho.antunes.silva@ubi.pt*

© 2024 The Author(s). This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

tion landscape. Consequently, there is a pressing need for more sustainable business models that consider the role of technology as both a facilitator and a resource within these networks.

In light of these challenges, the S-D Logic literature offers a valuable perspective for understanding value co-creation in networks, particularly where technology acts as both an enabler and a resource in service ecosystems (Vargo et al., 2024). S-D Logic shifts the focus from traditional goods-centric views to a service-oriented approach that emphasizes value co-creation through service exchanges within a network of actors (Vargo et al., 2023).

To address the gap identified, this study aims to develop a sustainable and practical framework for coopetition among SMEs, grounded in the principles of S-D Logic and enhanced by technological integration. Under an S-D Logic view and utilizing the Design Science methodology, the research aims to construct a comprehensive framework combining theoretical insights with practical applications, where technology and S-D Logic intersect, enabling SMEs to effectively navigate the complexities of coopetition within the digital supply chain environment. The forthcoming sections will explore several key steps: applying S-D Logic foundations to address technological innovation and developing a framework for coopetition networks to facilitate coopetition.

To evaluate the framework, a targeted survey will be conducted with managers from SMEs in the Portuguese stone industry. This survey will provide insights into these companies' digital integration and coopetition strategies. The paper concludes by highlighting the study's limitations and suggesting directions for future research.

Literature review

S-D Logic, introduced by Stephen L. Vargo and Robert F. Lusch in 2004, emphasizes that service – the application of skills and knowledge for the benefit of others – is the core driver of value co-creation (Vargo & Lusch, 2004). According to this perspective, value is not created in isolation but co-created through interactions between service providers and beneficiaries, facilitated by the competencies each party brings (Vargo & Lusch, 2008).

In the context of S-D Logic, value co-creation is deeply embedded within institutional frameworks and arrangements. These institutions act as the rules and norms that guide interactions within service ecosystems, ensuring that co-creating value is structured and effective (Lusch et al., 2016). Despite some debates around its application (Campbell et al., 2013), S-D Logic has profoundly shaped discussions on business models since its inception, especially over the past decade (Kleinaltenkamp et al., 2023). It has contributed significantly to developing service-centric business models, providing a clear and cohesive framework that continues to evolve (Jaakkola et al., 2024).

Recent advancements in S-D Logic suggest that value co-creation in service ecosystems goes beyond merely exchanging tangible resources. It encompasses intangible assets such as knowledge, relationships, and institutional structures (Razmdoost et al., 2023). This approach positions S-D Logic as a metatheoretical framework that aligns with and enhances other mid-range theories by integrating shared concepts and narratives. This alignment promotes a more profound, performative understanding of business models, emphasizing how these models operate and evolve in practice (Hartmann et al., 2018).

By focusing on how ecosystems function through the lens of S-D Logic, businesses can gain valuable insights into value cocreation mechanisms and the importance of fostering dynamic, collaborative networks. This perspective is particularly relevant for understanding how coopetition networks can be designed and managed to leverage both tangible and intangible resources effectively.

Ecosystems for Value Creation

As businesses shift towards services, value cocreation has evolved significantly. (Maglio and Spohrer (2008) were instrumental in this transition, moving the focus from isolated, localized processes to a broader, technology-enabled global network (Demirkan & Spohrer, 2018). This evolution gave rise to service science, a discipline dedicated to understanding and innovating within service systems – seen as abstract entities engaging in economic activities (Breidbach & Maglio, 2015).

Service science asserts that any interaction between entities is inherently a proposition to co-create value, shaping business models around value proposition design and systemic patterns (Ng et al., 2018). The service system is at the heart of service science – a complex configuration of people, technologies, organizations, and shared information. These systems create and deliver value through services, engaging stakeholders such as suppliers, users, and other entities (Spohrer & Maglio, 2010).

Although service science and S-D Logic use different terminologies, they share a similar essence. Both view service systems as dynamic entities that play unique and interconnected roles within ecosystems and networks, facilitating the reconfiguration of resources and fostering interactions (Cellary et al., 2019).

Current discussions in service science increasingly emphasize the role of networks of service systems, where multiple actors interact to co-create mutual value (Breidbach & Maglio, 2016). This view aligns closely with the S-D Logic perspective, which sees networks as adaptive ecosystems focused on value creation and sustainability (Lusch & Nambisan, 2015).

S-D Logic and service science naturally complement each other, sharing common research interests, perspectives, and foundational philosophies (Spohrer et al., 2007). Both fields promote a holistic approach to understanding and scaling business activities, integrating insights from various disciplines and blending tangible and intangible assets (Cellary et al., 2019). Despite some differences in terminology, they converge on a shared philosophical viewpoint: the significance of context in value co-creation. This complex phenomenon arises from service exchanges, resource integration, and the concept of value-in-context, offering a strong foundation for designing empirical frameworks (Pohlmann & Kaartemo, 2017).

In essence, both S-D Logic and service science advocate for viewing business ecosystems as dynamic, interconnected networks where the interplay of various elements and actors leads to value co-creation, supporting sustainable innovation and growth.

The Transformative Role of Technology in Value Co-creation

Technology is recognized as an essential resource for innovation within service science, fundamentally transforming how service is delivered, innovated, and managed (Breidbach & Maglio, 2016). S-D Logic literature also emphasizes technology's significant impact on service innovation and value co-creation within service ecosystems (Razmdoost et al., 2023), viewing technology as both an enabler and a driver of innovation (Akaka et al., 2023).

Degani et al. (2017) explores technology through the concept of "operant" resources, describing it as something that "works" or is "engaged in action". This perspective highlights technology's capacity for self-governance, autonomy, and independence, characterizing it through three key aspects: authority to create and apply its rules, self-sufficiency, and freedom from external influence (Degani et al., 2017).

This understanding aligns with the rise of intelligent technologies capable of autonomously generating algorithms and undertaking actions without human intervention, representing a significant advancement in technological capabilities (Bodkhe et al., 2020).

In coopetition, technology is crucial for fostering collective understanding and collaboration among various actors (Rusko, 2014). This perspective aligns with both S-D Logic and service science, which view technology as an essential operand resource (facilitator) and operant resource (initiator) in the value cocreation process (Barile et al., 2019). The interaction between operant resources (intelligence and competencies) and operand resources (tangible assets) is crucial for innovation and value creation. This dynamic is facilitated through human interactions, technology, value propositions, and shared information, forming the foundation for effective co-creation (Matthies et al., 2016). By integrating technology into coopetition networks, businesses can enhance their ability to innovate and create value collaboratively. This integration supports the development of new business models and operational strategies that are responsive to the evolving demands of the digital era.

In summary, both S-D Logic and service science literature underscore the transformative role of technology in enabling and driving value co-creation. Technology facilitates collaboration and the efficient exchange of resources, serving as a critical driver in the continuous evolution and improvement of service ecosystems.

Framework Designing for Coopetition Networks

Design Science underpins this study's approach, emphasizing creating and evaluating artefacts – ranging from models and methods to tools and frameworks – that address and resolve concrete, practical issues (Hevner, 2007; Lacerda et al., 2013). This methodology is inherently iterative and interactive, marrying theoretical underpinnings with real-world applicability to produce innovative outcomes grounded in rigorous academic research (Pakkala et al., 2020).

To construct empirically robust frameworks within this framework, it is imperative for designers to deeply engage with and leverage the extensive body of existing academic knowledge and insights. As highlighted by vom Brocke et al. (2020), the infusion of rich academic understanding into the development process not only strengthens the relevance and efficacy of the resulting frameworks but also serves as a critical driver for the creation of advanced, sophisticated artefacts. These artefacts act as vessels for the emergence of novel insights, fostering an environment where new knowledge can be cultivated from their application and impact.

Peffers et al. (2007) further elucidate this concept, illustrating how artefacts derived from a profound engagement with scholarly work contribute significantly to the broader academic and practical domains. The

iterative cycle of applying comprehensive academic knowledge to create practical solutions and deriving new theoretical insights from these applications exemplifies the dynamic synergy between theory and practice. This synergy is central to the Design Science methodology, illustrating its capacity to not only solve practical problems but also to propel the advancement of academic understanding and the generation of new knowledge (Hevner & Chatterjee, 2010).

Entities and Resources in Coopetition Networks

Understanding the dynamics of coopetition networks necessitates identifying the roles played by various actors and the resources they leverage for mutual benefit. Drawing from S-D Logic, the essence of these networks lies in the service exchange among entities aimed at reciprocal benefits (Barile et al., 2016). This exchange centres on two primary resource types: operant resources (people and organizations with the capacity to act) and operand resources (tangible assets such as technologies and knowledge). This distinction underscores that service is not merely an offering but the application of competencies for another's benefit (Joiner & Lusch, 2016).

Anchored on S-D Logic foundations, service science, with its interdisciplinary approach, seeks to unify the concept of resources, asserting that anything named and potentially valuable – physical or non-physical – constitutes a resource (Vargo & Akaka, 2009). These resources are characterized by their lifecycle (beginning, middle, and end), availability, creation cost, maintenance expense, and the cost of ceasing access or use. The dynamic interplay of these resources within coopetition networks, encompassing people, technology, organizations, and shared information, ignites actions that underpin the network's vitality (Maglio & Spohrer, 2013).

In the context of technology-enabled coopetition networks, the interaction among customers, providers, and coopetitors is intricate. These actors integrate multiple resources – market-facing, technological, financial, and public – to innovate or co-create value at different network levels (Vargo et al., 2023). This view posits customers as beneficiaries of value, evaluating offerings based on their experiences; providers as facilitators of value co-creation; coopetitors as collaborative competitors sharing resources under agreed conditions; competitors as independent entities vying for customer attention; and authorities as regulatory bodies ensuring sustainable and equitable interaction within the network (Vargo & Lusch, 2016).

Revenue expectations within these networks are shaped by value propositions, which, in turn, are driven by the perceived value and the co-creation process. This cyclical engagement fosters increased resource density, propelling the network towards innovative value propositions and enhanced co-creation opportunities (Ng & Wakenshaw, 2017). However, the success of this framework hinges on the seamless access to and sharing of resources among entities, with the understanding that value perception is inherently subjective and rooted in individual experiences (Akaka et al., 2013).

Anchored on S-D Logic and service science perspectives, technology-enabled coopetition networks must, therefore, consider customers, providers, rivals, competitors, and authorities as the main actors:

Customer Entity: Customers play a critical role in value networks by engaging with and assessing providers' value propositions. Their evaluation is deeply rooted in their experiences throughout the service process, shaping their acceptance or rejection of the offerings (Barile & Polese, 2010).

Provider Entity: The provider acts as a facilitator in co-creating value, working alongside customers. They offer value propositions by skilfully weaving together a constellation of activities and experiences, underlining the collaborative nature of service provision (van Riel et al., 2013).

Coopetitor Entity: Coopetitors are unique actors that, under agreed safety norms, willingly share and access specific resources among themselves to enhance mutual benefits. Viewed through the lens of S-D Logic and service science, coopetitors significantly enrich the network's resource density with each interaction, promoting a symbiotic environment for growth and innovation (Gast et al., 2015).

Competitor Entity: Competitors operate independently within networks, directly engaging with customers without collaborating with rivals. Their interactions are characterized by a competitive drive to offer distinct value propositions to the market.

Authority Entity: Official authorities strive to guide interactions among network actors towards sustainability and improved living conditions. They are crucial in fostering an ecosystem where all participants can thrive harmoniously (Boughnim & Yannou, 2005).

Upon joining a coopetition network, an actor anticipates revenue generation, with the process delineated by S-D Logic: initial expectations fuel the creation of value propositions, generating revenue, spurring further value propositions, and enhancing resource density for cocreation. This cycle necessitates mutual access to resources among entities, with the proposition's value uniquely shaped by each beneficiary's experience.

The Role of Technology in Coopetition Networks

In coopetition networks, technology becomes an essential component that initiates and facilitates activities within these complex ecosystems. Motivated by the potential for significant gains, companies may share and integrate their resources with competitors. This sharing fosters service exchanges that increase resource richness and enhance value co-creation (Lusch & Nambisan, 2015). Such a strategy requires all participants to provide mutual access to their resources, establishing a business model based on coopetition (Seepana et al., 2020). Technology serves dual roles within these networks: As an operant resource, technology initiates actions and drives processes (Sklyar et al., 2019). For example, advanced analytics can identify new opportunities for collaboration, or automated systems can streamline shared operations. As an operand resource, technology facilitates actions by enabling the infrastructure and tools needed for efficient resource sharing and value co-creation (Lusch & Nambisan, 2015). This includes digital platforms that support communication and integration among network participants (Silva et al., 2020).

Integrating technology into coopetition networks significantly increases resource density, enhancing the capacity for co-creating value (Razmdoost et al., 2023). This enriched interaction fosters the development of innovative solutions that benefit all participants within the network and improve the quality of life for the stakeholders involved (Akaka et al., 2023).

The unique combination and application of technology in these networks underscore its essential role in advancing competitive collaboration. Technology enables companies to operate more efficiently and drives innovation and mutual benefits across the ecosystem. By leveraging technology effectively, businesses within coopetition networks can enhance their competitive advantage while contributing to the overall health and sustainability of the ecosystem.

The Institutionalization of Coopetition Networks

The paradigm of value networks elucidates that value creation is inherently collaborative, engaging many actors and their intricate interactions in a concerted effort to generate and deliver value. This view is complemented by the ecosystem concept, which introduces an environmental dimension to the discussion, highlighting the ecological challenges in sustaining such networks (Willis, 1997).

Drawing from these foundational concepts, the value creation transcends simple bilateral exchanges, necessitating a more comprehensive array of resources and the involvement of multiple actors within an intricate network (Normann & Ramirez, 1993). The notion of micro-exchange within these vast ecosystems suggests that customers and providers represent just a fraction of the entire network, which includes numerous actors engaging in reciprocal resource exchange to co-create value (Chandler & Vargo, 2011) (Fig. 1).

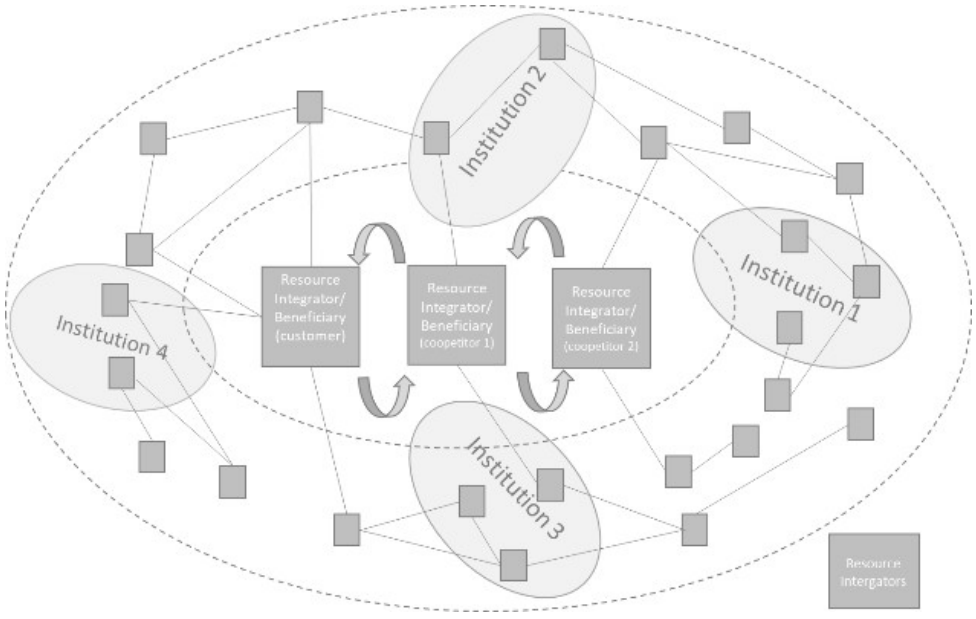


Fig. 1. Framework for coopetition networks, adapted from (Lusch & Vargo, 2014)

Such complex dynamics require a level of coordination facilitated by endogenously created institutions – comprising rules, norms, symbols, and practices that aid collaboration – and institutional arrangements, which are interdependent collections of these institutions, manifesting even at a societal scale (Meynhardt et al., 2016).

This comprehensive framework underscores the transition from micro-level interactions among actors, which foster behavioural patterns across the network, to a meso-level emergence of institutions and ecosystems (Wieland et al., 2017). In such an institutional environment, actors, including competitors, might collaborate for mutual benefits, showcasing the voluntary nature of cooperation even among rivals (Chandler & Vargo, 2011). The deployment of both operant and operand technologies facilitates this cooperation through resource liquefaction and enhanced resource density, further cementing the institutionalization of networks into fully-fledged service ecosystems (Lusch & Nambisan, 2015; Jaakkola et al., 2024). This narrative outlines a theoretical foundation for understanding and developing empirical frameworks for coopetition within networks, emphasizing the crucial role of institutional structures in facilitating value co-creation across service ecosystems (Vargo & Lusch, 2017).

Requirements for Enabling Coopetition in Networks

The advent of the Internet of Things (IoT) and embedded systems heralds a new era in which technology profoundly influences ecosystems, as recognized by S-D Logic (Ng & Wakenshaw, 2017; Lorenzo et al., 2017). This era is characterized by IoT's role within ecosystems, linking actors through advanced sensor technologies (Akaka et al., 2023). These sensors facilitate the localization and identification of actors and enable direct operations on or by these entities, thus significantly enhancing interaction and integration within technology-enabled networks (Müller et al., 2018).

Empirical evidence underscores the transformative potential of IoT in fostering novel service offerings. Companies leveraging IoT capabilities can extend their service portfolios to include remote control options and predictive maintenance solutions, advancing operational efficiency and opening new avenues for value co-creation within coopetition frameworks (Salih et al., 2022). This technological integration catalyzes the development of ecosystems where companies, by harnessing IoT, transcend traditional competitive boundaries, facilitating seamless exchange of resources and collaboration among once-competing entities (Mosch et al., 2023).

Under this view, the IoT is critical in enabling coopetition within networks, signifying a shift towards more interconnected, efficient, and innovative ecosystems. Through enhanced connectivity and data exchange, actors within these networks can unlock new potentials for collaboration, driving forward the principles of S-D Logic by expanding the scope and scale of value co-creation in the digital age.

Interoperability Mechanisms for Coopetition Networks

Interoperability is crucial for fostering effective collaboration within networks, allowing for the smooth achievement of shared goals and enabling the controlled dissolution of partnerships if needed ([x]Hoppe, 2023). In the context of coopetition, the seamless exchange of information between different technological resources is essential (Vargo et al., 2023). Therefore, any artefact that facilitates coopetition must include mechanisms to ensure interoperability, focusing on semantic and pragmatic aspects to maximize network capabilities ([x]Leal et al., 2019): (1) Semantic Interoperability ensures that the meaning of information exchanged between systems is consistently understood. This is essential for different technologies to interpret and process data accurately across various platforms (Cardoso et al., 2015). (2) Pragmatic Interoperability further ensures that the information exchanged is effectively utilized in practical, operational contexts. It involves appropriately understanding and applying the data to achieve the desired outcomes (Silva et al., 2016).

Addressing these mechanisms within IoT is critical for integrating diverse technologies and creating collaborative environments that support coopetition. Moreover, (Akaka and Vargo (2014) emphasize the need for systemic interoperability in digital technologies, highlighting the role of IoT in embedding service mechanisms that enhance interoperability (Coelho et al., 2022), including (1) Resource density mechanisms for processing and analyzing information to support decision-making and actions. By increasing the density of available resources, IoT provides a deeper response and facilitates more informed strategies for competition (Ng & Wakenshaw, 2017). (2) Digital materiality mechanisms referring the ability of the software embedded in physical objects to manipulate their digital representations, enabling new functionalities and interactions. Digital materiality bridges the physical and digital worlds, opening innovative avenues for collaboration and competition within coopetition networks (Lim et al., 2019).

By integrating these mechanisms, artefacts designed for coopetition can support the dynamic exchange of service information. This capability fosters an environment where both collaborative and competitive interactions can flourish. Such an approach enhances the effectiveness of coopetition networks. It aligns with the evolving needs of technology-enabled ecosystems, ensuring that networks are adaptable, responsive, and capable of leveraging the full potential of IoT for value co-creation.

Usability and Accessibility Mechanisms for Coopetition Networks

Usability and accessibility are crucial in coopetition networks to ensure secure and efficient service exchanges among competitors, enhancing value creation within the ecosystem (Kahkonen & Lintukangas, 2012). S-D Logic and service science emphasize the need for systemic structures and architectural modules designed specifically for managing transactions and services. These systems operate under the coordination of institutions and institutional arrangements, ensuring seamless and effective interactions ([x]Hietanen et al., 2018).

An effective coopetition network integrates a knowledge-based system with operant modules (such as artificial intelligence or cognitive assistant technologies) and operand modules. These technologies facilitate interactions within the network, acting on behalf of coopetitors. However, being non-sentient, these systems lack legal accountability and do not possess rights and duties (Ng et al., 2018). To mitigate this limitation, it is essential to incorporate human resources into the system who can operate, interact, and collaborate with these technologies. A designated individual within this team assumes the role of the legal and operational representative, ensuring accountability and overseeing the network's activities. Fig. 2, depicts the conceptual framework of the IoT system designed to facilitate coopetition (Ng & Wakenshaw, 2017).

Enabled by IoT, a coopetition network incorporates three types of critical resources (1) physical-with-no-rights, including the ICT infrastructure and hardware that provide the system's essential technical foundation and operational capabilities; (2) physical-with-rights offering necessary oversight, decision-making abilities, and legal accountability within the network. They ensure that the system functions smoothly and complies with legal and operational standards and (3) non-physical-with-no-rights encompassing data and software components (operant and operand) for enabling the digital interactions and processes that drive the coopetition network.

By equipping the system with these diverse resource types, coopetition networks can effectively manage usability and accessibility. This ensures secure and productive service exchanges, enhancing the ecosystem's capacity for value creation. Additionally, addressing

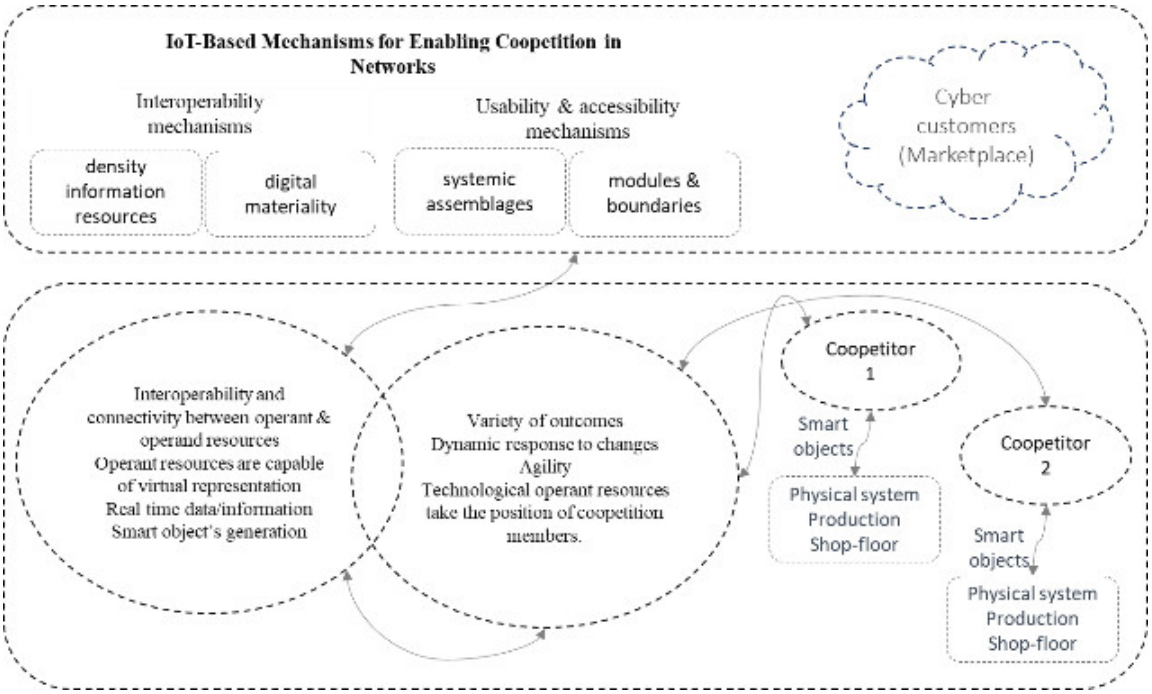


Fig. 2. IoT Mechanisms for Enabling Coopetition in Networks (Adapted from Ng & Wakenshaw, 2017)

the legal and operational challenges associated with advanced technologies like IoT in coopetition strategies is crucial for the system's success. This comprehensive approach fosters innovation and collaboration, aligning with the evolving requirements of technology-enabled ecosystems and supporting sustainable and scalable coopetition practices.

Framework Evaluation: A Survey in the Portuguese Stone Industry

To evaluate the proposed framework for coopetition networks, a survey was conducted with managers from SMEs within the Portuguese stone manufacturing industry. As of 2022, this sector plays a vital role in the Portuguese economy, directly employing over 16,600 individuals and contributing significantly to private sector employment, particularly in the country's inland regions (Machado et al., 2021; Silva & Marques Cardoso, 2023).

Despite numerous challenges, the Portuguese stone manufacturing sector has demonstrated remarkable resilience and sustained growth, especially in exports (Silva & Pata, 2022). This resilience has established Portugal as a prominent global player in the ornamental stone market. A targeted survey was carried out to explore how SMEs within this industry perceive and implement technology-enhanced collaboration networks. A convenience sample of thirty Portuguese stone manufacturing SMEs was selected for the survey. The insights gathered from these interviews were essential in understanding how technology can be strategically leveraged to improve SMEs' performance and competitive positioning in the stone manufacturing sector.

Digital Level Determination and Assessment

In the survey, each of the thirty surveyed SMEs was assigned a digital level to gauge their digital maturity. This assessment was conducted through face-to-face interviews and on-site visits, evaluating several critical aspects of their digitalization. The criteria for this evaluation included the deployment of digital production equipment, the integration of digital management processes, and the use of collaborative digital tools within their operations. Based on their degree of digitalization, companies were classified into five distinct Digital Levels (DL#): No Digital Level (DL#0) – companies in this level need to utilize computerized systems in their production processes, indicating a complete lack of digitalization initiatives. First Digital Level (DL#1) – companies have begun their digital journey by employing computerized production systems for over a year. This level marks the initial phase of integrating digital technology into their operations. Second Digital Level (DL#2) – at this stage, companies use digital equipment in production and have at least two computerized machines operational on the shop floor. This level reflects a more significant commitment to digital technology in their production processes. Third Digital Level (DL#3) – companies achieving this level integrate data from computerized machines on the shop floor with their management information systems. This integration enhances operational efficiency and improves coherence between production and management processes. Fourth Digital Level (DL#4) – represents the highest level of digital maturity; companies at this stage merge shop floor data with management systems and incorporate collaborative data across all organizational levels. This seamless flow of information optimizes overall operational synergy and strategic decision-making.

This classification system provided a clear framework to assess and understand the extent of digital integration within the Portuguese stone SMEs.

Inquiry to the Respondents

The interviews began with an overview of the industry's evolving landscape, particularly the impending adoption of Building Information Modeling (BIM) in the construction market. BIM transforms how materials are procured and utilized, emphasizing the need for precise and efficient processes in the construction industry. This shift highlights the necessity for stone fabricators to enhance their operations by scaling up, maintaining price flexibility, and increasing delivery speed. To remain competitive, firms were encouraged to consider collaborative strategies with competitors, leveraging coopetition to meet these new demands effectively (Shao & Cao, 2024).

To explore the potential benefits of competition, a hypothetical scenario was presented to the respondents: Companies are invited to utilize a system comparable to home banking designed to facilitate seamless collaboration with their competitors. This system would enable stone companies to achieve significant improvements in various operational aspects: (1) Scale – enhanced production capacity and ability to handle larger projects through shared resources; (2) Efficiency – streamlined operations leading to cost reductions and improved product quality; (3) Supply Chain Efficiency – better on-time delivery, more value-adding operations, optimized capacity utilization, and the ability to meet commercial demands without facing raw material shortages, thanks to resource sharing; (4) Customer Satisfaction – improving ability to meet customer ex-

pectations due to enhanced operational capabilities and resource availability. This scenario assessed how coopetition could help stone manufacturing companies adapt and thrive in a competitive market driven by BIM requirements.

To gather detailed insights, the participants were asked to evaluate the importance of these potential improvements for their companies. They were provided with a Likert scale ranging from 1 to 5, where 1 indicated "Not Important at All", 2 indicated "Slightly Important", 3 indicated "Moderately Important", 4 indicated "Very Important", and 5 indicated "Extremely Important".

Each respondent rated the significance of the following aspects: How crucial is it for "your company" to increase its scale through collaboration? How important is streamlining manufacturing processes? How critical is optimizing supply chain operations and ensuring on-time delivery? How essential is it to prevent raw material shortages and meet market demands? Increasing Customer Satisfaction: How significant is improving customer satisfaction through better resource and operational management?

The responses provided a comprehensive view of how the respondents perceived the impact and importance of integrating cooperative strategies with their competitors to address the evolving challenges and opportunities within the industry. The data gathered from this inquiry will help shape strategies for effective coopetition in the context of the BIM-driven future of the stone manufacturing sector.

Results and Discussion

The empirical evaluation of technology-enabled coopetition networks in the Portuguese stone SMEs reveals significant insights summarized in Table **??**. These findings are based on the averaged responses from all participating SMEs, demonstrating a link between their digital maturity (categorized by Digital Level, DL#) and various performance improvements.

The survey data reveals that respondents perceive significant benefits in scaling operations through technology-enabled coopetition networks as their companies progress in digital maturity. Notably, companies at the highest level of digital integration (DL#4) report the most substantial improvements in their ability to scale. These respondents gave an average rating of 4.9 out of 5 for their enhanced scaling capabilities. DL#4 companies also noted remarkable gains in operational efficiency, with an average rating of 4.8 out of 5. This underscores the pivotal role of advanced digital integration in leveraging technology to collaborate effectively with competitors.

Table 1
Survey Outcomes

Performance Metric	DL#0	DL#1	DL#2	DL#3	DL#4
Operational Scale	2.9	2.8	3.2	4.1	4.9
Production Efficiency	3.3	3.2	3.2	3.9	4.8
Sup. Chain Efficiency	3.1	2.7	3.6	3.6	4.9
Customer Satisfaction	2.9	3.9	4,2	4.8	5.0
Average Rating	3.1	3.2	3.6	4.1	4.9

Furthermore, DL#4 respondents highlighted the potential to significantly boost customer satisfaction, achieving a perfect average score of 5 out of 5. This score emphasizes the critical role of digital maturity in meeting and exceeding customer expectations. It also underscores how advanced digital integration fosters stronger customer relationships and enhances customer experience.

As depicted in Fig. 3, the trend line represents the linear correlation between digital maturity (x) and performance improvement ratings (y).

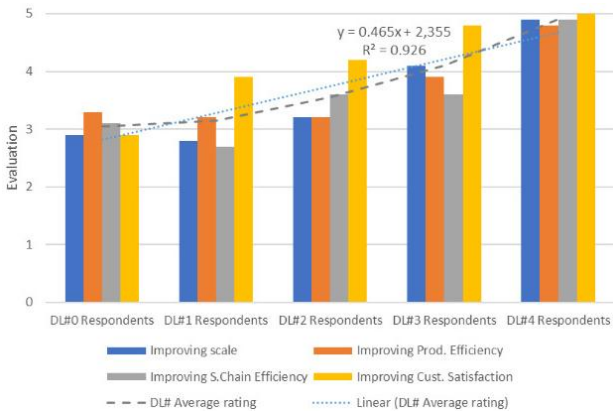


Fig. 3. Framework Evaluation in the Portuguese Stone SMEs

A slope of 0.465 reveals a positive and moderate performance improvement rate as the digital level increases. This implies that higher levels of digital integration are potentially associated with substantial enhancements in operational and competitive capabilities within the coopetition network. The

increase of 0.465 units per level of digital maturity is significant, indicating that as companies adopt more advanced digital technologies, they experience marked improvements in various performance metrics, such as scaling, production efficiency, supply chain efficiency, and customer satisfaction. The R^2 value of 0.926 indicates a high level of explained variance among the respondents. This means that the digital maturity level can explain 92.6% of the variability in the performance improvement ratings. A high R^2 value suggests a strong fit of the linear model to the data, indicating that the digital maturity level is a significant predictor of performance improvements in the context of technology-enabled coopetition.

As companies progress through higher levels of DL#, there is a growing tendency to engage in coopetition networks. This trend indicates that technological advancements encourage a more open and collaborative approach to competition, facilitating mutual benefits and shared successes. The overall average rating of 3.8 out of 5 reflects a positive evaluation of the framework for technology-enhanced coopetition networks.

This empirical study supports the foundational framework as a potentially viable strategy for ornamental SMEs in Portugal. By adopting a technology-enabled cooperation network, these SMEs can leverage collective strengths to navigate market challenges, build resilience, and secure a competitive edge on the international stage. This strategy aligns with current technological trends and prepares firms for future industry developments, ensuring agility and strategic foresight in their long-term planning.

Conclusions

This research addressed the critical gap in developing effective coopetition frameworks by integrating S-D Logic with technological advancements. The framework developed in this study provides actionable strategies for SMEs to navigate the complexities of coopetition within the digital supply chain landscape. Continued exploration and application of this framework will contribute to its refinement and the broader understanding of coopetition in various business contexts.

The framework was evaluated through a survey involving Portuguese stone manufacturing industry managers. The findings support the Design Science methodology's effectiveness in addressing real-world challenges. With 76% of participants endorsing the framework and its sources of innovation, the results affirm its potential capacity to improve operational efficiency, scalability, supply chain management, and customer satisfaction within SMEs. The positive reception underscores the framework's strength in promoting robust and sustainable coopetition strategies, significantly reducing the risk of failure and effectively integrating technological innovation with the principles of coopetition.

Incorporating S-D Logic into technology-enabled coopetition networks represents advancements in both theoretical and practical contexts. This innovative framework redefines how technology is perceived and utilized as a critical facilitator of value co-creation in service ecosystems. By addressing the identified gaps, the proposed framework provides SMEs with a robust framework to leverage coopetition for competitive advantage and significantly contributes to scholarly discussions on coopetition.

Despite the promising results, several limitations of this study should be acknowledged. Firstly, the survey was limited to a specific sector within a single country, which may affect the generalizability of the findings. Future research could broaden the scope by applying the framework across different industries and geographical regions to test its applicability and robustness.

Future research directions include exploring the framework's responsiveness to emerging technologies and its potential for continuous refinement in alignment with technological advancements.

In conclusion, this research merges academic theory with practical applications, charting a path where technology and S-D Logic converge to empower SMEs to adeptly manage the complexities of coopetition within the digital supply chain landscape. Continued exploration and application of this framework will contribute to its refinement and the broader understanding of coopetition in various business contexts.

Acknowledgments

CRediT: Authorship contribution statement Agostinho da Silva: Conceptualization, Data curation, Writing – original draft, Writing – review & editing, Formal analysis, Project administration. Antonio Cardoso: Conceptualization, Data curation, Writing – review & editing, Formal analysis.

Declaration of Competing Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of generative AI and AI-assisted technologies in the writing process: The authors further acknowledge the use of ChatGPT, an AI language model developed by OpenAI, to support language editing during the preparation of this article. ChatGPT (Version 3.5) helped refine the language of the manuscript. While ChatGPT aided in the editing

process, the intellectual content and findings presented in this article are solely attributed to the authors and their research. After using ChatGPT, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

References

Akaka, M., Vargo, S., & Lusch, R. (2013). The Complexity of Context: A Service Ecosystems Approach for International Marketing. *Journal of International Marketing*, *2*(4), 1–20.

Akaka, M., Schau, H., & Vargo, S. (2023). How Practice Diffusion Drives IoT Technology Adoption and Institutionalization of Solutions in Service Ecosystems. *Proceedings of the Annual Hawaii International Conference on System Sciences*, *2023 – January* (March), 1427–1435. DOI: 10.24251/HICSS.2023.178.

Barile, S., Lusch, R., Reynoso, J., Marialuisa, S., & Spohrer, J. (2016). Systems, Networks, and Ecosystems in Service Research. *Journal of Service Management*, *34*(1), 1–5. DOI: 10.1108/JOSM-09-2015-0268.

Barile, S., Piciocchi, P., Bassano, C., Spohrer, J., & Pietronudo, M. C. (2019). Re-defining the role of artificial intelligence (AI) in wiser service systems. *Advances in Intelligent Systems and Computing*, *787*, 159–170. DOI: 10.1007/978-3-319-94229-2_16.

Barile, S., & Polese, F. (2010). Linking the viable system and many-to-many network approaches to service-dominant logic and service science. *International Journal of Quality and Service Sciences*, *2*(1), 23–42. DOI: 10.1108/17566691011026586.

Bicen, P., Hunt, S., & Madhavaram, S. (2021). Coopetitive innovation alliance performance: Alliance competence, alliance's market orientation, and relational governance. *Journal of Business Research*, *123*(October 2020), 23–31. DOI: 10.1016/j.jbusres.2020.09.040.

Bodkhe, U., Tanwar, S., Parekh, K., Khanpara, P., Tyagi, S., Kumar, N., & Alazab, M. (2020). Blockchain for Industry 4.0: A comprehensive review. *IEEE Access*, *8*, 79764–79800. DOI: 10.1109/ACCESS.2020.2988579.

Boughnim, N., & Yannou, B. (2005). Using blueprinting method for developing product-service systems. *International Conference of Engineering Design (ICED)*, 1–16. http://hal.archives-ouvertes.fr/hal-00108215/.

Breidbach, C., & Maglio, P. (2016). Technology-enabled value co-creation: An empirical analysis of actors, resources, and practices. *Industrial Marketing Management*, *56*, 73–85. DOI: 10.1016/j.indmarman.2016.03.011.

Breidbach, C., & Maglio, P. (2015). A Service Science Perspective on the Role of ICT in Service Innovation. *ECIS 2015*, *May 2015*, 1–9.

Campbell, N., O'Driscoll, A., & Saren, M. (2013). Reconceptualising Resources: A Critique of Service-Dominant Logic. *Journal of Macromarketing*, *33*, 1–16. DOI: 10.1177/0276146713497755.

Cardoso, J., Fromm, H., Nickel, S., Satzger, G., & Studer, R. (2015). *Fundamentals of Service Systems* (Jorge Cardoso, H. Fromm, S. Nickel, G. Satzger, R. Studer, & C. Weinhardt (eds.)). Springer International Publishing. DOI: 10.1007/978-3-319-23195-2.

Cellary, W., Freund, L. E., Kwan, S. K., Leitner, C., & Spohrer, J. (2019). *The Human-Side of Service Engineering: Advancing Technologies Impact on Service Innovation*. 1–30.

Chandler, J., & Vargo, S. (2011). Contextualization and Value-in-Context: How Context Frames Exchange. *Marketing Theory*, *11*, 35–49. DOI: 10.1177/1470593110393713.

Coelho, P., Bessa, C., Landeck, J., & Silva, C. (2022). Industry 5.0: The Arising of a Concept. *Procedia Computer Science*, *217*(2022), 1137–1144. DOI: 10.1016/j.procs.2022.12.312.

Crick, J. (2019). The dark side of coopetition: when collaborating with competitors is harmful for company performance. *Journal of Business & Industrial Marketing*, *35*(2), 318–337. DOI: 10.1108/JBIM-01-2019-0057.

Degani, A., Goldman, C.V, Deutsch, O., & Tsimhoni, O. (2017). On human–machine relations. *Cognition, Technology & Work*, *19*(2), 211–231. DOI: 10.1007/s10111-017-0417-3.

Demirkan, H., & Spohrer, J.C. (2018). Commentary – Cultivating T-Shaped Professionals in the Era of Digital Transformation. *Service Science*, *10*(1), 98–109. DOI: 10.1287/serv.2017.0204.

Di Bella, L., Katsinis, A., Lag´uera-González, J., Odenthal, L., Hell, M., & Lozar, B. (2023). *Annual Report on European SMEs 2022/2023*.

Gast, J., Filser, M., Gundolf, K., & Kraus, S. (2015). Coopetition research: towards a better understanding of past trends and future directions. *Int. J. Entrepreneurship and Small Business*, *24*(4), 492–521.

Hartmann, N.N., Wieland, H., & Vargo, S.L. (2018). Converging on a New Theoretical Foundation for Selling. *Journal of Marketing*, *82*(2), 1–18. DOI: 10.1509/jm.16.0268.

Hevner, A. (2007). A Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems*, *19*.

Hevner, A., & Chatterjee, S. (2010). *Design Science Research in Information Systems BT – Design Research in Information Systems: Theory and Practice* (Alan

Hevner & S. Chatterjee (eds.); pp. 9–22). Springer US. DOI: 10.1007/978-1-4419-5653-8_2.

Jaakkola, E., Kaartemo, V., Siltaloppi, J., & Vargo, S.L. (2024). Advancing service-dominant logic with systems thinking. *Journal of Business Research*, 114592. DOI: 10.1016/j.jbusres.2024.114592.

Joiner, K., & Lusch, R. (2016). Evolving to a new service-dominant logic for health care. *Innovation and Entrepreneurship in Health*, 25. DOI: 10.2147/ieh.s93473.

Kahkonen, A.-K., & Lintukangas, K. (2012). The underlying potential of supply management in value creation. *Journal of Purchasing & Supply Management*, *18*, 68–75. DOI: 10.1016/j.pursup.2012.04.006.

Kleinaltenkamp, M., Kleinaltenkamp, M.J., & Karpen, I.O. (2023). Resource entanglement and indeterminacy: Advancing the service-dominant logic through the philosophy of Karen Barad. *Marketing Theory*. DOI: 10.1177/14705931231207327.

Lacerda, D.P., Dresch, A., Proença, A., & Júnior, J.A.V.A. (2013). Design Science Research: A research method to production engineering. *Gestao e Producao*, *20*(4), 741–761. DOI: 10.1590/S0104-530X2013005000014.

Lim, C., Kim, M. J., Kim, K.H., Kim, K.J., & Maglio, P. (2019). Customer process management: A framework for using customer-related data to create customer value. *Journal of Service Management*, *30*(1), 105–131. DOI: 10.1108/JOSM-02-2017-0031.

Lorenzo, A., Antonio, P., Umberto, P., & Achille, G. (2017). Towards Industry 4 . 0 Mapping digital technologies for supply chain management-marketing integration. *Business Process Management Journal*, *25*(2), 323–346. DOI: 10.1108/BPMJ-04-2017-0088.

Lusch, R., & Nambisan, S. (2015). Service Innovation: A Service-Dominant Logic Perspective. *MIS Quarterly*, *39*(1), 155–175. DOI: 10.25300/MISQ/2015/39.1.07.

Lusch, R., & Vargo, S. (2014). Service Ecosystems. In *Service-Dominant Logic* (pp. 158–176). Cambridge University Press. DOI: 10.1017/CBO9781139043120.012.

Lusch, R., Vargo, S., & Gustafsson, A. (2016). Fostering a trans-disciplinary perspectives of service ecosystems. *Journal of Business Research*, *69*(8), 2957–2963. DOI: 10.1016/j.jbusres.2016.02.028.

Machado, S., Mergulhão, L., Pereira, B.C., Pereira, P., Carvalho, J., Anacleto, J.A., Neto de Carvalho, C., Belo, J., Paredes, R., & Baucon, A. (2021). Geoconservation in the Cabeço da Ladeira Paleontological Site (Serras de Aire e Candeeiros Nature Park, Portugal): Exquisite Preservation of Animals and Their Behavioral Activities in a Middle Jurassic Carbonate Tidal Flat. *Geosciences*, *11*(9), 366. DOI: 10.3390/geosciences11090366.

Maglio, P.P., & Spohrer, J. (2013). A service science perspective on business model innovation. *Industrial Marketing Management*, *42*(5), 665–670. DOI: 10.1016/j.indmarman.2013.05.007.

Maletič, D., Lovrenčić, V., Grabowska, M., & Maletič, M. (2020). Value Creation in Physical Asset Management: A Case Study. *Acta Mechanica Slovaca*, *24*(3), 32–39. DOI: 10.21496/ams.2020.034.

Matthies, B.D., D'Amato, D., Berghäll, S., Ekholm, T., Hoen, H.F., Holopainen, J., Korhonen, J.E., Lähtinen, K., Mattila, O., Toppinen, A., Valsta, L., Wang, L., & Yousefpour, R. (2016). An ecosystem service-dominant logic? – integrating the ecosystem service approach and the service-dominant logic. *Journal of Cleaner Production*, *124*, 51–64. DOI: 10.1016/j.jclepro.2016.02.109.

Meena, A., Dhir, S., & Sushil, S. (2023). A review of coopetition and future research agenda. *Journal of Business and Industrial Marketing*, *38*(1), 118–136. DOI: 10.1108/JBIM-09-2021-0414.

Meynhardt, T., Chandler, D., & Strathoff, P. (2016). Systemic principles of value co-creation: Synergetics of value and service ecosystems. *Journal of Business Research*, *69*(8), 2981–2989. DOI: 10.1016/j.jbusres.2016.02.031.

Mosch, P., Majocco, P., & Obermaier, R. (2023). Contrasting value creation strategies of industrial-IoT-platforms – a multiple case study. *International Journal of Production Economics*, *263*, 108937. DOI: https://doi.org/10.1016/j.ijpe.2023.108937.

Müller, J.M., Buliga, O., & Voigt, K.-I. (2018). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technological Forecasting and Social Change*, *132*(September 2017), 2–17. DOI: 10.1016/j.techfore.2017.12.019.

Müller, P., Shaan, D., Ladher, R., Cannings, J., Murphy, E., Robin, N., Illán, S., Carsa, F., Gorgels, S., Priem, M., Econ, D., Smid, S., Bohn, N., Lefebvre, V., & Frizis, I. (2021). *Annual Report on European SMEs* (Issue July).

Ng, I., & Wakenshaw, S. (2017). The Internet-of-Things: Review and research directions. *International Journal of Research in Marketing*, *34*(1), 3–21. DOI: 10.1016/j.ijresmar.2016.11.003.

Ng, Irene, Maglio, P.P., Spohrer, J., & Wakenshaw, S. (2018). The Study of Service: From Systems to Ecosystems to Ecology. In SAGE Publications Ltd (Ed.), *The SAGE Handbook of Service-Dominant Logic* (pp. 230–240). SAGE Publications Ltd. DOI: 10.4135/9781526470355.n14.

Normann, R., & Ramirez, R. (1993). From value chain to value constellation: Designing interactive strategy. In *Harvard Business Review* (Vol. 71,

Issue 4, pp. 65–77). http://search.ebscohost.com/login.aspx?direct$=$true{&}db$=$bth{&}AN$=$9309166477{&}site$=$eds-live

Pakkala, D., Koivusaari, J., Pääkkönen, P., & Spohrer, J. (2020). An Experimental Case Study on Edge Computing Based Cyber-Physical Digital Service Provisioning with Mobile Robotics. *Proceedings of the 53rd Hawaii International Conference on System Sciences*, 1165–1174. DOI: 10.24251/hicss.2020.145.

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems*, *24*(3), 45–77. DOI: 10.2753/MIS0742-1222240302.

Pohlmann, A., & Kaartemo, V. (2017). Research trajectories of Service-Dominant Logic: Emergent themes of a unifying paradigm in business and management. *Industrial Marketing Management*, *63*, 53–68. DOI: 10.1016/j.indmarman.2017.01.001.

Ramírez-López, C., Till, K., Boyd, A., Bennet, M., Piscione, J., Bradley, S., Giuliano, P., Leduc, C., & Jones, B. (2021). Coopetition: Cooperation among competitors to enhance applied research and drive innovation in elite sport. *British Journal of Sports Medicine*, *55*(10), 522–523. DOI: 10.1136/bjsports-2020-102901.

Razmdoost, K., Alinaghian, L., Chandler, J.D., & Mele, C. (2023). Service ecosystem boundary and boundary work. *Journal of Business Research*, *156*(November 2022), 113489. DOI: 10.1016/j.jbusres.2022.113489.

Rouyre, A., Fernandez, A.-S., & Bruyaka, O. (2024). Big problems require large collective actions: Managing multilateral coopetition in strategic innovation networks. *Technovation*, *132*, 102968. DOI: 10.1016/j.technovation.2024.102968.

Rusko, R. (2014). Mapping the perspectives of coopetition and technology-based strategic networks: A case of smartphones. *Industrial Marketing Management*, *43*(5), 801–812. DOI: 10.1016/j.indmarman.2014.04.013.

Salih, K.O.M., Rashid, T.A., Radovanovic, D., & Bacanin, N. (2022). A Comprehensive Survey on the Internet of Things with the Industrial Marketplace. *Sensors*, *22*(3), 730. DOI: 10.3390/s22030730.

Seepana, C., Paulraj, A., & Huq, F.A. (2020). The architecture of coopetition: Strategic intent, ambidextrous managers, and knowledge sharing. *Industrial Marketing Management*, *91*(August), 100–113. DOI: 10.1016/j.indmarman.2020.08.012.

Shao, S., & Cao, D. (2024). Contagion of BIM Implementation Practices in Interproject Networks: An Empirical Study in China. *Journal of Management in Engineering*, *40*(1). DOI: 10.1061/JMENEA.MEENG-5639.

Silva, A., & Marques Cardoso, A. (2023). BIM-based Supply Chain in AEC – Threats on the Portuguese Stone sector. In I. 978-972-778-327-4 (Ed.), *Proceedings of the 7th Globalstone Congress, Batalha, 2023; ISBN 978-972-778-327-4*. https://repositorio.lneg.pt/bitstream/10400.9/4150/1/GSC2023_PTNaturalStones-CommercialNamesharmonization.pdf.

Silva, A., & Pata, A. (2022). Value Creation in Technology Service Ecosystems – Empirical Case Study. In J. Machado, F. Soares, J. Trojanowska, V. Ivanov, K. Antosz, Y. Ren, V.K. Manupati, & A. Pereira (Eds.), *Innovations in Industrial Engeneering II* (pp. 26–36). Springer International Publishing. DOI: 10.1007/978-3-031-09360-9_3.

Silva, A., Rabadão, C., & Capela, C. (2020). Towards Industry 4.0 |A case study of BIM deployment in ornamental stones sector. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, *67*, 24535. DOI: ISSN 2307-4531.

Silva, A., Silva, J., & Almeida, I. (2016). The role of digital technologies in the innovation of collaborative networks: the case of the ornamental stones in Portugal. *The 20th Cambridge International Manufacturing Symposium, September*.

Sklyar, A., Kowalkowski, C., Sörhammar, D., & Tronvoll, B. (2019). Resource integration through digitalization: a service ecosystem perspective. *Journal of Marketing Management*, *35*(11–12), 974–991. DOI: 10.1080/0267257X.2019.1600572.

Spohrer, J.C., & Maglio, P.P. (2010). *Toward a Science of Service Systems* (Issue 2008, pp. 157–194). DOI: 10.1007/978-1-4419-1628-0_9.

Spohrer, J., Maglio, P.P., Bailey, J., & Gruhl, D. (2007). Steps toward a science of service systems. *Computer*, *40*(1), 71–77. DOI: 10.1109/MC.2007.33.

van Riel, A.C.R., Calabretta, G., Driessen, P.H., Hillebrand, B., Humphreys, A., Krafft, M., & Beckers, S.F.M. (2013). Consumer perceptions of service constellations: implications for service innovation. *Journal of Service Management*, *24*(3), 314–329. DOI: 10.1108/09564231311327012.

Vargo, S.L., & Lusch, R. (2017). Service-dominant logic 2025. *International Journal of Research in Marketing*, *34*(1), 46–67. DOI: 10.1016/j.ijresmar.2016.11.001.

Vargo, S.L., & Lusch, R. (2016). Institutions and axioms: an extension and update of service-dominant logic. *Journal of the Academy of Marketing Science*, *44*(1), 5–23. DOI: 10.1007/s11747-015-0456-3.

Vargo, S.L., & Akaka, M.A. (2009). Service-Dominant Logic as a Foundation for Service Science: Clarifications. *Service Science*, *1*(1), 32–41. DOI: 10.1287/serv.1.1.32.

Vargo, S.L., Fehrer, J.A., Wieland, H., & Nariswari, A. (2024). The nature and fundamental elements of digital service innovation. *Journal of Service Management*, *35*(2), 227–252. DOI: 10.1108/JOSM-02-2023-0052.

Vargo, S.L., & Lusch, R.F. (2004). Evolving to a New Dominant Logic for Marketing. *Journal of Marketing*, *68*(1), 1–17. DOI: 10.1509/jmkg.68.1.1.24036.

Vargo, S.L., & Lusch, R.F. (2008). From goods to service(s): Divergences and convergences of logics. *Industrial Marketing Management*, *37*(1), 254–259. DOI: 10.1016/j.indmarman.2007.07.004.

Vargo, S.L., Wieland, H., & O'Brien, M. (2023). Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline. *Journal of Business Research*, *164*, 113965. DOI: 10.1016/j.jbusres.2023.113965.

vom Brocke, J., Hevner, A., & Maedche, A. (2020). *Introduction to Design Science Research* (Issue September, pp. 1–13). DOI: 10.1007/978-3-030-46781-4_1.

Wieland, H., Hartmann, N., & Vargo, S. (2017). Business models as service strategy. *Journal of the Academy of Marketing Science*, *45*(6), 925–943. DOI: 10.1007/s11747-017-0531-z.

Willis, A.J. (1997). The Ecosystem: An Evolving Concept Viewed Historically. *British Ecological Society, Functional Ecology*, *11*(2), 268–271. http://www.jstor.org/stable/2390328.

Xie, Q., Gao, Y., Xia, N., Zhang, S., & Tao, G. (2023). Coopetition and organizational performance outcomes: A meta-analysis of the main and moderator effects. *Journal of Business Research*, *154*(October 2022), 113363. DOI: 10.1016/j.jbusres.2022.113363.

applied system innovation

MDPI

Article

Coopetition with the Industrial IoT: A Service-Dominant Logic Approach

Agostinho da Silva [1,2,*] and Antonio J. Marques Cardoso [1]

[1] CISE—Electromechatronic Systems Research Centre, University of Beira Interior, 6201-001 Covilhã, Portugal; ajmar@ieee.org
[2] CIGEST—Centre for Research in Management, Lisbon Business School, 1000-002 Lisboa, Portugal
* Correspondence: a.silva@zipor.com

Abstract: Abstract: This research addresses the critical gap in enabling effective coopetition networks through technological innovation with the development of Cockpit4.0+, an Industrial Internet of Things (IIoT) artefact tailored for small- and medium-sized enterprises (SMEs). By employing the principles of Service-Dominant Logic (S-D Logic) and leveraging the Design Science Research (DSR) methodology, Cockpit4.0+ represents a pioneering approach to incorporating the IIoT within ecosystems for value co-creation. This facilitates competition and cooperation among firms, enhancing the operational dynamics within SME networks. Evaluated by experts in the ornamental stone sector, a significant sector of the Portuguese economy, the system demonstrated a positive functional acceptance rate of 78.9%. An experimental test was conducted following the positive preliminary functional evaluation of Cockpit4.0+, especially among more digitally advanced companies. The findings revealed that the on-time delivery performance under current best practices (CB.Ps) was 67.1%. In contrast, implementing coopetition network practices (CN.Ps) increased on-time delivery to 77.5%. These positive evaluations of Cockpit4.0+ underscore the practical applicability of S-D Logic and provide fresh insights into the dynamics of coopetition, particularly beneficial for SMEs. Despite its promising results, the real-world efficacy of IIoT systems like Cockpit4.0+ requires further empirical studies to verify these findings. Future research should focus on examining the scalability of Cockpit4.0+ and its adaptability across various sectors and enhancing its cybersecurity measures to ensure its long-term success and broader adoption.

Keywords: coopetition; service ecosystems; networks; industrial IoT; S-D logic

check for updates

Citation: da Silva, A.; Cardoso, A.J.M. Coopetition with the Industrial IoT: A Service-Dominant Logic Approach. *Appl. Syst. Innov.* **2024**, *7*, 47. https://doi.org/10.3390/asi7030047

Academic Editors: Mario Di Nardo and Maryam Gallab

Received: 21 March 2024
Revised: 17 May 2024
Accepted: 29 May 2024
Published: 31 May 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

In the dynamically shifting business environment, the integration of technological advancements with strategic partnerships among competitors, particularly within the European Union [1], has emerged as a critical strategy for securing competitive advantage, especially for small- and medium-sized enterprises (SMEs) [2,3]. This phenomenon, known as coopetition, marries the seemingly contradictory forces of cooperation and competition and has significantly captured the attention of management scholars [4].

The rise of the Industrial Internet of Things (IIoT) offers unparalleled opportunities for businesses to boost operational efficiency and foster innovation [5]. Ongoing developments in artificial intelligence (AI) and machine learning (ML) underscore the transformative potential of the IIoT [5]. When integrated with interoperability and accessibility, these technologies are crucial to boosting market responsiveness and facilitating value co-creation [6]. This is particularly evident through coopetition among manufacturing small- and medium-sized enterprises (SMEs) [7,8]. However, despite these advancements, there needs to be more solutions oriented towards leveraging the IIoT for coopetition networks, particularly among SMEs. A study by the BCG Henderson Institute, featured in the MIT Sloan Management Review, reveals a concerning 85% failure rate of coopetition networks in the short

term, with success rates not exceeding 15% in the long term, predominantly in networks led by dominant firms like Microsoft and Amazon [9]. This highlights a significant research gap in understanding and facilitating successful coopetition networks for SMEs, which need to merge corporations' resources and market dominance.

Addressing this gap, this research aims to explore IIoT systems' multiple levels of interoperability and accessibility within SME networks and design an IIoT system for facilitating coopetition. Adopting the value co-creation perspective of Service-Dominant Logic (S-D Logic) [10], this study aims to develop an IoT artefact that empowers SME coopetition networks, fostering an ecosystem that encourages collaborative innovation and mutual value creation. By utilizing the Design Science Research (DSR) methodology, this research seeks to bridge the theoretical insights of S-D Logic with practical applications in the IIoT, specifically targeting SME coopetition [11].

This paper is structured to first explore the synergies and challenges of integrating coopetition networks with the IIoT through the lens of S-D Logic. After laying the theoretical groundwork, it discusses the methodology employed and details the design and development of the IIoT system, Cockpit4.0+, which is specifically tailored to facilitate coopetition among stone industry SMEs. The paper then presents a preliminary acceptance evaluation of the Cockpit4.0+ prototype, followed by an experimental pilot test. It concludes with a comprehensive discussion that synthesizes the findings, explores their broader implications, and proposes directions for future research.

1.1. Coopetition Networks for Value Co-Creation

S-D Logic represents a paradigm shift from the traditional goods-dominant logic, which emphasizes tangible products, to focus on service as the fundamental basis of economic exchange and value creation [12]. Introduced by Vargo and Lusch in 2004, this perspective has evolved into a comprehensive narrative that views economic activities through the lens of service-for-service exchanges within service ecosystems [13]. These ecosystems are orchestrated by institutions endogenously generated by the actors, underscoring value creation's collaborative nature [14]. Central to S-D Logic is the reconceptualization of exchange and value co-creation as primarily occurring through the provision of service, understood singularly rather than as multiple intangible outputs. In this context, service is defined as applying competencies (skills and knowledge) to benefit another entity or the entity itself, positioning resource integration as the cornerstone of value co-creation [15]. This perspective highlights that services can be exchanged directly, such as through personal interactions, or indirectly, via goods, which serve as vehicles for service delivery.

According to recent insights from Vargo et al. (2023a), adopting a systems viewpoint allows for conceptualizing markets and marketing phenomena as inherently relational, dynamic, and emergent. From these insights, technology is viewed as a crucial resource for networks, referred to as an increasing enabler of innovation [11], and technological advancements are viewed as enablers for firms' interactions [16], pushing networks to co-create more value for actors [12].

The various contributions in the literature underscore the role of S-D Logic in dissecting a wide range of empirical scenarios and enriching our theoretical comprehension of value co-creation processes [10]. Aligning with the S-D Logic premises, the discourse within the business literature increasingly recognizes coopetition networks as strategic, technology-supported networks [4]. This perspective positions technology not merely as a tool but as a central element that functions as an operant resource (initiator) and an operand resource (enabler). This dual role facilitates the formation of shared understandings among collective actors within ecosystems, enhancing collaboration and competitive advantage [17].

Under this view, technology's operant role in coopetition networks involves initiating new interactions and engagements, catalyzing value creation and exchange [15]. As an operand resource, technology is an enabler that supports these interactions, allowing for the seamless integration and utilization of resources across the network [18]. This nuanced

role of technology underscores its critical importance in fostering an environment where businesses can collaborate and compete effectively.

This evolving understanding of technology's role in coopetition networks signals a significant shift towards more collaborative and adaptive networks. It highlights the necessity of rethinking traditional competition paradigms and advocates for a more integrated approach that embraces the complexities and opportunities of the digital age.

1.2. IIoT Challenges and Potential Solutions for Coopetition Enabling

Digitization involves transforming analogue information into digital format, facilitating data processing, storage, and transmission across digital platforms [19]. Building upon this foundation, digitalization expands the scope by integrating Information and Communication Technologies (ICTs) throughout the value chain. This integration challenges enterprises to evolve, adopting digital networks that revolutionize traditional concepts of workspace and resource distribution [20,21].

Within digitalization, the term "Internet of Things" (IoT) was introduced by Kevin Ashton, initially at Procter & Gamble and subsequently at MIT's Auto-ID Center in 1998 [22]. Ashton envisioned a world where "every object is part of the Internet", irrespective of the business proposition behind the IoT [23]. This vision has materialized over two decades, with advancements in wireless communication, sensors, and computing power. Today, the IoT encompasses uniquely identifiable objects capable of transmitting data over the Internet autonomously, minimizing or eliminating the need for human intervention [24,25]. The evolution of the IoT has facilitated the creation of interconnected networks, ushering in innovative service offerings such as remote monitoring and predictive maintenance [15]. These developments underscore the profound impact of digitization and digitalization on shaping the future of technology, enabling businesses to harness the power of the IoT for enhanced efficiency and novel solutions [26].

The IIoT, an extension of the IoT focusing on industrial applications, aims at elevating manufacturing SMEs to new efficiency levels through innovative, interconnected industrial systems [5,27]. These systems facilitate global connectivity and ensure meaningful communication between devices, paving the way for intelligent artefacts that respond to user interactions and contribute to complex value creation processes [28].

The IIoT represents a non-stop state-of-the-art updating, incorporating new improvements continuously and increasingly embedding the capability to take collaborative actions without humans [22], leading to a hyper-connected society and an increasingly global economy [29]. These collaborative capabilities [25] make IIoT technologies crucial to linking the shop floor directly with customers, enabling modern networks [30]. In technology-enabled networks, these collaborative actions happen not only among machines but also between providers and customers [5] and among rivals (coopetitors), from which value creation is created by multiple actors and determined by the beneficiary, thus converging to S-D Logic foundations [31].

1.3. Addressing the IIoT under an S-D Logic Perspective

Despite some recently developed IIoT-based systems representing methods in service knowledge [6–8], no solution oriented toward creating value through cooperation, namely, with manufacturing SMEs, was found.

Further bolstering the IoT and embedded systems era [32], the S-D Logic literature links the IoT and IIoT to ecosystems [15]. For S-D Logic, in ecosystems, resources are connected through any form of a sensor [23], enabling resources to be located, identified, and even operated upon [33] to promote more interactions among actors.

The S-D Logic focuses on value co-creation involving actors through operant and operand technologies [15], while the IIoT combines the global reach of the Internet with industrial capabilities to control, coordinate, and manage the physical world of goods, machines, factories, and infrastructure [21].

Aligned with this S-D Logic perspective on operand and operant resources [18], some authors in ICTs and service management refer to intelligent artefacts or systems able to execute specific functions [34] and reacting toward user interaction according to property sets of objects. However, for other authors, although this feasibility occurs successfully in some simple cases, in complex processes, the in-box thinking smart objects lead to creativity needing to be improved [35].

Viewing the IIoT through the S-D Logic perspective presents a strategic approach to leveraging technology for value co-creation. IIoT technologies facilitate the sharing of information and resources, enhancing the visibility and responsiveness of firms within networks [18]. By enabling more effective resource integration and service exchange, the IIoT empowers firms to engage in S-D Logic's core principle of creating value with and for their customers and partners. This integration highlights the role of technology not just as a tool or enabler but as a participatory resource in the service ecosystem, actively shaping opportunities for value creation [36].

From this perspective, IIoT technologies catalyze cooperation and competition among SMEs within coopetition networks. By providing a platform for data exchange and collaborative innovation, the IIoT enables firms to share insights and resources while maintaining competitive advantages [37,38]. This dual functionality supports the development of coopetition networks where SMEs can mitigate weaknesses like scale and explore new market opportunities without diluting their unique value propositions. The dynamic interplay facilitated by IIoT technologies underscores the complex nature of coopetition networks, where shared value creation and competitive differentiation coexist and reinforce each other.

1.4. IIoT Challenges and Potential Solutions for Coopetition Enabling

Drawing from the core principles of the IoT, the IIoT is heralded for elevating operational efficiency, particularly in small- and medium-sized manufacturing enterprises. It prioritizes advancing smart, autonomous, and interconnected industrial processes to boost the manufacturing industry's competitive advantage [39]. This approach underscores the transition towards intelligent manufacturing and highlights the IIoT's role in fostering a more connected, efficient, and competitive industrial landscape.

However, anchoring coopetition networks in the IIoT faces numerous challenges. Success in these networks largely hinges on the presence of key players, with leading companies playing a central role in the survival and profitability of digital networks [40]. This trend towards high failure rates supports the literature's focus on the crucial impact of "keystone" members on the viability of ecosystems. Notably, there have been no successful cases of coopetition networks composed solely of SMEs [9].

These challenges include issues related to data security and ensuring the confidentiality and integrity of shared information in a landscape where entities might also be competitors [41]. Interoperability, or the ability of diverse systems and organizations to work together, becomes critical in environments where collaboration is essential for scale but must be balanced against competitive interests [42]. Furthermore, intellectual property management assumes heightened importance as entities navigate the fine line between sharing enough to co-create value while safeguarding their competitive advantages [43].

In the context of coopetition, the stakes of technological integration are heightened. Entities must navigate the dual objectives of leveraging shared platforms for mutual benefit while maintaining enough competitive edge to survive and thrive. This balancing act requires a strategic approach to technology adoption and collaboration, where the goal is to win or lose deals not just as individual entities but as interconnected parts of a larger ecosystem. In the state of the art, the success of one can contaminate the entire network forward, illustrating the complex but potentially rewarding nature of coopetition facilitated by IIoT artefacts.

From these challenges grounded in the S-D Logic foundations, to enhance value co-creation in coopetition networks, the IIoT artefact must ensure the actors' expectations by

fulfilling, requiring capabilities: (1) operant and operand technological capabilities—the seamless adaptation to coopetition networks' dynamic environments [44]; (2) technical, semantic, and pragmatic interoperability—which ensures that the artefact can not only communicate and operate across diverse technological platforms (technical interoperability) but also interpret and utilize the information meaningfully (semantic interoperability) and support actionable insights and decisions (pragmatic interoperability) [12]; (3) accessibility and usability for network actors—this focus acknowledges the importance of human-centered design principles, ensuring that the system can be effectively utilized by a broad spectrum of users to facilitate collaboration and value co-creation [45]; and (4) facilitation of simultaneous collaboration among competitors—recognizing the inherent complexities of coopetition, the artefact must enable and enhance collaboration among competing entities from the lead to winning or losing the business opportunity [4].

2. Methodology

DSR is a distinctive methodological paradigm transcending traditional research frameworks such as positivist, interpretive, and critical approaches. It focuses on creating and systematically evaluating artefacts to address real-world issues [46]. This methodology, as detailed by Peffers et al. (2007) and Baskerville et al. (2018), is centered on the conception and assessment of a wide array of artefacts, including but not limited to models, methods, constructs, software, and technological systems [47]. The primary goal of DSR is to devise practical solutions that effectively tackle existing problems and enrich our theoretical understanding of the problems at hand and the proposed solutions [48]. This approach is particularly relevant in the IIoT context, where the design and implementation of innovative artefacts can significantly contribute to advancing both practical capabilities and scholarly knowledge.

Accordingly, as prescribed by the DSR methodology, this study developed an IoT artefact to facilitate coopetition networks among SMEs. Subsequently, it was evaluated by experts representing manufacturing SMEs.

The Cockpit4.0 system, as introduced by Silva et al. (2020), was developed within the framework of the Inovstone4.0 R&D Project. This project, financed by the European Union under the Mineral Resources Cluster Action Plan, aimed to harness advanced technologies and software for the natural stone industry. Specifically, Cockpit4.0 was designed to facilitate connectivity between ornamental stone companies and the cyber market [49]. Beyond serving as a mediator resource that interacts with cyber customers, Cockpit4.0 is equipped with the innovative "fingerprint4.0" feature, including a dual-compartment cargo vehicle: the first compartment houses detailed descriptions of the co-created product, which may include comments, notes, remarks, or other pertinent information. The second compartment carries the IFC/XML code, facilitating the creation of smart objects. Cockpit4.0 is considered state-of-the-art within the stone industry [50], showcasing the transformative potential of the IIoT to revolutionize traditional market dynamics by enhancing direct interaction and collaboration. However, it cannot connect competing rivals within a coopetition network.

Analyzing the Cockpit4.0 system through the S-D Logic framework reveals its effectiveness as a dynamic facilitator of cyber value offerings, enhancing service provision [51]. This perspective highlights an opportunity to push the boundaries of state-of-the-art in-stone processing by leveraging advanced technological capabilities. Significantly, it promotes coopetition by connecting the shop floors of manufacturing rivals within a network to co-create increased value for all stakeholders. By harnessing the integration of resources from these rivals, there is a substantial potential to enhance value creation across networks, ultimately providing superior service to customers.

To address the challenge of coopetition network failures, particularly in the absence of key companies, an evolved version of the system, Cockpit4.0+, is proposed. This advancement aims to bridge the gap, ensuring higher industry ecosystem connectivity, efficiency, and responsiveness. Committing to this evolution aims to foster an environment

where SMEs can flourish, benefiting from collaborative innovation and strategic flexibility. Cockpit4.0+ represents a step forward in realizing a more integrated and cooperative industry landscape, where the synergy between technology and coopetition principles can lead to sustainable growth and enhanced customer satisfaction.

2.1. Cockpit4.0+ Development

The Cockpit4.0+ system, grounded in S-D Logic, requires effective orchestration of the interplay between operant (initiator) and operand (actuator) resources, a central strategy for enhancing coopetition networks [52]. This strategic integration necessitates a deliberate approach to technology implementation, where operant capabilities initiate actions and operand resources—physical or tangible assets—execute or respond to these initiatives. By synergizing these capabilities, Cockpit4.0+ drives innovation, boosts efficiency, and fosters collaboration among SMEs. This harmonious integration potentially elevates SME competitiveness and nurtures a dynamic environment where coopetition flourishes, merging cooperation with competition to discover new value and opportunities in the market. Additionally, Cockpit4.0+ must ensure that each coopetitor only shares the desired information, assuring that other network members maintain this reciprocity.

By incorporating these concepts into the existing Cockpit4.0 framework, the new Cockpit4.0+ emerges as an advanced version designed to facilitate network coopetition. This enhancement requires (1) a modular architecture that seamlessly integrates with SMEs' current digital infrastructures, including ERP and CRM systems, as well as manufacturing equipment; (2) a commitment to data protection through the use of advanced encryption methods and secure exchange protocols, which safeguard sensitive information against digital threats and ensure data integrity; (3) user-friendly interfaces that are accessible to a broad range of users, promoting engagement across various platforms, including mobile devices. Furthermore, Cockpit4.0+ encompasses a comprehensive upgrade of the existing Cockpit4.0 modules, including replacing sensors with more advanced technology, enhanced cloud computing capabilities, and high-speed networking equipment. Through the strategic amalgamation of these operant and operand resources, the Cockpit4.0+ system is set to significantly boost innovation, efficiency, and collaboration within the competitive sphere of SMEs, thereby advancing coopetition networks.

2.2. Operant Capabilities: Artificial Intelligence and Machine Learning

By incorporating artificial intelligence (AI) and machine learning (ML), the Cockpit4.0+ system discreetly enhances the network resources of coopetitors, such as machines and inventory. This integration facilitates sophisticated data analysis, market trend forecasting, and the generation of actionable intelligence. Such capabilities support dynamic pricing strategies, predictive maintenance, and the customization of offerings to meet specific customer needs. The AI module within Cockpit4.0+ provides real-time advisories to each coopetitor about the optimal combination of resources—including those from competitors—throughout the sales cycle, from lead acquisition to the outcome of a deal. Meanwhile, the ML module continuously offers real-time insights into the performance optimization of various resources, including manufacturing assets, human resources, and financial capital.

2.3. Multiple Levels of Interoperability

The interoperability of Cockpit4.0+ must extend its capabilities beyond the foundational layers, weaving a complex fabric of robust and flexible connectivity. By embedding the OPC Unified Architecture (OPC UA), Cockpit4.0+ ensures seamless data exchange across various platforms and devices and paves the way for advanced collaborative frameworks within the industrial sector (Figure 1).

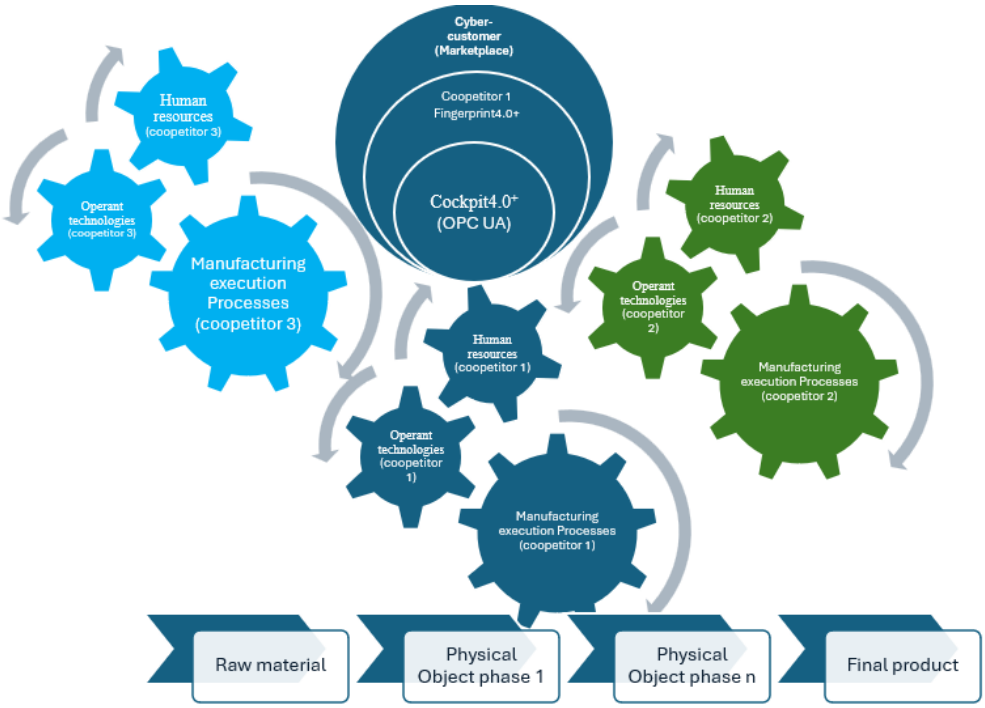


Figure 1. OPC UA interoperability mechanisms in coopetition technology-enabled networks.

Through the advanced interoperability facilitated by Cockpit4.0+, the networks foster deeper collaboration among actors, allowing them to leverage shared resources and capabilities more effectively. This enhanced level of connectivity ensures that all network participants, regardless of their technological infrastructure, can partake in the value creation process.

Leveraging resource density and digital materiality must be embedded at the heart of Cockpit4.0+ to become instrumental in redefining how value is co-created within networks. This way, Cockpit4.0+ facilitates the liquefication and unbundling of network resources, thereby enabling the dynamic recombination of capabilities tailored to meet specific customer needs. This approach enhances flexibility and amplifies the potential for innovation in the network. In particular, the digital materiality mechanism [21] underscores the system's capacity to bridge the gap between the virtual and physical realms. By enabling the manipulation of digital representations of physical objects, Cockpit4.0+ allows for a more nuanced and sophisticated approach to product development and customization. This capability is critical for SMEs seeking to differentiate themselves through unique value propositions [21].

Embedding the OPC UA into the Cockpit4.0+ architecture underscores a commitment to establishing a genuinely interoperable ecosystem. This decision aligns with the system's overarching goal of facilitating seamless and secure communication across all levels of operation—from machine-to-machine interactions to broader device-to-cloud data exchanges. The OPC UA's role in ensuring data integrity and security is paramount, particularly when handling sensitive information or executing complex transactions across the network. Furthermore, the integration of the OPC UA supports the pre-validation process, allowing stakeholders to assess and refine value propositions before they enter the manufacturing phase. This capability is essential to maintaining high standards of quality and compliance, as well as for minimizing waste and optimizing resource use.

2.4. Network Actors' Accessibility and Usability

The Cockpit4.0+ system must strongly emphasize making the digital ecosystem accessible and user-friendly for all participants, grounding its design in human-centered principles that align with S-D Logic. This perspective views value creation as a collaborative

process among network actors, emphasizing resource integration and exchange. By designing Cockpit4.0+ to facilitate cooperation—even among competitors—Cockpit4.0+ sets the stage for secure and efficient service exchanges that elevate the network's collective value proposition. As key mechanisms for enhancing usability and accessibility, Cockpit4.0+ embodies systemic assemblages and architectural modules for transactions and service (Figure 2).

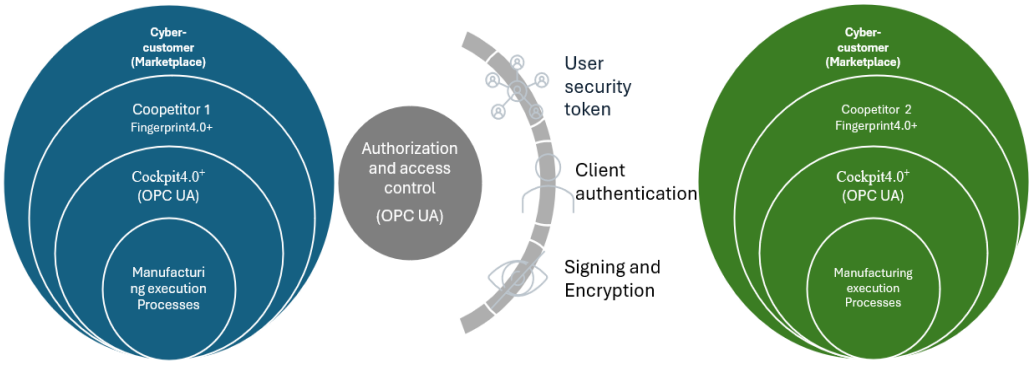


Figure 2. OPC UA security mechanisms in coopetition technology-enabled networks.

Cockpit4.0+ must adopt a holistic approach by integrating various technological components into cohesive assemblages. These assemblages are more than the sum of their parts. They offer enhanced functionalities by leveraging the interconnectedness of diverse technological systems, reflecting the S-D Logic view that service ecosystems are intricate structures, combining various social and technological aggregation levels. The system's architecture is thus designed to facilitate this integration, ensuring that all network actors can interact seamlessly within this diverse technological landscape.

Cockpit4.0+ must feature modular designs to allow for the flexible reconfiguration of products and services to meet different needs, facilitating personalization and customization. This modular approach can support the disintermediation and fragmentation of physical products, a concept that the S-D Logic literature suggests can foster value within ecosystems. By enabling the tailored recombination of operant and operand functionalities, Cockpit4.0+ acts as a dynamic architectural framework that adapts to and supports the evolving requirements of the network's participants.

The OPC UA's comprehensive security features—including digitally signed certificates and encryption—are crucial to preventing data tampering and eavesdropping, thus maintaining the integrity and confidentiality of network exchanges. The adoption of the OPC UA facilitates the creation of a coopetition network wherein multiple instances of the Cockpit4.0+ system can represent various stakeholders, fostering value co-creation across the dimensions of customers, rivals, and providers. This setup promotes sustained collaboration throughout the lifecycle of business opportunities, from their inception to their conclusion, regardless of the outcome.

By embedding systemic assemblages and modular architectural designs into the foundation of Cockpit4.0+ and leveraging the robust security and interoperability of the OPC UA, the system is poised to offer a secure, intuitive platform. This IIoT system can support dynamic collaboration and value co-creation, enabling technology-enabled networks to thrive aiming to redefine coopetition networks, making them more inclusive, adaptable, and conducive to innovation and mutual success for SMEs.

2.5. Algorithm: Cockpit4.0+ System Development

The development of the Cockpit4.0+ system initiates by identifying specific features and functionalities critical to addressing the dynamics of coopetition. These elements provide a foundation for an understanding of, engagement with, and the collective pursuit of new business opportunities. The Cockpit4.0+ development process involved designing an

algorithm that integrates operant and operand technological capabilities. This integration ensures interoperability across different levels, enhances accessibility and usability for network participants, and promotes effective collaboration among competitors. The algorithm, detailed in Table 1, encompasses the core functionalities, and ensures a systematic implementation of the system's features as described below.

Table 1. Systematic implementation algorithm for Cockpit4.0+ features.

Algorithm Steps	Core Functionalities
Initialize System Core Components	Set up the foundational architecture, including cloud computing, high-speed networking, and basic security protocols.
Integrate Operant Technological Capabilities	Implement AI/ML for data analysis and trend prediction. Develop modular architecture for ERP/CRM integration. Enforce data protection with encryption. Design intuitive, mobile-compatible UI. Design intuitive user interface that ensures accessibility and mobile compatibility.
Incorporate Operand Capabilities	Install devices for real-time monitoring. Utilize cloud computing for scalable storage/processing. Ensure secure high-speed data transmission. Connect with digital marketplaces.
Interoperability Across Levels	Establish technical, semantic, and pragmatic interoperability pathways.
Implement S-D Logic Foundations	Integrate resource density mechanisms and digital materiality mechanisms.
Deploy OPC UA	Use OPC UA for interoperability and security measures like digitally signed certificates and encryption.
Enhance Usability and Accessibility	Apply human-centered design. Develop modules for transaction/service customization. Create interconnected technological components.
Facilitate Coopetition Collaboration	Implement advanced communication, data-sharing tools, APIs for third-party integration, and privacy mechanisms. Provide platforms for co-creation and innovation. Establish governance and trust-building features.
Testing and Deployment	Conduct comprehensive testing (usability, security, and interoperability). Deploy for pilot testing with SMEs. Collect feedback and adjust.
Launch and Monitor	Launch Cockpit4.0+ for broader use. Monitor performance and user feedback. Implement updates and enhancements.

Advanced communication and data-sharing tools: (i) secure messaging and file sharing—the implementation of encrypted communication channels and secure file-sharing capabilities ensures the safe exchange of information and resources among competitors, maintaining confidentiality and integrity; (ii) real-time collaboration spaces—the provision of tools like shared digital whiteboards and co-editing documents facilitates seamless collaboration, enabling participants to work together effectively from various locations.

Access control and privacy mechanisms: (i) granular permission settings—a sophisticated access control system allows for precise control over shared data and resources, safeguarding sensitive information by restricting access based on roles or needs; (ii) data anonymization and aggregation—employing data anonymization techniques to share insights without compromising competitive advantages, enabling the collective benefit from aggregated data without revealing proprietary information.

Interoperability and integration capabilities: (i) APIs for third-party integration—robust APIs ensure smooth integration with existing systems and platforms, streamlining workflows and facilitating efficient data exchange among competitors; (ii) standards compliance—ensuring the system adheres to industry standards for data exchange and

interoperability, facilitating seamless communication and collaboration across diverse technological environments.

Co-creation and innovation platforms: (i) idea management tools—tools that support the collection, development, and evaluation of ideas collaboratively, driving innovation within the coopetition framework; (ii) prototype testing environments—virtual spaces where new products or services can be tested and refined together, speeding up the innovation process and reducing the time to market.

Conflict resolution and governance structures: (i) transparent governance mechanisms—clear rules and governance structures are established for managing coopetition, ensuring all parties have input in decision-making processes and access to dispute resolution mechanisms; (ii) performance tracking and reporting—integrating tools for monitoring collaboration progress and outcomes, ensuring transparency and accountability for all network participants.

Trust building and relationship management: (i) reputation systems: a system that allows companies to rate their experiences with competitors, fostering trust and reliability within the network; (ii) facilitated networking events—organizing events and workshops to strengthen relationships among competitors, promoting a culture of openness and mutual respect.

By integrating these features into Cockpit4.0+, the system has been fully developed to support and actively promote collaboration among competitors. The algorithm lays out a structured pathway for developing the Cockpit4.0+ system, ensuring that all critical aspects—from operant and operand technological capabilities to interoperability, usability, and coopetition facilitation—are systematically addressed.

A preliminary evaluation was undertaken within the Portuguese ornamental stone (OS-PT) sector. This assessment aimed to gauge the functional acceptance of Cockpit4.0+ and explore its potential to enhance coopetition among stone SMEs.

2.6. Functional Acceptance and Evaluation of Cockpit4.0+ Prototype

The OS-PT sector, a cornerstone of Portugal's rich cultural heritage and forward-looking innovation, has significantly contributed to iconic stone monuments worldwide since the 15th century [53]. Recent data from the Portuguese Stone Federation (2022) illuminate the sector's substantial economic impact: exporting to 116 countries, ranking as the ninth most significant player in the World International Stone Trade, and securing the second position globally regarding international trade per capita [54]. With exports outstripping imports by 660% and a significant share of exports reaching markets outside Europe, the industry boasts a turnover of EUR 1.230 million. It supports over 16,600 direct jobs, making it a critical employment source, particularly in inland regions [55].

A preliminary evaluation involved technical experts and engineers from 24 OS-PT SMEs. These SMEs were strategically selected to represent a wide range of digital maturity levels within the OS-PT sector, thus providing a diverse and representative sample for the evaluation. This approach yielded valuable insights into accepting the Cockpit4.0+ prototype's functionalities across various stages of digital readiness among the SMEs involved.

For the study, each participating company was assigned a digital level (DL) based on comprehensive site visits, categorized as follows: DL#0: no digital tools are used; DL#1: at least one computerized machine on the manufacturing shop floor; DL#2: all machines are computerized; DL#3: all machines are computerized and connected to the ERP system; and DL#4: all machines are connected to the ERP system and can connect to Building Information Modeling (BIM) architects' stations.

The evaluation included a detailed assessment of each company's digital production equipment, management, integration processes with production, and involvement in digital marketplaces. The survey was structured into four actions.

First Action (Introduction): Highlighting the shift towards BIM and the upcoming need for stone companies to adapt to BIM-shaped procurement in the Architecture, Engi-

neering, and Construction (AEC) market, with a tangible demonstration of the Cockpit interface. Second Action (Explanation): Explanation of the Cockpit's functionalities regarding innovation, usefulness, cybersecurity, and usability in facilitating coopetition among rival SMEs, including features for resource sharing without prior partner knowledge, maintaining commercial confidentiality, and automated resource allocation based on buyer decisions. Third Action (Questions): Participants were asked to rate, on a scale from one to five, their opinion on Cockpit4.0+ regarding technological disruptiveness, usefulness, cybersecurity, and usability. Fourth Action (Data Collection): The survey was conducted throughout 2023, with the data anonymized to maintain confidentiality and documented in an Excel file. Average responses are detailed in Table 2.

Table 2. Summary of average responses from the questionnaire.

Cockpit4.0+ Functional Acceptance (Average)	Disruptive Innovation	Company's Usefulness	Cybersecurity	Usability	Average Rating
DL#0 respondents	4.3	1.2	2.6	4.0	3.0
DL#1 respondents	4.7	2.3	3.8	4.2	3.8
DL#2 respondents	4.9	3.1	3.0	4.2	3.8
DL#3 respondents	5.0	4.6	3.0	4.9	4.4
DL#4 respondents	4.9	5.0	4.1	5.0	4.8
Average functional acceptance	4.8	3.2	3.3	4.5	3.9

The aggregated ratings from respondents underscored the perceived innovation of the Cockpit4.0+ system, with an impressive average score of 3.9 out of 5. This highlights the prototype's potential functional efficacy within the sector. Notably, the perceived usefulness of the system exhibited a positive correlation with the companies' digital maturity. Among the most digitally advanced respondents (DL#4), the system achieved high scores, averaging 4.8 out of 5.

Even though cybersecurity emerged as an area for improvement, with an average rating of 3.3 out of 5, the prototype demonstrated significant promise as a tool for enabling coopetition, especially among SMEs with higher digital levels.

Converting the quantitative data from the questionnaire into percentages reveals an overall positive acceptance rate of 78.9% for the Cockpit4.0+ prototype, demonstrating its considerable potential to foster coopetition within SME networks (Figure 3). The feedback particularly underscores the exceptional value of the system for entities at the forefront of digital integration. However, a focused review and the enhancement of the system's security features are advisable, given the cybersecurity concerns. Strengthening these aspects will bolster confidence in the prototype and enhance its overall utility and acceptance among SMEs.

The positive preliminary functional evaluation of Cockpit4.0+, especially by the DL#4 respondents, created solid conditions for the next step: conducting the first experimental test. However, the lower acceptance rates among respondents with lower digital levels (DL#0, DL#1, and DL#2) suggest that these companies are not yet prepared to integrate collaborative software like Cockpit4.0+. This integration requires a digital mindset and needs to be improved in these less digitally mature enterprises.

Using the Cockpit4.0+ prototype, a strategic implementation of an experimental pilot test began for the first objective evaluation of Cockpit4.0+. Two companies from the DL#4 group, which rated Cockpit4.0+ the highest in functional acceptance, were formally invited to participate in this pilot test (Figure 4). These two companies, recognized as leaders in the Portuguese stone sector, have all their machines connected to the ERP system, which connects to BIM architects' stations. This setup represents the OS-PT sector's current best practices (CB.Ps). A comprehensive confidentiality agreement was drafted to protect sensitive information regarding the companies' operations, clientele, employees, resources, and competitors.

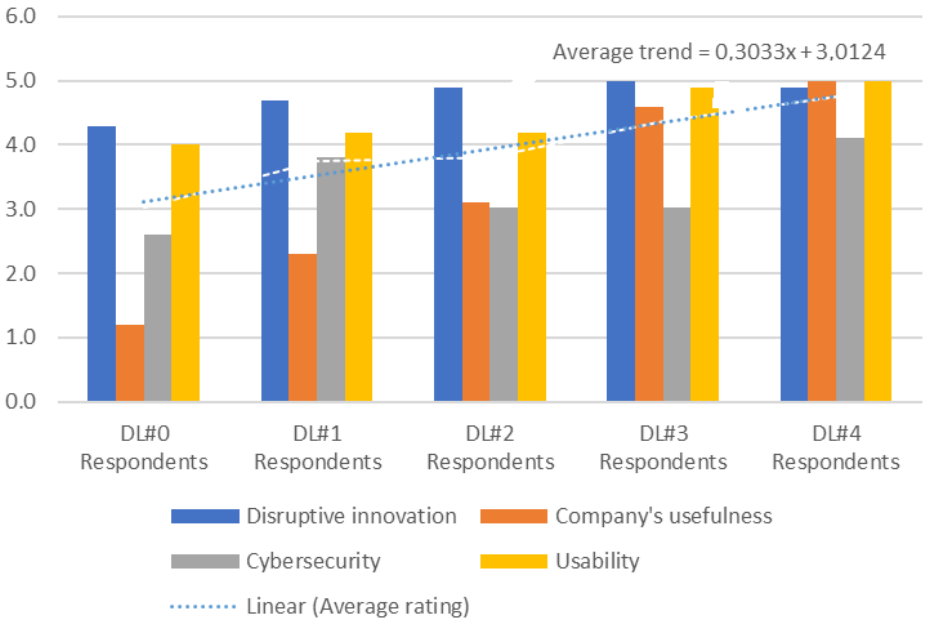


Figure 3. Evaluation of Cockpit4.0+ by SMEs in the stone manufacturing sector.

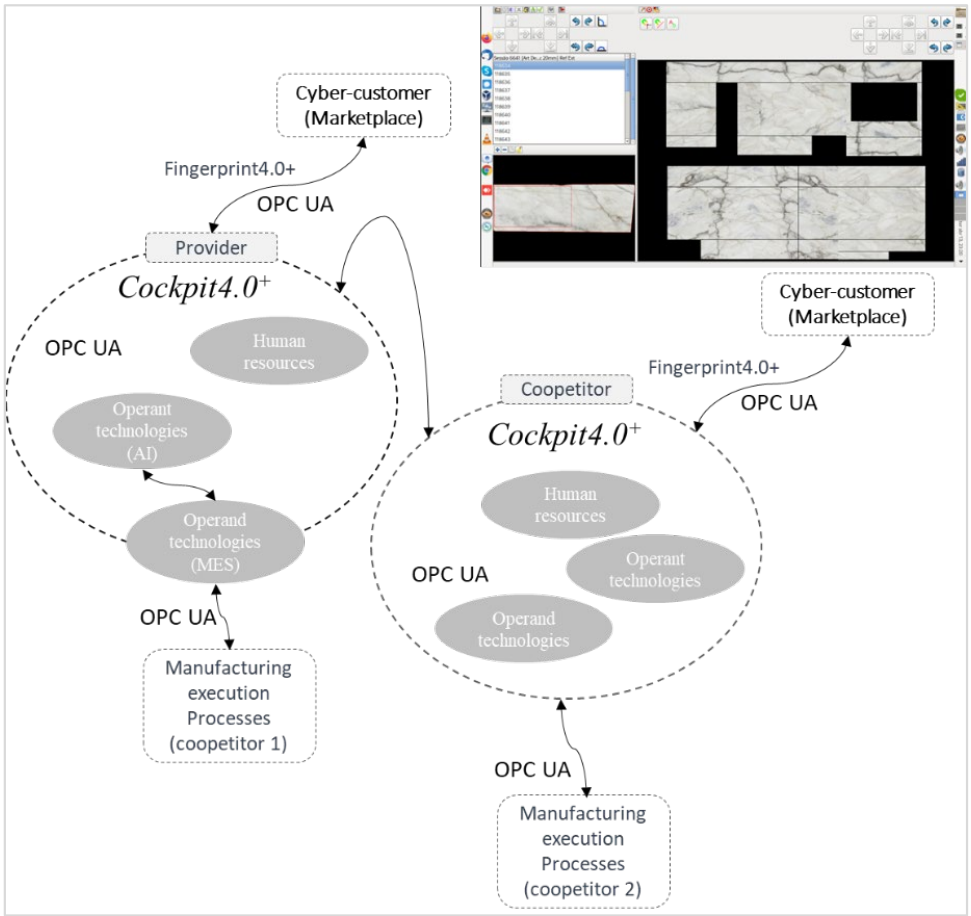


Figure 4. Implementation of the Cockpit4.0+ experimental pilot test.

As BIM integrates the crucial aspect of time, marking a significant evolution in project management and coordination within the construction industry [56], stone fabricators must enhance their scheduling, coordination, and productivity processes to respond to BIM-shaped industry demands effectively. Therefore, "On-Time Delivery KPI" was selected as the key performance indicator (KPI_{OtD}) for evaluating stone fabricators' responses, reflecting their ability to meet project deadlines (Equation (1)) consistently.

$$KPI_{OtD}\ (\%) = \sum_{1}^{n} \left(\frac{parts_delivered_on_time_{(daily)}}{\sum parts_delivered)_{(daily)}} \right) \quad (1)$$

Improvements in KPI_{OtD} directly enhance the effectiveness of ensuring timely project execution and schedule adherence.

This study employed a data collection strategy across two fifty-four-day intervals to explore the transition from CB.Ps to cooperative network practices (CN.Ps) enhanced by Cockpit4.0+, enabling a robust comparative analysis of on-time delivery outcomes.

CB.P phase: The first interval focused on capturing standard operations at the two anonymized companies. This baseline phase documented each company's reliance on internal resources for production and delivery, providing essential reference data for subsequent comparisons.

CN.P phase: The second interval assessed the effects of integrating these entities into a coopetition-based network enhanced by the Cockpit4.0+ prototype.

Data management and privacy were rigorously maintained throughout the study in compliance with confidentiality agreements. All data were anonymized and referred to only by company labels. Data collection, recording, and exportation procedures were followed, with results exported to Excel files. This ensured a secure and consistent approach to data handling, enabling detailed analysis while safeguarding the privacy and proprietary information of the participating companies. The data collected were used to assess KPI_{OtD} under CB.Ps and CN.Ps, as summarized in Table 3.

Table 3. Summary of average data collected daily.

Data Type	Description	CB.Ps—Average Data (Daily)	CN.Ps—Average Data (Daily)
Data type 1	Parts delivered daily	339	454
Data type 2	Parts delivered on time	240	358
KPI	On-time delivery	0.671	0.775

Based on these findings, under CB.Ps, the on-time delivery performance was recorded as 67.1%, with 240 out of 339 parts being delivered as scheduled. In contrast, CN.Ps resulted in a significant increase in KPI_{OtD} to 77.5%, with 358 out of 454 parts being delivered on time. Figure 5 shows the daily average on-time delivery performance for both CB.Ps and CN.Ps.

These results demonstrate that by transitioning to a coopetition network facilitated by Cockpit4.0+, the OS-PT companies experienced substantial improvements in on-time delivery performance.

In summary, this evaluation text of the Cockpit4.0+ prototype confirmed the preliminary functionalities. By focusing on the identified areas for improvement and capitalizing on its existing strengths, the system is strategically positioned to significantly influence the OS-PT sector digital transformation. Specifically, it promises to enhance dynamic and secure competition networks, which is essential for evolving competitive landscapes.

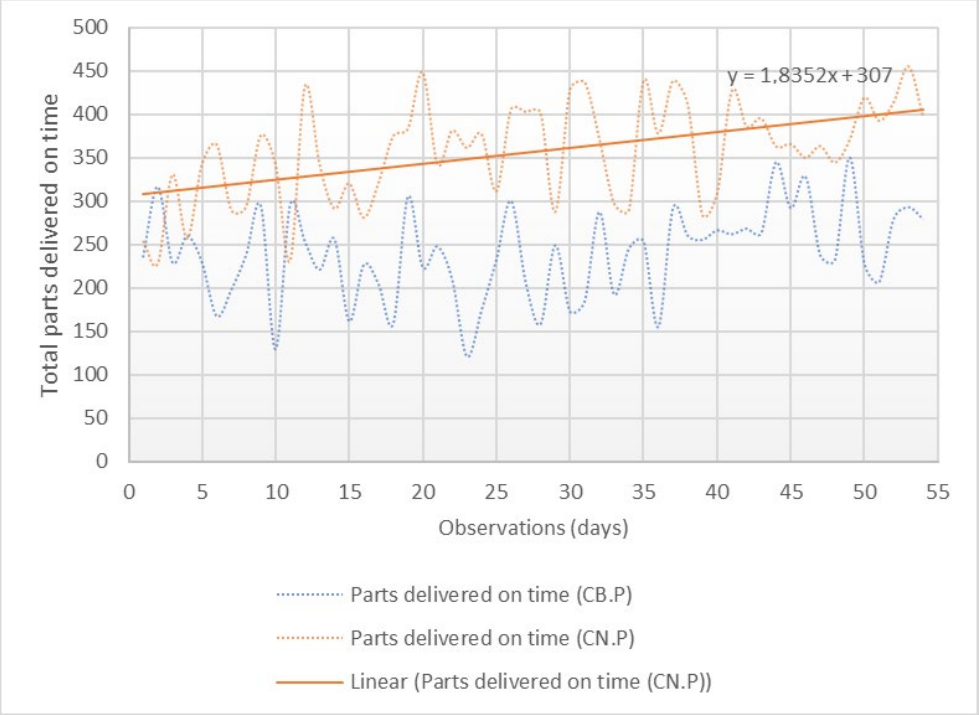


Figure 5. Daily trend in on-time-delivery.

3. Conclusions

This study has highlighted the significant potential of the Cockpit4.0+ prototype to enhance operational efficiency and collaborative practices within the Portuguese stone manufacturing sector (OS-PT). The sector, deeply embedded in Portugal's cultural heritage and innovation landscape, plays a vital role in the global stone trade. The findings underscore the prototype's promise in fostering digital transformation, mainly through improved coopetition strategies among SMEs.

The OS-PT sector's historical and economic significance is substantial, with exports reaching 116 countries and a turnover of EUR 1.230 million. This sector supports over 16,600 direct jobs, making it crucial for regional employment. Given its pivotal role, adopting advanced digital tools like Cockpit4.0+ is essential to maintaining and enhancing its competitive edge.

The preliminary functional evaluation of Cockpit4.0+ involved technical experts and engineers from 24 OS-PT SMEs, categorized across five digital maturity levels (DL#0 to DL#4), emphasizing the prototype's strategic fit for digitally advanced environments.

The experimental pilot test, involving two DL#4 companies, further validated the system's efficacy. These results demonstrate that the Cockpit4.0+ system can significantly contribute to the digital transformation of the OS-PT sector. By focusing on the identified areas for improvement and leveraging its strengths, the system is well positioned to foster dynamic and secure coopetition networks. It is particularly relevant in a landscape where advanced management practices, potentially aligned with ISO standards, can further refine and enhance operational efficiency.

Future research should explore integrating advanced management systems based on ISO standards to complement the Cockpit4.0+ prototype. Such integration could provide a robust framework for continuous improvement and standardization across the sector, offering valuable insights for other industries aiming to adopt similar digital transformation initiatives.

The Cockpit4.0+ prototype holds significant promise for revolutionizing the OS-PT sector. Its strategic implementation can drive the sector's digital evolution, enhance collaborative practices, and sustain its competitive edge in the global market.

Despite the promising results, this study has several limitations. First, the evaluation was conducted in a specific sector, limiting the generalizability of the findings. Future research should replicate the study in diverse sectors and geographic regions to assess scalability and adaptability comprehensively. Further refinement of the system's algorithms and a closer examination of cybersecurity dimensions are imperative for ensuring robustness and security in practical applications.

Author Contributions: A.d.S.—conceptualization, original draft writing, and review and editing; A.J.M.C.—conceptualization, original draft writing, and review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data supporting this study's findings are available from the corresponding author, Agostinho da Silva, upon request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Thierry, E.C. *EU Space Policy: Boosting EU Competitiveness and Accelerating the Twin Ecological and Digital Transition*; European Parliamentary Research Service: Brussels, Belgium, 2022.
2. Mitropoulos, S.; Douligeris, C. Why and how informatics and applied computing can still create structural changes and competitive advantage. *Appl. Comput. Inform.* **2021**. [CrossRef]
3. Di Bella, L.; Katsinis, A.; Lagüera-González, J.; Odenthal, L.; Hell, M.; Lozar, B. *Annual Report on European SMEs 2022/2023*; European Commission: Brussels, Belgium, 2023.
4. Bicen, P.; Hunt, S.; Madhavaram, S. Coopetitive innovation alliance performance: Alliance competence, alliance's market orientation, and relational governance. *J. Bus. Res.* **2021**, *123*, 23–31. [CrossRef]
5. Yazdinejad, A.; Zolfaghari, B.; Dehghantanha, A.; Karimipour, H.; Srivastava, G.; Parizi, R. Accurate threat hunting in industrial internet of things edge devices. *Digit. Commun. Networks* **2023**, *9*, 1123–1130. [CrossRef]
6. Mosch, P.; Majocco, P.; Obermaier, R. Contrasting value creation strategies of industrial-IoT-platforms—A multiple case study. *Int. J. Prod. Econ.* **2023**, *263*, 108937. [CrossRef]
7. Lyu, M.; Li, X.; Chen, C.-H. Achieving Knowledge-as-a-Service in IIoT-driven smart manufacturing: A crowdsourcing-based continuous enrichment method for Industrial Knowledge Graph. *Adv. Eng. Informatics* **2022**, *51*, 101494. [CrossRef]
8. Manurung, H.; Yudoko, G.; Okdinawati, L. A conceptual framework of supply chain resilience towards sustainability through a service-dominant logic perspective. *Heliyon* **2023**, *9*, e13901. [CrossRef] [PubMed]
9. Reeves, M.; Lotan, H.; Legrand, J.; Jacobides, M.G. How Business Ecosystems Rise (and Often Fall). *MIT Sloan Manag. Rev.* **2019**, *60*, 1–6.
10. Jaakkola, E.; Kaartemo, V.; Siltaloppi, J.; Vargo, S.L. Advancing service-dominant logic with systems thinking. *J. Bus. Res.* **2024**, *177*, 114592. [CrossRef]
11. Vargo, S.L.; Fehrer, J.A.; Wieland, H.; Nariswari, A. The nature and fundamental elements of digital service innovation. *J. Serv. Manag.* **2024**, *35*, 227–252. [CrossRef]
12. Vargo, S.L.; Wieland, H.; O'Brien, M. Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline. *J. Bus. Res.* **2023**, *164*, 113965. [CrossRef]
13. Vargo, S.L.; Lusch, R.F. Evolving to a New Dominant Logic for Marketing. *J. Mark.* **2004**, *68*, 1–17. [CrossRef]
14. Greer, C.; Lusch, R.; Vargo, S. A service perspective. Key managerial insights from service-dominant (S-D) logic. *Organ. Dyn.* **2016**, *45*, 28–38. [CrossRef]
15. Vargo, S.L.; Lusch, R. Service-dominant logic 2025. *Int. J. Res. Mark.* **2017**, *34*, 46–67. [CrossRef]
16. Breidbach, C.; Maglio, P. A Service Science Perspective on the Role of ICT in Service Innovation. In Proceedings of the Twenty-Third European Conference on Information Systems (ECIS), Münster, Germany, 26–29 May 2015; ECIS 2015. pp. 1–9.
17. Doganova, L.; Eyquem-Renault, M. What do business models do? *Res. Policy* **2009**, *38*, 1559–1570. [CrossRef]
18. Lusch, R.; Nambisan, S. Service Innovation: A Service-Dominant Logic Perspective. *MIS Q.* **2015**, *39*, 155–175. [CrossRef]
19. Chen, C.L. Cross-disciplinary innovations by Taiwanese manufacturing SMEs in the context of Industry 4.0. *J. Manuf. Technol. Manag.* **2020**, *31*, 1145–1168. [CrossRef]
20. Aldoseri, A.; Al-Khalifa, K.N.; Hamouda, A.M. Methodological Approach to Assessing the Current State of Organizations for AI-Based Digital Transformation. *Appl. Syst. Innov.* **2024**, *7*, 14. [CrossRef]
21. Ng, I.C.L.; Wakenshaw, S.Y.L. The Internet-of-Things: Review and research directions. *Int. J. Res. Mark.* **2017**, *34*, 3–21. [CrossRef]
22. Salih, K.O.M.; Rashid, T.A.; Radovanovic, D.; Bacanin, N. A Comprehensive Survey on the Internet of Things with the Industrial Marketplace. *Sensors* **2022**, *22*, 730. [CrossRef]
23. Khanboubi, F.; Boulmakoul, A.; Tabaa, M. Impact of digital trends using IoT on banking processes. *Procedia Comput. Sci.* **2019**, *151*, 77–84. [CrossRef]

24. Urbaniak, M.; Zimon, D.; Madzik, P. Expectations of manufacturing companies towards suppliers in terms of implementing improvement activities. *Cent. Eur. Manag. J.* **2024**. [CrossRef]
25. Garay-Rondero, C.L.; Martinez-Flores, J.L.; Smith, N.R.; Caballero Morales, S.O.; Aldrette-Malacara, A. Digital supply chain model in Industry 4.0. *J. Manuf. Technol. Manag.* **2020**, *31*, 887–933. [CrossRef]
26. Slavic, D.; Marjanovic, U.; Medic, N.; Simeunovic, N.; Rakic, S. The Evaluation of Industry 5.0 Concepts: Social Network Analysis Approach. *Appl. Sci.* **2024**, *14*, 1291. [CrossRef]
27. Arqué-Castells, P.; Spulber, D.F. Firm Matching in the Market for Technology: Business Stealing and Business Creation. *J. Ind. Econ.* **2023**, *71*, 961–1003. [CrossRef]
28. Hoppe, S. *OPC Unified Architecture-Interoperability for Industrie 4.0 and the Internet of Things*; OPC Foundation: Scottsdale, AZ, USA, 2023.
29. Serror, M.; Hack, S.; Henze, M.; Schuba, M.; Wehrle, K. Challenges and Opportunities in Securing the Industrial Internet of Things. *IEEE Trans. Ind. Inform.* **2021**, *17*, 2985–2996. [CrossRef]
30. Silva, A.; Gil, M. Industrial processes optimization in digital marketplace context: A case study in ornamental stone sector. *Results Eng.* **2020**, *7*, 100152. [CrossRef]
31. Vargo, S.L. Conceptual reconciliation for clarity and impact. *AMS Rev.* **2023**, *13*, 169–172. [CrossRef]
32. Chou, C.J.; Chen, C.W.; Conley, C. A systematic approach to generate service model for sustainability. *J. Clean. Prod.* **2012**, *29–30*, 173–187. [CrossRef]
33. Müller, J.M.; Kiel, D.; Voigt, K.I. What drives the implementation of Industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustainability* **2018**, *10*, 247. [CrossRef]
34. Matzner, M.; Büttgen, M.; Demirkan, H.; Spohrer, J.; Alter, S.; Fritzsche, A.; Ng, I.C.L.; Jonas, J.M.; Martinez, V.; Möslein, K.M.; et al. Digital Transformation in Service Management. *J. Serv. Manag. Res.* **2018**, *2*, 3–21. [CrossRef]
35. Barenji, A.V.; Li, Z.; Wang, W.M. Blockchain Cloud Manufacturing: Shop Floor and Machine Level. In Proceedings of the Smart SysTech 2018; European Conference on Smart Objects, Systems and Technologies, Dresden, Germany, 12–13 June 2018; pp. 1–6.
36. Barrett, M.; Davidson, E.; Prabhu, J.; Vargo, S.L. Service Innovation in the Digital Age: Key Contributions and Future Directions. *MIS Q.* **2015**, *39*, 135–154. [CrossRef]
37. Latif, G.; Ben Brahim, G.; Abdelhamid, S.E.; Alghazo, R.; Alhabib, G.; Alnujaidi, K. Learning at Your Fingertips: An Innovative IoT-Based AI-Powered Braille Learning System. *Appl. Syst. Innov.* **2023**, *6*, 91. [CrossRef]
38. Bouncken, R.B.; Fredrich, V.; Ritala, P.; Kraus, S. Coopetition in New Product Development Alliances: Advantages and Tensions for Incremental and Radical Innovation. *Br. J. Manag.* **2018**, *29*, 391–410. [CrossRef]
39. Boyes, H.; Hallaq, B.; Cunningham, J.; Watson, T. The industrial internet of things (IIoT): An analysis framework. *Comput. Ind.* **2018**, *101*, 1–12. [CrossRef]
40. Aliyari, M.; Ayele, Y.Z. Application of Artificial Neural Networks for Power Load Prediction in Critical Infrastructure: A Comparative Case Study. *Appl. Syst. Innov.* **2023**, *6*, 115. [CrossRef]
41. Crick, J. The dark side of coopetition: When collaborating with competitors is harmful for company performance. *J. Bus. Ind. Mark.* **2019**, *35*, 318–337. [CrossRef]
42. Leal, G.; Guédria, W.; Panetto, H. An ontology for interoperability assessment: A systemic approach. *J. Ind. Inf. Integr.* **2019**, *16*, 100100. [CrossRef]
43. Akaka, M.; Schau, H.; Vargo, S. How Practice Diffusion Drives IoT Technology Adoption and Institutionalization of Solutions in Service Ecosystems. In Proceedings of the Annual Hawaii International Conference on System Sciences, Maui, HI, USA, 3–6 January 2023; pp. 1427–1435.
44. Akaka, M.A.; Vargo, S.L. Technology as an operant resource in service (eco)systems. *Inf. Syst. E Bus. Manag.* **2014**, *12*, 367–384. [CrossRef]
45. Ahn, K.-U.; Kim, Y.-J.; Park, C.-S.; Kim, I.; Lee, K. BIM interface for full vs. semi-automated building energy simulation. *Energy Build.* **2014**, *68*, 671–678. [CrossRef]
46. Lacerda, D.P.; Dresch, A.; Proença, A.; Júnior, J.A.V.A. Design Science Research: A research method to production engineering. *Gest. Prod.* **2013**, *20*, 741–761. [CrossRef]
47. Peffers, K.; Tuunanen, T.; Rothenberger, M.A.; Chatterjee, S. A Design Science Research Methodology for Information Systems Research. *J. Manag. Inf. Syst.* **2007**, *24*, 45–77. [CrossRef]
48. Baskerville, R.; Baiyere, A.; Gregor, S.; Hevner, A.; Rossi, M. Design science research contributions: Finding a balance between artifact and theory. *J. Assoc. Inf. Syst.* **2018**, *19*, 3. [CrossRef]
49. Silva, A.; Dionisio, A.; Almeida, I. Enabling Cyber-Physical Systems for Industry 4.0 operations: A Service Science Perspective. *Int. J. Innov. Technol. Explor. Eng.* **2020**, *9*, 838–846. [CrossRef]
50. Silva, A.; Rabadão, C.; Capela, C. Towards Industry 4.0 | A case study of BIM deployment in ornamental stones sector. *Int. J. Innov. Technol. Explor. Eng.* **2020**, *67*, 24535.
51. Akaka, M.; Vargo, S.; Lusch, R. The Complexity of Context: A Service Ecosystems Approach for International Marketing. *J. Int. Mark.* **2013**, *21*, 1–20. [CrossRef]
52. Kleinaltenkamp, M.; Kleinaltenkamp, M.J.; Karpen, I.O. Resource entanglement and indeterminacy: Advancing the service-dominant logic through the philosophy of Karen Barad. *Mark. Theory* **2023**. [CrossRef]

53. Carvalho, J.; Lopes, C.; Mateus, A.; Martins, L.; Goulão, M. Planning the future exploitation of ornamental stones in Portugal using a weighed multi-dimensional approach. *Resour. Policy* **2018**, *59*, 298–317. [CrossRef]
54. Silva, A.; Marques Cardoso, A. BIM-based Supply Chain in AEC—Threats on the Portuguese Stone sector. In Proceedings of the 7th Globalstone Congress, Batalha, Portugal, 18–23 June 2023; ISBN 978-972-778-327-4. Available online: https://repositorio.lneg.pt/bitstream/10400.9/4150/1/GSC2023_PT%20Natural%20Stones-Commercial%20Names%20harmonization.pdf (accessed on 21 April 2024).
55. Silva, A.; Pata, A. Value Creation in Technology Service Ecosystems—Empirical Case Study. In *Innovations in Industrial Engeneering II*; Machado, J., Soares, F., Trojanowska, J., Ivanov, V., Antosz, K., Ren, Y., Manupati, V.K., Pereira, A., Eds.; Springer International Publishing: Cham, Switzerland, 2022; pp. 26–36.
56. Abdumutalibovich, K.A.; Lutfillaevna, B.M. The Role of Bim Technologies in the Information System of Education. *Eur. J. Contemp. Bus. Law Technol. Cyber Law Blockchain Leg. Innov.* **2023**, *1*, 9–13. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

An Innovative Service Blueprint for Enhancing Coopetition Networks

(*) Agostinho da Silva1[1,2,3,4], Antonio J. Marques Cardoso[1]
[1] CISE - Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal
[2] ISG – Business & Economics School, Lisboa, Portugal
[3] CEFAGE-UE, Center for Advanced Studies in Management and Economics, Évora, Portugal
[4] MARE, Marine and Environnemental Sciences Centre, Portugal

(*) a.silva@zipor.com (corresponding author)
ajmcardoso@ieee.org

Purpose – This research aims to design a service blueprint for enhancing technology-enabled coopetition networks to boost the collaboration among Small and Medium-sized Enterprises (SMEs).

Approach – By adopting Service-Dominant Logic (S-D Logic) perspective to address the challenge outlined in the stated purpose, the approach involves several key steps: identifying existing gaps in the field, seeking solutions grounded in knowledge, and developing a service blueprint framework tailored explicitly for technology-enabled coopetition networks, with a focus on facilitating value co-creation processes among rivals.

Findings – Drawing upon service science literature, this research successfully addresses identified gaps in the service blueprint methodology. This includes enhancements at the level of actors and their resources and in delineating and mapping interactions within the service process using new lines and lanes. The solutions to these gaps have led to the proposal of a specialized framework for the service blueprint methodology. This new framework is specifically designed to foster innovative co-creative interactions within technology-enabled coopetition networks.

Theoretical and practical implications - By integrating the foundations of Service-Dominant Logic into coopetition networks, the proposed knowledge-based service blueprint framework for technology-enabled coopetition networks represents a significant advancement in service knowledge. Although its effectiveness and practical applicability need to be validated through real-world case studies, considering SMEs' pivotal role in developing countries' economies, this framework offers a valuable tool to enhance their competitiveness through coopetition networks.

Suggestions for future investigations - The newly designed service blueprint framework for technology-enabled coopetition networks signifies a step forward in the current state-of-the-art. However, its effectiveness and practical value need to be assessed through application in real-world scenarios.

Originality – Bringing the Service-Dominant Logic into coopetition marks a significant advancement in the field. These knowledge-based developments push the boundaries of current understanding and represent a substantial enhancement in the knowledge of service ecosystems, particularly when applied within coopetition networks.

Keywords - Coopetition, Service Blueprint, Networks, S-D Logic, Service Science

1. Introduction and motivation

Referred to as the backbone of Europe's economy (European Commission, 2021), although somewhat neglected, manufacturing SMEs remain an essential source of employment and wealth creation in developed economies (Radicic et al., 2020). By integrating into coopetition networks, SMEs can achieve economies of scale, access strategic resources, and create inter-organizational synergies (Bouncken et al., 2015).

However, although the great attention in academia (Bengtsson et al., 2016) and officials (European Commission, 2021), given the coopetition contradictory nature, these networks also present potential risks, such as the loss of trade secrets and the loss of control over capabilities (Ritala et al., 2014). These risks generate potential loss of expectations among members of the coopetition network, which ultimately could lead to the end of the network itself (Bicen et al., 2021).

On this matter, a study conducted by the BCG Henderson Institute and published by the MIT Sloan Management Review (2019) highlights, to some extent, worrying signs about the '*rise and often fall*' of coopetition networks. From a sample of fifty-seven networks, according to this study, only those coopetition networks supported by a leading member such as Amazon or Microsoft survived beyond the short term. All those composed exclusively of SMEs did not reach the medium term (Reeves et al., 2019). Assuming that the end of a coopetition network is related to the frustration of expectations throughout the coopetition process, it becomes necessary to find a supporting body of knowledge, and within this, a methodology for identifying which resources are involved when the frustration of expectations occurs, and subsequently proposing innovative interaction solutions namely for SMEs.

2. The service blueprint Flowcharts

By adopting the Service-Dominant logic (S-D logic) foundations, Service Science is an emerging discipline (P. P. Maglio et al., 2009) focused on innovation and the enhancement of value co-creation among service systems (Maglio & Spohrer, 2013). Given its multidisciplinary nature and orientation towards technologies (Bill & Murphy, 2008) (P. P. Maglio & Spohrer, 2013), the Service Science has been increasingly used to support innovation and competitiveness in activities related to the production of tangible goods (manufacturing companies), especially in supporting their shift towards digital and global technologies (A. Silva, Dionísio, et al., 2020).

Focused on the development and scaling of service systems, various methods and tools have been introduced by the Service Science community (Breidbach & Maglio, 2016) to support improvement in service innovation (S. L. Vargo et al., 2020), and ensure that interactions between stakeholders result in value in the expected dimension for all (Suhardi et al., 2015). Among these methodologies, because of their usable processes involving both tangible and intangible goods, the Service Science literature has placed significant emphasis on the service blueprint methodology (Wang et al., 2017).

Shostack (1982) initially introduced the service blueprint methodology to study processes related to commerce and service activities. It involved a layout representing a sequence of actions, where the customer and provider are separated by an abstract concept known as the *line of visibility* (G. Shostack, 1982).

In the late 1980s, Kingman-Brundage (1989) improved Shostack's service blueprint initial version, replacing the *line of visibility* with three new imaginary lines (Kingman-Brundage, 1989): the *line of interaction*, which separated the customer from the provider, the *line of internal interaction* which separated, inside the provider, support functions from customer service functions and the *line of execution* separating management functions from support functions (Seyring et al., 2009). Kingman-Brundage also proposed the concept of *back-stage* and *front-stage* lanes where providers move and develop their activities (Pöppel et al., 2018), (Bitner et al., 2008b).

With this new service blueprint format introduced by Kingman-Brundage (1989), the mapping of a service process maintained the Shostack's (1982) original linear representation composed of individual sequential steps, above the *line of visibility* (A. Silva, Gil, et al., 2020a). However, it now gave stage to the various resources of the provider (Boughnim & Yannou, 2005). Through the representation of these resources involved in each step, the service blueprint now allowed all influences of the resources to become visible throughout the process (Bitner et al., 2008a). This made the methodology widely used by the Service Science community and beyond, adapting this methodology to each specific case (Kwan et al., 2016).

Regarding the symbols used in service blueprint flowcharts, the direction of each arrow holds significant symbolic meaning (A. Silva, Gil, et al., 2020a). On the one hand, it indicates the direction of the information flow, and on the other, the resource or resources influential in the outcome at each step of the process (Seyring et al., 2009). A single unidirectional arrow means that the source of the arrow has control over the information at that point. In contrast, a double arrow indicates that at that stage, an agreement between two involved resources was necessary for the process to move on to the next step (Boughnim & Yannou, 2005).

3. The Gap and the Aim

In today's global networks, digital technologies such as the Internet of Things (IoT) or Artificial Intelligence, among many others, play a fundamental role in connecting members (Büyüközkan & Göçer, 2018). In the modern competition network, it is through these technologies that the rivals interconnect and can make value propositions to customers (Bagheri et al., 2019), wherever they may be geographically located. Given the technology level in modern coopetition networks, the service blueprint should allow for monitoring of the cocreation process in order to identify the moment when a breakdown in expectations or trust occurs (Bicen et al., 2021).

However, despite being effectively used today to innovate in multiple processes, from the literature in business and management, cases have yet to be found where the service blueprint methodology has been successfully used in coopetition networks enabled by digital technologies.

This is probably because the service blueprint framework by Kingman-Brundage (1989) has some gaps that prevent the current version of this methodology from accommodating the specificities of coopetition technology-enabled networks.

Gap 1 (Inter-connectivity) - Being a network enabled by digital technologies (Khanboubi et al., 2019), where factories tend to be increasingly directly connected to the customer (Geissbauer et al., 2018), the lines of the service blueprint (service blueprint) flowchart must show this inter-connectivity. This situation does not occur in the framework of Kingman-Brundage (1989).

Gap 2 (Actors and Resources) - For some authors, the service blueprint loses its effectiveness when used to optimize the interests of multiple actors simultaneously, which is one of the limitations of this methodology (Suhardi et al., 2015), (A. Silva, Gil, et al., 2020b), (H. M. Silva et al., 2021). The entity "supplier", for example, although it may subcontract external support resources, does not consider the possibility of being a coopetitor - a unique entity composed of two rival suppliers who collaborate at a particular moment in the co-creative process.

Gap 3 (Stages and Lanes) – In coopetition technology-enabled networks, the *Frontstage, Backstage*, and *SupportStage Lanes* must reveal the resources of the coopetitors (Estrada & Dong, 2020) involved in each step of the process, as only then can it be understood which resource is involved at the moment when the process interruption occurs.

From these literature gaps arises the following research question: **What service blueprinting framework is suitable for coopetition technology-enabled networks?**

Supported by the principles of the Service Science discipline and building on the framework of Kingman-Brundage (1989), the objective of this research will therefore be to search for a solution for the gaps mentioned above and, from there, design a new framework to be called coopetition-service blueprint, which will allow for mapping and innovating co-creative interactions in coopetition technology-enabled networks. Once applied in practical cases, this coopetition service blueprint should enable the identification of the resources involved when an interruption of the service process occurs.

4. Literature Review

For S-D logic, the service is the application of competencies for the benefit of another entity and is exchanged for service. The value is always cocreated; goods are appliances for delivery (R. F. Lusch & Vargo, 2006) (E. Gummesson et al., 2014); all economies are service economies, and all businesses are service businesses (S. L. Vargo & Lusch, 2004). Anchored on these S-D logic premises, the Service Science literature highlights the role of value propositions networks (P. Maglio et al., 2009) as they motivate the actor's resource access in networks (P. P. Maglio & Spohrer, 2013).

Looking at the business process through this S-D logic lens, in a network, the providers offer value propositions (Chandler & Vargo, 2011) by applying specialized knowledge and skills for the benefit of other actors (customers) who may realize the value of such propositions through use (S. L. Vargo & Lusch, 2004) or experience of the interaction itself (Gronroos, 2011). Along with this service process, multiple competitors try to substitute the providers while authorities ensure legal conformity and taxation.

According to this S-D logic and Service Science perspective, a value proposition is viewed as a request from one actor to another to run an *algorithm* from the perspective of multiple actors (P. P. Maglio & Spohrer, 2008a). These value propositions must consider culturally determined value principles and identify four primary actors' (players) perspectives or concerns: customer, provider, authority, and competitor (P. Maglio et al., 2009). The customer concern is about how quality impacts revenue, the provider concern is about how productivity impacts profit, the competitor concern is about how innovation impacts the market share, and authorities are concerned about compliance (Jim Spohrer & Maglio, 2008).

Today, information and communication technologies (ICT) are fundamental resources in the digital economy (P. P. Maglio & Spohrer, 2013), incorporating true physical, symbolic systems in the most classic sense of the term (Newell, 1980). Similarly, for Service Science, in networks, the service system entities compute and coordinate actions with others through symbolic processes of valuing and communicating (S. L. Vargo & Akaka, 2009). Accepting that symbols guide internal behaviour and immediate interactions (P. P. Maglio & Spohrer, 2013), value co-creation often depends on symbolic reasoning about the actual value of proposals. Therefore, it can be believed that symbolism, organized into formal systems of symbols, will

tend to become a central component of markets and marketing in the digital context, incorporating each market type's specific practices and meanings (S. L. Vargo & Akaka, 2009). Nevertheless, for SS, in service innovation processes, symbols cannot be separated from phenomenological practices, institutions, and values, as symbols and practices guide how actors evaluate themselves, others, or the value of proposals (P. Maglio et al., 2019).

Building on these foundational premises in Service Science, in technology-enabled Coopetition networks, the relationships are primarily characterized by digital interconnections of manufacturing systems, products, value chains, providers, customers, networks, and many others (Barrett et al., 2015).

The flowchart must map the customer's role in value co-creation because value-in-use and service experiences are central to the S-D logic view. This is emphasized as value-in-use, and service experiences are key to S-D logic (Akaka & Vargo, 2014). For S-D logic, whenever a given step does not generate value for the actors, innovation is needed in the resources involved in that step, both in terms of the form and content of interactions (Evert Gummesson et al., 2010).

Similarly, for Service Science, the service blueprint methodology should enable the design of innovative interactions that generate value for all involved actors (Jim Spohrer & Kwan, 2009). Representing more than just a representational game (Kwan et al., 2016), in Service Science, at each stage of the service, the points of contact between each resource are interpreted in light of the observed outputs (Ganz et al., 2012). During each stage of the process, various resources of the involved actors will carry out activities, the results of which, once measured, are used considering the concerns of each involved stakeholder (Jim Spohrer & Kwan, 2009).

In this context, the *Internal Interaction Line* of the traditional version of the service blueprint separates, within the supplier, the activities directly involved in the value proposition or execution of the order from the activities that support this value proposition or order execution. To facilitate visualization, the Service Science community proposes that the *Evidence and Outcomes* band be placed at the top of the customer actions (Kwan et al., 2016), a designation usually replaced by Innovation Outcomes, positioned at the bottom of the service blueprint map. Regardless of the designation, this band represents the tangible elements of the co-creative actions and their results in facts, places, formulas, products, or signs used or seen by the customer (Bitner et al., 2008b) throughout the co-creative journey.

The *Customer Actions Lane* describes the customer's interactions with the supplier throughout the service process, as in Shostack's model (Hsu, 2016). For Service Science, if the customer does not interact, they cease to be a service system (J. Spohrer et al., 2007), resulting in no further co-creation of value (Seyring et al., 2009) and interrupting the service process. As for the *Frontstage Contact Actions Lane* in its traditional model, it is delimited (1) above by the line of interaction, separating the customer's independent activities from the supplier's activities (Seyring et al., 2009), and (2) below by the *Line of Visibility*, where the *Frontstage Lane* represents the activity of people or physical evidence that the customer can observe during the service process (Boughnim & Yannou, 2005), a situation that satisfies the Service Science value cocreation view of value. The same applies to the *Backstage Contact Actions Lane*, which is delimited by the line of visibility, separating the customer from the visible activities from the supplier's hidden activities (Seyring et al., 2009), and by the line of internal interaction, separating the supplier's activities related to the value proposition from the activities that support this value proposition or order execution (Bitner et al., 2008b). Moreover, the *Backstage Lane* contains all the activities and means necessary to produce the tangible or intangible product that the customer expects to receive. In some service blueprint variants, this band is designated as the *Execution Lane* (Kwan et al., 2016).

Additionally, and in line with Service Science Principles, the *Support Processes* are all the means and external actions that, on the supplier's side, support the service and value co-creation (Boughnim & Yannou, 2005). These are designated as the *Support Actions Provider Lane*, delimited at the top by the *Line of Internal Interaction* (Ganz et al., 2012).

5. A Service Blueprint Framework for Coopetition Networks

The coopetition networks arise from the recognition by organizations that it is more advantageous to work together with competitors than alone. This assumes that, although organizations join forces to achieve objectives, they continue to be competitors in the market and in the differentiation of products and services. Managing coopetition is essential for the success of coopetition strategies.

The interactions in modern networks are primarily characterized by digital and collaborative interconnection among means of production, products, value chains, suppliers, customers, business models, and many other actors and resources. The interconnection between the physical and virtual/cybernetic

worlds - Cyber-Physical Systems and the Internet of Things - is a central characteristic of coopetition technology-enabled networks. To ensure that a coopetition network does not break down due to actors' frustrated expectations, the digital technologies, particularly the Internet of Things and Artificial Intelligence, today play a fundamental role in trust-building among actors in coopetition networks.

Inter-connectivity

Supported by the Service Science value cocreation view, in Kingman-Brundage's service blueprint, the *Customer Interaction Line* separates the activities of the customer from those of the supplier and satisfies the purposes of traditional customer-supplier interactions, which typically involves close contact, a phone call, or more recently, emails. However, in technology-driven coopetition networks (Matthies et al., 2016), this line must interpret the interconnectivity between a potential cyber customer and the physical shop floors. Whether a simple 3D printer or a large-scale factory, a cyber customer and a digital supplier interact through value propositions, so the *Customer Interaction Line* must be renamed as the *Line of Cyber Interaction* and represented by a dashed line.

Resources Visibility

Supported by the S-D logic and Service Science literature, the systemic value cocreation on economic exchange (Meynhardt et al., 2016) accepts all economic actors as service-providing and value cocreators (S. L. Vargo, 2011), the actor's and actors' resources for a coopetition-based business model can be framed.

Customers - Currently, individuals, firms, and other customers increasingly search to satisfy their needs from digital and global marketplaces (Johnson & Whang, 2002) (Kumar et al., 2019). To do this, customers use technologies (smartphones, computers, tablets, etc.) connected to the Internet as a frontage to make global procurement (G. L. Shostack, 1982) (Seddon et al., 2011).

Providers - A supply market is only a supply market when viewing a provider as a supply source or service provider beneficiary (R. Lusch & Vargo, 2014**).** It follows from this assumption that a customer market is only a customer market when viewing another actor as a buyer-demand source or service customer beneficiary (R. Lusch & Vargo, 2014**).** This S-D logic perspective goes beyond inviting customers to participate in production or design processes. It suggests that there can only be value when the customer incorporates the firm offering into his or her life (S. L. Vargo & Akaka, 2009). For this customer-centric view, the provider plays the role of a facilitator of value cocreation (S. Vargo & Lusch, 2016), pointing out customer and provider as service providers that offer value propositions by integrating within their constellation of activities and experiences (van Riel et al., 2013).

Coopetitors - The above-stated coopetition concept refers to providers that, in addition to their typical provider role, voluntarily accept to collaborate with other providers (Bicen et al., 2021). The coopetitors are, therefore, providers that additionally use specific operant and operand technology resources, under certain safety assumptions, to voluntarily access and give access to specific resources with other providers. As this contradictory interdependent role (Dagnino & Padula, 2002) may generate tensions (Crick, 2019), a coopetitor is understood as a provider that alternatively, to the typical role of a provider, adopts a coopetition-based business model voluntarily. Looking at this new actor from the S-D logic and Service Science perspective (Dagnino & Padula, 2002) (Gast et al., 2015), a coopetitor is an actor that increases the resource density in the **network.**

Competitors - At a particular time, competitors are free to quit the coopetition-based business model. Therefore, competitors are rivals that compete by themselves in ecosystems. The competitors' concerns are related to sustainable innovation (J. Spohrer et al., 2009) since, without competition, there are no longer incentives to innovate in ecosystems (Bolton et al., 2007)

Stages and Lanes

The lanes in coopetition service blueprint flowcharts must visualize the resources of the digital providers and digital coopetitors. These resources must be arranged in horizontal lanes from the left, and the description at each step of their involvement requires knowledge of the access rights to each resource. Therefore, the cyber customer action lane represents the actions of a potential cybernetic customer linked to smart factories (Kocsi & Oláh, 2017), whose evidence will be described in a lane immediately above, called Physical & Virtual Evidences, and cooperation with the provider, represented by the line of cyber interaction. In this regard, the lanes and stages can be described as:

The **Cyber.frontstage** which includes (1) the Frontstage Human Resources Lane, (2) the Technology Operant Resources Lane, and (3) the Technology Operand Resources Lane.

The **Physical.Backstage** which includes (1) Backstage Human Resources Lane, (2) the Provider Backstage Operant and Operand Technologies, and (3) the Coopetitor Backstage Operant and Operand Technologies.

The **SupportStage** which includes (1) Support Partnerships Resources Lane, (2) Management Resources, (3) Coopetition Support Resources, and (4) Other Resources (Figure 1).

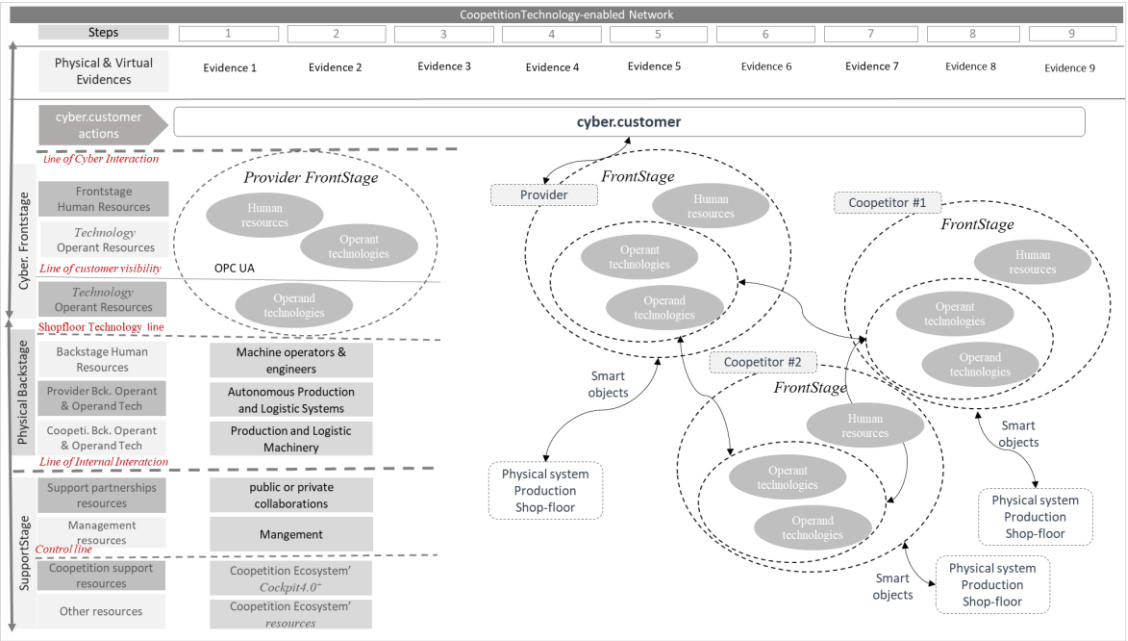


Figure 1. Service blueprint framework for coopetition networks.

The plan between the *Shopfloor Technology Line* and the *Line of Internal Interactions* is the area of action of the smart plant shop floor resources, including the coopetitors' resources. The dash lines mean that there is technological transparency, even with the *cyber customer* if necessary. The lanes of the *Support Stage* are where Support Resources carry out their activities in the service process, once again separated by dash lines.

At the top of the coopetition service blueprint map, there are the Cyber or Physical Evidences or just the Outcomes (Kocsi & Oláh, 2017) resulting from co-operative actions between the cyber customer and the digital provider.

For Service Science, the customer and provider are the products' co-creators (Breznik & Lahovnik, 2014). As one of Service Science's main challenges is to innovate in value propositions, this means that to improve Innovation outcomes (P. P. Maglio & Spohrer, 2013), it is necessary to know at the outset what resources are involved in these propositions (Wong et al., 2014). Improving a value proposition does not mean benefit for the customer or provider but rather adding value to all directly interested stakeholders, competition being the main driver of innovation (Hüttinger et al., 2012). As stakeholders (service systems) gain experience from lessons learned over time, systematic refinements will improve proposals based on historical statistical and anticipated future standards; a lean thinking concept designated *continuous improvement process* (Melton, 2005; Taylor et al., 2014).

The description of a service process by the service blueprint method thus involves positioning the resources that make up each of the horizontal bands or stages and their activities as much as possible supported by official documentation (Kingman-Brundage, 1989). This should be consistently supported by data collection tools, observations, tracking, and monitoring (Meynhardt et al., 2016). Since the process stages are chronological, the description of the activities should be synchronized with the unfolding of the service process (Cardeal, 2012).

Conclusion

Coopetition networks, characterized by simultaneous collaboration and competition among companies, are identified in the literature as crucial for small and medium-sized enterprises (SMEs) in achieving scale and competitiveness within today's global digital supply chains. This aspect is especially vital considering that SMEs form the backbone of developed economies (Müller et al., 2018). However, while these networks are

often seen as vital support for these businesses, several studies present a disheartening scenario - most coopetition networks fail to sustain themselves even in the short term.

This research was initiated in response to the issue above, aiming to develop a methodology that can accurately identify the resources of the involved actors when interruptions in interactions occur within coopetition networks.

From a review of service-oriented literature, it has been observed that value co-creation has evolved from isolated local processes to interconnected, global, and technology-based networks. This evolution gave rise to disciplines like Service Science. As a field focused on the development of service systems (P. P. Maglio & Spohrer, 2008b) (P. P. Maglio & Spohrer, 2013), Service Science is rooted in the foundations of S-D logic, viewing any request from one actor to another as an opportunity for value co-creation (J. C. Spohrer & Maglio, 2010). Moreover, since S-D logic does not differentiate between tangible and intangible goods, this dematerialized perspective (Barile et al., 2016) is particularly suited for studies in digital-based networks (Fritzsche et al., 2018) (Zatsarinnyy & Shabanov, 2019). Within this context, the service blueprint has emerged as one of the primary methodologies for innovating service processes.

Initially introduced by Shostack in 1982, the service blueprint methodology gained significant popularity through the advancements introduced by Kingman-Brundage in 1989. While it has been effectively employed in numerous research studies documented in the literature, certain areas for improvement have been identified within the existing service blueprint framework, particularly concerning actors, their resources, lines, and bands. These shortcomings must be addressed in order to adapt this methodology to the unique requirements of technology-enabled networks in the context of coopetition.

Supported by the Service Science literature, this research has successfully identified solutions to address the Kingman-Brundage (1989) framework gaps, particularly concerning actors and their resources and delineating and mapping interactions along the service process. With these solutions in hand, the outcome of this research is a specialized framework for the service blueprint methodology, designed to foster innovation in co-creative interactions within technology-enabled networks operating in a coopetition context.

Theoretical and practical implications: By integrating the foundational principles of Service-Dominant Logic into coopetition networks, the knowledge-based service blueprint framework signifies significant progress in service-related knowledge. Furthermore, its application within coopetition networks represents advancements that propel the state-of-the-art to new heights.

Future Research Directions: The crafted service blueprint framework for coopetition networks signifies a significant advancement in the field. Consequently, we strongly encourage researchers and practitioners to leverage this framework to foster innovative interactions within coopetition networks.

References

Akaka, M. A., & Vargo, S. L. (2014). Technology as an operant resource in service (eco)systems. *Information Systems and E-Business Management*, *12*(3), 367–384. https://doi.org/10.1007/s10257-013-0220-5

Bagheri, S., Kusters, R. J., & Trienekens, J. J. M. (2019). Customer knowledge transfer challenges in a co-creation value network: Toward a reference model. *International Journal of Information Management*, *47*(September 2018), 198–214. https://doi.org/10.1016/j.ijinfomgt.2018.12.019

Barile, S., Lusch, R., Reynoso, J., Marialuisa, S., & Spohrer, J. (2016). Systems, Networks, and Ecosystems in Service Research. *Journal of Service Management*, *34*(1), 1–5. https://doi.org/https://doi.org/10.1108/JOSM-09-2015-0268

Barrett, M., Davidson, E., Prabhu, J., & Vargo, S. L. (2015). Service Innovation in the Digital Age: Key Contributions and Future Directions. *MIS Quarterly*, *39*(1), 135–154. https://doi.org/10.25300/MISQ/2015/39:1.03

Bengtsson, M., Kock, S., Lundgren-Henriksson, E.-L., & Näsholm, M. H. (2016). Coopetition research in theory and practice: Growing new theoretical, empirical, and methodological domains. *Industrial Marketing Management*, *57*, 4–11. https://doi.org/10.1016/j.indmarman.2016.05.002

Bicen, P., Hunt, S., & Madhavaram, S. (2021). Coopetitive innovation alliance performance : Alliance competence , alliance ' s market orientation , and relational governance. *Journal of Business Research*, *123*(June 2019), 23–31. https://doi.org/10.1016/j.jbusres.2020.09.040

Bill, H., & Murphy, W. (2008). *Service Science, Management and Engineering: Education for the 21st Century*.

Bitner, M. J., Ostrom, A. L., & Morgan, F. N. (2008a). Service Blueprinting: A Practical Technique for Service Innovation. *CALIFORNIA MANAGEMENT REVIEW VOL. 50,NO. 3 SPRING 2008*

CMR.BERKELEY.EDU, *50*(3), 66–94. https://doi.org/10.2307/41166446

Bitner, M. J., Ostrom, A. L., & Morgan, F. N. (2008b). Service Blueprinting: A Practical Technique For Service Innovation. In *Center for Services Leadership, Arizona State University* (Vol. 50, Issue 3). https://doi.org/10.2307/41166446

Bolton, R. N., Grewal, D., & Levy, M. (2007). Six strategies for competing through service: An agenda for future research. *Journal of Retailing*, *83*(1), 1–4. https://doi.org/10.1016/j.jretai.2006.11.001

Boughnim, N., & Yannou, B. (2005). Using blueprinting method for developing product-service systems. *International Conference of Engineering Design (ICED)*, 1–16. http://hal.archives-ouvertes.fr/hal-00108215/

Bouncken, R. B., Gast, J., Kraus, S., & Bogers, M. (2015). Coopetition: a systematic review, synthesis, and future research directions. *Review of Managerial Science*, *9*(3), 577–601. https://doi.org/10.1007/s11846-015-0168-6

Breidbach, C., & Maglio, P. (2016). Technology-enabled value co-creation: An empirical analysis of actors, resources, and practices. *Industrial Marketing Management*, *56*, 73–85. https://doi.org/10.1016/j.indmarman.2016.03.011

Breznik, L., & Lahovnik, M. (2014). Renewing the resource base in line with the dynamic capabilities view : a key to sustained competitive advantage in the IT industry. *Journal of East European Management Studies*, *19*(4), 453–485. https://doi.org/10.1688/JEEMS-2014-04

Büyüközkan, G., & Göçer, F. (2018). Digital Supply Chain: Literature review and a proposed framework for future research. *Computers in Industry*, *97*, 157–177. https://doi.org/10.1016/j.compind.2018.02.010

Cardeal, N. (2012). Valuable, rare, inimitable resources and organization (VRIO) resources or valuable, rare, inimitable resources (VRI) capabilities: What leads to competitive advantage? *AFRICAN JOURNAL OF BUSINESS MANAGEMENT*, *6*(37), 10159–10170. https://doi.org/10.5897/AJBM12.295

Chandler, J. D., & Vargo, S. L. (2011). *Contextualization and value-in-context: How context frames exchange*. https://doi.org/10.1177/1470593110393713

Crick, J. (2019). The dark side of coopetition: when collaborating with competitors is harmful for company performance. *Journal of Business and Industrial Marketing*, *35*(2), 318–337. https://doi.org/10.1108/JBIM-01-2019-0057

Dagnino, G., & Padula, G. (2002). Coopetition Strategy. Towards a New Kind of Interfirm Dynamics?". *EURAM – The European Academy of Management Second Annual Conference - "Innovative Research in Management," May 2002*, 9–11.

Estrada, I., & Dong, J. (2020). Learning from experience? Technological investments and the impact of coopetition experience on firm profitability. *Long Range Planning*, *53*(1), 101866. https://doi.org/10.1016/j.lrp.2019.01.003

European Commission. (2021). *Annual Report on European SMEs* (Issue July).

Fritzsche, K., Niehoff, S., & Beier, G. (2018). Industry 4.0 and climate change-exploring the science-policy gap. *Sustainability (Switzerland)*, *10*(12). https://doi.org/10.3390/su10124511

Ganz, Satzeger, & Schultz. (2012). *Methods in Service Innovation: Current trends and future perspectives* (F. Verlag (ed.)). Fraunhofer. https://www.ksri.kit.edu/downloads/Ganz_Satzger_Schultz_2012_Methods_in_Service_Innovation.pdf

Gast, J., Filser, M., Gundolf, K., & Kraus, S. (2015). Coopetition research : towards a better understanding of past trends and future directions. *Int. J. Entrepreneurship and Small Business*, *24*(4), 492–521.

Geissbauer, R., Lübben, E., Schrauf, S., & Pillsbury, S. (2018). Global Digital Operations Study 2018 - Digital Champions. In *strategy @ pwc*. http://www.pwc.com/m1/en/about-us.html

Gronroos, C. (2011). Value co-creation in service logic: A critical analysis. *Sage - Marketing Theory*, *11*(3), 279–301. https://doi.org/10.1177/1470593111408177

Gummesson, E., Mele, C., & Polese, F. (2014). Service Dominant Logic and Service Science: A Contribute Deriving from Network Theories. *The 2009 Naples Forum on Service*.

Gummesson, Evert, Lusch, R. F., & Vargo, S. L. (2010). Transitioning from service management to service-dominant logic: Observations and recommendations. *International Journal of Quality and Service Sciences*, *2*(1), 8–22. https://doi.org/10.1108/17566691011026577

Hsu, Y. (2016). Integrating Service Science and Information System Technology : A Case Study. *The International Journal of Organizational Innovation*, *9*(1), 158–173. https://doi.org/10.4236/ti.2011.22015

Hüttinger, L., Schiele, H., & Veldman, J. (2012). The drivers of customer attractiveness , supplier satisfaction and preferred customer status : A literature review. *Industrial Marketing Management*, *41*(8), 1194–1205. https://doi.org/10.1016/j.indmarman.2012.10.004

Johnson, E., & Whang, S. (2002). E-BUSINESS AND SUPPL y CHAIN MANAGEMENT: AN OVERVIEW AND FRAMEWORK. *Production and Operations Management Vol. 11, No.4, Winter 2002*, *11*(4), 413–423.

Khanboubi, F., Boulmakoul, A., & Tabaa, M. (2019). Impact of digital trends using IoT on banking processes. *Procedia Computer Science*, *151*, 77–84. https://doi.org/10.1016/j.procs.2019.04.014

Kingman-Brundage, J. (1989). The ABC's of service system Blueprinting: Designing a winning service strategy. *7th Annual Services Marketing Conference Proceedings- Chicago*.

Kocsi, B., & Oláh, J. (2017). Potential Connections of Unique Manufacturing and Industry 4.0. *LogForumJ.LOG*, *134*(134), 389–400. https://doi.org/10.17270/J.LOG.2017.4.1

Kumar, R., Gunasekaran, A., Gupta, S., & Kamboj, S. (2019). Personalized digital marketing recommender engine. *Journal of Retailing and Consumer Services*, *September 2018*, 101799. https://doi.org/10.1016/j.jretconser.2019.03.026

Kwan, S., Spohrer, J., & Sawatani, Y. (2016). Global Perspectives on Service Science : Japan. In S. N. Y. D. H. London (Ed.), *Springer Science+Business Media*.

Lusch, R. F., & Vargo, S. L. (2006). Service-dominant logic: Reactions, reflections and refinements. *Marketing Theory*, *6*(3), 281–288. https://doi.org/10.1177/1470593106066781

Lusch, R., & Vargo, S. (2014). Service Ecosystems. In *Service-Dominant Logic* (pp. 158–176). Cambridge University Press. https://doi.org/10.1017/CBO9781139043120.012

Maglio, P., Kieliszewski, C., Spohrer, J., Kelly, L., Patrício, L., & Sawatani, Y. (2019). *Handbook of Service Science, Volume II: Vol. II*. https://doi.org/10.1007/978-3-319-98512-1_5

Maglio, P. P., & Spohrer, J. (2008a). Fundamentals of service science. *Journal of the Academy of Marketing Science*, *36*(1), 18–20. https://doi.org/10.1007/s11747-007-0058-9

Maglio, P. P., & Spohrer, J. (2008b). Fundamentals of service science. *Journal of the Academy of Marketing Science*, *36*(1), 18–20. https://doi.org/10.1007/s11747-007-0058-9

Maglio, P. P., & Spohrer, J. (2013). A service science perspective on business model innovation. *Industrial Marketing Management*, *42*(5), 665–670. https://doi.org/10.1016/j.indmarman.2013.05.007

Maglio, P. P., Vargo, S. L., Caswell, N., & Spohrer, J. (2009). The service system is the basic abstraction of service science. *Information Systems and E-Business Management*, *7*(4), 395–406. https://doi.org/10.1007/s10257-008-0105-1

Maglio, P., Vargo, S., Caswell, N., & Spohrer, J. (2009). The service system is the basic abstraction of service science. *Information Systems and E-Business Management*, *7*(4 SPEC. ISS.), 395–406. https://doi.org/10.1007/s10257-008-0105-1

Matthies, B. D., D'Amato, D., Berghäll, S., Ekholm, T., Hoen, H. F., Holopainen, J., Korhonen, J. E., Lähtinen, K., Mattila, O., Toppinen, A., Valsta, L., Wang, L., & Yousefpour, R. (2016). An ecosystem service-dominant logic? – integrating the ecosystem service approach and the service-dominant logic. *Journal of Cleaner Production*, *124*, 51–64. https://doi.org/10.1016/j.jclepro.2016.02.109

Melton, T. (2005). The Benefits of Lean Manufacturing: What Lean Thinking has to Offer the Process Industries. *Chemical Engineering Research and Design*, *83*(6), 662–673. https://doi.org/10.1205/cherd.04351

Meynhardt, T., Chandler, D., & Strathoff, P. (2016). Systemic principles of value co-creation: Synergetics of value and service ecosystems. *Journal of Business Research*, *69*(8), 2981–2989. https://doi.org/10.1016/j.jbusres.2016.02.031

Müller, J. M., Buliga, O., & Voigt, K.-I. (2018). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technological Forecasting and Social Change*, *132*(September 2017), 2–17. https://doi.org/10.1016/j.techfore.2017.12.019

Newell, A. (1980). Physical Symbol Systems. In *Research Showcase @ CMU* (Vol. 183). http://repository.cmu.edu/compsci

Pöppel, J., Finsterwalder, J., & Laycock, R. A. (2018). Developing a film-based service experience blueprinting technique. *Journal of Business Research*, *85*(xxxx), 459–466. https://doi.org/10.1016/j.jbusres.2017.10.024

Radicic, D., Pugh, G., & Douglas, D. (2020). Promoting cooperation in innovation ecosystems: evidence from European traditional manufacturing SMEs. *Small Business Economics*, *54*(1), 257–283. https://doi.org/10.1007/s11187-018-0088-3

Reeves, M., Lotan, H., Legrand, J., & Jacobides, M. G. (2019). *How Business Ecosystems Rise (and Often Fall)* (Issue July). MIT Sloan Management Review.

Ritala, P., Golnam, A., & Wegmann, A. (2014). Coopetition-based business models: The case of Amazon.com. *Industrial Marketing Management*, *43*(2), 236–249. https://doi.org/10.1016/j.indmarman.2013.11.005

Seddon, J., Donovan, B., & Zokaei, K. (2011). Service Science: Research and Innovations in the Service

Economy. In *Service Design and Delivery* (Issue 1972).
Seyring, M., Dornberger, U., Suvelza, A., & Byerns, T. (2009). Service Blue Printing Handbook. In *SEPT - Universitat Leipzig*. https://pt.scribd.com/document/225764709/Handbook-Service-Blueprinting
Shostack, G. (1982). How to Design a Servicelllllllllll. *European Journal of Marketing*, *16*(1), 49–63. http://vir.liu.se/~TDDD51/mtrl/litteratur/Blueprint/ServiceBlueprinting.pdf
Shostack, G. L. (1982). How to Design a Service. *European Journal of Marketing*, *16*(1), 49–63. https://doi.org/10.1108/EUM0000000004799
Silva, A., Dionísio, A., & Coelho, L. (2020). Improving Industry4.0 Through the Service Science. *International Journal of Sciences: Basic and Applied Research (IJSBAR) ISSN 2307-4531 Vol 52 No 2 (2020)*, *52*, 17–32.
Silva, A., Gil, M. M., & Duarte, E. (2020a). Service Innovation | A Service Blueprinting for Industry 4 . 0. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, 24535.
Silva, A., Gil, M. M., & Duarte, E. (2020b). Service Innovation | A Service Blueprinting for Industry 4 . 0. In *International Journal of Sciences: Basic and Applied Research (IJSBAR) ISSN 2307-4531 Vol 52 No 2 (2020): Vol. ISSN 2307-* (ISSN 2307-, pp. 33–49).
Silva, H. M., Gonzaga do Nascimento, M. M., de Morais Neves, C., Oliveira, I. V., Cipolla, C. M., Batista de Oliveira, G. C., de Almeida Nascimento, Y., & Ramalho de Oliveira, D. (2021). Service blueprint of comprehensive medication management: A mapping for outpatient clinics. *Research in Social and Administrative Pharmacy*, *17*(10), 1727–1736. https://doi.org/10.1016/j.sapharm.2021.01.006
Spohrer, J., Anderson, L., Pass, N., & Ager, T. (2009). Service science and service-dominant logic. In O. F. 2 (2008) (Ed.), *Otago Forum 2* (Vol. 1, Issue 2, pp. 133–156). http://link.springer.com/10.1007/978-1-4419-1628-0_8
Spohrer, J. C., & Maglio, P. P. (2010). *Toward a Science of Service Systems* (Issue 2008, pp. 157–194). https://doi.org/10.1007/978-1-4419-1628-0_9
Spohrer, J., Maglio, P., Bailey, J., & Gruhl, D. (2007). Steps Toward a Science of Service Systems. *IEE Computer Society*, *40*(1), 71–77.
Spohrer, Jim, & Kwan, S. K. (2009). Service Science, Management, Engineering, and Design (SSMED). *International Journal of Information Systems in the Service Sector*, *1*(3), 1–31. https://doi.org/10.4018/jisss.2009070101
Spohrer, Jim, & Maglio, P. P. (2008). The Emergence of Service Science: Toward Systematic Service Innovations to Accelerate Co-Creation of Value. *Production and Operations Management*, *17*(3), 238–246. https://doi.org/10.3401/poms.1080.0027
Suhardi, S., Doss, R., & Yustianto, P. (2015). Service Engineering Based on Service Oriented Architecture Methodology. *Telkomnika*, *13*(4), 1466. https://doi.org/10.12928/telkomnika.v13i4.2388
Taylor, P., Jylhä, T., & Junnila, S. (2014). Partnership practices and their impact on value creation – reflections from lean management. *International Journal of Strategic Property Management*, *18*(1), 37–41. https://doi.org/10.3846/1648715X.2013.863813
van Riel, A. C. R., Calabretta, G., Driessen, P. H., Hillebrand, B., Humphreys, A., Krafft, M., & Beckers, S. F. M. (2013). Consumer perceptions of service constellations: implications for service innovation. *Journal of Service Management*, *24*(3), 314–329. https://doi.org/10.1108/09564231311327012
Vargo, S. L. (2011). Market systems, stakeholders and value propositions: Toward a service-dominant logic-based theory of the market. *European Journal of Marketing*, *45*(1), 217–222. https://doi.org/10.1108/03090561111095667
Vargo, S. L., & Akaka, M. A. (2009). Service-Dominant Logic as a Foundation for Service Science: Clarifications. *Service Science*, *1*(1), 32–41. https://doi.org/10.1287/serv.1.1.32
Vargo, S. L., Akaka, M. A., & Wieland, H. (2020). Rethinking the process of diffusion in innovation: A service-ecosystems and institutional perspective. *Journal of Business Research*, *116*(December 2018), 526–534. https://doi.org/10.1016/j.jbusres.2020.01.038
Vargo, S. L., & Lusch, R. F. (2004). Evolving to a New Dominant Logic for Marketing. *Journal of Marketing*, *68*(1), 1–17. https://doi.org/10.1509/jmkg.68.1.1.24036
Vargo, S., & Lusch, R. (2016). Institutions and axioms: an extension and update of service-dominant logic. *Journal of the Academy of Marketing Science*, *44*(1), 5–23. https://doi.org/10.1007/s11747-015-0456-3
Wang, Y. H., Lee, C. H., & Trappey, A. J. C. (2017). Service design blueprint approach incorporating TRIZ and service QFD for a meal ordering system: A case study. *Computers and Industrial Engineering*, *107*, 388–400. https://doi.org/10.1016/j.cie.2017.01.013
Wong, W. P., Ignatius, J., & Soh, K. L. (2014). What is the leanness level of your organisation in lean transformation implementation? An integrated lean index using ANP approach. *Production Planning & Control, 2014 Vol. 25, No. , 273–287, April*, 1–15. https://doi.org/10.1080/09537287.2012.674308
Zatsarinnyy, A. A., & Shabanov, A. P. (2019). Model of a Prospective Digital Platform to Consolidate the

Resources of Economic Activity in the Digital Economy. *Procedia Computer Science*, *150*, 552–557. https://doi.org/10.1016/j.procs.2019.02.092

Engineering Business Solutions: Advancing SME Competitiveness through IIoT-Driven Coopetition

Agostinho da Silva1[1,2], Antonio J. Marques Cardoso[1]

[1] CISE - Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal

[2] CIGEST – Business & Economics School, Lisboa, Portugal

a.silva@zipor.com; ajmarcar@ieee.org

Abstract. This study examines the integration of the Industrial Internet of Things (IIoT) within coopetition frameworks among SMEs in Portugal's ornamental stone sector, highlighting engineering systems' role in business applications. Utilizing the advanced IIoT system, Cockpit4.0+, grounded in Service-Dominant Logic (S-D Logic), this paper evaluates the market performance brought about by coopetition networks. The transition from Current Best Practices (CB.P) to Coopetition Network Practices (CN.P) resulted in a significant increase in conversion rates, from 31.36% to 44.6%, demonstrating the potential of shared technological resources and collaborative competitive strategies. This research underscores the effectiveness of engineering systems in facilitating competitive collaboration, offering a new paradigm for SMEs to leverage technology for competitiveness and sustainability. Future implications and the need for broader studies on technology-driven coopetition across various sectors are discussed.

Keywords: Coopetition, Industrial Internet of Things (IIoT), Service-Dominant Logic (S-D Logic), Ornamental Stone Industry, Digital Transformation.

1 Introduction

In the era of digital transformation, Small and Medium Enterprises (SMEs) face heightened global market vulnerabilities, particularly in managing digital supply chains [1]. To address these challenges, a strategic blend of competition and collaboration, known as "coopetition," has been promoted by academics [2] and governmental organizations as a vital strategy for SMEs [3]. Despite this, a significant gap remains in the implementation success rates. According to a study from the MIT Sloan Management Review (2019), over 85% of coopetition initiatives among SMEs fail in the short term [4]. This startling statistic raises a crucial question: How should a Coopetition Network be structured to effectively tackle the specific challenges SMEs face in a global and digital context?

The Industrial Internet of Things (IIoT) has emerged as a transformative force within the manufacturing sector, propelling industries toward more intelligent, autonomous, and interconnected processes [5]. Despite significant advancements in IIoT technologies that enhance service knowledge, there remains a notable gap in their application for fostering value cocreation through coopetition, especially among manufacturing SMEs [6] [7]. A pertinent example is the IIoT system called "Cockpit4.0," developed through the Inovstone4.0 R&D Project. While it enables cyber-physical systems in ornamental stone SMEs, it lacks the functionalities necessary for effective collaboration among these enterprises [8]. Addressing this deficiency, Silva & Pata (2022) have emphasized the need to evolve this system into what is now referred to as Cockpit4.0+ [9]. In response to this identified research gap, this study aims to (1) enhance the IIoT-based Cockpit4.0+ to enable effective coopetition among ornamental stone SMEs (OS.PT) and (2) conduct a case study to demonstrate the benefits of Cockpit4.0+ through a proof of concept, assessing its capabilities within the OS.PT sector.

2 Integrating Theories in Coopetition: A Service Ecosystems Perspective

Recent advances in service ecosystems, supported by Service-Dominant Logic (S-D Logic), advocate for an integrative view that effectively bridges S-D Logic with other theoretical frameworks [10]. This integration aims to provide a comprehensive understanding of service-centric networks, proposing a shift from traditional firm-centric models to a service-centric approach [11]. This paradigm emphasizes the importance of facilitating broad institutional changes and underscores the critical role of coopetition in driving innovation within ecosystems [12]. Such dynamics are evident in ongoing logistics, learning, and knowledge transfer processes, which illustrate how coopetition can propel innovation [13].

The concept of coopetition is elaborated within this framework as encompassing multiple innovation processes that enhance a network's collective capacity for innovation [2]. This ecosystemic view is supported by research indicating that coopetition fosters an environment where actors are encouraged to share resources, thereby enhancing the network's collective capacity for innovation and enabling firms to effectively capitalize on the benefits of coopetition [14]. From this perspective, innovation is viewed as a product of and a contributor to dynamic reconfiguration processes within institutional spaces, emphasizing the ongoing interaction and co-creation vital for sustaining and enhancing coopetitive relationships [15].

3 Empowering Coopetition in the Ornamental Stone Industry through IIoT

The discourse surrounding the Internet of Things (IoT), a concept first introduced by Kevin Ashton in 1998, has evolved significantly, leading to the specialized emergence of the Industrial Internet of Things (IIoT) [16]. This progression marks a pivotal shift

of IoT applications into the industrial sector, aimed at revolutionizing manufacturing efficiencies through the adoption of intelligent, interconnected systems [17]. The IIoT integrates diverse technologies, catalyzing new avenues for value creation and competitive advantage in manufacturing by leveraging networks to enhance connectivity and communication across industrial components [6].

Incorporating the S-D Logic theory into this technological evolution underscores the collaborative ecosystems of value creation facilitated by the interplay between operant resources (such as skills and knowledge) and operand resources (physical assets) [7]. This integrative approach illuminates the transformative potential of IIoT technologies in industrial settings, enhancing control, coordination, and management capabilities. The convergence of digital and physical domains through IIoT not only opens unprecedented opportunities for innovation and efficiency gains but also presents challenges in fostering creativity and maintaining adaptability within complex systems [6].

A prime example of IIoT innovation is the Inovstone4.0 R&D project, which led to the development of the pioneering Cockpit4.0 for the stone industry [8]. Currently in use by multiple stone processing industries, Cockpit4.0 benefits from dedicated project funding and presents a unique opportunity for development, laying the groundwork for collecting valuable quantitative research data.

3.1 Enhancing Cockpit4.0's Interoperability

The integration of OPC Unified Architecture (OPC UA) into Cockpit4.0 significantly enhances its interoperability capabilities, extending its reach across various platforms and devices. This advancement is crucial for fostering deep collaboration among SMEs in the ornamental stone sector, as it effectively utilizes shared resources and capabilities [18]. Such integration ensures that all participants can contribute to and benefit from the value-creation process regardless of their technological infrastructure.

In this research, the upgraded version of this system will be referred to as Cockpit4.0+. The enhancements in Cockpit4.0+ are underpinned by S-D Logic's concepts of resource density [19] and digital materiality. These mechanisms are embedded into the Cockpit4.0+'s algorithm, enhancing value cocreation to enable competition in SME networks. The digital materiality mechanism, in particular, bridges digital and physical dimensions, facilitating intricate product development and customization [20]. This is critical for SMEs aiming to differentiate themselves with unique value propositions in competitive markets.

As illustrated in Figure 1, implementing OPC UA within Cockpit4.0+ underscores a strategic commitment to creating a fully interoperable network. This setup enables seamless and secure communication across various operational layers, from machine-to-machine interactions to comprehensive device-to-cloud data exchanges. OPC UA plays a critical role in ensuring data integrity and security, essential for handling sensitive information and executing complex transactions across the network. Furthermore, the integration of OPC UA supports a pre-validation process, allowing stakeholders to assess and refine value propositions before manufacturing begins. This capability is

crucial for maintaining high-quality standards, reducing waste, and optimizing resource efficiency.

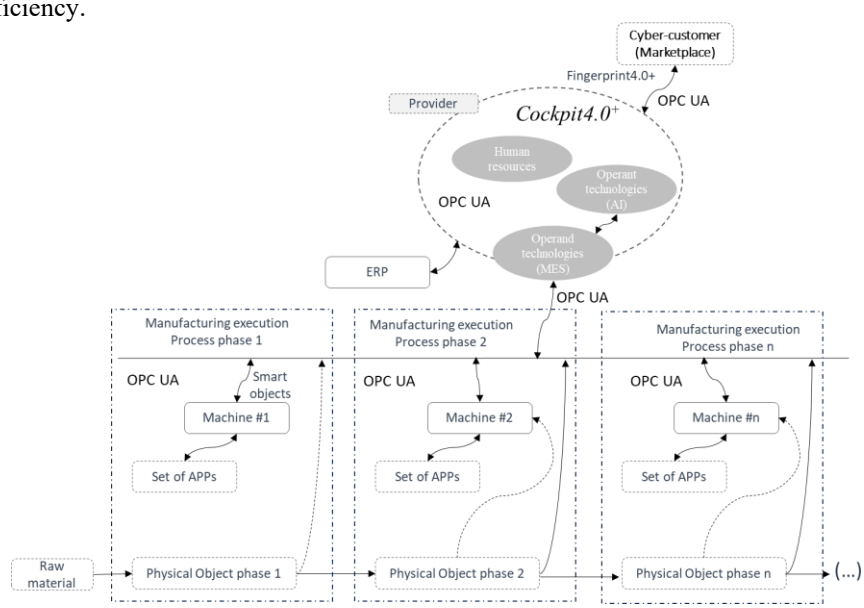


Figure 1. OPC UA interoperability mechanisms in coopetition networks.

Overall, these enhancements boost the competitiveness and agility of SMEs in a rapidly evolving market and facilitate a more connected and collaborative industrial environment, demonstrating the potential of OPC UA interoperability mechanisms in coopetition networks.

3.2 Developing the Cockpit4.0+'s Usability

The design of Cockpit4.0+ exemplifies a solid commitment to creating an accessible and intuitive digital network tailored to meet the needs of all participants in the network. Grounded in human-centred design principles, this system embodies the S-D Logic approach to collaborative value creation. By fostering cooperative interactions, even among competitors, Cockpit4.0+ seeks to streamline secure and efficient service exchanges, thereby enhancing the collective value proposition of the network. Key Features of Cockpit4.0+:

Systemic Assemblages: This feature integrates diverse technological components into cohesive, functional units that exceed the capabilities of their individual elements. These assemblages ensure the complex interconnectivity required in Coopetition Networks, facilitating seamless interactions across various technological and social layers.

Architectural Modules for Transactions and Services: Employing a modular design strategy, Cockpit4.0+ allows for the flexible configuration of products and services to meet varied user needs. This approach supports customization and personalization,

aligning with S-D Logic's perspective that service fragmentation and recombination can significantly boost ecosystem value.

Integration of OPC Unified Architecture (OPC UA): Cockpit4.0+ incorporates OPC UA to leverage its standardized services, promoting compatibility across different technological systems. OPC UA's sophisticated security protocols, including digital certificate signing and encryption, are vital in ensuring the integrity and privacy of data exchanges within the network.

This Cockpit4.0+ setup supports a multifaceted value cocreation process, fostering sustained collaboration throughout the business opportunity lifecycle—from the lead initiation to the conclusion (win or lose). By integrating systemic assemblages and modular designs and enhancing these with OPC UA's robust security and interoperability features, Cockpit4.0+ establishes itself as a secure, adaptable, and user-friendly platform. It facilitates dynamic collaboration and value co-creation and propels technology-enabled networks towards greater inclusivity and a shared commitment to innovation and success.

3.3 Empowering Coopetition in OS.PT through Technological Synergy in Cockpit4.0+

Rooted in S-D Logic, Cockpit4.0+ masterfully integrates operant (initiator) and operand (actuator) resources, essential for enriching coopetition networks. This strategic technological blend allows operant capabilities, grounded in expertise, to initiate actions while operand resources, or tangible assets, respond effectively. This synergy drives innovation, optimizes operational efficiency, and fosters collaboration among SMEs. Such integration enhances SME competitiveness and creates an environment conducive to coopetition, merging collaborative and competitive dynamics to unlock new value and opportunities in the marketplace.

Operant Capabilities Enabled by Cockpit4.0+

Artificial Intelligence and Machine Learning: Facilitate advanced data analytics for dynamic pricing, predictive maintenance, and personalized offerings.

Modular Architecture: Ensures seamless integration with existing digital infrastructures, enhancing connectivity and operational fluidity.

Data Protection: Implements state-of-the-art encryption and secure exchange protocols to safeguard information.

Operand Capabilities Enhanced by Cockpit4.0+

Sensors and IoT Devices: Provide real-time monitoring of production, quality control, and logistics, ensuring accurate data collection.

Cloud Computing: Offers scalable storage and computational power, supporting data analytics and remote access.

High-Speed Networking Equipment: Essential for fast and secure data exchanges, enhancing device and cloud connectivity.

Direct Connections with Digital Marketplaces: Streamline transactions and interactions, increasing market presence.

By embedding these operant and operand capabilities within Coopetition Networks, Cockpit4.0+ becomes a fully realized and comprehensive instrument for enabling coopetition within OS.PT SME networks. The subsequent development of a Proof-of-Concept for Cockpit4.0+ within the OS.PT sector domain will provide preliminary insights into the benefits of adopting such coopetition practices by companies in this sector.

4 Methodology: Assessing Coopetition Impact through Conversion Rates and Innovation Outcomes

This study employs a case study methodology focused on the proof-of-concept of Cockpit4.0+ to evaluate the effectiveness of coopetition networks within the ornamental stone sector. This approach addresses the multifaceted nature of coopetition in an industrial SME context and emphasizes its benefits through the prism of the Conversion Rate (CR).

Key Performance Indicator - Conversion Rate (KPICR): The Conversion Rate, labelled KPICR, calculates the ratio of leads successfully converted into customers. In this research context, the KPICR is a critical measure for assessing the efficacy of a company's scalability in capturing business opportunities within the complex networks of digital and global supply chains. This indicator is instrumental in gauging whether initiatives to augment market penetration effectively yield measurable business results, such as securing bids, finalizing contracts, or broadening market presence.

Innovation Outcome (IO): Adopting the S-D Logic view, the concept of Innovation Outcomes (IO) [19], which tracks the evolution of KPIs as companies innovate within coopetition networks or leverage new technologies. By assessing changes in KPI, the Innovation Outcome quantifies the effects of the innovations, providing insights into how such strategic moves enhance operational metrics and overall competitiveness [21]. IO is particularly valuable for highlighting the benefits of conversion rate and its role in improving competitiveness within the ornamental stone companies.

Operationalization and Data Collection: The case study will operationalize these concepts by collecting and analyzing data from a targeted sample of OS.PT SMEs engaged in the Proof-of-Concept of Cockpit4.0+. Data will be gathered through a combination of direct observations, semi-structured interviews, and operational data reviews to provide a comprehensive view of the impact of competition-enhanced practices on the selected key performance indicators.

5 Population and Sample: Analyzing the Ornamental Stone Sector in Portugal

The dataset provided by the Portuguese Association of the Mineral Resources Industry[1] (2023) predominantly features SMEs within the ornamental stone sector (OS.PT), a critical component of Portugal's economic landscape. This sector contributes over 16,600 direct jobs and boasts an extensive export network to 116 countries, positioning Portugal as the eighth-largest exporter in the global ornamental stone market. Remarkably, Portugal holds the second position worldwide in per capita international trade within this sector, highlighting its significant impact on the global ornamental stone industry. These metrics underscore the sector's resilience, adaptability, and strategic importance in bolstering Portugal's economic stability and international growth.

The Inovminetal4.0 Project represents a groundbreaking venture through the conception and execution of the Experimental Coopetition Network Pilot (ECNP). This initiative has facilitated digital connectivity among competing firms by establishing a cohesive framework for coopetition, bolstered by financial support to develop Cockpit4.0+.

Selection of Sample: For this study, three ornamental stone producers were selected to evaluate the benefits stemming from the ECNPP enabled by Cockpit4.0+. These companies were chosen based on their engagement with the Inovminetal4.0 Project and their representativeness of the broader sector's operational and economic dynamics.

Data Collection Process: The data collection was conducted in two phases: an initial assessment of the operations as they stood, followed by a subsequent data gathering stage after the implementation and activation of the ECNPP. Direct and informal communications were initially established with the managing directors of these companies, who were formally invited to participate in the study. A written contract was drafted to ensure confidentiality, covering sensitive information about the companies, their clients, employees, materials, resources, and competitors. The consent provided by these managers granted the researcher unparalleled access to a wealth of confidential data, including analytical and financial records, order histories, and insights into management and production protocols.

Ensuring Integrity and Confidentiality: To maintain the integrity of the data collection and ensure confidentiality, the researcher engaged in rigorous oversight of the operational processes. This involved direct, daily monitoring and recording of quantitative data from digital machinery and databases, ensuring the accuracy and security of the data procured from these stone-producing companies.

[1] https://www.assimagra.pt/pt/

6 Data Collection and Procedures: Assessing the Impact of Coopetition Practices

To examine and assess the transition from Current Best practices (CB.P) to Coopetition Network practices (CN.P), this study implemented a structured data collection strategy over two distinct intervals, each spanning fifty-four days. This approach facilitated a comparative analysis of operational efficiencies between standard practices and those augmented by coopetition dynamics, maintaining strict confidentiality throughout.

Phase 1 - Current Best Practices (CB.P): This initial phase, from April 17th, 2023, to June 10th, 2023, focused on collecting data on how companies operated under traditional business practices. During this period, companies relied solely on their internal resources for production and delivery, establishing a detailed operational baseline to serve as a foundation for future comparisons.

Phase 2 - Coopetition Production Practices (CN.P): The second phase, from September 9th, 2023, to November 14th, 2023, marked a strategic transition toward establishing a cooperative yet competitive framework among the companies involved. This phase promoted the adoption of shared technologies and resources, fostering an environment ripe for innovation through collaboration and competition. Designed to parallel the first phase in duration and methodology, this approach enabled direct comparisons of operational efficiencies between traditional practices and those influenced by coopetition.

Confidentiality and Data Integrity: In alignment with the confidentiality agreements, all data procured during the study was anonymized. All data was systematically processed and stored in computer files, including comprehensive procedures for data collection, documentation, and exportation. This ensured a uniform and secure method for managing the data, facilitating detailed analysis while upholding the privacy and proprietary rights of the companies participating in the study.

7 Results and Discussion: Evaluating the Impact of Coopetition Network Practices in OS.PT SMEs

This section analyses the data collected from operations under CB.P and CN.P, focusing on the Conversion Rate (KPICR), quantifying the percentage of leads successfully transformed into customers.

Performance under Current Best Practices: Under the CB.P strategy, companies achieved an average of 8.4 leads per day, with 2.5 successfully converted, resulting in a KPICR of 31.4% across these entities.

Performance under Coopetition Network Practices: The adoption of CN.P led to a significant increase in daily leads, with the daily acceptance rate climbing to 3.7, bringing about a KPICR of 44.6%. This performance boost is directly linked to embracing coopetition practices, which enabled companies to respond more dynamically and effectively. Figure 2 illustrates the upward trend in the average daily successful

lead among companies, highlighting that transitioning to CN.P practices significantly elevates the acceptance rate of leads, thereby facilitating improved performance.

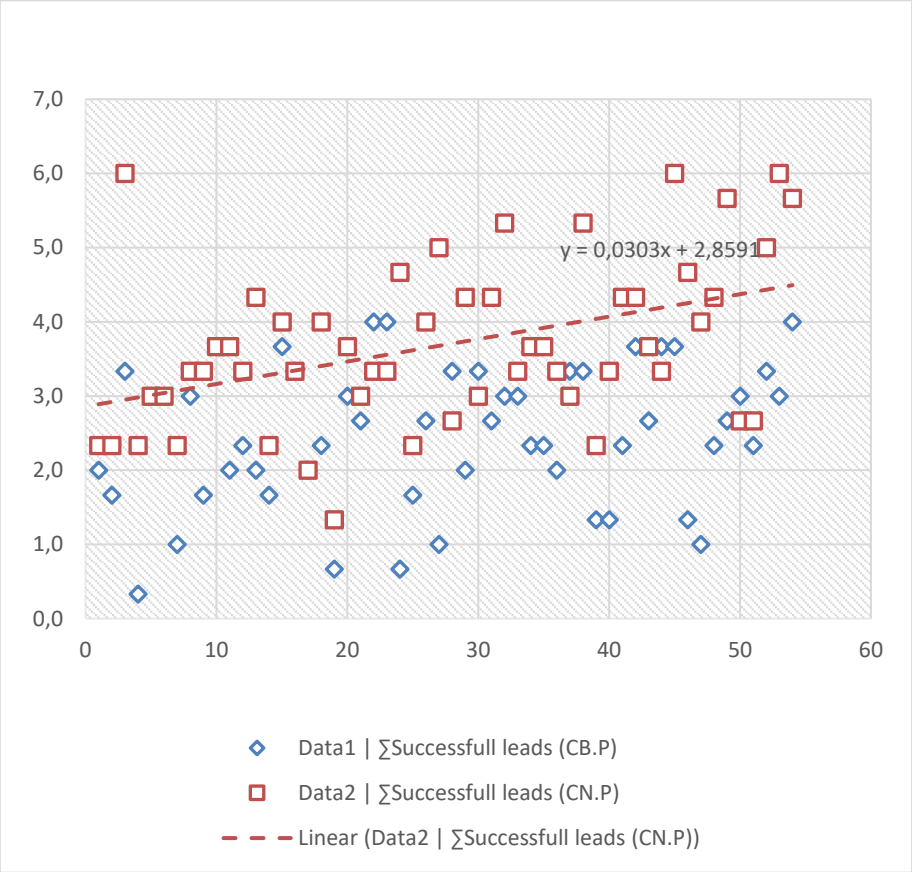


Figure 2. Average Daily Trend - Successful Leads

The tangible benefits of engaging in a collaborative, competitive network are documented through the Innovation Outcomes (IOs). Figure 3 shows that implementing cooperative network practices leads to positive improvements across all metrics for OS.PT SMEs.

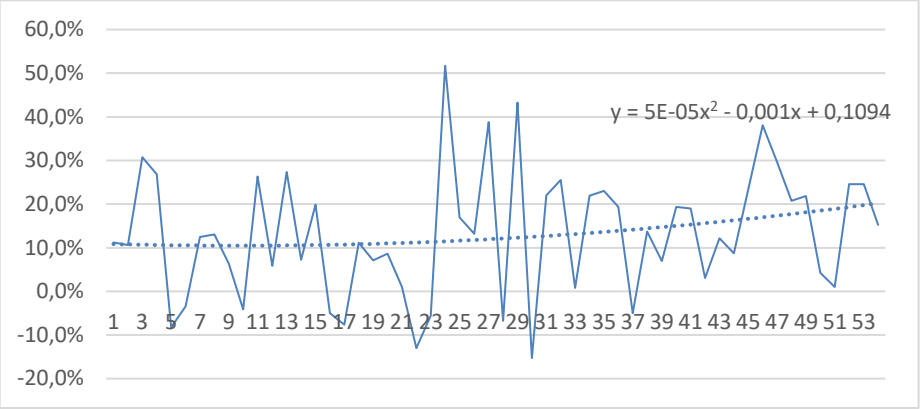


Figure 3. Conversion Rate Gains Trend: Coopetition Network Practices in OS.PT SMEs

These innovation outcomes reveal an average positive impact of 13.2% on the conversion ratio as companies transition from current operations to engaging in coopetition practices within networks.

Conclusions

This study has provided compelling evidence of the effectiveness of competition strategies facilitated by the innovative deployment of the IIoT system Cockpit4.0+ within the ornamental stone sector in Portugal. By transitioning from Current Best Practices (CB.P) to Coopetition Network Practices (CN.P), SMEs within this sector demonstrated notable improvements in operational efficiency and market performance.

The implementation of CN.P led to a significant increase in the Conversion Rate KPI from 31.36% under CB.P to 44.6% under CN.P. This increase underscores the effectiveness of coopetition practices in enhancing the commercial success of participating SMEs by leveraging shared resources and collaborative, competitive strategies.

These findings demonstrate that coopetition is not merely a theoretical concept but a practical strategy that can lead to tangible benefits, including increased scalability, improved market penetration, and enhanced competitive positioning within global markets.

Implications for Practice: The adoption of cooperative practices, as evidenced by this study's results, offers a viable pathway for SMEs in the ornamental stone sector to navigate the complexities of the global market. The strategic use of technologies like Cockpit4.0+ to facilitate this cooperation provides a blueprint for other sectors seeking to enhance their competitiveness and operational efficiency through collaborative dynamics.

Future Research: Further research is needed to explore the long-term impacts of coopetition practices across different sectors and cultural contexts. Additionally, subsequent studies could investigate how technology-enhanced coopetition networks

contribute to sustainability and resilience in SMEs, particularly in the face of global economic fluctuations and supply chain disruptions.

In conclusion, this research affirms the transformative potential of integrating coopetition strategies within SME networks, driven by IIoT. It is evident that such strategic integrations bolster competitive edges and enhance the overall vitality of industries operating in increasingly complex and interconnected markets.

References

[1] L. Di Bella, A. Katsinis, J. Lagüera-González, L. Odenthal, M. Hell, and B. Lozar, "Annual Report on European SMEs 2022/2023," 2023.

[2] R. Bouncken, A. Kumar, J. Connell, A. Bhattacharyya, and K. He, "Coopetition for corporate responsibility and sustainability: does it influence firm performance?," *Int. J. Entrep. Behav. Res.*, vol. 30, no. 1, pp. 128–154, Jan. 2024, doi: 10.1108/IJEBR-05-2023-0556.

[3] U. von der Leyen, "A Union that strives for more. My agenda for Europe : political guidelines for the next European Commission 2019-2024," *EU Publ.*, p. 24, 2019, [Online]. Available: https://ec.europa.eu/commission/sites/beta-political/files/political-guidelines-next-commission_en.pdf%0Ahttps://op.europa.eu/en/publication-detail/-/publication/43a17056-ebf1-11e9-9c4e-01aa75ed71a1.

[4] M. Reeves, H. Lotan, J. Legrand, and M. G. Jacobides, "How Business Ecosystems Rise (and Often Fall)," *MIT Sloan Manag. Rev.*, no. July, 2019.

[5] A. Yazdinejad, B. Zolfaghari, A. Dehghantanha, H. Karimipour, G. Srivastava, and R. Parizi, "Accurate threat hunting in industrial internet of things edge devices," *Digital Communications and Networks*, vol. 9, no. 5. pp. 1123–1130, 2023, doi: 10.1016/j.dcan.2022.09.010.

[6] P. Mosch, P. Majocco, and R. Obermaier, "Contrasting value creation strategies of industrial-IoT-platforms – a multiple case study," *Int. J. Prod. Econ.*, vol. 263, p. 108937, 2023, doi: https://doi.org/10.1016/j.ijpe.2023.108937.

[7] M. Akaka, H. Schau, and S. Vargo, "How Practice Diffusion Drives IoT Technology Adoption and Institutionalization of Solutions in Service Ecosystems," in *Proceedings of the Annual Hawaii International Conference on System Sciences*, 2023, vol. 2023-Janua, no. March, pp. 1427–1435, doi: 10.24251/HICSS.2023.178.

[8] A. Silva, A. Dionisio, and I. Almeida, "Enabling Cyber-Physical Systems for Industry 4.0 operations: A Service Science Perspective," *Int. J. Innov. Technol. Explor. Eng.*, vol. 9, no. 8, pp. 838–846, Jun. 2020, doi: 10.35940/ijitee.H6804.069820.

[9] A. Silva and A. Pata, "Value Creation in Technology Service Ecosystems - Empirical Case Study," in *Innovations in Industrial Engeneering II*, 2022, pp. 26–36, doi: doi.org/10.1007/978-3-031-09360-9_3.

[10] S. L. Vargo *et al.*, “Emergence in marketing: an institutional and ecosystem framework,” *J. Acad. Mark. Sci.*, vol. 51, no. 1, pp. 2–22, 2023, doi: 10.1007/s11747-022-00849-8.

[11] K. Razmdoost, L. Alinaghian, J. D. Chandler, and C. Mele, “Service ecosystem boundary and boundary work,” *J. Bus. Res.*, vol. 156, no. November 2022, p. 113489, 2023, doi: 10.1016/j.jbusres.2022.113489.

[12] S. L. Vargo, H. Wieland, and M. O’Brien, “Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline,” *J. Bus. Res.*, vol. 164, p. 113965, Sep. 2023, doi: 10.1016/j.jbusres.2023.113965.

[13] E. Bacon, M. D. Williams, and G. Davies, “Coopetition in innovation ecosystems: A comparative analysis of knowledge transfer configurations,” *J. Bus. Res.*, vol. 115, no. November, pp. 307–316, 2020, doi: 10.1016/j.jbusres.2019.11.005.

[14] D. R. Gnyawali and T. Ryan Charleton, “Nuances in the Interplay of Competition and Cooperation: Towards a Theory of Coopetition,” *J. Manage.*, vol. 44, no. 7, pp. 2511–2534, 2018, doi: 10.1177/0149206318788945.

[15] S. Barile, R. Lusch, J. Reynoso, S. Marialuisa, and J. Spohrer, “Systems, Networks, and Ecosystems in Service Research,” *J. Serv. Manag.*, vol. 34, no. 1, pp. 1–5, 2016, doi: https://doi.org/10.1108/JOSM-09-2015-0268.

[16] N. Khan, W. D. Solvang, and H. Yu, “4 . 0 Technologies in Spare Parts Warehousing in the Oil and Gas,” 2024.

[17] D. G. S. Pivoto, L. F. F. de Almeida, R. da Rosa Righi, J. J. P. C. Rodrigues, A. B. Lugli, and A. M. Alberti, “Cyber-physical systems architectures for industrial internet of things applications in Industry 4.0: A literature review,” *J. Manuf. Syst.*, vol. 58, pp. 176–192, Jan. 2021, doi: 10.1016/j.jmsy.2020.11.017.

[18] S. Hoppe, “OPC Unified Architecture-Interoperability for Industrie 4.0 and the Internet of Things,” 2023. [Online]. Available: https://opcfoundation.org/wp-content/uploads/2023/05/OPC-UA-Interoperability-For-Industrie4-and-IoT-EN.pdf.

[19] R. Lusch and S. Nambisan, “Service Innovation: A Service-Dominant Logic Perspective,” *MIS Q.*, vol. 39, no. 1, pp. 155–175, Jan. 2015, doi: 10.25300/MISQ/2015/39.1.07.

[20] I. C. L. Ng and S. Y. L. Wakenshaw, “The Internet-of-Things: Review and research directions,” *Int. J. Res. Mark.*, vol. 34, no. 1, pp. 3–21, Mar. 2017, doi: 10.1016/j.ijresmar.2016.11.003.

[21] D. Radicic, G. Pugh, and D. Douglas, “Promoting cooperation in innovation ecosystems: evidence from European traditional manufacturing SMEs,” *Small Bus. Econ.*, vol. 54, no. 1, pp. 257–283, Jan. 2020, doi: 10.1007/s11187-018-0088-3.

TELKOMNIKA Telecommunication Computing Electronics and Control
Vol. 22, No. 5, October 2024, pp. 1138~1146
ISSN: 1693-6930, DOI: 10.12928/TELKOMNIKA.v22i5.26016

Navigating the digital shift: a service blueprint for coopetition technology-enabled networks

Agostinho da Silva[1,2], Antonio J. Marques Cardoso[1]
[1]CISE-Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal
[2]ISG–Business and Economics School, Lisboa, Portugal

Article Info

Article history:

Received Jan 28, 2024
Revised May 26, 2024
Accepted Jul 12, 2024

Keywords:

Coopetition
Networks
SD logic
Service blueprint
Service science

ABSTRACT

This study addresses the gap in applying traditional service blueprint methodologies to technology-enabled coopetition networks characterized by simultaneous collaboration and competition among actors. Leveraging service science insights, it proposes an enhanced service blueprint framework designed for the complexities of digital coopetition. This framework introduces the cyber. Frontstage lane, physical backstage lane, and support stage lane aim to provide a holistic view of interactions, value co-creation processes, and resource allocations. Empirical validation within the Portuguese stone sector-a key player in the national economy-demonstrates the framework's effectiveness in identifying network dysfunctions and its ease of use by industry professionals. Feedback confirms its relevance in capturing today's coopetition environments' multifaceted engagements and digital nuances. The study emphasizes adapting service blueprint methodology to better manage and innovate service processes in digital ecosystems. Future research should extend this framework's application across various sectors and explore the integration of emerging technologies to optimize service delivery and value co-creation.

This is an open access article under the CC BY-SA license.

Corresponding Author:

Agostinho da Silva
CISE-Electromechatronic Systems Research Centre, University of Beira Interior
Covilhã, Portugal
Email: a.silva@zipor.com

1. INTRODUCTION

In today's global economy, a company's ability to swiftly scale its operations is paramount to securing a competitive advantage and ensuring sustainability. Scale capacity, defined as the capability to expand production and service offerings efficiently, is a critical strategic consideration [1]. This is because scaling enables businesses to meet international customers' diverse and growing demands, facilitating market entry and enhancing global presence and profitability [2]. Additionally, scaling allows companies to achieve economies of scale, spreading fixed costs over a larger output, thereby reducing the average cost per unit. This cost efficiency improves profit margins and positions companies competitively in international markets through aggressive pricing strategies [3].

Small and medium-sized enterprises (SMEs), particularly in the industrial sector, play a vital role in developed economies by driving innovation, providing employment, and stimulating economic growth [4]. However, their limited scale can hinder their ability to leverage scaling benefits [5]. The strategic integration of SMEs into coopetition networks, which combine cooperation and competition, has been identified as a solution [6]. These networks enhance SMEs' scale and competitive edge, especially within the intricate global digital supply chains [7].

However, the success of coopetition networks often hinges on the involvement of a leading company that acts as a central anchor, ensuring the network's effectiveness [8]. Insights from the Boston Consulting Group (BCG) Henderson Institute (2019) suggest that major corporations, such as Microsoft and Amazon, play pivotal roles within these networks and achieve significant financial benefits, with profit margins averaging over 29% [9]. In contrast, smaller firms may become overly dependent on these dominant players, exacerbating their collaboration challenges [10]. Furthermore, in the absence of a leading company, coopetition networks rarely survive their initial years, underscoring the critical need for a central, guiding entity to sustain the collective effort, and ensure long-term viability [9].

This challenge is likely due to SMEs' inherently competitive nature and lack of a collaborative mindset, which presents significant obstacles to digital transformation and scaling objectives. This issue is further highlighted by a report from the economist intelligence unit (2021), which identifies a pronounced lack of cooperation among European SMEs, thus impeding their digital progress [11].

- Problem

In the digital age, businesses are increasingly embedded in complex, digitally interconnected environments, accentuating the need for methodologies capable of capturing, and optimizing intricate service processes. The service blueprint, a strategic tool developed to visually depict service processes [12], has significantly evolved, offering critical insights into service delivery's tangible and intangible aspects. Its evolution has broadened its utility across diverse operational landscapes, indicating a profound grasp of service dynamics [13]. However, the advent of coopetition networks, propelled by advancements in the IoT [14], among other technologies, introduces novel challenges that contemporary service blueprint methodologies are ill-equipped to handle.

Despite its adaptability, the application of the service blueprint in technology-driven coopetition networks still needs to be explored, uncovering a notable gap in current business and management scholarship. The complex nature of these networks, characterized by simultaneous collaboration and competition among firms [15], necessitates a framework adept at managing the intricate web of interconnections and multiple stakeholder engagements typical of such ecosystems. Present approaches fall short in several key areas: they do not accurately depict direct digital interactions between producers and consumers, they struggle to optimize the interests of varied stakeholders, especially in contexts of ephemeral collaboration among rivals, and they lack clarity in illustrating the participation of resources from competing entities at every service delivery step. These deficiencies hinder the identification of critical process failures [16], which are central to understanding the reasons behind the premature demise of coopetition networks [17]. This leads to an urgent question: which service blueprinting framework is suitable for efficiently mapping and enhancing service processes within technology-enabled coopetition networks?

- Underlying a potential solution

Confronting the intricacies of digital coopetition networks requires a novel approach, and service science [18], rooted in service-dominant (SD) logic, emerges as a promising solution [19]. This transdisciplinary field, focusing on service systems as its primary object of study, champions the cocreation of value across service ecosystems [20]. It advocates for a multidisciplinary method to seamlessly integrate cutting-edge technologies into service systems. Such an approach is central for enhancing scale and competitiveness and facilitating the transition toward more digitally-focused and globalized service and manufacturing networks [3], [21].

This research aims to leverage the principles of service science to fill the gaps currently observed in service blueprint methodologies, proposing an innovative service blueprint framework tailored for coopetition networks. This proposed framework is designed with the digital complexities of contemporary coopetition networks in mind, providing a sophisticated tool for precise mapping of service processes within these complex environments. A key feature of this framework is its focus on the detailed documentation of value cocreation interactions and the explicit representation of resource sharing among service systems (stakeholders), particularly in the face of service disruptions. By enhancing the visualization of resource engagement and facilitating the identification of potential failure points, this service blueprint framework seeks to refine service innovation practices. It aims to adapt these practices to meet the distinctive needs of technology-enabled coopetition networks, thereby cultivating a more robust, collaborative network.

This discourse lays the groundwork for addressing the gaps in the literature related to service blueprinting within technology-enabled coopetition networks. By weaving together the foundations of SD logic and the multidisciplinary perspectives of service science, the following section proposes concrete solutions for each identified gap, culminating in a novel service blueprint framework. This framework aims to adeptly navigate modern coopetition networks' digital complexities and multi-actor engagements, thereby advancing service innovation and management.

2. LITERATURE REVIEW

The exploration of service's role in economic exchanges has been profoundly rich, evolving significantly over centuries. Frederick Bastiat's concept of "services exchanging for services" in 1848 laid the foundational stone for the modern understanding of the service economy. This intellectual journey was notably advanced by Vargo and Lusch [22] with the introduction of SD logic. They proposed a paradigm shift in marketing and economic thought, emphasizing that the essence of economic exchange lies in providing and reciprocating intangible services rather than the transaction of tangible goods [23]. This perspective challenges traditional goods-centric paradigms, positioning products merely as vessels for service delivery and underscoring the importance of derived benefits and utilities [24].

SD logic offers a nuanced understanding of economic exchanges, stressing the co-creation of value through dynamic interactions among a network of actors. It distinguishes between operant resources-such as knowledge and skills-and operand resources, like technologies and physical goods, as crucial to facilitating service exchanges. This framework posits that value is collaboratively crafted, leveraging the resources available to actors within these exchanges.

In coopetition networks-where competition and collaboration occur simultaneously among actors SD logic provides essential insights [7]. These networks represent a complex layer of interactions vital for service ecosystems' dynamism [25]. Coopetition networks are seen as intricate webs of relationships, enriched by digital technologies and governed by institutional mechanisms that foster mutual value creation despite competitive tensions [26], [27].

Service science, inspired by SD logic, emphasizes innovation and value co-creation within service systems [28]. It calls for a multidisciplinary approach, integrating technology to enhance competitiveness across service and manufacturing sectors [29]. This field recognizes the central role of technology in improving service exchange and resource integration towards operational efficiency, especially within complex ecosystems such as digital coopetition networks [3].

3. METHOD

In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables, and others that make the reader understand easily [30], [31]. The discussion can be made in several sub-sections.

Adopting a service science perspective requires the service blueprint to evolve, capturing real-time value co-creation processes within service systems' resources. This service science view is adopted as the methodology to develop an advanced able to map the sequence of actions and the flow of information, resources, and interactions facilitated by digital technologies under coopetition practices. It must identify critical moments of expectation or trust breakdowns, providing insights into how digital elements influence value co-creation, thereby capturing the fluid nature of rival interactions [7].

Initially introduced by Shostack (1982) and further developed by Kingman-Brundage (1989), the service blueprint methodology has been a fundamental tool for visualizing and innovating service processes [30]. It effectively separates customer and provider domains, using conceptual lines and stages to detail the sequence of service actions [31]. This methodology captures both tangible and intangible aspects of service delivery. It facilitates a deep understanding of the interactions between service providers and recipients, which is crucial for identifying and improving key elements of service delivery [13].

In today's digital coopetition networks, advanced technologies such as the IoT, among others, play essential roles in enhancing connectivity and interactions among network participants [32]. These technologies enable a more seamless integration of competing value propositions to customers, breaking down geographical limitations and promoting a vibrant ecosystem for value co-creation [33]. Introducing these technologies in coopetition networks necessitates an evolution of the service blueprint to reflect the digital and multi-actor dynamics characteristic of contemporary coopetition networks more accurately.

Adopting a service science perspective requires the service blueprint to evolve, capturing real-time value co-creation processes within service systems' resources. This advanced blueprint should map the sequence of actions and the flow of information, resources, and interactions facilitated by digital technologies under coopetition practices. It must identify critical moments of expectation or trust breakdowns, providing insights into how digital elements influence value co-creation, thereby capturing the fluid nature of rival interactions [7].

To meet these challenges, effectively, the coopetition service blueprint needs to be intricately layered, showcasing digital connections and interactions across the entire network at every stage of the process. It should explicitly map out direct connections between factories' shop-floors and customers, ensure the alignment of interests among a variety of stakeholders, and vividly delineate the sharing of resources throughout each phase of service delivery. This refined blueprint will offer a dynamic, real-time perspective of

the service ecosystem by leveraging digital tools. This approach not only illuminates areas of potential discord or misalignment but also establishes a robust framework for ongoing enhancement and innovation. Such a comprehensive tool is essential for identifying critical intervention points that can significantly improve value cocreation, ultimately leading to a more harmonious, efficient, and innovative coopetition network.

Reimagining the service blueprint through the lens of SD logic, service science and digital technology operant capabilities offers a robust framework for understanding and navigating the complexities of modern service delivery within technology-enabled coopetition networks. This methodological evolution promises not only to enrich our comprehension of service processes but also to foster more resilient, adaptive, and collaborative service ecosystems.

3.1. Inter-connectivity visualization

As conceptualized by Kingman-Brundage [31], the service blueprint has traditionally facilitated the delineation of customer and supplier activities through the customer interaction line. This line has been instrumental in visualizing direct interactions between customers and suppliers, encompassing a range of communication methods from in-person engagements to digital correspondences like emails and telephone conversations. However, the advent of digital technologies and the rise of technology-driven coopetition networks have significantly expanded the scope and nature of these interactions [34].

The emergence of digital coopetition networks has extended these interactions into the cyber environment, enabling direct connections between cyber customers and shop-floor manufacturing operations. These connections span diverse digital interfaces, from small-scale operations to expansive, interconnected factory networks, thereby challenging the conventional boundaries of customer-supplier interactions.

To accurately represent this evolution in the service blueprint, it is imperative to reconceptualize the traditional customer interaction line. The proposed line of cyber interaction emerges as a novel construct designed to encapsulate the digital interconnectivity that defines modern customer-supplier relationships. This re-envisioned line aims to capture the essence of digital exchanges and the seamless and often instantaneous nature of these interactions, facilitated by the proliferation of advanced digital technologies.

The visual representation of the line of cyber interaction as a dashed line serves a dual purpose. Stylistically, it signifies digital interactions' fluid and permeable nature, setting them apart from the more rigid and linear modes of communication prevalent in the past. This depiction underscores the dynamic, ever-evolving landscape of digital coopetition, where interactions are not bounded by physical proximity or conventional communication channels. Instead, they are characterized by a continuous flow of information, resources, and value propositions that traverse the digital sphere.

Integrating the line of cyber interaction into the service blueprint enhances the methodology to reflect the complex and immediate connections more accurately between cyber customers and factories' digital shopfloors. This adaptation lays a robust foundation for comprehensively understanding and mapping the value propositions and interaction dynamics within digital coopetition networks. Emphasizing inter-connectivity in this manner is crucial for ensuring that the service blueprint continues to serve as a relevant and effective tool for navigating the intricacies and opportunities of the digital coopetition networks, fostering a deeper comprehension of how value is co-created in these innovative service ecosystems.

3.2. Coopetition networks' stakeholders

At the heart of service science and SD logic lies the recognition that all participants in economic exchange, including customers, providers, and rivals, are service providers actively engaged in value creation. This insight is crucial for developing a service blueprint that maps out the interactions and exchanges within coopetition networks and highlights each actor's diverse contributions to the network's value creation dynamics.

Customers in the digital environment: under the SD logic view, customers are envisioned as the linchpins of value co-creation. Digital technology has transformed how customers' needs are met, ushering individuals and organizations into global digital marketplaces powered by advanced technologies such as smartphones, computers, and tablets. This shift requires a service blueprint that can adeptly illustrate the digital customer's journey, showcasing their technological interactions with providers and underscoring the critical role of digital interfaces in facilitating global procurement processes. The blueprint must, therefore, evolve to vividly capture these digital touchpoints, ensuring a comprehensive visualization of the customer's engagement in the value co-creation process.

The role of providers in value co-creation: central to the ethos of SD logic, providers are depicted not merely as suppliers but as participants in value cocreation. They deliver value propositions that span a broad spectrum of activities and experiences, fostering a collaborative process wherein value is co-created rather than unilaterally delivered. This perspective emphasizes that customers do not passively receive value; instead, they actively integrate the provider's offerings into their life narratives, weaving these services into the fabric of their daily routines and experiences. Thus, a practical service blueprint must capture this dynamic, showcasing

how providers play an integral role in this intricate dance of co-creation. It should illuminate the myriad ways providers' services become interlaced with the customer's everyday life, thereby facilitating a deeper understanding of the symbiotic relationship between providers and customers in the co-creative process.

Coopetitors and collaboration: coopetitors, entities that uniquely meld competitive drive with a collaborative spirit, significantly enrich the network's resource pool. The service blueprint must delineate this dual role, showing how coopetitors utilize operant (skills, knowledge), and operand (physical goods, technologies) resources to nurture collaboration while managing the competitive tensions inherent to the network. This detailed representation is crucial for a holistic understanding of coopetitors' contributions, spotlighting their distinctive capability to simultaneously compete and collaborate, thus propelling collective innovation and success within the network.

Competitors and innovation: within coopetition networks, the dynamic nature of competitor relationships-marked by the freedom to engage or disengage-underscores the fluidity that drives innovation. The blueprint should portray competitors as autonomous yet interconnected entities within the ecosystem, emphasizing how competitive pressures catalyze continual innovation and improvement. This portrayal reinforces the significance of maintaining an adaptable and responsive blueprint capable of capturing the dynamic interplays that foster a conducive environment for innovation and growth.

3.3. Mapping stages and lanes

In the context of service science, the dynamic interplay between service systems involved in value cocreation underscores the imperative for continuous innovation in value propositions [35]. The challenge lies in innovating and systematically identifying and integrating the resources central to these propositions right from their inception [36]. The goal of improving a value proposition transcends the benefit to the customer or provider alone, aiming instead to enrich the entire ecosystem, with competition catalyzing innovation [37]. Service systems can refine their contributions based on historical insights and future projections, embodying a principle of perpetual enhancement to meet the evolving demands of the market.

Therefore, a service blueprint framework tailored for coopetition networks must adeptly delineate the interaction stages and resource lanes, encapsulating the multifaceted nature of value cocreation. This blueprint should feature: i) cyber frontstage lane-designed to visualize the frontstage interactions that blend human and technological resources, spotlighting the technology-mediated exchanges between cyber customers and providers. It emphasizes the integration of physical and virtual evidence, capturing the essence of digital interactions in the value co-creation process; ii) physical backstage lane-reveals behind-the-scenes resources and activities; this lane unravels the support structures that underpin the co-creation process. It highlights the roles of providers and coopetitors, providing insights into the operational and strategic foundations that enable seamless value delivery; and iii) supportstage lane-captures the expansive network of partnerships, management resources, and coopetition support frameworks. It underscores the external collaborations and resources that bolster the network, facilitating a robust infrastructure for coopetition.

As depicted in a conceptual service blueprint for coopetition networks (Figure 1), these delineated lanes and stages are instrumental in mapping and enhancing value interactions. The blueprint employs dashed lines to represent the shopfloor technology line and the line of internal interactions, symbolizing technological transparency and the seamless flow of information between the shop floor and cyber customers.

Within the support stage lanes, support resources engage in tasks vital to the service process, with their openness and fluid exchange of information demarcated by dashed lines. This representation fosters a clear understanding of the roles and contributions of all network actors, enhancing the governance and strategic decision-making within these collaborative and competitive environments.

At the summit of the comprehensive service blueprint for coopetition, networks lie either cyber or physical evidence or outcomes, which are the fruits of cooperative endeavours between the cyber customer and the digital provider [38]. This section captures the tangible results of collaborative actions, emphasizing the concrete benefits of such partnerships.

By addressing the contemporary demands and intricacies of digital coopetition networks, this enhanced service blueprint offers a strategic framework for organizations to navigate the complexities of digital coopetition. Its comprehensive approach facilitates more profound insights into co-creative interactions and empowers businesses to bolster their collaborative efforts while maintaining competitive edges. Through its application, organizations can ensure the sustainability and success of their coopetition strategies in the digital era, driving innovation and value creation in an increasingly interconnected marketplace.

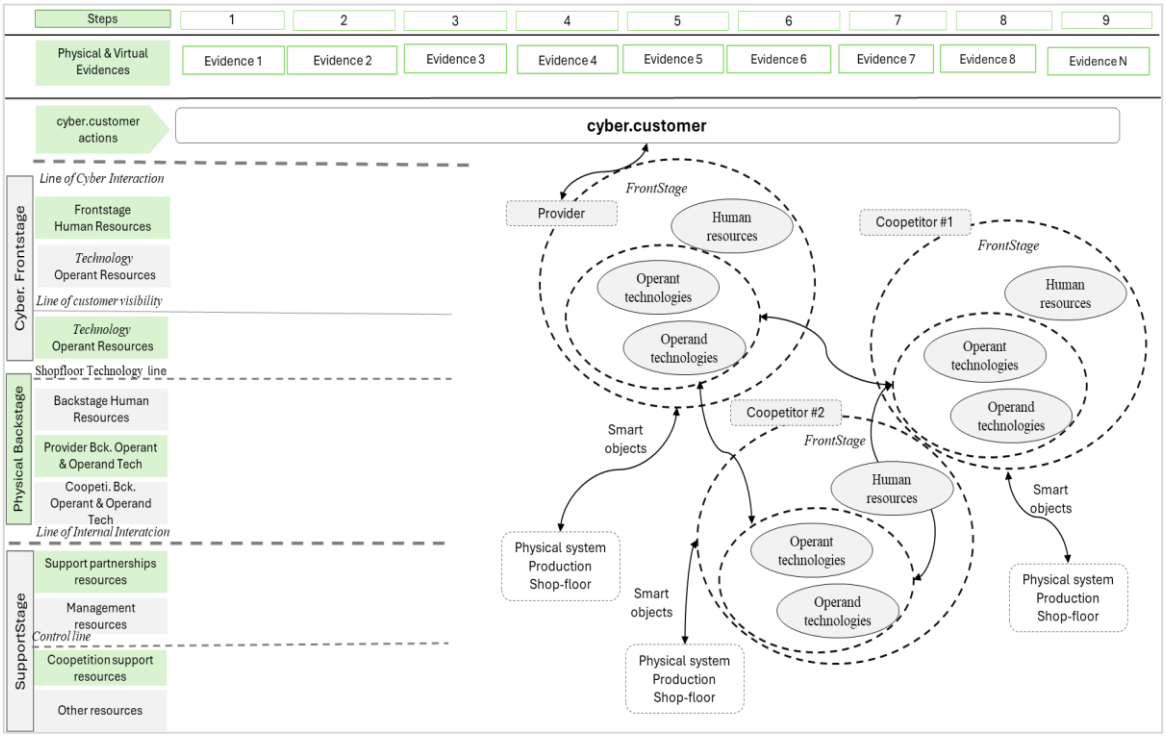


Figure 1. Service blueprint framework for coopetition networks

4. EMPIRICAL VALIDATION OF THE SERVICE BLUEPRINT

To empirically validate the proposed service blueprint, thirty interviews were conducted with managers from diverse Portuguese stone manufacturing companies, a sector crucial to the Portuguese economy [39]. These companies, primarily SMEs, collectively provide over 16,600 direct jobs, significantly contributing to employment in inland regions [40]. Despite ongoing challenges, this sector has seen sustained export growth, positioning Portugal as a leading player in the international ornamental stone market [41].

These interviews aimed to assess the utility of the new service blueprint framework for technology enabled coopetition networks within the stone manufacturing industry. It explored each company's adoption of digital technologies, ranging from digital production machines to collaborative marketplace technologies, to gauge the digital maturity of respondents on a scale from DL#0 (no digital integration) to DL#4 (fully digital operations).

A streamlined questionnaire was distributed to participants, focusing on two principal areas: i) introduction: this section emphasized the construction sector's forthcoming transition towards building information modeling (BIM) technology and its repercussions for materials procurement [42]. The discussion centred on stone companies' need to augment their scale, price flexibility, and delivery timeliness through collaborative efforts with competitors to sustain market competitiveness; ii) presentation of the new service blueprint framework: respondents assessed the framework's ease of use and effectiveness in identifying potential dysfunctions in inter-company relationships within a network, assigning a rating on a scale from 1 to 5. The face-to-face interviews, conducted from October 1st to November 1st, 2023, revealed the framework's growing relevance as firms enhance their digital capabilities, with findings illustrated in Figure 2.

Garnering a favorable average manager rating of 3.6 out of 5, the feedback compellingly affirms the efficacy of the newly developed service blueprint framework. This framework is particularly adept at uncovering and rectifying dysfunctions in the relationships among interconnected companies. Its proven utility and relevance in promoting collaborative dynamics underscore its indispensable role in sectors undergoing digital transformation.

The observed exponential growth highlights the intensified inclination towards digitalization, signaling a marked shift towards more digitally oriented operations. However, the relatively modest magnitude of this exponent (0.1467) may also indicate that companies at a lower digital maturity level-predominantly representing the majority within this sector-may experience slower progress towards digitalization. This suggests a pressing need for public initiatives aimed at catalyzing the digital transformation journey.

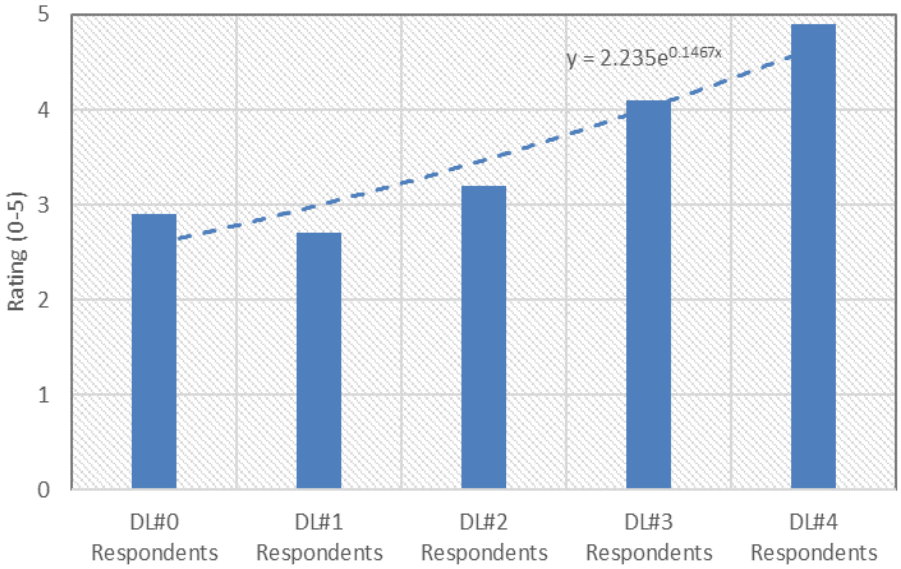


Figure 2. Service blueprint's user-friendliness evaluation in coopetition networks

5. CONCLUSION

Despite the acknowledged versatility of the service blueprint methodology, its application to technology-enabled coopetition networks has been surprisingly limited, marking a gap in the existing business and management literature. The unique dynamics of these networks, characterized by the simultaneous collaboration and competition among actors, necessitate a more sophisticated framework capable of capturing the nuanced interconnectivity and the multifaceted engagements that define these digital ecosystems. Building upon the insights from service science literature, this study proposes an enhanced service blueprint framework that addresses these identified gaps. This knowledge-based service blueprint framework is tailored to the intricacies of coopetition networks, facilitating innovation in value cocreation interactions and offering a robust tool incorporating the cyber. Frontstage lane, physical backstage lane and supportstage lane highlight the value cocreation interactions and resource allocations within technology-enabled coopetition networks. This framework aims to provide a holistic view of the interactions and value co-creation processes, emphasizing the roles of customers, providers, and coopetitors in fostering innovation and enhancing value propositions.

The empirical validation of the service blueprint demonstrates its utility in identifying potential dysfunctions within coopetition networks, with positive feedback from the Portuguese stone sector highlighting its user-friendliness and relevance. The study's findings validate the proposed framework's effectiveness in fostering a deeper understanding of the digital nuances and multi-actor engagements characteristic of today's coopetition environments.

The study sheds light on the need for continuous adaptation of service blueprint methodology and illustrates the potential for such frameworks to facilitate more effective management of service processes. Future research should refine and test the service blueprint framework across different sectors and geographies to validate its universality and applicability. Additionally, exploring the integration of emerging technologies, such as artificial intelligence and blockchain, into the service blueprint could offer deeper insights into optimizing service delivery and value co-creation processes.

REFERENCES

[1] R. Geissbauer, E. Lübben, S. Schrauf, and S. Pillsbury, "Global Digital Operations Study 2018-Digital Champions," *PwC*, p. 64, 2018, [Online]. Available: http://www.pwc.com/m1/en/about-us.html.

[2] G. Medberg and C. Grönroos, "Value-in-use and service quality: do customers see a difference?," *Journal of Service Theory and Practice*, vol. 30, no. 4/5, pp. 507–529, Nov. 2020, doi: 10.1108/JSTP-09-2019-0207.

[3] A. Da Silva, A. Dionísio, and L. Coelho, "Improving Industry 4.0 through service science," *International Journal of Services Sciences*, vol. 7, no. 2, p. 58, 2020, doi: 10.1504/IJSSCI.2020.113189.

[4] L. Di Bella, A. Katsinis, J. Lagüera-González, L. Odenthal, M. Hell, and B. Lozar, "Annual report on European SMEs 2022/2023," pp. 1–92, 2023.

[5] A. Razy, S. Mirnoori, J. Silva, A. Silva, M. Mohoring, and I. Duarte de Almeida, "Sustainable Customer Relationship Management for BIM Procurement in the Ornamental Stones Cluster under Industry 4.0," *26th EurOMA Conference–Operations adding value to society*, p. 26, 2019.

[6] European Commission, "Unleashing the full potential of European SMEs," *European Comission*, no. March, pp. 1–3, 2020, doi:

10.2775/218854.
[7] P. Bicen, S. D. Hunt, and S. Madhavaram, "Coopetitive innovation alliance performance: Alliance competence, alliance's market orientation, and relational governance," *Journal of Business Research*, vol. 123, pp. 23–31, Feb. 2021, doi: 10.1016/j.jbusres.2020.09.040.
[8] M. Tsujimoto, Y. Kajikawa, J. Tomita, and Y. Matsumoto, "A review of the ecosystem concept—Towards coherent ecosystem design," *Technological Forecasting and Social Change*, vol. 136, pp. 49–58, Nov. 2018, doi: 10.1016/j.techfore.2017.06.032.
[9] M. Reeves, H. Lotan, J. Legrand, and M. G. Jacobides, "How business ecosystems rise (and often fall)," *Business Ecosystems*, pp. 27–34, 2022, doi: 10.1515/9783110775167-003.
[10] A. R. Razavi, P. J. Krause, and A. Strommen-Bakhtiar, "From business ecosystems towards digital business ecosystems," in *4th IEEE International Conference on Digital Ecosystems and Technologies*, IEEE, Apr. 2010, pp. 290–295, doi: 10.1109/DEST.2010.5610633.
[11] Appian, "Poor collaboration holds back European businesses digital ambitions," 2021, [Online]. Available: https://assets.appian.com/uploads/assets/economist-europe.pdf
[12] D. -H. Ryu, C. Lim, and K. -J. Kim, "Development of a service blueprint for the online-to-offline integration in service," *Journal of Retailing and Consumer Services*, vol. 54, p. 101944, May 2020, doi: 10.1016/j.jretconser.2019.101944.
[13] J. Pöppel, J. Finsterwalder, and R. A. Laycock, "Developing a film-based service experience blueprinting technique," *Journal of Business Research*, vol. 85, pp. 459–466, Apr. 2018, doi: 10.1016/j.jbusres.2017.10.024.
[14] E. Bacon, M. D. Williams, and G. Davies, "Coopetition in innovation ecosystems: A comparative analysis of knowledge transfer configurations," *Journal of Business Research*, vol. 115, pp. 307–316, Jul. 2020, doi: 10.1016/j.jbusres.2019.11.005.
[15] T. Raza-Ullah, M. Bengtsson, and S. Kock, "The coopetition paradox and tension in coopetition at multiple levels," *Industrial Marketing Management*, vol. 43, no. 2, pp. 189–198, Feb. 2014, doi: 10.1016/j.indmarman.2013.11.001.
[16] H. M. Silva *et al.*, "Service blueprint of comprehensive medication management: A mapping for outpatient clinics," *Research in Social and Administrative Pharmacy*, vol. 17, no. 10, pp. 1727–1736, Oct. 2021, doi: 10.1016/j.sapharm.2021.01.006.
[17] I. Estrada and J. Q. Dong, "Learning from experience? Technological investments and the impact of coopetition experience on firm profitability," *Long Range Planning*, vol. 53, no. 1, p. 101866, Feb. 2020, doi: 10.1016/j.lrp.2019.01.003.
[18] H. Demirkan and J. C. Spohrer, "Commentary-Cultivating T-Shaped Professionals in the Era of Digital Transformation," *Service Science*, vol. 10, no. 1, pp. 98–109, Mar. 2018, doi: 10.1287/serv.2017.0204.
[19] S. L. Vargo, H. Wieland, and M. O'Brien, "Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline," *Journal of Business Research*, vol. 164, p. 113965, Sep. 2023, doi: 10.1016/j.jbusres.2023.113965.
[20] N. N. Hartmann, H. Wieland, and S. L. Vargo, "Converging on a New Theoretical Foundation for Selling," *Journal of Marketing*, vol. 82, no. 2, pp. 1–18, Mar. 2018, doi: 10.1509/jm.16.0268.
[21] P. P. Maglio and J. Spohrer, "A service science perspective on business model innovation," *Industrial Marketing Management*, vol. 42, no. 5, pp. 665–670, Jul. 2013, doi: 10.1016/j.indmarman.2013.05.007.
[22] S. L. Vargo and R. F. Lusch, "Evolving to a New Dominant Logic for Marketing," *Journal of Marketing*, vol. 68, no. 1, pp. 1–17, Jan. 2004, doi: 10.1509/jmkg.68.1.1.24036.
[23] S. Michel, S. L. Vargo, and R. F. Lusch, "Reconfiguration of the conceptual landscape: a tribute to the service logic of Richard Normann," *Journal of the Academy of Marketing Science*, vol. 36, no. 1, pp. 152–155, 2008, doi: 10.1007/s11747-007-0067-8.
[24] S. L. Vargo and M. A. Akaka, "Value Cocreation and Service Systems (Re)Formation: A Service Ecosystems View," *Service Science*, vol. 4, no. 3, pp. 207–217, Sep. 2012, doi: 10.1287/serv.1120.0019.
[25] D. R. Gnyawali and T. R. Charleton, "Nuances in the Interplay of Competition and Cooperation: Towards a Theory of Coopetition," *Journal of Management*, vol. 44, no. 7, pp. 2511–2534, Sep. 2018, doi: 10.1177/0149206318788945.
[26] R. F. Lusch and S. Nambisan, "Service Innovation: A Service-Dominant Logic Perspective," *MIS Quarterly*, vol. 39, no. 1, pp. 155–175, Jan. 2015, doi: 10.25300/MISQ/2015/39.1.07.
[27] S. Barile, R. Lusch, J. Reynoso, M. Saviano, and J. Spohrer, "Systems, networks, and ecosystems in service research," *Journal of Service Management*, vol. 27, no. 4, pp. 652–674, Aug. 2016, doi: 10.1108/JOSM-09-2015-0268.
[28] C. F. Breidbach and P. P. Maglio, "Technology-enabled value co-creation: An empirical analysis of actors, resources, and practices," *Industrial Marketing Management*, vol. 56, pp. 73–85, Jul. 2016, doi: 10.1016/j.indmarman.2016.03.011.
[29] D. Pakkala and J. Spohrer, "Digital service: Technological agency in service systems," *Proceedings of the Annual Hawaii*
[30] G. L. Shostack, "How to Design a Service," *European Journal of Marketing*, vol. 16, no. 1, pp. 49–63, Jan. 1982, doi: 10.1108/EUM0000000004799.
[31] J. Kingman-Brundage, "The ABCs of Service System Blueprinting: Designing a Winning Service Strategy," *Designing a Winning Service Strategy*, pp. 30–33, 1989.
[32] J. D. Chandler, I. Danatzis, C. Wernicke, M. A. Akaka, and D. Reynolds, "How Does Innovation Emerge in a Service Ecosystem?," *Journal of Service Research*, vol. 22, no. 1, pp. 75–89, Feb. 2019, doi: 10.1177/1094670518797479.
[33] S. Bagheri, R. J. Kusters, and J. J. M. Trienekens, "Customer knowledge transfer challenges in a co-creation value network: Toward a reference model," *International Journal of Information Management*, vol. 47, pp. 198–214, Aug. 2019, doi: 10.1016/j.ijinfomgt.2018.12.019.
[37] B. D. Matthies *et al.*, "An ecosystem service-dominant logic? – integrating the ecosystem service approach and the service-dominant logic," *Journal of Cleaner Production*, vol. 124, pp. 51–64, Jun. 2016, doi: 10.1016/j.jclepro.2016.02.109.
[38] L. Breznik and M. Lahovnik, "Renewing the resource base in line with the dynamic capabilities view: a key to sustained competitive advantage in the IT industry," *Journal of East European Management Studies*, vol. 19, no. 4, pp. 453–485, 2014, doi: 10.5771/0949-6181-2014-4-453.
[39] W. P. Wong, J. Ignatius, and K. L. Soh, "What is the leanness level of your organisation in lean transformation implementation? An integrated lean index using ANP approach," *Production Planning & Control*, vol. 25, no. 4, pp. 273–287, Mar. 2014, doi: 10.1080/09537287.2012.674308.
[40] L. Hüttinger, H. Schiele, and J. Veldman, "The drivers of customer attractiveness, supplier satisfaction and preferred customer status: A literature review," *Industrial Marketing Management*, vol. 41, no. 8, pp. 1194–1205, Nov. 2012, doi: 10.1016/j.indmarman.2012.10.004.
[41] B. Kocsi and J. Oláh, "Potential Connections of Unique Manufacturing and Industry 4.0," *Logforum*, vol. 13, no. 4, pp. 389–400, Dec. 2017, doi: 10.17270/J.LOG.2017.4.1.
[42] A. da Silva, A. Dionisio, and I. Almeida, "Enabling Cyber-Physical Systems for Industry 4.0 operations: A Service Science Perspective," *International Journal of Innovative Technology and Exploring Engineering*, vol. 9, no. 8, pp. 838–846, Jun. 2020, doi: 10.35940/ijitee.H6804.069820.

BIOGRAPHIES OF AUTHORS

Agostinho da Silva is industry 4.0 Academic Researcher and Managing Director at CEI Group (ceigroup.net), specialized in industry 4.0 factories design, with the Master's degree in Mechanical Engineering, the Master's degree in Strategy and International Investment and the Ph.D. degree in Management with High Distinction. His main area of specialization and research is digital manufacturing, simulation, and optimization. Project leader in several projects since 2001 which have involved more than 100 companies and 50 academic research units, he has been awarded the honour of comendador of the order of business merit, class of industrial merit, by his excellency the President of the Republic of Portugal. Presently is collaborating as Professor in the Department of Management and Industrial Engineering at the Leiria Polytechnic Institute (ipleiria.pt) and is research member at Advanced Studies in Management and Economics Center of the University of Évora (CEFAGE), research member at Marine and Environmental Sciences Centre, Polytechnic of Leiria, Portugal (MARE) and research member at computer science, communication research centre, polytechnic of Leiria, Portugal (CIIC). He can be contacted at email: a.silva@zipor.com.

Antonio J. Marques Cardoso received the Dipl. Eng., Dr. Eng., and Habilitation degrees from the University of Coimbra, Coimbra, Portugal, in 1985, 1995, and 2008, respectively, all in Electrical Engineering. From 1985 until 2011 he was with the University of Coimbra, Coimbra, Portugal, where he was Director of the Electrical Machines Laboratory. Since 2011 he has been with the University of Beira Interior (UBI), Covilhã, Portugal, where he is Full Professor at the Department of Electromechanical Engineering and Director of CISE- Electromechatronic Systems Research Centre (http://cise.ubi.pt). He was Vice-Rector of UBI (2013-2014). His current research interests are in fault diagnosis and fault tolerance in electrical machines, power electronics and drives. He is the author of a book entitled Fault Diagnosis in Three-Phase Induction Motors (Coimbra, Portugal: Coimbra Editora, 1991), (in Portuguese), editor of a book entitled Diagnosis and Fault Tolerance of Electrical Machines, Power Electronics and Drives (IET/SciTech, UK, 2018), and also author of more than 600 papers published in technical journals and conference prceedings. He currently serves as Editor-in-Chief of the MDPI journal Machines, Editor of the IEEE Transactions on Energy Conversion and IEEE Power Engineering Letters, and Associate Editor of the IEEE Transactions on Industry Applications, IEEE Transactions on Power Electronics, IEEE Journal of Emerging and Selected Topics in Power Electronics, IEEE Open Journal of the Industrial Electronics Society, IET The Journal of Engineering, as well of the Springer journal Electrical Engineering and the International Journal of Systems Assurance Engineering and Management. He can be contacted at email: ajmar@ieee.org.

Journal of Infrastructure, Policy and Development 2024, 8(9), 7072.
https://doi.org/10.24294/jipd.v8i9.7072

Article

Rethinking service blueprint for digital coopetition: A new framework for networked collaboration

Agostinho da Silva[1,2,*], Antonio J. Marques Cardoso[1]

[1] CISE—Electromechatronic Systems Research Centre, University of Beira Interior, 6201-001 Covilhã, Portugal
[2] CIGEST—Centre for Research in Management, Lisbon Business School, 1649-023 Lisboa, Portugal
*** Corresponding author:** Agostinho da Silva, a.silva@zipor.com

CITATION

da Silva A, Cardoso AJM. (2024). Rethinking service blueprint for digital coopetition: A new framework for networked collaboration. Journal of Infrastructure, Policy and Development. 8(9): 7072. https://doi.org/10.24294/jipd.v8i9.7072

ARTICLE INFO

Received: 6 June 2024
Accepted: 4 July 2024
Available online: 3 September 2024

COPYRIGHT

Copyright © 2024 by author(s). *Journal of Infrastructure, Policy and Development* is published by EnPress Publisher, LLC. This work is licensed under the Creative Commons Attribution (CC BY) license. https://creativecommons.org/licenses/by/4.0/

Abstract: This study adapts traditional service blueprint methodologies for technology-driven coopetition networks, where companies simultaneously collaborate and compete. Integrating insights from service science, we developed an enhanced service blueprint framework with three key components: the cyber frontstage Lane for digital interactions, the physical backstage Lane for physical operations, and the support stage lane for supporting processes. Empirical validation in the Portuguese stone sector demonstrated the framework's effectiveness in identifying network dysfunctions and its ease of use for industry professionals. Feedback highlights its relevance in capturing the complexities of modern digital coopetition and managing interactions and resources. This research underscores the necessity of updating service blueprint methods to optimize service delivery and value co-creation in digitally evolving sectors.

Keywords: service blueprint; coopetition networks; digital transformation; service science; value co-creation

1. Introduction

In today's global economy, a company's ability to swiftly scale its operations is paramount to securing a competitive advantage and ensuring sustainability. Scale capacity, defined as the capability to expand production and service offerings efficiently, is a critical strategic consideration (Geissbauer et al., 2018). It is because scaling enables businesses to meet international customers' diverse and growing demands, facilitating market entry and enhancing global presence and profitability (Medberg and Grönroos, 2020). Additionally, scaling allows companies to achieve economies of scale, spreading fixed costs over a larger output, thereby reducing the average cost per unit. This cost efficiency improves profit margins and positions companies competitively in international markets through aggressive pricing strategies (Silva et al., 2020).

Small and medium-sized enterprises (SMEs), particularly in the industrial sector, play a vital role in developed economies by driving innovation, providing employment, and stimulating economic growth (Di Bella et al., 2023). However, their limited scale can hinder their ability to leverage scaling benefits (Razy et al., 2019). The strategic integration of SMEs into coopetition networks, which combine cooperation and competition (Rouyre et al., 2024), has been identified as a solution (European Commission and Directorate General for Communication, 2020). These networks enhance SMEs' scale and competitive edge, especially within the intricate global digital supply chains (Bouncken et al., 2024).

However, the success of coopetition networks often hinges on the involvement of a leading company that acts as a central anchor, ensuring the network's effectiveness (Tsujimoto et al., 2018; Xie et al., 2023). Insights from the Reeves et al. (2019) suggest that major corporations, such as Microsoft and Amazon, play pivotal roles within these networks and achieve significant financial benefits, with profit margins averaging over 29% (Reeves et al., 2019). In contrast, smaller firms may become overly dependent on these dominant players, exacerbating their collaboration challenges (Corbo et al., 2023; Razavi et al., 2010). Furthermore, in the absence of a leading company, coopetition networks rarely survive their initial years, underscoring the critical need for a central, guiding entity to sustain the collective effort and ensure long-term viability (Reeves et al., 2019).

This challenge is likely due to SMEs' inherently competitive nature and lack of a collaborative mindset, which presents significant obstacles to digital transformation and scaling objectives. A report from the Economist Intelligence Unit (2021) further highlights this issue, identifying a pronounced lack of cooperation among European SMEs, thus impeding their digital progress.

In the digital age, businesses are increasingly embedded in complex, digitally interconnected environments, emphasizing the need for methodologies that capture and optimize intricate service processes. The service blueprint, a strategic tool developed to visually depict service processes (Ryu et al., 2020), has significantly evolved, offering critical insights into service delivery's tangible and intangible aspects. Its evolution has broadened its utility across diverse operational landscapes, indicating a profound grasp of service dynamics (Pöppel et al., 2018). However, the advent of coopetition networks, propelled by advancements in the Internet of Things (IoT) (Bacon et al., 2020), among other technologies, introduces novel challenges that contemporary service blueprint methodologies are ill-equipped to handle.

Despite its adaptability, the application of the service blueprint in technology-driven coopetition networks still needs to be explored, uncovering a notable gap in current business and management scholarship. The complex nature of these networks, characterized by simultaneous collaboration and competition among firms (Corbo et al., 2023), necessitates a framework adept at managing the intricate web of interconnections and multiple stakeholder engagements typical of such ecosystems. Present approaches fall short in several key areas: they do not accurately depict direct digital interactions between producers and consumers, they struggle to optimize the interests of varied stakeholders—especially in contexts of ephemeral collaboration among rivals—and they lack clarity in illustrating the participation of resources from competing entities at every step of service delivery. These deficiencies hinder the identification of critical process failures, which are central to understanding the reasons behind the premature demise of coopetition networks (Estrada and Dong, 2020). This leads to an urgent question: Which service blueprinting framework is suitable for efficiently mapping and enhancing service processes within technology-enabled coopetition networks?

Confronting the intricacies of digital coopetition networks requires a novel approach, and service science (Demirkan and Spohrer, 2015), rooted in Service-Dominant (S-D) Logic, emerges as a promising solution (Vargo et al., 2024). This transdisciplinary field, focusing on service systems as its primary object of study,

champions the cocreation of value across service ecosystems (Hartmann et al., 2018). It advocates for a multidisciplinary method to integrate cutting-edge technologies into service systems seamlessly. Such an approach is central for enhancing scale and competitiveness and facilitating the transition toward more digitally-focused and globalized service and manufacturing networks (Maglio and Spohrer, 2013; Silva et al., 2020).

This research aims to leverage the principles of service science to fill the gaps currently observed in the service blueprint method, proposing an innovative service blueprint framework tailored for coopetition networks. This proposed framework is designed with the digital complexities of contemporary coopetition networks in mind, providing a sophisticated tool for precisely mapping service processes within these complex environments. A key feature of this framework is its focus on the detailed documentation of value cocreation interactions and the explicit representation of resource sharing among service systems (actors), particularly in the face of service disruptions. By enhancing the visualization of resource engagement and facilitating the identification of potential failure points, this service blueprint framework seeks to refine service innovation practices. It aims to adapt these practices to meet the distinctive needs of technology-enabled coopetition networks, thereby cultivating a more robust, collaborative network.

This discourse lays the groundwork for addressing the gaps in the literature related to service blueprinting within technology-enabled coopetition networks. By weaving together, the foundations of S-D Logic and the multidisciplinary perspectives of service science, the following section proposes concrete solutions for each identified gap, culminating in a novel service blueprint framework. This framework aims to navigate modern coopetition networks' digital complexities and multi-actor engagements, advancing service innovation and management.

2. Literature review

The exploration of service's role in economic exchanges has been profoundly rich, evolving significantly over centuries. Frederick Bastiat's concept of "services exchanging for services" in 1848 laid the foundational stone for the modern understanding of the service economy. This intellectual journey was advanced by Stephen L. Vargo and Robert F. Lusch in 2004 with the introduction of S-D Logic (Vargo and Lusch, 2004). They proposed a paradigm shift in marketing and economic thought, emphasizing that the essence of economic exchange lies in providing and reciprocating intangible services rather than the transaction of tangible goods (Michel et al., 2008). This perspective challenges traditional goods-centric paradigms, positioning products merely as vessels for service delivery and underscoring the importance of derived benefits and utilities (Vargo and Akaka, 2012).

S-D Logic offers a nuanced understanding of economic exchanges, stressing the co-creation of value through dynamic interactions among a network of actors. It distinguishes between operant resources—such as knowledge and skills—and operand resources, like technologies and physical goods, as crucial to facilitating service exchanges (Siltaloppi and Vargo, 2017). This framework posits that value is

collaboratively crafted, leveraging the resources available to actors within these exchanges (Vargo and Lusch, 2017).

S-D Logic provides essential insights into coopetition networks—where competition and collaboration co-occur among actors (Bicen et al., 2021). These networks represent a complex layer of interactions vital for service ecosystems' dynamism (Gnyawali and Ryan Charleton, 2018). Coopetition networks are seen as intricate relationships enriched by digital technologies and governed by institutional mechanisms that foster mutual value creation despite competitive tensions (Barile et al., 2016; Lusch and Nambisan, 2015).

Service science, inspired by S-D Logic, emphasizes innovation and value co-creation within service systems (Breidbach and Maglio, 2016). It calls for a multidisciplinary approach, integrating technology to enhance competitiveness across service and manufacturing sectors (Spohrer and Pakkala, 2019). This field recognizes the central role of technology in improving service exchange and resource integration towards operational efficiency, especially within complex ecosystems such as digital coopetition networks (Maglio et al., 2009; Silva et al., 2020).

3. Methodology

Adopting a service science perspective requires the service blueprint to evolve, capturing real-time value co-creation processes within service systems' resources (Akaka et al., 2023). This service science view is adopted to develop an advanced able to map the sequence of actions and the flow of information, resources, and interactions facilitated by digital technologies under coopetition practices. It must identify critical moments of expectation or trust breakdowns, providing insights into how digital elements influence value co-creation, thereby capturing the fluid nature of rival interactions (Bicen et al., 2021).

Initially introduced by Shostack (1982) and further developed by Kingman-Brundage (1989), the service blueprint has been a fundamental tool for visualizing and innovating service processes (Shostack, 1982). It effectively separates customer and provider domains, using conceptual lines and stages to detail the sequence of service actions (Kingman-Brundage, 1989). This method captures both tangible and intangible aspects of service delivery. It facilitates a deep understanding of the interactions between service providers and recipients, crucial for identifying and improving key elements of service delivery (Pöppel et al., 2018).

In today's digital coopetition networks, advanced technologies such as the Internet of Things (IoT), among others, play essential roles in enhancing connectivity and interactions among network participants (Chandler et al., 2019). These technologies enable a more seamless integration of competing value propositions to customers, breaking down geographical limitations and promoting a vibrant ecosystem for value co-creation (Bagheri et al., 2019). Introducing these technologies in coopetition networks necessitates an evolution of the service blueprint to reflect the digital and multi-actor dynamics characteristic of contemporary coopetition networks more accurately. Adopting a service science perspective requires the service blueprint to evolve, capturing real-time value co-

creation processes within service systems' resources. This advanced blueprint should map the sequence of actions and the flow of information, resources, and interactions facilitated by digital technologies under coopetition practices. It must identify critical moments of expectation or trust breakdowns, providing insights into how digital elements influence value co-creation, thereby capturing the fluid nature of rival interactions (Bicen et al., 2021).

To meet these challenges effectively, the coopetition service blueprint must be intricately layered, showcasing digital connections and interactions across the entire network at every stage. It should explicitly map out direct connections between factories shop floors and customers, ensure the alignment of interests among various stakeholders, and vividly delineate the sharing of resources throughout each phase of service delivery. This refined blueprint will leverage digital tools to offer a dynamic, real-time perspective of the service ecosystem. This approach illuminates areas of potential discord or misalignment and establishes a robust framework for ongoing enhancement and innovation. Such a comprehensive tool is essential for identifying critical intervention points that can significantly improve value cocreation, ultimately leading to a more harmonious, efficient, and innovative coopetition network. Reimagining the service blueprint through the lens of S-D Logic, service science, and digital technology operant capabilities offers a framework for understanding and navigating the complexities of modern service delivery within technology-enabled coopetition networks. This methodological evolution promises to enrich our comprehension of service processes and foster more resilient, adaptive, and collaborative service ecosystems.

4. Evolving the service blueprint: Addressing the complexities of digital coopetition networks

The service blueprint, as conceptualized by Kingman-Brundage, has historically been an important tool in delineating customer and supplier activities through the customer interaction line. This line has been instrumental in visualizing direct interactions between customers and suppliers, covering a spectrum of communication methods from in-person engagements to digital correspondences such as emails and telephone conversations (Ryu et al., 2020). Its primary function has been to provide a clear and structured visualization of these interactions, thereby enhancing the understanding of service processes and facilitating the identification of potential areas for improvement. The advent of digital technologies and the rise of technology-driven coopetition networks have significantly expanded the scope and nature of these interactions (Bouncken et al., 2024). The traditional service blueprint, well-suited to static, linear interactions, now faces challenges in capturing the dynamic and multifaceted exchanges that characterize modern digital ecosystems (Matthies et al., 2016).

4.1. Inter-connectivity visualization

In digital coopetition networks, interactions are no longer confined to straightforward customer-supplier exchanges (Xie et al., 2023). Instead, they involve a complex web of engagements among multiple stakeholders, including competitors,

who cooperate to create and deliver value. These networks leverage advanced digital platforms, Internet of Things (IoT) technologies, and real-time data exchanges, further complicating the service delivery landscape (Akaka et al., 2023), as illustrated in **Figure 1**.

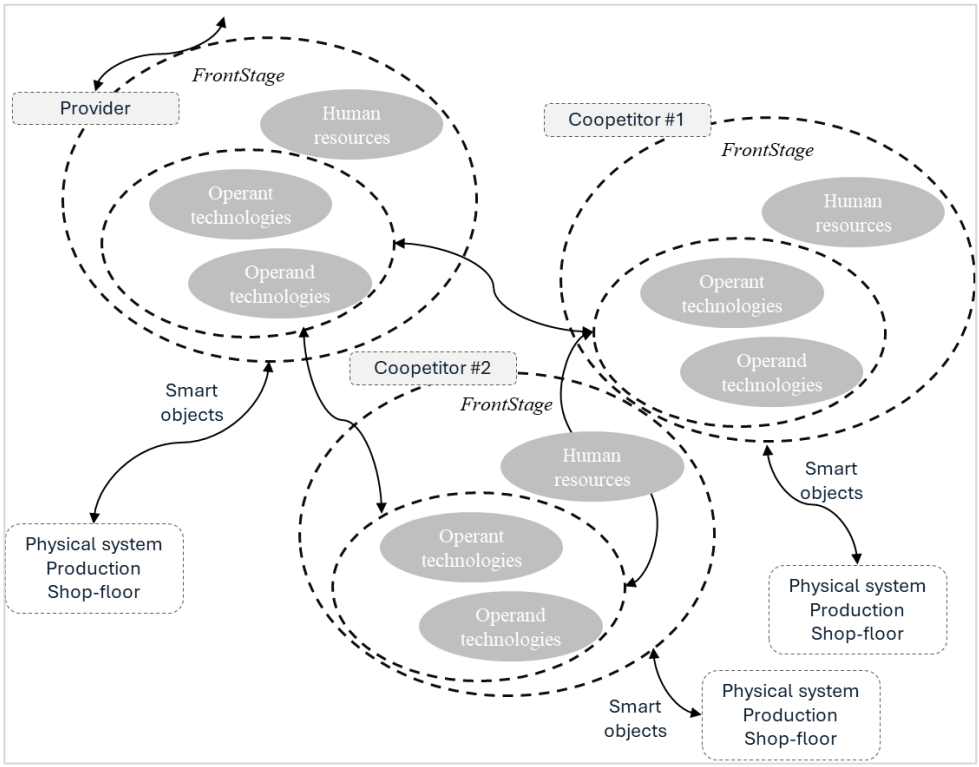


Figure 1. Digital coopetition networks.

Therefore, the evolution of service blueprints must account for these new realities. The traditional Customer Interaction Line needs to be re-envisioned to include digital touchpoints and critical cyber interactions in today's service environments (Mosch et al., 2023). This re-envisioning involves recognizing that service interactions now span physical and virtual realms, requiring a more sophisticated framework to capture both the tangible and intangible elements of service processes. Moreover, the role of technology in these interactions has shifted. While technology was once primarily an operand resource—tools used by human operant to deliver services—it is increasingly becoming an operant resource in its own right (Kleinaltenkamp et al., 2023). Advanced technologies such as artificial intelligence and machine learning systems can now perform tasks autonomously, interacting directly with customers and other stakeholders without human intervention (Silva et al., 2024). This shift necessitates a service blueprint that accurately represents these autonomous interactions and their implications for service delivery and value co-creation (Vargo et al., 2024). In this regard, while the foundational principles of the service blueprint articulated by Kingman-Brundage remain relevant, there is a critical need for its evolution. To effectively serve the modern service ecosystem, the service blueprint must incorporate the complexities introduced by digital technologies and coopetition networks. It must provide a comprehensive framework that maps direct interactions and captures the broader,

more intricate web of relationships and value exchanges that define contemporary service environments.

The proposed line of cyber interaction emerges as a novel construct designed to encapsulate the digital interconnectivity that defines modern customer-supplier relationships. This re-envisioned line aims to capture the essence of digital exchanges and the seamless and often instantaneous nature of these interactions, facilitated by the proliferation of advanced digital technologies. The visual representation of the line of cyber interaction as a dashed line serves a dual purpose. Stylistically, it signifies digital interactions' fluid and permeable nature, setting them apart from the more rigid and linear modes of communication prevalent in the past. This depiction underscores the dynamic, ever-evolving landscape of digital coopetition, where interactions are not bounded by physical proximity or conventional communication channels. Instead, they are characterized by a continuous flow of information, resources, and value propositions that traverse the digital sphere. Integrating the line of cyber interaction into the service blueprint enhances this method to more accurately reflect the complex and immediate connections between cyber customers and factories' digital shopfloors. This adaptation lays a robust foundation for comprehensively understanding and mapping the value propositions and interaction dynamics within digital coopetition networks. Emphasizing interconnectivity in this manner is crucial for ensuring that the service blueprint continues to serve as a relevant and effective tool for navigating the intricacies and opportunities of digital coopetition networks, fostering a deeper comprehension of how value is co-created in these innovative service ecosystems.

4.2. Actors in technology-enabled coopetition networks

At the heart of service science and S-D Logic lies the recognition that all participants in economic exchange, including customers, providers, and rivals, are service providers actively engaged in value creation. This insight is crucial for developing a service blueprint that maps out the interactions and exchanges within coopetition networks and highlights each actor's diverse contributions to the network's value creation dynamics (Vargo et al., 2023).

Under the S-D Logic view, customers are envisioned as the linchpins of value co-creation. Digital technology has transformed how customers' needs are met, ushering individuals and organizations into global digital marketplaces powered by advanced technologies such as smartphones, computers, and tablets (Jaakkola et al., 2024). This shift requires a service blueprint that can adeptly illustrate the digital customer's journey, showcasing their technological interactions with providers and underscoring the critical role of digital interfaces in facilitating global procurement processes. The blueprint must, therefore, evolve to vividly capture these digital touchpoints, ensuring a comprehensive visualization of the customer's engagement in the value co-creation process.

Central to the ethos of S-D Logic, providers are depicted not merely as suppliers but as participants in value cocreation. They deliver value propositions that span a broad spectrum of activities and experiences, fostering a collaborative process wherein value is co-created rather than unilaterally delivered. This perspective

emphasizes that customers do not passively receive value; instead, they actively integrate the provider's offerings into their life narratives, weaving these services into the fabric of their daily routines and experiences. Thus, a practical service blueprint must capture this dynamic, showcasing how providers play an integral role in this intricate dance of co-creation. It should illuminate the myriad ways providers' services become interlaced with the customer's everyday life, thereby facilitating a deeper understanding of the symbiotic relationship between providers and customers in the co-creative process.

Coopetitors, entities that uniquely meld competitive drive with a collaborative spirit, significantly enrich the network's resource pool. The service blueprint must delineate this dual role, showing how coopetitors utilize operant (skills, knowledge) and operand (physical goods, technologies) resources to nurture collaboration while managing the competitive tensions inherent to the network. This detailed representation is crucial for a holistic understanding of coopetitors' contributions, spotlighting their distinctive capability to simultaneously compete and collaborate, thus propelling collective innovation and success within the network. Within coopetition networks, the dynamic nature of competitor relationships—marked by the freedom to engage or disengage—underscores the fluidity that drives innovation. The blueprint should portray competitors as autonomous yet interconnected entities within the ecosystem, emphasizing how competitive pressures catalyze continual innovation and improvement. This portrayal reinforces the significance of maintaining an adaptable and responsive blueprint capable of capturing the dynamic interplays that foster a conducive environment for innovation and growth.

4.3. Mapping stages and lanes

For service science, the dynamic interplay between service systems involved in value cocreation underscores the imperative for continuous innovation in value propositions (Kleinaltenkamp et al., 2023). The challenge lies in systematically identifying and integrating the resources central to these propositions' inception (Breznik and Lahovnik, 2014). The goal of improving a value proposition transcends the benefit to the customer or provider alone, aiming instead to enrich the entire ecosystem, with competition catalyzing innovation (Hüttinger et al., 2012). Service systems can refine their contributions based on historical insights and future projections, embodying a principle of perpetual enhancement to meet the evolving demands of the market (Silva and Gil, 2020).

To effectively support coopetition networks, a tailored service blueprint framework must delineate the interaction stages and resource lanes, encapsulating the multifaceted nature of value co-creation. This advanced blueprint is designed to feature several critical components, each serving a distinct purpose in the visualization and management of these complex networks (**Figure 2**).

Figure 2. Service blueprint framework for coopetition networks.

The cyber frontstage lane is designed to visualize frontstage interactions that blend human and technological resources, spotlighting the technology-mediated exchanges between cyber customers and providers. It emphasizes integrating physical and virtual evidence, capturing the essence of digital interactions in the value co-creation process by mapping these digital touchpoints. The cyber frontstage lane highlights how technological interfaces facilitate seamless communication and interaction, ultimately enhancing the service experience.

The physical backstage lane includes the behind-the-scenes resources and activities essential to the co-creation process. It unravels the support structures that underpin value delivery, highlighting the roles of providers and coopetitors. By providing insights into the operational and strategic foundations that enable seamless value delivery, the physical. Backstage lane showcases the essential background operations that support the visible frontstage activities. This comprehensive view ensures that all aspects of service provision, from production to logistics, are effectively managed and integrated. The support stage lane captures the expansive network of partnerships, management resources, and coopetition support frameworks. It underscores the external collaborations and resources that bolster the network, facilitating a robust infrastructure for coopetition. By detailing the contributions of various external stakeholders, the support stage lane illustrates how external partnerships and resource integrations contribute to the network's overall stability and effectiveness. This lane is crucial for understanding how external factors and collaborations influence coopetition networks' internal dynamics and success.

Together, these components form a holistic framework that maps out the

intricate interactions and resource allocations within technology-enabled coopetition networks and provides a robust tool for enhancing value co-creation. This comprehensive approach ensures that all facets of the network are accounted for, facilitating a deeper understanding of the complex, multi-actor engagements that drive innovation and success in the digital age.

The number of steps where physical & virtual evidence occur depends on the specific case, represented here as "*N*". Traditionally, technology was an operand resource. In contrast, human resources were the sole source of operant resources. However, in the digital era, some technologies can act independently, becoming operant resources. Therefore, it is necessary to distinguish between skill resources (human) and operant technology resources on the front stage. Within the support stage lane, support resources engage in tasks vital to the service process, with their openness and fluid exchange of information demarcated by dashed lines. This representation fosters a clear understanding of the roles and contributions of all network actors, enhancing governance and strategic decision-making within these collaborative and competitive environments.

At the summit of the comprehensive service blueprint for coopetition, networks lie either cyber or physical evidence or outcomes, which are the fruits of cooperative endeavours between the cyber customer and the digital provider (Kocsi and Oláh, 2017). This section captures the tangible results of collaborative actions, emphasizing the concrete benefits of such partnerships.

By addressing the contemporary demands and intricacies of digital coopetition networks, this enhanced service blueprint offers a strategic framework for organizations to navigate the complexities of digital coopetition. Its comprehensive approach facilitates more profound insights into co-creative interactions and empowers businesses to bolster their collaborative efforts while maintaining competitive edges. Through its application, organizations can ensure the sustainability and success of their coopetition strategies in the digital era, driving innovation and value creation in an increasingly interconnected marketplace.

5. Empirical validation of the service blueprint framework for digital coopetition networks

To empirically validate the proposed service blueprint, a hundred and thirty interviews were conducted with managers from diverse Portuguese stone manufacturing companies, a sector crucial to the Portuguese economy (Silva et al., 2024). These companies, primarily SMEs, collectively provide over 16,600 direct jobs, significantly contributing to employment in inland regions. Despite ongoing challenges, this sector has seen sustained export growth, positioning Portugal as a leading player in the international ornamental stone market (Silva and Marques, 2023).

These interviews aimed to assess the utility of the new service blueprint framework for technology-enabled collaboration networks within the stone manufacturing industry. The study explored each company's adoption of digital technologies, ranging from digital production machines to collaborative marketplace technologies, to gauge respondents' digital maturity on a scale from DL#0 (no digital

integration) to DL#4 (fully digital operations).

A streamlined questionnaire was distributed to participants: (1) Questionnaire introduction: Emphasizing the construction sector's forthcoming transition towards Building Information Modeling (BIM) technology and its repercussions for materials procurement. The discussion centred on stone companies' need to augment their scale, price flexibility, and delivery timeliness through collaborative efforts with competitors to sustain market competitiveness. (2) Presentation of the new service blueprint framework: Respondents assessed the framework's ease of use and effectiveness in identifying potential dysfunctions in inter-company relationships within a network. They assigned a rating on a scale from 1 to 5.

The sample selection process targeted managers from Portuguese stone manufacturing SMEs. Selection criteria included companies' active involvement in the industry and varying levels of digital integration. Participants were selected to represent a diverse range of digital maturities, from no digital integration (DL#0), one computerized machine (DL#1), three computerized machines in operation for two years back (DL#2), production machines integrated with ERP (DL#3) and fully digital operations (DL#4). All respondents held managerial positions with significant experience in the stone manufacturing industry, averaging 15 years of professional experience. Most had at least a bachelor's degree, with some holding advanced degrees in engineering, business management, or related fields.

Several steps were undertaken to ensure the questionnaire's reliability and validity: The questionnaire was pilot tested with a small group of industry experts to refine the questions and ensure clarity. Reliability was measured using Cronbach's Alpha, which yielded a value of 0.83, indicating high internal consistency. Expert reviews ensured content validity, whereas industry professionals evaluated the questionnaire for relevance and comprehensiveness. Construct validity was assessed by correlating the questionnaire items with established measures of digital maturity and collaborative effectiveness.

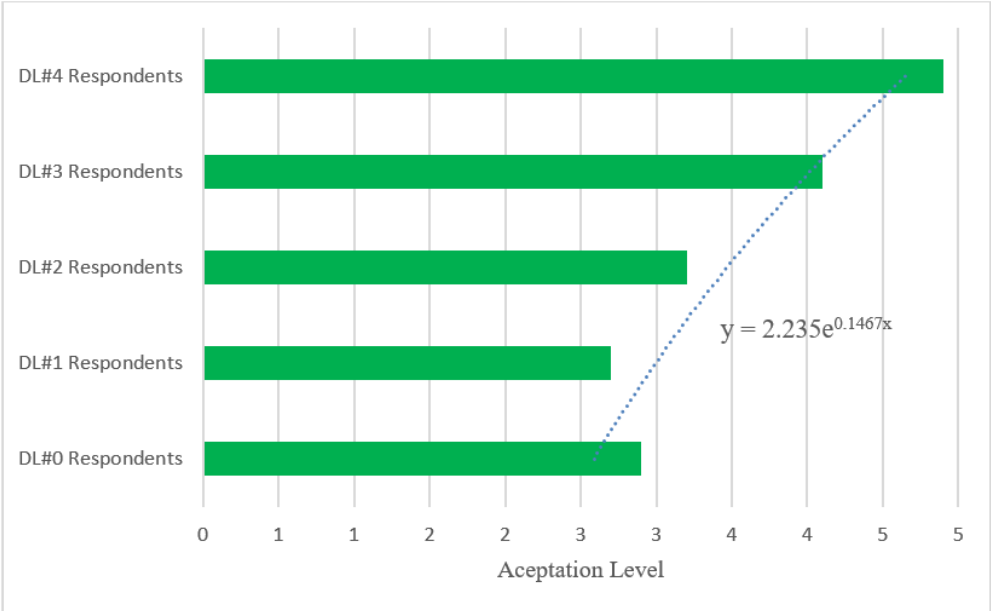


Figure 3. Service blueprint's evaluation for coopetition networks.

The face-to-face interviews, conducted from 1 October to 1 November 2023, revealed the framework's growing relevance as firms enhance their digital capabilities. The findings are illustrated in **Figure 3**.

Dependent variable (y): Rating the frameworks' effectiveness (scale 1–5). Independent variable (x): Levels of framework implementation. Intercept (2.235): Initial effectiveness rating. Growth rate (0.1467): Indicates a 14.67% increase in effectiveness with each unit increase in x.

The regression model relates to the effectiveness of the new service blueprint framework in coopetition networks within the construction sector, particularly concerning BIM adoption. The exponential increase suggests a significant improvement in effectiveness as the framework is more thoroughly implemented. With an average rating of 3.6/5 from managers, the feedback validates the new service blueprint framework's effectiveness in identifying and addressing dysfunctions in the relations among networked companies, demonstrating its applicability and value in facilitating cooperative dynamics in digitally evolving sectors.

By addressing the contemporary demands and intricacies of digital coopetition networks, this enhanced service blueprint offers a strategic framework for organizations to navigate the complexities of digital coopetition. Its comprehensive approach facilitates more profound insights into co-creative interactions and empowers businesses to bolster their collaborative efforts while maintaining competitive edges. Through its application, organizations can ensure the sustainability and success of their coopetition strategies in the digital era, driving innovation and value creation in an increasingly interconnected marketplace.

6. Conclusions and future directions

Despite the acknowledged versatility of the service blueprint method, its application to technology-enabled coopetition networks has been surprisingly limited, marking a gap in the existing business and management literature. The unique dynamics of these networks, characterized by the simultaneous collaboration and competition among actors, necessitate a more sophisticated framework capable of capturing the nuanced interconnectivity and the multifaceted engagements that define these digital ecosystems.

This study presents an innovative service blueprint framework tailored for digital coopetition networks, specifically within the context of the Portuguese ornamental stone SMEs. By integrating service science and S-D Logic principles, this framework addresses the unique challenges posed by digitally interconnected and collaborative environments. The empirical validation conducted through structured interviews with industry managers indicates that the proposed framework effectively enhances the visualization of value co-creation processes, identifies potential dysfunctions in inter-company relationships, and supports the integration of digital technologies.

The critical distinctions between the proposed service blueprint framework and traditional models lie in its ability to capture digital coopetition networks' complex and dynamic interactions. Traditional service blueprints primarily focus on linear,

often static interactions between customers and service providers. In contrast, the proposed framework incorporates the multifaceted roles of coopetitors, the fluid nature of digital interactions, and the seamless integration of human and operant technological resources. This holistic approach ensures a more accurate and comprehensive representation of value co-creation in modern digital ecosystems, highlighting its relevance and applicability in digitally evolving sectors.

Despite its contributions, this study has several limitations that should be acknowledged. The empirical validation was conducted with a relatively small sample size of thirty managers from Portuguese stone manufacturing SMEs. While this provides valuable insights, a more extensive and diverse sample could offer a more comprehensive validation. The study is focused on the Portuguese ornamental stone sector, which may limit the generalizability of the findings to other industries and regions. Future research should explore the applicability of the proposed framework across different sectors and geographical contexts. The assessment of digital maturity levels was based on a self-reported scale, which might introduce biases.

Building on the findings and limitations of this study, several avenues for future research are recommended. Future studies should involve a more extensive and diverse sample of companies across various industries and regions. This would enhance the robustness and generalizability of the findings. Conducting longitudinal studies to track the long-term impacts of the service blueprint framework on coopetition networks would provide deeper insights into its sustainability and effectiveness over time. Integrating objective measures and metrics to assess digital maturity levels could offer a more accurate and unbiased evaluation of the framework's applicability and success. Further comparative analysis between the proposed framework and traditional service blueprint models across different contexts would help clearly delineate the new framework's innovations and advantages. By addressing these future directions, research can continue to refine and expand the proposed service blueprint framework, ensuring its relevance and effectiveness in the rapidly evolving landscape of digital coopetition networks.

Author contributions: Conceptualization, AdS and AJMC; methodology, AdS; software, AdS; validation, AdS and AJMC; formal analysis, AdS; investigation, AdS; resources, AdS; data curation, AdS; writing—original draft preparation, AdS; writing—review and editing, AdS; visualization, AdS; supervision, AdS; project administration, AdS; funding acquisition, AJMC. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare no conflict of interest.

References

Akaka, M., Schau, H., & Vargo, S. (2023). How Practice Diffusion Drives IoT Technology Adoption and Institutionalization of Solutions in Service Ecosystems. In: Proceedings of the Annual Hawaii International Conference on System Sciences. ScholarSpace. pp. 1427–1435. https://doi.org/10.24251/HICSS.2023.178

Bacon, E., Williams, M. D., & Davies, G. (2020). Coopetition in innovation ecosystems: A comparative analysis of knowledge transfer configurations. Journal of Business Research, 115, 307–316. https://doi.org/10.1016/j.jbusres.2019.11.005

Bagheri, S., Kusters, R. J., & Trienekens, J. J. M. (2019). Customer knowledge transfer challenges in a co-creation value network:

Toward a reference model. International Journal of Information Management, 47, 198–214. https://doi.org/10.1016/j.ijinfomgt.2018.12.019

Barile, S., Lusch, R., Reynoso, J., et al. (2016). Systems, Networks, and Ecosystems in Service Research. Journal of Service Management, 34(1), 1–5. https://doi.org/10.1108/JOSM-09-2015-0268

Bicen, P., Hunt, S., & Madhavaram, S. (2021). Coopetitive innovation alliance performance: Alliance competence, alliance's market orientation, and relational governance. Journal of Business Research, 123, 23–31. https://doi.org/10.1016/j.jbusres.2020.09.040

Bouncken, R., Kumar, A., Connell, J., et al. (2024). Coopetition for corporate responsibility and sustainability: does it influence firm performance? International Journal of Entrepreneurial Behavior & Research, 30(1), 128–154. https://doi.org/10.1108/IJEBR-05-2023-0556

Breidbach, C., & Maglio, P. (2016). Technology-enabled value co-creation: An empirical analysis of actors, resources, and practices. Industrial Marketing Management, 56, 73–85. https://doi.org/10.1016/j.indmarman.2016.03.011

Breznik, L., & Lahovnik, M. (2014). Renewing the resource base in line with the dynamic capabilities view: a key to sustained competitive advantage in the IT industry. Journal of East European Management Studies, 19(4), 453–485. https://doi.org/10.1688/JEEMS-2014-04

Chandler, J. D., Danatzis, I., Wernicke, C., et al. (2019). How Does Innovation Emerge in a Service Ecosystem? Journal of Service Research, 22(1), 75–89. https://doi.org/10.1177/1094670518797479

Corbo, L., Kraus, S., Vlačić, B., et al. (2023). Coopetition and innovation: A review and research agenda. Technovation, 122, 102624. https://doi.org/10.1016/j.technovation.2022.102624

Da Silva, A., & Cardoso, A. J. M. (2024). Coopetition with the Industrial IoT: A Service-Dominant Logic Approach. Applied System Innovation, 7(3), 47. https://doi.org/10.3390/asi7030047

Demirkan, H., & Spohrer, J. (2015). T-Shaped Innovators: Identifying the Right Talent to Support Service Innovation. Research-Technology Management, 1(6), 12–15. https://doi.org/10.5437/08956308X5805007

Di Bella, L., Katsinis, A., Lagüera-González, J., et al. (2023). Annual Report on European SMEs 2022/2023. Office of the European Union, Luxembourg.

Estrada, I., & Dong, J. (2020). Learning from experience? Technological investments and the impact of coopetition experience on firm profitability. Long Range Planning, 53(1), 101866. https://doi.org/10.1016/j.lrp.2019.01.003

European Commission, & Directorate General for Communication. (2020). A European industrial strategy: unleashing the full potential of European SMEs. Publications Office. https://doi.org/10.2775/296379

Geissbauer, R., Lübben, E., Schrauf, S., et al. (2018). Global Digital Operations Study 2018—Digital Champions. Available online: http://www.pwc.com/m1/en/about-us.html (accessed on 2 May 2014).

Gnyawali, D. R., & Ryan Charleton, T. (2018). Nuances in the Interplay of Competition and Cooperation: Towards a Theory of Coopetition. Journal of Management, 44(7), 2511–2534. https://doi.org/10.1177/0149206318788945

Hartmann, N. N., Wieland, H., & Vargo, S. L. (2018). Converging on a New Theoretical Foundation for Selling. Journal of Marketing, 82(2), 1–18. https://doi.org/10.1509/jm.16.0268

Hüttinger, L., Schiele, H., & Veldman, J. (2012). The drivers of customer attractiveness , supplier satisfaction and preferred customer status: A literature review. Industrial Marketing Management, 41(8), 1194–1205. https://doi.org/10.1016/j.indmarman.2012.10.004

Jaakkola, E., Kaartemo, V., Siltaloppi, J., et al. (2024). Advancing service-dominant logic with systems thinking. Journal of Business Research, 177, 114592. https://doi.org/10.1016/j.jbusres.2024.114592

Kingman-Brundage, J. (1989). The ABC's of service system Blueprinting: Designing a winning service strategy. In: Proceedings of the 7th Annual Services Marketing Conference; Chicago.

Kleinaltenkamp, M., Kleinaltenkamp, M. J., & Karpen, I. O. (2023). Resource entanglement and indeterminacy: Advancing the service-dominant logic through the philosophy of Karen Barad. Marketing Theory. https://doi.org/10.1177/14705931231207327

Lusch, R., & Nambisan, S. (2015). Service Innovation: A Service-Dominant Logic Perspective. MIS Quarterly, 39(1), 155–175. https://doi.org/10.25300/MISQ/2015/39.1.07

Maglio, P. P., & Spohrer, J. (2013). A service science perspective on business model innovation. Industrial Marketing Management, 42(5), 665–670. https://doi.org/10.1016/j.indmarman.2013.05.007

Maglio, P. P., Vargo, S. L., Caswell, N., et al. (2009). The service system is the basic abstraction of service science. Information

Systems and E-Business Management, 7(4), 395–406. https://doi.org/10.1007/s10257-008-0105-1

Matthies, B. D., D'Amato, D., Berghäll, S., et al. (2016). An ecosystem service-dominant logic?—Integrating the ecosystem service approach and the service-dominant logic. Journal of Cleaner Production, 124, 51–64. https://doi.org/10.1016/j.jclepro.2016.02.109

Medberg, G., & Grönroos, C. (2020). Value-in-use and service quality: do customers see a difference? Journal of Service Theory and Practice, 30(4/5), 507–529. https://doi.org/10.1108/JSTP-09-2019-0207

Michel, S., Vargo, S. L., & Lusch, R. F. (2008). Reconfiguration of the conceptual landscape: A tribute to the service logic of Richard Normann. Journal of the Academy of Marketing Science, 36(1), 152–155. https://doi.org/10.1007/s11747-007-0067-8

Mosch, P., Majocco, P., & Obermaier, R. (2023). Contrasting value creation strategies of industrial-IoT-platforms—a multiple case study. International Journal of Production Economics, 263, 108937. https://doi.org/https://doi.org/10.1016/j.ijpe.2023.108937

Pöppel, J., Finsterwalder, J., & Laycock, R. A. (2018). Developing a film-based service experience blueprinting technique. Journal of Business Research, 85, 459–466. https://doi.org/10.1016/j.jbusres.2017.10.024

Razavi, A. R., Krause, P. J., & Strommen-Bakhtiar, A. (2010). From business ecosystems towards digital business ecosystems. In: Proceedings of the 4th IEEE International Conference on Digital Ecosystems and Technologies. pp. 290–295. https://doi.org/10.1109/DEST.2010.5610633

Razy, A., Mirnoori, S., Silva, J., et al. (2019). Sustainable Customer Relationship Management for BIM Procurement in the Ornamental Stones Cluster under Industry 4.0. Available online: https://www.econbiz.de/events/event/26th-international-euroma-conference-2019-operations-adding-value-to-society-european-operations-management-association-euroma/10011997846 (accessed on 2 March 2014).

Reeves, M., Lotan, H., Legrand, J., & Jacobides, M. G. (2019). How Business Ecosystems Rise (and Often Fall). MIT Sloan Management Review.

Rouyre, A., Fernandez, A. S., & Bruyaka, O. (2024). Big problems require large collective actions: Managing multilateral coopetition in strategic innovation networks. Technovation, 132, 102968. https://doi.org/https://doi.org/10.1016/j.technovation.2024.102968

Ryu, D. H., Lim, C., & Kim, K. J. (2020). Development of a service blueprint for the online-to-offline integration in service. Journal of Retailing and Consumer Services, 54, 101944. https://doi.org/10.1016/j.jretconser.2019.101944

Shostack, G. L. (1982). How to Design a Service. European Journal of Marketing, 16(1), 49–63. https://doi.org/10.1108/EUM0000000004799

Siltaloppi, J., & Vargo, S. L. (2017). Triads: A review and analytical framework. Marketing Theory, 17(4), 395–414. https://doi.org/10.1177/1470593117705694

Silva, A., & Gil, M. (2020). Industrial processes optimization in digital marketplace context: A case study in ornamental stone sector. Results in Engineering, 7, 100152. https://doi.org/10.1016/j.rineng.2020.100152

Silva, A., & Marques, C. A. (2023). BIM-based Supply Chain in AEC—Threats on the Portuguese Stone sector. Available online: https://repositorio.lneg.pt/bitstream/10400.9/4150/1/GSC2023_PTNatural Stones-Commercial Names harmonization.pdf (accessed on 19 March 2014).

Silva, A., Dionísio, A., & Coelho, L. (2020). Improving Industry 4.0 through service science. International Journal of Services Sciences, 7(2), 58. https://doi.org/10.1504/IJSSCI.2020.113189

Silva, A., Gil, M. M., & Duarte, E. (2020). Service Innovation—A Service Blueprinting for Industry 4.0. International Journal of Sciences: Basic and Applied Research (IJSBAR), 52(2).

Spohrer, J., & Pakkala, D. (2019). Digital Service: Technological Agency in Service Systems. Available online: https://hdl.handle.net/10125/59628 (accessed on 24 March 2014).

The Economist Intelligence Unit. (2021). Poor collaboration holds back European businesses digital ambitions. Available online: https://appian.com/resources/resource-center/google-success/economist-survey-european-businesses-digital-ambitions-success.html (accessed on 26 March 2014).

Tsujimoto, M., Kajikawa, Y., Tomita, J., et al. (2018). A review of the ecosystem concept—Towards coherent ecosystem design. Technological Forecasting and Social Change, 136, 49–58. https://doi.org/10.1016/j.techfore.2017.06.032

Vargo, S. L., & Lusch, R. (2017). Service-dominant logic 2025. International Journal of Research in Marketing, 34(1), 46–67. https://doi.org/10.1016/j.ijresmar.2016.11.001

Vargo, S. L., & Lusch, R. F. (2004). Evolving to a New Dominant Logic for Marketing. Journal of Marketing, 68(1), 1–17. https://doi.org/10.1509/jmkg.68.1.1.24036

Vargo, S. L., Fehrer, J. A., Wieland, H., et al. (2024). The nature and fundamental elements of digital service innovation. Journal of Service Management, 35(2), 227–252. https://doi.org/10.1108/JOSM-02-2023-0052

Vargo, S. L., Wieland, H., & O'Brien, M. (2023). Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline. Journal of Business Research, 164, 113965. https://doi.org/10.1016/j.jbusres.2023.113965

Vargo, S., & Akaka, M. (2012). Value Cocreation and Service Systems (Re)Formation: A Service Ecosystems View. Service Science, 4(3), 207–217. https://doi.org/10.1287/serv.1120.0019

Xie, Q., Gao, Y., Xia, N., et al. (2023). Coopetition and organizational performance outcomes: A meta-analysis of the main and moderator effects. Journal of Business Research, 154, 113363. https://doi.org/10.1016/j.jbusres.2022.113363

Journal of Open Innovation: Technology, Market, and Complexity 10 (2024) 100363

Contents lists available at ScienceDirect

Journal of Open Innovation: Technology, Market, and Complexity

journal homepage: www.sciencedirect.com/journal/journal-of-open-innovation-technology-market-and-complexity

Enhancing operational scale in SMEs through coopetition: Insights from the Portuguese ornamental stone industry

Agostinho da Silva [a,b,*], Antonio J. Marques Cardoso [a,**]

[a] CISE - Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal
[b] CIGEST - Centre for Research in Management, Lisbon Business School, Lisboa 1000-002, Portugal

ARTICLE INFO

Keywords:
Coopetition
Open innovation
Service-dominant logic
Ornamental stone
Sustainable development goals

ABSTRACT

This study explores whether coopetition enhances scale determinants for SMEs, focusing on a case study in the Portuguese Ornamental Stone sector. The findings show that transitioning to coopetition networks positively impacts scale determinants in this sector. These improvements highlight coopetition's potential to drive operational efficiency, resource optimization, and market responsiveness, aligning with Sustainable Development Goals (SDGs) 8, 9, and 12. However, the study's limitations include a specific focus on Portuguese SMEs and a limited data collection period, indicating the need for broader and longer-term research. Future research should extend to different sectors and regions, incorporate a broader range of KPIs, and consider external factors affecting coopetition outcomes. This would provide a more comprehensive understanding of coopetition's role in fostering sustainable growth and innovation in SMEs. This research contributes to theory by leveraging S-D Logic and open innovation to enhance coopetition, showcasing their practical application in SMEs.

1. Introduction

Small and Medium-sized Enterprises (SMEs) are essential to Europe's economy, driving employment, innovation, and wealth creation. Accounting for over 20 % of the EU27's total value-added and employing upwards of 35 million people, SMEs are indispensable for economic vitality (Di Bella et al., 2023). However, these enterprises face a critical challenge in the global marketplace: efficiently responding to global demands, regardless of order size—a key determinant of competitiveness (Ragazou et al., 2022). The ability to respond to any demand enables businesses to meet the evolving demands of international customers and facilitates entry into new markets, bolstering global presence and profitability (Hernandez et al., 2017). Furthermore, scaling operations can yield economies of scale, spreading fixed costs over a larger output to reduce unit costs and enhance global competitive pricing (Lindström et al., 2016).

Despite the promotion by official entities (European Commission, 2020) and the growing academic interest in coopetition—the strategic collaboration between competitors (Meena et al., 2023)—the prevalent competitive mindset among SME owners often leads to widespread resistance to cooperation (Osobajo et al., 2023). This situation jeopardizes the survival of European SMEs by limiting their participation in coopetition strategies, which are referred to as crucial for enhancing their scaling efforts (Rouyre et al., 2024).

The term "coopetition" was initially coined by Ray Noorda, the founder and CEO of Novell, in the 1980s, gaining theoretical foundation through Nalebuff and Brandenburger (1997) game theory work (Nalebuff and Brandenburger, 1997). They posited coopetition as a groundbreaking business strategy, advocating for its role in fostering innovation and enhancing the success of both individuals and organizations (R. Bouncken et al., 2024). This conceptual framework suggests that competition allows rivals to benefit from a unique relationship characterized by simultaneous cooperation and competition, thereby driving strategic benefit and innovation (Klimas et al., 2023). Since its introduction, the discourse around coopetition has become an essential topic within the literature, emphasizing its relevance and application across various domains (Manzhynski and Biedenbach, 2023).

However, despite the growing academic interest in coopetition, a significant empirical gap persists in quantitatively assessing the improvements in SMEs' competitiveness determinants, particularly those related to the capacity to respond to large-scale demands through coopetition.

* Corresponding author at: CISE - Electromechatronic Systems Research Centre, University of Beira Interior, Covilhã, Portugal
** Corresponding author.
E-mail addresses: a.silva@zipor.com (A. da Silva), ajmcardoso@ieee.org (A.J. Marques Cardoso).

https://doi.org/10.1016/j.joitmc.2024.100363

Available online 17 August 2024
2199-8531/© 2024 The Authors. Published by Elsevier Ltd on behalf of Prof JinHyo Joseph Yun. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

In search of a solution to this problem, insights from literature on open innovation (Loučanová et al., 2022) highlight internal and external determinants for business innovation in SMEs (An and Mikhaylov, 2024). These determinants are critical as they influence SMEs' ability to compete on a global scale (Osobajo et al., 2023). Scaling through coopetition (Ragazou et al., 2022) presents internal and external challenges (Rouyre et al., 2024).

Service-Dominant (S-D) Logic provides a unifying framework for service innovation, covering both physical and digital service provisions (Stephen L. Vargo et al., 2024). It posits that all innovation processes, including digital service innovation, are rooted in combinatorial evolution (S. Vargo et al., 2015). This is where service-providing actors (re) combine technologies and institutions to adapt their value co-creation practices. These combinations exhibit emergence, distributed governance, and symbiotic design (Stephen L. Vargo et al., 2023).

An S-D Logic-informed approach highlights that service, defined as "the process of doing something for the benefit of another party" (Lusch and Vargo, 2007), is fundamental to all value co-creation and innovation processes. S-D Logic transcends the traditional divide between service and product innovation by integrating both into a holistic approach (M. A. Akaka and Vargo, 2014). It emphasizes that innovation processes are embedded in social structures and occur within nested sociotechnical systems. Within these systems, resource-integrating actors are interconnected and actively shape institutional arrangements and mutual value creation (S. Vargo et al., 2015).

Moreover, the S-D Logic framework aligns closely with open innovation literature, which advocates leveraging both external and internal ideas through collaborative network interactions to drive innovation (An and Mikhaylov, 2024). Both S-D Logic and open innovation underscore the importance of innovation outcomes. In S-D Logic, these outcomes go beyond tangible outputs and focus on mutually beneficial services, where "service" is defined as "the process of doing something for the benefit of another party" (Elo et al., 2024). Additionally, S-D Logic highlights the importance of resource integration to achieve strategic benefits (S. Vargo and Lusch, 2016) and contribute to the Sustainable Development Goals (SDGs) (Loučanová et al., 2022).

Anchored in the value co-creation view, this study addresses the research question: Does coopetition enhance the innovation outcomes related to scale for SMEs? To answer this question, a case study has been conducted within a group of Portuguese Ornamental Stone SMEs, a vital sector for the national economy. This study aims to test the hypothesis that coopetition networks enhance innovation outcomes related to scale determinants as a group of OS-PT SMEs transitions to coopetition practices.

2. Literature review

The definition of coopetition remains varied despite its widespread discussion, with interpretations spanning different goals, relationships, and organizational contexts (R. B. Bouncken et al., 2018; Dagnino and Padula, 2002; Rungtusanatham et al., 2003). It has been described as a strategy encompassing the simultaneous pursuit of cooperation and competition among firms (Bengtsson and Kock, 2000), a hybrid activity within the same business entities, and a complex interplay affecting competitive dynamics among different market players (Bouncken et al., 2018; Dagnino and Padula, 2002; Rungtusanatham et al., 2003).

The academic discourse on coopetition also identifies various typologies of coopetition relationships. For instance, Bengtsson and Kock (2003) introduce "reciprocal coopetition" as a relationship where two firms engage in both competition and cooperation on equal footing (Bengtsson et al., 2016). Other scholars view coopetition as inter-firm relationships born from a partial alignment of interests, manifesting in simultaneous cooperative and competitive interactions across different business operations (Luo, 2007; Tsai, 2002).

Despite the diversity in definitions, the essence of coopetition converges on the notion of a hybrid relationship where competition and collaboration intertwine to benefit the intervenient companies (Estrada and Dong, 2020; Gnyawali and Park, 2011). However, Bengtsson (2016) critiques the field for its fragmentation and the lack of theoretical cohesion in how to address coopetition in networks (Bengtsson et al., 2016), a sentiment echoed by other scholars who highlight the tendency of the existing literature to treat competition and cooperation theories in isolation (Mwesiumo et al., 2023; Rouyre et al., 2024).

2.1. Coopetition networks

At the intersection of coopetition and networks, a strategic orientation centered around innovation emerges, essential for firms seeking to bridge competitive gaps and effectively manage market challenges (Corbo et al., 2023). This orientation emphasizes coopetition's role in navigating competitive terrains and highlights its potential as a catalyst for transformative growth and resilience (Rouyre et al., 2024). Despite broad agreement on the strategic importance of coopetition for fostering innovation and strategic benefit, the academic discourse presents a fragmented view of the value creation mechanisms within coopetition networks (Nguyen et al., 2022). This fragmentation underscores the need for a more unified exploration of value co-creation processes in these complex networks (Gernsheimer et al., 2021).

Traditionally, coopetition has been examined through various theoretical lenses, each providing valuable but often isolated insights. Game Theory, for instance, examines coopetition networks to determine optimal strategies for managing competition and cooperation simultaneously (Klimas et al., 2023). While offering a mathematical foundation for strategic decision-making, it faces challenges in real-world scenarios due to assumptions about information symmetry and rational behavior (Devece et al., 2019).

Resource-Based View posits that coopetition enables firms to expand their resource pools, amplifying innovation potential and competitive strength (Bouncken et al., 2018). However, it often overlooks the dynamic value co-creation emerging from cooperative arrangements, focusing primarily on resource acquisition and development. Paradox Theory perceives the contradictions in coopetition as avenues for strategic innovation and organizational learning (Raza-Ullah et al., 2014). Yet, it tends to under-explore the process of value co-creation that unfolds within these relationships, where competing entities collaborate for mutual benefits (Bengtsson et al., 2016).

While these frameworks offer valuable perspectives on coopetition, they often fail to fully capture the evolving nature of coopetition strategies or adequately address the mechanisms of value creation, technology integration, and long-term sustainability (Navío-Marco et al., 2021). This limitation highlights the need for a more comprehensive perspective.

Recent advances in Open Innovation and S-D Logic provide new insights into the dynamics of coopetition networks. Open Innovation emphasizes leveraging external and internal resources and ideas through collaboration, aligning with S-D Logic's focus on co-creation through interactions (An and Mikhaylov, 2024). This integrated approach enhances innovation capacity and strategic benefit, particularly for SMEs (Vargo and Lusch, 2016).

S-D Logic offers a promising framework for reinterpreting and enriching the understanding of coopetition networks for value co-creation (Vargo and Lusch, 2017). S-D Logic emphasizes that innovation processes are embedded in social structures and occur within nested sociotechnical systems, where resource-integrating actors are connected by institutional arrangements and mutual value creation (Vargo et al., 2015). It highlights the importance of actor-to-actor networks, the role of institutions, and technology in ecosystems, providing a foundation for exploring coopetition dynamics (Jaakkola et al., 2024).

Adopting an S-D Logic perspective reveals that products, whether tangible or intangible, are primarily vehicles for service delivery through interactions, emphasizing the importance of benefits over physical goods (Elo et al., 2024). In modern networks, interactions are

coordinated by institutions and facilitated by technology (Vargo et al., 2024). This approach underscores how coopetitors merge their unique competencies and resources to create value surpassing individual capabilities (Razmdoost et al., 2023). This perspective, complemented by Open Innovation principles, provides a strategic pathway for SMEs to enhance innovation outcomes through value co-creation (Rouyre et al., 2024), strengthening their competitive position in the digital economy (Ragazou et al., 2022).

2.2. Paving the way for S-D logic in coopetition networks

Recent advances in S-D Logic literature emphasize the critical role of institutional enhancement in improving firm performance within coopetition networks (Meena et al., 2023). Additionally, environmental sustainability has been identified as one of the main areas for the fruitful application of the S-D Logic framework (Vargo et al., 2019). Firms engage in coopetition networks to achieve strategic objectives (Lascaux, 2020), highlighting the need for seamless knowledge flow between competing partners to unlock innovative capabilities (Navío-Marco et al., 2021).

While traditional frameworks provide valuable insights into coopetition networks, their complexity and dynamism suggest that these frameworks may not fully capture the evolving nature of coopetition strategies or adequately address the mechanisms of value creation (Rouyre et al., 2024), technology integration, coordination, and long-term sustainability (Navío-Marco et al., 2019). This limitation underscores the need for a value co-creation perspective that comprehensively encompasses the diverse aspects of coopetition networks.

S-D Logic, developed by Vargo and Lusch (2016), offers a promising avenue for understanding coopetition networks as service ecosystems. It is built upon five key axioms that redefine the traditional views of market interactions. (1) Service, defined as the application of competencies for the benefit of others, is the basis of all economic exchanges. Goods are merely mechanisms for service delivery. (2) Value is co-created through interactions among multiple actors, including firms, customers, and other stakeholders. This process is collaborative and contextual rather than linear and product-centric. (3) In S-D Logic, all market actors are resource integrators engaging in service-for-service exchanges. This perspective reframes firms and consumers as fellow value co-creators rather than predefined competitors or collaborators. (4) Value is determined by the beneficiary's perception, occurring within the context of use. This axiom emphasizes the experiential and subjective nature of value creation. S-D Logic views service ecosystems as dynamic and adaptive systems of actors, resources, and institutions. These service ecosystems facilitate value co-creation through shared institutional arrangements and mutual adaptation (Vargo and Lusch, 2016).

Examining coopetition through the lens of S-D Logic provides a dynamic, value-centric approach to understanding cooperation among SMEs. In this perspective, SMEs are seen as resource integrators looking to engage in mutually beneficial exchanges within a service ecosystem. This framework suggests that the status of actors as competitors or collaborators is not predetermined but depends on the exchange context (Vargo et al., 2024).

By adopting S-D Logic, the analysis of coopetition networks shifts to focus on how these networks function as service ecosystems. In these service ecosystems, seamless knowledge integration, strategic technology use, and effective coordination among diverse actors are essential for fostering innovation, growth, and sustainability (Jaakkola et al., 2024). Products, whether tangible or intangible, serve primarily as vehicles for service delivery, emphasizing the importance of benefits over physical goods (Elo et al., 2024).

Interactions within coopetition networks are coordinated by institutions and facilitated by technology, allowing providers to directly engage with competitors for value co-creation (Bicen et al., 2021). This engagement is reinforced by integrating resources governed by shared institutional arrangements—norms, rules, and expectations that guide collaborative and competitive actions (Wieland et al., 2017). In these networks, technology plays a crucial role in facilitating interactions involving dynamic and adaptive exchanges that foster an environment conducive to value co-creation (Mosch et al., 2023).

This theoretical exploration serves as a foundation for analyzing improvements in scale determinants as innovation outcomes for SMEs (Vargo, 2023). It underscores the transformative potential of integrating service-centric approaches with coopetition strategies, even in tangible sectors (Vargo et al., 2024). Integrating S-D Logic and open innovation within coopetition leverages collaborative dynamics and co-creation principles, allowing scale determinants to be viewed as a value co-creation process. This process can be measured through indicators related to value creation (An and Mikhaylov, 2024), while technology, as an institutional phenomenon, is considered part of the institutional structure of the coopetition network.

Anchored in this framework, it is hypothesized that coopetition networks enhance the innovation outcomes related to scale determinants in SMEs. To test this hypothesis, a case study is conducted within a group of Portuguese Ornamental Stone SMEs, a vital sector for the national economy.

3. Methodology

To test the hypothesis, a case study method is particularly valuable for delineating the interface between a phenomenon and its context. It offers a structured approach for event analysis, data collection, and result reporting (Hsu, 2016). This methodology enables researchers to deeply understand the underlying reasons and potential future research directions of the studied instance. To evaluate whether coopetition enhances the innovation outcomes related to scale for SMEs, an Experimental Pilot Network (EPN) is implemented within a selected group of Portuguese Ornamental Stone SMEs (OS-PT). The methodology will proceed through the following sequential steps:

- Identify and onboard SMEs for participation in the EPN.
- Conduct the EPN within the selected SMEs to collect data.
- Develop quantitative metrics and KPIs to measure improvements in scale determinants, providing a clear basis for performance evaluation.
- Gather comprehensive baseline and post-implementation data to enable practical comparative analysis and capture the direct impact of coopetition practices.
- Analyze the collected data using predefined KPIs to quantitatively assess the changes brought about by coopetition practices, identifying critical areas of impact and potential improvement.
- Evaluate the overall gains from coopetition practices, particularly their contribution to achieving the SDGs, and assess the ecosystem's capacity to foster innovation within the sector.

This systematic approach will explore the effects of coopetition networks on innovation outcomes related to scale for SMEs in the OS-PT sector, testing the hypothesis and offering insights into both the immediate and long-term impacts of such coopetition arrangements.

3.1. Identify SMEs for participation in the EPN

The OS-PT sector represents Portugal's cultural heritage and innovative prowess, contributing to globally recognized stone monuments since the 15th century (Machado et al., 2021). Characterized by distinctive stone varieties, engineering excellence, and generational expertize, the OS-PT sector is integral to Portugal's national identity (Machado et al., 2021). In the 21st century, Portugal has affirmed its status as a leading stone producer, effectively integrating into the global Architecture, Engineering, and Construction (AEC) supply chain despite its relatively small size (Silva, Dionísio, et al., 2020).

Recent statistics underscore the sector's substantial economic footprint: it exports to 116 countries, ranks as the ninth largest player in the global stone trade, and holds the second position in international trade per capita (Silva and Pata, 2022). The industry's exports surpassed imports by 660 %, generating a turnover of €1.230 million and supporting over 16,600 direct jobs, particularly bolstering employment in inland regions (Machado et al., 2021).

The Portuguese OS-PT sector is noted for its adaptability and resilience, emerging as a significant industrial force in Europe (Silva and Gil, 2020). However, the digital and global procurement shaped by the Building Information Modeling (BIM) within the AEC industry introduces new challenges, particularly concerning scaling operations (Silva and Marques Cardoso, 2023). The capacity to respond to projects regardless of the dimension is crucial for this sector as it directly impacts the ability to meet international demand and maintain competitive pricing in the global market. The relevance of the OS-PT sector to the study's research question lies in its position within the global AEC supply chain and its demonstrated capacity for innovation and adaptation. The sector's dynamics and SMEs based provide a pertinent context for exploring the impact of coopetition on scale determinants.

3.2. Conduct the EPN within the selected SMEs

The emergence of the Internet of Things (IoT) and embedded systems marks a transformative era in which technology significantly influences service ecosystems (Ng and Wakenshaw, 2017). For S-D Logic, the IoT plays a vital role within these service ecosystems by linking actors through sophisticated sensor technologies, enhancing connectivity and data exchange for value creation (Akaka et al., 2023).

Building on traditional IoT frameworks, the Industrial Internet of Things (IIoT) introduces higher levels of integration to industrial settings (Yazdinejad et al., 2023). This enhances machinery connectivity and facilitates direct device-to-device communication, supporting the creation of intelligent artifacts that dynamically adapt to user interactions and actively enhance value-creation processes (Hoppe, 2023).

Empirical evidence underscores the transformative potential of IIoT-based innovations in creating novel service offerings such as remote control and predictive maintenance solutions (Liu et al., 2024). These capabilities enhance operational efficiency and open new avenues for value co-creation within coopetition frameworks, thus expanding service portfolios and bolstering enterprises' competitive and cooperative capacities (Latif et al., 2023).

An example in the OS-PT sector is the Cockpit4.0 technology, developed as part of R&D projects (Silva et al., 2020). This IoT artifact connects stone companies to the digital market, notably through its 'fingerprint4.0′ functionality (Silva et al., 2020), which refines product specifications and facilitates communication between providers and customers. This enhances customization and operational productivity (Silva et al., 2020).

Cockpit4.0 epitomizes the IoT's capacity to redefine market dynamics through direct engagement and collaborative efforts (Silva et al., 2020). As a state-of-the-art technology in the OS-PT sector, it serves as an optimal starting point for transforming operational technology to facilitate coopetition in the EPN. It dynamically enables cyber value propositions, enhancing service delivery and operational competitiveness among SMEs (Vargo et al., 2024).

Although beyond the scope of this investigation, new functionalities were added to Cockpit4.0 to harness its potential further, enabling secure OPC-UA (Open Platform Communications Unified Architecture) connections between competing firms (Fahma et al., 2024). Specifically, the IoT Cockpit4.0 advanced to a more sophisticated version, including OPC-UA integration (Hoppe, 2023) and a sensor network to connect all machines on the shop floor, now designated as Cockpit4.0+. This IIoT system combines operand technologies, such as hardware and software operated by human resources, to execute tasks, with operant technologies, like AI, to initiate tasks. Designed to connect SMEs, it promotes coopetition, ensuring SME shop floors are connected, and manufacturing execution is seamless, regardless of the factory where each phase occurs (Fig. 1). Through OPC-UA protocols, Cockpit4.0+ bridges gaps in connectivity, efficiency, and responsiveness, fostering an ecosystem where SMEs can thrive through collective opportunities.

Using the Cockpit4.0+ prototype, the implementation of the EPN began with direct and informal conversations with the managing directors of potential participant companies, who were formally invited to participate in the study. A comprehensive confidentiality agreement was drafted to protect sensitive information regarding the companies' operations, clientele, employees, resources, and competitors.

Due to the high costs involved, the prototype state of the artifact (never tested before in an industrial environment), and potential disruptions to the participating companies' activities, only three ornamental stone SME managers representing the state-of-the-art sector agreed to participate in the EPN after careful negotiations. The data collection process involved a two-phased approach: an initial assessment phase of current best practices (B.P) followed by a data collection phase after implementing the EPN among OS-PT SMEs engaged in coopetition network practices (C.P), as illustrated in Fig. 2. Under coopetition practices, SMEs can share production means and raw material stock in real-time across the network's companies to respond to daily demands.

The project's oversight ensured data integrity and confidentiality through direct, daily monitoring and recording of quantitative data using digital machinery and databases. This approach safeguarded the accuracy and privacy of the data collected from participating entities. The process began with a baseline assessment of B.P within the SMEs, systematically transitioning to capture the dynamics of change under C.P, and documenting their impacts.

3.3. Scale determinants KPIs and innovation outcomes

Understanding the multifaceted nature of scale is crucial, particularly for SMEs, due to its reliance on production processes, logistics, and overarching business strategies. In this context, S-D Logic provides a robust framework for assessing innovation outcomes by emphasizing value co-creation through dynamic interactions and resource integration among various actors within service ecosystems (Hartmann et al., 2018).

A central element of S-D Logic is the **value proposition**, which is not the value itself but rather an invitation or proposal made by a company to its stakeholders to engage in value co-creation. Actors, including SMEs and their partners, cannot deliver value directly; instead, they participate in crafting value propositions that can lead to value creation when embraced by others (Stephen L. Vargo and Lusch, 2004a).

Value-in-use refers to the perceived benefits derived by the beneficiary from using a service or product. This type of value is experienced by applying resources in a specific context, highlighting the subjective and experiential nature of value creation (Edvardsson et al., 2011). **Value-in-context** further emphasizes that value is contingent upon the specific circumstances and environment in which a service is used, acknowledging the influence of social, cultural, and situational factors (Akaka and Vargo, 2014).

In contrast, **value-in-exchange** is the traditional view of value, typically quantified as the price or sales value in the marketplace. It is more standardized and often determined by broader market conditions rather than the unique experiences of the individual beneficiary (Vargo and Lusch, 2004b). The distinction between these types of value is critical within S-D Logic, as it shifts the focus from a goods-centered view, where value is embedded in the product itself, to a service-centered view, where value is co-created through the application of operant resources, such as knowledge and skills, acting upon operand resources, like raw materials (Akaka and Vargo, 2014).

In this framework, key performance indicators (KPIs) that reflect the innovation outcomes of SMEs must capture the essence of these value dimensions. Open innovation literature complements this approach by

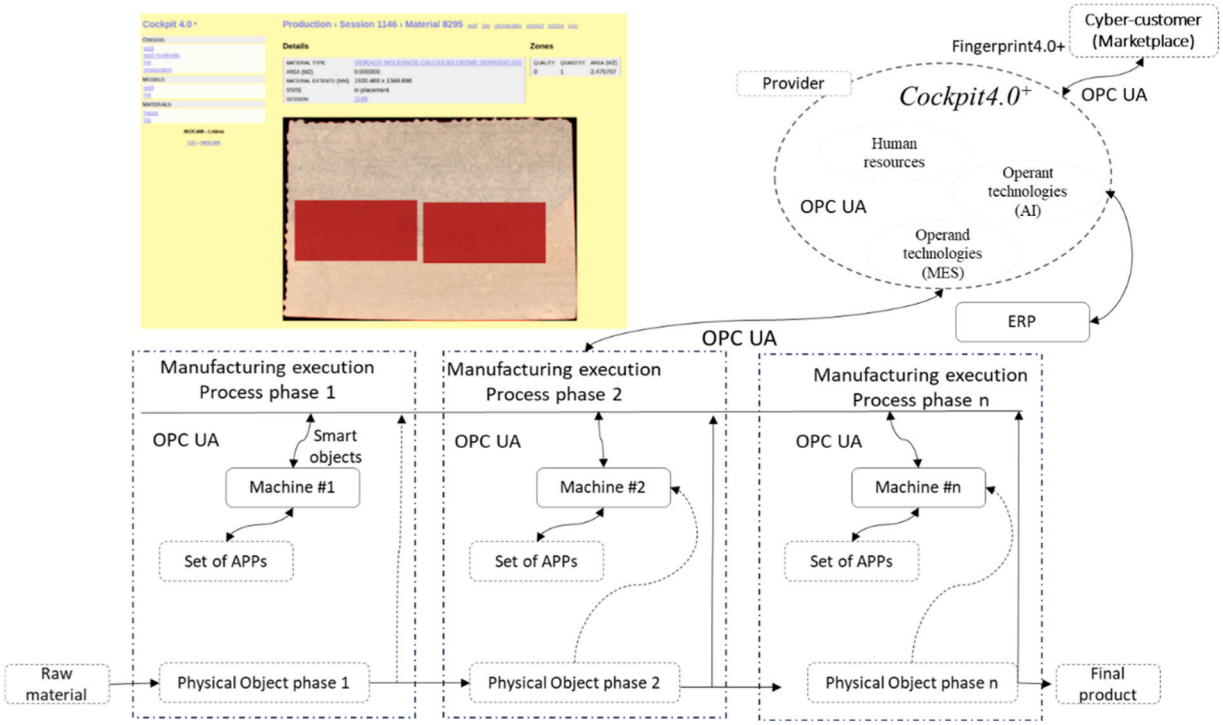


Figure 1. Configuration of Cockpit4.0+ and Shop Floor Connectivity.

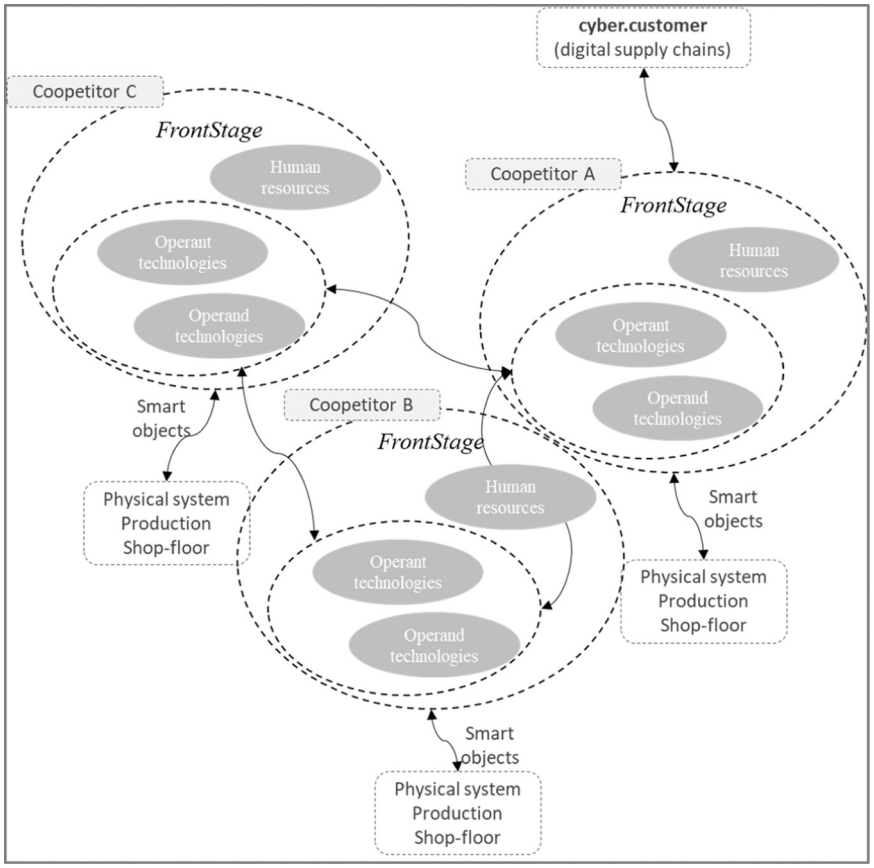


Figure 2. Experimental Pilot Network for Data Collection from SMEs Engaged in Coopetition Practices.

advocating using both internal and external ideas to drive innovation, enhance competitiveness, and foster collaborative growth (An and Mikhaylov, 2024). Open innovation leverages external ideas and technologies to foster a dynamic ecosystem where diverse stakeholders contribute to and benefit from innovation outcomes, leading to more relevant and impactful solutions (West and Bogers, 2017).

To effectively measure the impact of these integrated approaches on SMEs' scale determinants, it is essential to adopt KPIs that reflect the multifaceted nature of value creation as described by S-D Logic. These KPIs should assess not only transactional success but also the enhancement of potential value-in-use and value-in-context through collaborative efforts and resource integration (Xie et al., 2023). Such an approach enables SMEs to strategically leverage their resources and partnerships to achieve sustainable growth and competitive advantage.

3.3.1. Conversion rate

Understanding the leads as value propositions that turn into exchange value (sales), S-D Logic emphasizes the importance of interactions and value co-creation in economic exchanges. This perspective highlights that conversion rates are not merely a measure of transactional success but a reflection of how effectively a company engages with potential customers to co-create value. Businesses can enhance their conversion rates and achieve more sustainable growth by fostering meaningful interactions and integrating customer feedback. Reflecting this principle, the Conversion Rate (KPI_{CR}) reflects the effectiveness of sales and marketing value co-creation (Gupta and Ramachandran, 2021), measuring the effectiveness of converting leads into actual sales (Eq. 1.). Under this perspective, the KPI_{CR} is not merely a measure of transactional success but a reflection of the quality of interactions between the company and its potential customers (Razmdoost et al., 2023). Effective conversion indicates that the company is successfully co-creating value with its customers, understanding their needs, and delivering solutions that meet them (Kumar et al., 2019).

$$KPI_{CR} = \text{Avarage}\left(\frac{\sum^{Number\ sold\ parts}\left(daily\right)}{\sum^{Led\ \ parts}\left(daily\right)}\right).100\% \quad (1)$$

In this context, improving the KPI_{CR} suggests that the company is enhancing its ability to engage with customers meaningfully, thereby co-creating value more effectively. This aligns with the S-D Logic view that value is co-created through service delivery and interactions rather than being embedded in the product. As companies improve their KPI_{CR}, they demonstrate an increased capability to engage in value-creating interactions, leading to more sustainable business growth and scalability. The open innovation literature highlights the importance of leveraging external and internal ideas through collaborative networks to drive innovation (Fahma et al., 2024). The KPI_{CR}, when viewed through this lens, becomes a measure of how well a company can integrate external insights and internal capabilities to create compelling value propositions for its customers. By improving KPI_{CR}, companies indicate their proficiency in utilizing open innovation practices to enhance their offerings. This might involve integrating external partners' customer feedback, market insights, and innovative ideas into their sales and marketing strategies. As a result, they can more effectively convert leads into sales by offering products and services that are aligned with customer needs and market demands.

Improvements in the KPI_{CR} can significantly enhance a company's scale in several ways: (1) higher conversion rates lead to increased sales, directly contributing to revenue growth. (2) effective conversion strategies allow companies to capture a larger market share by efficiently turning leads into loyal customers. (3) Improved conversion rates indicate efficient use of marketing and sales resources, reducing costs and increasing profitability. (4) by focusing on value co-creation and open innovation, companies can build stronger customer relationships, leading to higher customer satisfaction and retention rates. (5) developing robust conversion processes that leverage open innovation can be scaled across different markets and segments, supporting business expansion.

3.3.2. Product stockouts

Understanding commitment to deliveries as a form of co-creation for beneficiaries (Vargo and Lusch, 2017), the Product Stockouts (KPI_{PsO}) can be used to measure the frequency at which inventory shortages occur, directly affecting a company's ability to meet customer demand (Cai et al., 2009) (Eq. 2). In this context, the occurrence of product stockouts represents a failure in the value co-creation process. Stockouts indicate a failure for exchange value to materialize, as there is a delay or interruption in the service-for-service exchange that is fundamental to S-D Logic. This failure prevents the intended exchange of value between the company and its customers, leading to unmet needs and expectations (Jaakkola et al., 2024).

Additionally, stockouts represent a failure to facilitate value-in-context because the necessary resources are not made available for exchange partners to co-create value at the appropriate time. In S-D Logic, value-in-context emphasizes the importance of delivering value through timely and relevant resource integration tailored to the specific circumstances and needs of the customer. When stockouts occur, SMEs fail to provide the resources required for their partners and customers to create value within their particular contexts, resulting in dissatisfaction and potential loss of trust.

By understanding the implications of stockouts in the value co-creation process, SMEs can better anticipate and mitigate these issues, ensuring a more seamless and effective service-for-service exchange that meets customer expectations and fosters trust.

Improving the KPI_{PsO} entails optimizing inventory management to ensure that products are available when and where customers need them. This improvement enhances the company's ability to co-create value consistently by ensuring customer interactions successfully deliver desired services. By minimizing stockouts, companies can maintain a steady flow of service delivery, reinforcing customer relationships and building a reputation for reliability and responsiveness. Similarly, open innovation literature emphasizes integrating internal and external ideas to drive innovation and improve business processes (Yun et al., 2024). From this perspective, reducing product stockouts can be achieved by leveraging innovative inventory management solutions and collaborative networks.

$$KPI_{PsO} = \text{Avarage}\left(\frac{\sum^{Number\ of\ Stockout\ Incident}\left(daily\right)}{\sum^{Total_inventory_requests}\left(daily\right)}\right).100\% \quad (2)$$

Improvements in KPI_{PsO} can be driven by adopting technologies such as IoT and advanced analytics, which provide real-time data on inventory levels and demand forecasting (Fahma et al., 2024). Collaborating with suppliers and logistics partners to develop more efficient supply chain processes is also crucial. Companies can create a more responsive and adaptive inventory management system by incorporating external innovations and internal insights. Improvements in the KPI_{PsO} can significantly enhance a company's scale through several mechanisms: (1) Reducing stockouts ensures that customer demand is consistently met, leading to higher satisfaction and loyalty. Satisfied customers are more likely to make repeat purchases and recommend the company to others, driving organic growth. (2) Fewer stockouts mean more sales opportunities are captured rather than lost. This directly contributes to revenue growth by maximizing the potential of existing demand. From a S-D Logic perspective, reducing stockouts enhances the facilitation of value co-creation processes. When products are readily available, companies can promptly fulfill customer needs, allowing the materialization of value-in-exchange as transactions occur seamlessly. Moreover, ensuring product availability supports value-in-context and value-in-use, as customers can access the resources they need to co-create value within their specific circumstances. This timely

provision of resources strengthens customer satisfaction and loyalty, further driving revenue growth. (3) Effective inventory management reduces the costs associated with excess inventory and emergency restocking. This efficiency translates into better resource allocation and increased profitability. (4) Companies that can reliably meet customer demand are more competitive. By leveraging open innovation to enhance inventory processes, companies can differentiate themselves through superior service reliability. (5) Innovative inventory management practices developed to reduce stockouts can be scaled across different product lines and markets, supporting business expansion and adaptability to changing market conditions. In summary, the Product Stockout KPI is a critical measure of a company's ability to meet customer demand and co-create value consistently. By improving this KPI, companies can enhance customer satisfaction, operational efficiency, and market competitiveness, thereby driving scalable growth and long-term success.

3.3.3. Manufacturing value-added

The Manufacturing Value Added (KPI_{MvA}) represents the economic value added by the manufacturing process. This metric is crucial for assessing the contribution of manufacturing to the overall business value (Wiesner and Thoben, 2017) (Table 1, Eq. 3). S-D Logic emphasizes that value is co-created through interactions and service delivery rather than being embedded in products. In this framework, KPI_{MvA} measures economic output and indicates how well a company integrates and utilizes its resources to co-create value (Mosch et al., 2023). The manufacturing process is a collaborative activity that involves various stakeholders, including suppliers, employees, and customers, all contributing to the value-creation process.

The Manufacturing Value Added (KPI_{MvA}) metric represents the economic value generated by the manufacturing process. It is essential for assessing how manufacturing contributes to the overall business value (Wiesner and Thoben, 2017) (Eq. 3). Traditionally, the concept of "value-added" has been rooted in goods-dominant logic, which assumes that producers create value independently by embedding it within products and then delivering those products to consumers.

This perspective, however, stands in contrast to the principles of S-D Logic, which argues that actors cannot independently deliver value but can only participate in creating and offering value propositions (FP 7) (Lusch and Vargo, 2007). In S-D Logic, value is co-created through service delivery and collaborative engagement among various stakeholders, including suppliers, employees, and customers. Instead of being embedded in products, value emerges from the interaction and collaboration of these actors within a service ecosystem.

Thus, the KPI_{MvA} should be viewed as a reflection of the enhancement of value potential, focusing on efforts to improve value propositions rather than merely measuring economic output. This metric assesses how effectively a company integrates and utilizes its resources to facilitate value co-creation with all stakeholders involved in the manufacturing process. By emphasizing the enhancement of value potential, the KPI_{MvA} aligns more closely with S-D Logic's principles, highlighting the collaborative nature of manufacturing and the continuous improvement of value propositions.

$$KPI_{MvA} = Avarage\left(\frac{\sum^{Usefull\ _\ operations\ to\ finish\ \ products}\left(daily\right)}{\sum^{Total\ \ required\ \ operations}\left(daily\right)}\right).100\% \quad (3)$$

Improvements in KPI_{MvA} suggest that a company effectively leverages its manufacturing capabilities to enhance the overall value proposition. This can be achieved by optimizing production processes, ensuring high-quality standards, and innovating manufacturing techniques. By focusing on these aspects, companies can create products that better meet customer needs and expectations, enhancing their ability to co-create value with customers. Open innovation literature underscores the importance of integrating external and internal ideas to drive innovation and improve business processes. From this viewpoint, increasing KPI_{MvA} involves embracing innovative manufacturing technologies and practices (Imjai et al., 2024). This might include adopting advanced manufacturing techniques such as additive manufacturing, utilizing real-time data analytics for process optimization, and collaborating with external partners for technology transfer and innovation.

Improvements in the KPI_{MvA} can significantly enhance a company's scale through several mechanisms: (1) Higher KPI_{PoR} indicates more efficient use of resources, leading to cost savings and increased profitability. This efficiency enables the company to reinvest in further innovations and expansion initiatives. (2) By adding more value through manufacturing, companies can produce higher-quality products that stand out in the market. This differentiation can attract more customers and increase market share. (3) Enhanced manufacturing processes improve product performance and reliability, increasing customer satisfaction and loyalty. Satisfied customers are likelier to repeat purchases and recommend the company to others. (4) Efficient and innovative manufacturing practices contribute to sustainable business growth. Companies can scale their operations more effectively when they have optimized production processes that are both cost-effective and environmentally sustainable. (5) By leveraging open innovation to improve manufacturing value-added continuously, companies can maintain a competitive edge. This involves staying ahead of industry trends, adopting cutting-edge technologies, and fostering a culture of continuous improvement.

Table 1
Formulation of innovation outcomes related to scale in SMEs.

Equation	Innovation Outcomes	Formulation
Eq.6	$IO_{(QTT)CR}$	$\frac{KPI_{(CR)C.P} - KPI_{(CR)B.P}}{KPI_{(CR)B.P}}.100\%$
Eq.7	$IO_{(\sigma)CR}$	$\frac{KPI\sigma_{(CR)C.P} - KPI\sigma_{(CR)B.P)}}{KPI\sigma_{(CR)B.P}}.100\%$
Eq.8	$IO_{(QTT)PsO}$	$\frac{KPI_{(PsO)C.P} - KPI_{(PsO)B.P)}}{KPI_{(PsO)B.P}}.100\%$
Eq.9	$IO_{(\sigma)\ PsO}$	$\frac{-(KPI\sigma_{\sigma(PsO)C.P} - KPI\sigma_{(PsO)B.P)})}{KPI\sigma_{(PsO)B.P}}.100\%$
Eq.10	$IO_{(QTT)MvA}$	$\frac{KPI_{(MvA)C.P} - KPI_{(MvA)B.P)}}{KPI_{(MvA)B.P}}.100\%$
Eq.11	$IO_{(\sigma)MvA}$	$\frac{KPI\sigma_{(MvA)C.P} - KPI\sigma_{(MvA)B.P)}}{KPI\sigma_{(MvA)B.P}}.100\%$
Eq.12	$IO_{(QTT)PoR}$	$\frac{KPI_{(PoR)C.P} - KPI_{(PoR)B.P)}}{KPI_{(PoR)B.P}}.100\%$
Eq.13	$IO_{(\sigma)PoR}$	$\frac{KPI\sigma_{(PoR)C.P} - KPI\sigma_{(PoR)B.P}}{KPI\sigma_{(PoR)B.P}}.100\%$
Eq.14	$IO_{(QTT)SCALE}$	$\frac{IO_{(QTT)CR} + IO_{(QTT)PsO} + IO_{(QTT)MvA} \quad IO_{(QTT)PoR}}{4}.100\%$
Eq.15	$IO_{(\sigma)SCALE}$	$\frac{IO_{(\sigma)CR} + IO_{(\sigma)PsO} + IO_{(\sigma)MvA} + IO_{(\sigma)PoR}}{4}.100\%$

3.3.4. Production output ratio

Understanding productivity as a way to co-create value for all beneficiaries, including collaborators, customers, and providers (Stephen L. Vargo et al., 2020), the Production Output Ratio (KPI_{PoR}) quantifies the production volume relative to the resources used, providing insight into operational efficiency (Neves et al., 2019) (Eq. 4). Instead of merely measuring the output of tangible products, the KPI_{PoR} serves as an indicator of how effectively a company utilizes its resources to create value through its production processes.

Improved KPI_{PoR} implies an enhanced use of operant resources, such as skills and knowledge, including through technologies like the IIoT, which enable actors to act more effectively on operand resources. This improvement demonstrates a company's ability to integrate resources such as labor, technology, and materials to maximize production efficiency and value creation (Adi et al., 2023). By leveraging advanced skills and technologies, companies can optimize resource utilization, enhance operational efficiency, and ensure high-quality product and

service delivery.

Higher production output relative to resource usage indicates a well-coordinated and optimized production process contributing to overall value creation and customer satisfaction. Additionally, open innovation literature highlights the significance of leveraging internal and external ideas to drive innovation and improve business processes (An and Mikhaylov, 2024). From this perspective, enhancing the KPI_{PoR} involves adopting innovative production techniques, integrating advanced technologies, and collaborating with external partners to optimize resource utilization.

$$KPI_{PoR} = \text{Avarage}\left(\frac{\sum^{Total_units_produced}\left(daily\right)}{\sum^{Total_resources_capacity}\left(daily\right)}\right).100\% \quad (4)$$

By improving KPI_{PoR} through open innovation, companies can achieve higher production volumes with the same or fewer resources, leading to cost savings and increased productivity. This might involve implementing lean manufacturing principles, utilizing real-time data analytics for process optimization, and engaging in collaborative innovation projects with suppliers and technology partners. These efforts result in a more efficient and agile production system capable of swiftly responding to market demands and opportunities. Improvements in the Production KPI_{PoR} can significantly enhance a company's scale through several mechanisms: (1) A higher KPI_{PoR} indicates more efficient use of resources, leading to reduced production costs and increased profitability. This efficiency enables the company to scale its operations without a proportional increase in resource utilization. (2) Enhanced production efficiency allows companies to increase their output capacity, meet higher demand levels, and expand their market reach. (3) By optimizing resource utilization, companies can offer competitive pricing without compromising quality, attracting more customers and gaining market share. (4) Efficient resource use contributes to sustainability by minimizing waste and reducing the environmental impact of production processes. This aligns with broader corporate social responsibility goals and enhances the company's reputation. (5) Leveraging open innovation to improve KPI_{PoR} fosters a culture of continuous improvement and innovation. This adaptability ensures that companies remain competitive in dynamic markets and can quickly implement new technologies and processes.

3.4. Innovation outcomes

This innovation-oriented set of KPIs provides a framework of how effectively SMEs co-create value through efficient resource integration, innovative practices, and collaborative efforts, ultimately driving their ability to scale and compete in the global market.

The study assesses the innovation outcomes from C.P. By incorporating a KPI for evaluating the consistency ($KPI_{\sigma\text{-Scale}}$), as outlined in Equation 5, the study gains insights into the stability and predictability of scale determinants' improvement in SMEs. This enables a deeper understanding of how C.P can sustainably enhance operational scale and provides a comprehensive analysis of the effects of coopetition practices in promoting effective management.

$$KPI_{(\sigma-\text{scale})} = \sqrt[2]{\frac{\sum_{1}^{n}\left[KPI(CR;PsO;MvA;PoR)_{(daily)} - \overline{KPI(FR;PsO;MvA;PoR)_{(daily)}}\right]^2}{\left(Observations(R;PsO;MvA;PoR)_{(test\ period)}\right)}} \quad (5)$$

A thorough analysis of shifts in these KPIs offers evidence of significant improvements following the adoption of C.P., thereby enhancing scale determinants' effectiveness. Table 1, Equations 6 through 15, details the formulas used to evaluate the innovation outcomes and their consistency across KPI_{CR}, KPI_{PsO}, KPI_{MvA}, and KPI_{PoR}, providing a nuanced understanding of coopetition's impact on SMEs' scale determinants.

Table 2
Summary of data collected under current best practices (B.P).

Data ID	Description	Current Practices (B.P)	Coopetition Practices (C.P)
Data 1	Successful leads	2.5	3.7
Data 2	Number of daily leads	8.4	8.6
Data 3	Stockout incidents	1.6	1.1
Data 4	Inventory requests	8.4	8.6
Data 5	useful operations	1480	1819
Data 6	Production operations	1486	1822
Data 7	Total units produced	339	416
Data 8	Resources capacity	590	590

4. Data collection

To explore the transition from B.P. to C.P., a data collection strategy was adopted across two fifty-four-day intervals, enabling a comparative analysis of operational outcomes.

Phase 1 - B.P: The first interval, from April 17th, 2023, to June 10th, 2023, focused on capturing standard operations at three anonymized companies. This baseline phase documented each company's reliance on internal resources for production and delivery, providing essential reference data for subsequent comparisons.

Phase 2 - C.P: The second interval, from September 9th, 2023, to November 14th, 2023, assessed the effects of integrating these entities into a coopetition network. This phase represented a significant shift by fostering cooperative interactions and shared use of technologies and resources, moving beyond standard practices.

Data management and privacy were maintained throughout the study in compliance with confidentiality agreements. All data were anonymized and referred to only by company labels. Data collection, recording, and exportation procedures were meticulously followed, with results exported to Excel files as detailed in the methodology section. This ensured a secure and consistent approach to data handling, enabling detailed analysis while safeguarding the privacy and proprietary information of the participating companies. The structured methodology facilitated not only a direct comparison of operational outcomes but also upheld the integrity and confidentiality of the data throughout the research process.

5. Assessing and analyzing innovation outcomes

Table 2 summarize the average findings derived from data collected under B.P. and C.P. from the three selected SMEs, providing a comprehensive view of each set of practices.

Equations 1–5 are used to detail the KPI findings in Table 3, which provides a comprehensive analysis of the involved SMEs.

Table 3
KPIs assessment under best practices (B.P) and coopetition practices (C.P).

Key Performance Indicators (KPIs)	Current Practices (B.P)	Coopetition Practices (C.P)
KPI_{CR} - Conversion Rate	KPI_{CR}: 31.36 %$KPI_{(\sigma)CR}$: 0.126	KPI_{CR}: 44.60 %$KPI_{(\sigma)CR}$: 0.140
KPI_{PsO} - Product Stockouts	KPI_{PsO}: 19.01 %$KPI_{(\sigma)PsO}$: 0.078	KPI_{PsO}: 12.70 %$KPI_{(\sigma)PsO}$: 0.640
KPI_{MvA} – Manufact. Value Added	KPI_{MvA}: 99.40 %$KPI_{(\sigma)MvA}$: 0.003	KPI_{MvA}: 99,8 %$KPI_{(\sigma)MvA}$: 0.001
KPI_{PoR} - Production Output Ratio	KPI_{PsO}: 55.57 %$KPI_{(\sigma)PsO}$: 0.105	KPI_{PsO}: 69,9 % $KPI_{(\sigma)PsO}$: 0.102

These findings can provide insights into the scale determinants, showcasing remarkable changes when OS-PT SMEs shift their practices to cooperation (Table 4).

5.1. Conversion rate analysis

The inconsistency observed, with a −1.38 % change, may be due to several factors despite an overall average quantitative improvement of 13.2 % in the KPI_{CR}. Possible reasons for this inconsistency include short-term fluctuations, data outliers, the implementation phase, market dynamics, segment-specific performance, or measurement errors. However, the enhancement stemming from the transition to C.P significantly increases the number of order confirmations and, consequently, the volume of potential work. Improved conversion rates reflect better customer engagement and satisfaction, aligning with SDG 8, which promotes sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all.

Fig. 3 illustrates the positive trajectory in average daily successful lead conversions under C.P, highlighting a substantial increase in lead acceptance rate and showcasing enhanced scalability through coopetition networks.

The coefficient of x in the regression equation indicates the average increase in the number of successful leads per day. Specifically, it shows that the daily average number of successful leads increases by approximately 0.0303 for each additional day. This positive slope suggests a gradual upward trend in successful leads over time, highlighting the beneficial impact of coopetition practices on lead conversion. The intercept of the regression equation represents the estimated number of successful leads at the beginning of the observed period (when x=0). The value of 2.8591 indicates that at the start of the observation period, the daily average number of successful leads was approximately 2.8591. This trend reflects the potential effectiveness of coopetition practices in enhancing the market processes of SMEs, leading to better conversion rates and overall business growth.

5.2. Product stockouts analysis

The number of product stockout events under C.P has reduced by 6.3 %, indicating a significant improvement in stock availability. Additionally, there is a 1.43 % increase in stability, underscoring the effectiveness of C.P in utilizing the raw materials available within the

Table 4
Innovation outcomes on scale determinants from best practices (B.P) and coopetition practices (C.P).

Operational Scale-Related KPIs	Current Practices (B.P)	Coopetition Practices (C.P)	Quantitative IO	Consistency IO
KPI_{CR} Conversion Rate	0.31	0.45	13.2 %	−1.38 %
KPI_{PsO} Product Stockouts	0.19	0.13	6.3 %	1.43 %
KPI_{MvA} Manufact. Value Added	0.99	1.00	0.4 %	0.18 %
KPI_{PoR} Production Output Ratio	0.56	0.70	14.1 %	0.26 %
Impact on Scale Determinants			8.5 %	0.1 %

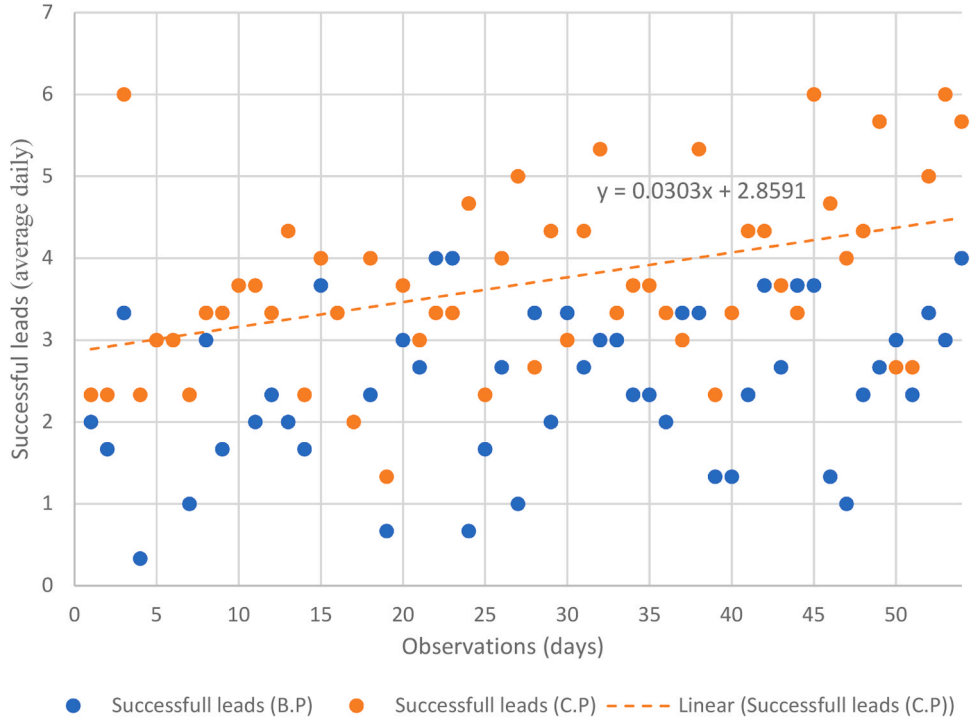


Figure 3. Daily average trend in successful leads under coopetition practices.

coopetition network to meet customer demand. This enhancement in stock management allows companies to fulfill larger orders promptly and highlights the benefits of collaborative raw material management and responsiveness in the OS-PT sector. These improvements contribute to SDG 9, which focuses on building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation.

5.3. Manufacturing value added analysis

The improvement in KPI_{MvA} is modest at 0.4 %, but there is a notable enhancement in the stability of production processes. This reflects the enhanced predictability introduced by C.P, which can lead to long-term gains in production efficiency and value creation. Improved production stability contributes to SDG 9 by supporting sustainable industrial growth and innovation.

5.4. Production output ratio analysis

A substantial increase of 14.1 % in the KPI_{PoR} underscores the significant benefits of adopting C.P. This improvement signifies enhanced utilization of production capacities facilitated by coopetition. Better utilization of production resources boosts operational efficiency and reduces waste and environmental impact, contributing to SDG 12, which focuses on ensuring sustainable consumption and production patterns.

Drawing from the comprehensive analysis of the collected data, Fig. 4 depicts the innovation outcomes impacting the scale determinants of Portuguese Ornamental Stone SMEs.

Overall, the transition to cooperative practices in the OS-PT sector positively impacts innovation outcomes, supports sustainable growth, and contributes to achieving multiple SDGs.

6. Conclusions, limitations, and future research

In addressing the question, "Does coopetition enhance the innovation outcomes related to scale for SMEs?" the findings revealed that the transition to coopetition networks in the OS-PT sector positively impacted innovation outcomes, supporting sustainable growth and achieving multiple SDGs. By reducing product stockouts and improving the stability of manufacturing processes, SMEs significantly enhanced their ability to meet customer demand and increased market responsiveness. The positive changes in conversion rates and production output ratios demonstrated that coopetition could substantially improve operational efficiency and business growth, contributing to SDGs 8, 9, and 12.

This case study validated the hypothesis that coopetition networks enhance innovation outcomes related to scale determinants as a group of OS-PT SMEs transitioned to coopetition practices. The results showed significant improvements in KPIs after adopting coopetition practices, underscoring the benefits of collaborative strategies among SMEs.

This research contributed to theory by leveraging S-D Logic and open innovation to improve coopetition, demonstrating how these frameworks can effectively enhance innovation outcomes in SMEs. By understanding actors as resource integrators, S-D Logic reframes coopetition as a value co-creation process. This perspective emphasizes collaboration among market actors who engage as mutually beneficial resource integrators, rather than simply as rivals.

Furthermore, value co-creation helps redefine the manufacturing and production processes, not merely as value-adding activities but as opportunities to enhance value propositions through continuous stakeholder engagement. This shift from viewing production as a linear process to one that focuses on co-creation highlights the dynamic nature of manufacturing in a collaborative network.

Additionally, distinguishing between value-in-exchange and value-in-context offers a deeper interpretation of scale determinants. Value-in-exchange, often seen as the traditional market price or sales value, is expanded by S-D Logic to include value-in-context, which considers the specific circumstances and unique benefits experienced by each stakeholder. This broader understanding enables a more comprehensive analysis of how the context and interactions within the service ecosystem influence scale determinants.

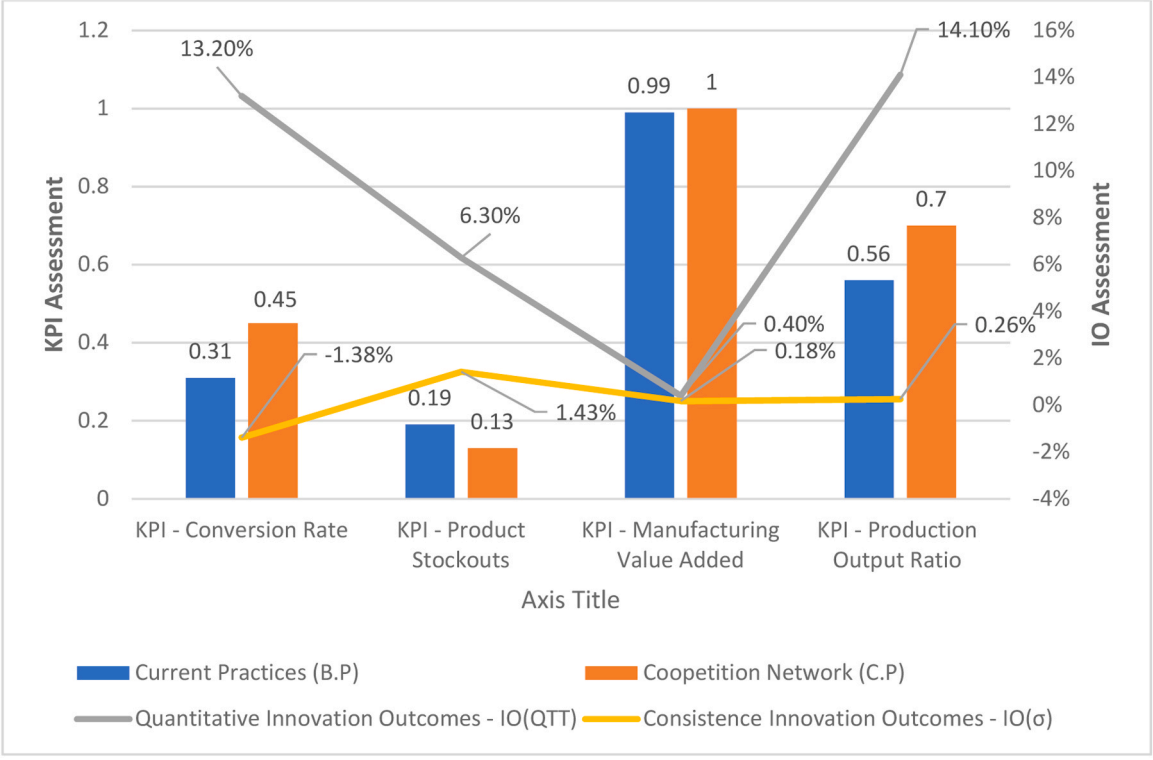


Figure 4. Innovation outcomes on the scale determinants of portuguese ornamental stone SMEs.

In conclusion, applying S-D Logic provides valuable insights into how SMEs can leverage coopetition to foster innovation, enhance value propositions, and achieve sustainable growth. By focusing on resource integration, value co-creation, and contextual value, SMEs can better navigate competitive landscapes and thrive in complex market environments.

However, several limitations should be acknowledged. The study was conducted within a specific group of OS-PT SMEs, which may limit the generalizability of the findings to other sectors or regions. The data collection period may have needed longer to capture the full extent of the impact of coopetition practices, particularly for long-term innovation outcomes. While key KPIs were analyzed, other potential indicators of innovation and scale might have been overlooked, which could provide additional insights into the benefits of coopetition. Additionally, the study did not account for external factors such as market conditions, economic fluctuations, or regulatory changes that could have influenced the results.

Future research should address these limitations and explore additional dimensions. Longitudinal studies are needed to assess the long-term impact of coopetition on innovation outcomes and business scalability. Expanding the research to include SMEs from different sectors and regions would provide a more comprehensive understanding of coopetition's effectiveness across various contexts. Incorporating a broader range of KPIs, including qualitative measures such as customer satisfaction and employee engagement, could offer deeper insights into the benefits of coopetition. Examining the role of external factors such as economic conditions, technological advancements, and policy changes could help understand their influence on coopetition practices' outcomes. Future studies could also focus on integrating emerging technologies such as AI and blockchain to enhance coopetition and innovation outcomes.

By addressing these areas, future research can build on the findings of this study to further elucidate the potential of coopetition in fostering sustainable growth and innovation in SMEs.

Funding

The authors declare that no funding was received for conducting this study.

Data available on request from the authors

The data supporting this study's findings are available from the corresponding author, upon request.

Ethical Statement

The authors confirm that all research conducted in this study complies with ethical standards. Informed consent was obtained from all participating SMEs, and ethical guidelines were followed to ensure the integrity and confidentiality of the data collected.

CRediT authorship contribution statement

Antonio Cardoso: Validation, Supervision, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Agostinho da Silva:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper. All authors have disclosed any potential conflicts of interest and affirm that the results presented are free from any bias influenced by personal or financial relationships.

References

Adi, S.P.S., Ghinahana, S., Yudianto, B.R., Wibowo, A.J.I., 2023. Institutions, technology and resource integration in the value co-creation process: a study of service-dominant logic in higher education. J. Appl. Res. High. Educ. https://doi.org/10.1108/JARHE-03-2023-0104.

Akaka, M., Schau, H., & Vargo, S. (2023). How practice diffusion drives IoT TEchnology Adoption and Institutionalization of Solutions in Service Ecosystems. In: Proceedings of the Annual Hawaii International Conference on System Sciences, 2023-Janua (March), 1427–1435. ⟨https://doi.org/10.24251/HICSS.2023.178⟩.

Akaka, M.A., Vargo, S.L., 2014. Technology as an operant resource in service (eco) systems. Inf. Syst. E-Bus. Manag. *12* (3), 367–384. https://doi.org/10.1007/s10257-013-0220-5.

An, J., Mikhaylov, A., 2024. Technology-based forecasting approach for recognizing trade-off between time-to-market reduction and devising a scheduling process in open innovation management. J. Open Innov.: Technol., Mark., Complex. *10* (1), 100207 https://doi.org/10.1016/j.joitmc.2024.100207.

Bengtsson, M., Kock, S., 2000. Coopetition" in business networks—to cooperate and compete simultaneously. Ind. Mark. Manag. *29* (5), 411–426. https://doi.org/10.1016/S0019-8501(99)00067-X.

Bengtsson, M., Kock, S., Lundgren-Henriksson, E.-L., Näsholm, M.H., 2016. Coopetition research in theory and practice: growing new theoretical, empirical, and methodological domains. Ind. Mark. Manag. *57*, 4–11. https://doi.org/10.1016/j.indmarman.2016.05.002.

Bicen, P., Hunt, S., Madhavaram, S., 2021. Coopetitive innovation alliance performance: alliance competence, alliance's market orientation, and relational governance. J. Bus. Res. *123* (October 2020), 23–31. https://doi.org/10.1016/j.jbusres.2020.09.040.

Bouncken, R.B., Fredrich, V., Ritala, P., Kraus, S., 2018. Coopetition in new product development alliances: advantages and tensions for incremental and radical innovation. Br. J. Manag. *29* (3), 391–410. https://doi.org/10.1111/1467-8551.12213.

Bouncken, R., Kumar, A., Connell, J., Bhattacharyya, A., He, K., 2024. Coopetition for corporate responsibility and sustainability: does it influence firm performance? Int. J. Entrep. Behav. Res. *30* (1), 128–154. https://doi.org/10.1108/IJEBR-05-2023-0556.

Cai, J., Liu, X., Xiao, Z., Liu, J., 2009. Improving supply chain performance management: a systematic approach to analyzing iterative KPI accomplishment. Decis. Support Syst. *46* (2), 512–521. https://doi.org/10.1016/j.dss.2008.09.004.

Corbo, L., Kraus, S., Vlačić, B., Dabić, M., Caputo, A., Pellegrini, M.M., 2023. Coopetition and innovation: a review and research agenda. Technovation *122* (September 2022). https://doi.org/10.1016/j.technovation.2022.102624.

Dagnino, G., & Padula, G. (2002). Coopetition Strategy. Towards a New Kind of Interfirm Dynamics?". In: Proceedings of the EURAM – The European Academy of Management Second Annual Conference - "Innovative Research in Management," *May 2002* , 9–11.

Devece, C., Ribeiro-Soriano, D.E., Palacios-Marqués, D., 2019. Coopetition as the new trend in inter-firm alliances: literature review and research patterns. Rev. Manag. Sci. *13* (2), 207–226. https://doi.org/10.1007/s11846-017-0245-0.

Di Bella, L., Katsinis, A., Lagüera-González, J., Odenthal, L., Hell, M., & Lozar, B. (2023). Annual Report on European SMEs 2022/2023.

Edvardsson, B., Tronvoll, B., Gruber, T., 2011. Expanding understanding of service exchange and value co-creation: a social construction approach. J. Acad. Mark. Sci. *39* (2), 327–339. https://doi.org/10.1007/s11747-010-0200-y.

Elo, J., Lumivalo, J., Tuunanen, T., & Vargo, S.L. (2024). Enabling value co-creation in partner collaboration ecosystems: an institutional work perspective. In: Proceedings of the 57th Hawaii International Conference on System Sciences, March. ⟨https://hdl.handle.net/10125/106412⟩.

Estrada, I., Dong, J., 2020. Learning from experience? Technological investments and the impact of coopetition experience on firm profitability. Long. Range Plan. *53* (1), 101866 https://doi.org/10.1016/j.lrp.2019.01.003.

European Commission. (2020). Unleashing the full potential of European SMEs (Issue March). ⟨https://doi.org/10.2775/296379⟩.

Fahma, F., Sutopo, W., Pujiyanto, E., Nizam, M., 2024. Dynamic open innovation to determine technology-based interoperability requirement for electric motorcycle swappable battery. J. Open Innov.: Technol., Mark., Complex. *10* (2), 100259 https://doi.org/10.1016/j.joitmc.2024.100259.

Gernsheimer, O., Kanbach, D.K., Gast, J., 2021. Coopetition research - a systematic literature review on recent accomplishments and trajectories. Ind. Mark. Manag. *96* (May), 113–134. https://doi.org/10.1016/j.indmarman.2021.05.001.

Gnyawali, D.R., Park, B.J., 2011. Co-opetition between giants: collaboration with competitors for technological innovation. Res. Policy *40* (5), 650–663. https://doi.org/10.1016/j.respol.2011.01.009.

Gupta, S., Ramachandran, D., 2021. Emerging market retail: transitioning from a product-centric to a customer-centric approach. J. Retail. *97* (4), 597–620. https://doi.org/10.1016/j.jretai.2021.01.008.

Hartmann, N.N., Wieland, H., Vargo, S.L., 2018. Converging on a new theoretical foundation for selling. J. Mark. *82* (2), 1–18. https://doi.org/10.1509/jm.16.0268.

Hernandez, J.E., Kacprzyk, J., Panetto, H., De-angelis, M., 2017. Collaboration in a data-rich world. IFIP Int. Fed. Inf. Process. 2017 *506* (July 2018), 761–774. https://doi.org/10.1007/978-3-319-65151-4.

Hoppe, S. (2023). OPC unified architecture-interoperability for industrie 4.0 and the internet of things. ⟨https://opcfoundation.org/wp-content/uploads/2023/05/OPC-UA-Interoperability-For-Industrie4-and-IoT-EN.pdf⟩.

Hsu, Y., 2016. Integrating service science and information system technology: a case study. Int. J. Organ. Innov. *9* (1), 158–173. https://doi.org/10.4236/ti.2011.22015.

Imjai, N., Swatdikun, T., Rungruang, P., Basiruddin, R., Aujirapongpan, S., 2024. Empowering generation z accountants in the era of data complexity and open innovation: nurturing big data analytics, diagnostic, and forensic accounting skills. J. Open Innov.: Technol., Mark., Complex. *10* (2), 100308 https://doi.org/10.1016/j.joitmc.2024.100308.

Jaakkola, E., Kaartemo, V., Siltaloppi, J., Vargo, S.L., 2024. Advancing service-dominant logic with systems thinking. J. Bus. Res., 114592 https://doi.org/10.1016/j.jbusres.2024.114592.

Klimas, P., Ahmadian, A.A., Soltani, M., Shahbazi, M., Hamidizadeh, A., 2023. Coopetition, where do you come from? Identification, categorization, and configuration of theoretical roots of coopetition. SAGE Open *13* (1), 1–19. https://doi.org/10.1177/21582440221085003.

Kumar, R., Gunasekaran, A., Gupta, S., Kamboj, S., 2019. Personalized digital marketing recommender engine. J. Retail. Consum. Serv. (*September 2018*), 101799 https://doi.org/10.1016/j.jretconser.2019.03.026.

Lascaux, A., 2020. Coopetition and trust: what we know, where to go next. Ind. Mark. Manag. *84* (May)), 2–18. https://doi.org/10.1016/j.indmarman.2019.05.015.

Latif, G., Brahim, G.Ben, Abdelhamid, S.E., Alghazo, R., Alhabib, G., Alnujaidi, K., 2023. Learning at your fingertips: an innovative IoT-based AI-powered braille learning system. Appl. Syst. Innov. *6* (5), 91. https://doi.org/10.3390/asi6050091.

Lindström, T., Polsa, P., Pellegrin-Boucher, E., Le Roy, F., Gurău', C., Filieri, R., Bouncken, R.B., Gast, J., Kraus, S., Bogers, M., Barney, J., Wright, M., Ketchen, D.J., Gnyawali, D.R., Song, Y., Devece, C., Ribeiro-Soriano, D.E., Palacios-Marqués, D., Grängsjö, Y., Kock, S., 2016. Destination networking: co-opetition in peripheral surroundings. Ind. Mark. Manag. *33* (2), 427–448. https://doi.org/10.1108/09600030310481997.

Liu, H., Li, S., Li, W., Sun, W., 2024. A distributed resource sharing mechanism in edge-enabled IIoT systems. IEEE Internet Things J. *11* (8), 14296–14312. https://doi.org/10.1109/JIOT.2023.3342321.

Loučanová, E., Olšiaková, M., Štofková, J., 2022. Open business model of eco-innovation for sustainability development: implications for the open-innovation dynamics of Slovakia. J. Open Innov.: Technol., Mark., Complex. *8* (2), 98 https://doi.org/10.3390/joitmc8020098.

Luo, Y., 2007. A coopetition perspective of global competition. J. World Bus. *42* (2), 129–144. https://doi.org/10.1016/j.jwb.2006.08.007.

Lusch, R., Vargo, S., 2007. Service-dominant logic: continuing the evolution. J. Acad. Mark. Sci. *36* (1), 1–10. https://doi.org/10.1007/s11747-007-0069-6.

Machado, S., Mergulhão, L., Pereira, B.C., Pereira, P., Carvalho, J., Anacleto, J.A., Neto de Carvalho, C., Belo, J., Paredes, R., Baucon, A., 2021. Geoconservation in the Cabeço da Ladeira Paleontological Site (Serras de Aire e Candeeiros Nature Park, Portugal): exquisite preservation of animals and their behavioral activities in a middle Jurassic carbonate tidal flat. Geosciences *11* (9), 366. https://doi.org/10.3390/geosciences11090366.

Manzhynski, S., Biedenbach, G., 2023. The knotted paradox of coopetition for sustainability: investigating the interplay between core paradox properties. Ind. Mark. Manag. *110*, 31–45. https://doi.org/10.1016/j.indmarman.2023.02.013.

Meena, A., Dhir, S., Sushil, S., 2023. A review of coopetition and future research agenda. J. Bus. Ind. Mark. *38* (1), 118–136. https://doi.org/10.1108/JBIM-09-2021-0414.

Mosch, P., Majocco, P., Obermaier, R., 2023. Contrasting value creation strategies of industrial-IoT-platforms – a multiple case study. Int. J. Prod. Econ. *263*, 108937 https://doi.org/10.1016/j.ijpe.2023.108937.

Mwesiumo, D., Harun, M., Hogset, H., 2023. Unravelling the black box between coopetition and firms' sustainability performance. Ind. Mark. Manag. *114*, 110–124. https://doi.org/10.1016/j.indmarman.2023.08.008.

Nalebuff, B.J., Brandenburger, A.M., 1997. Co-opetition: competitive and cooperative business strategies for the digital economy. Strategy Leadersh. *25* (6), 28–33. https://doi.org/10.1108/eb054655.

Navío-Marco, J., Bujidos-Casado, M., Rodrigo-Moya, B., 2019. Coopetition as an innovation strategy in the European Union: analysis of the German case. Ind. Mark. Manag. *82*, 9–14. https://doi.org/10.1016/j.indmarman.2019.05.014.

Navío-Marco, J., Ibar-Alonso, R., Bujidos-Casado, M., 2021. Interlinkages between coopetition and organisational innovation in Europe. J. Bus. Ind. Mark. *36* (9), 1665–1677. https://doi.org/10.1108/JBIM-01-2020-0054.

Neves, A., Godina, R., Azevedo, S., 2019. A comprehensive review of industrial symbiosis. J. Clean. Prod. *November* https://doi.org/10.1016/j.jclepro.2019.119113.

Ng, I., Wakenshaw, S., 2017. The Internet-of-Things: review and research directions. Int. J. Res. Mark. *34* (1), 3–21. https://doi.org/10.1016/j.ijresmar.2016.11.003.

Nguyen, T.Q.T., Johnson, P., Young, T., 2022. Networking, coopetition and sustainability of tourism destinations. J. Hosp. Tour. Manag. 50, 400–411. https://doi.org/10.1016/j.jhtm.2022.01.003.

Osobajo, O.A., Oke, A., Ajimmy, M., Otitoju, A., Adeyanju, G.C., 2023. The role of culture in stakeholder engagement: its implication for open innovation. J. Open Innov.: Technol., Mark., Complex. *9* (2), 100058 https://doi.org/10.1016/j.joitmc.2023.100058.

Ragazou, K., Passas, I., Garefalakis, A., Dimou, I., 2022. Investigating the research trends on strategic ambidexterity, agility, and open innovation in SMEs: perceptions from bibliometric analysis. J. Open Innov.: Technol., Mark., Complex. *8* (3), 118 https://doi.org/10.3390/joitmc8030118.

Raza-Ullah, T., Bengtsson, M., Kock, S., 2014. The coopetition paradox and tension in coopetition at multiple levels. Ind. Mark. Manag. *43* (2), 189–198. https://doi.org/10.1016/j.indmarman.2013.11.001.

Razmdoost, K., Alinaghian, L., Chandler, J.D., Mele, C., 2023. Service ecosystem boundary and boundary work. J. Bus. Res. *156* (November 2022), 113489 https://doi.org/10.1016/j.jbusres.2022.113489.

Rouyre, A., Fernandez, A.-S., Bruyaka, O., 2024. Big problems require large collective actions: managing multilateral coopetition in strategic innovation networks. Technovation *132*, 102968. https://doi.org/10.1016/j.technovation.2024.102968.

Rungtusanatham, M., Salvador, F., Forza, C., Choi, T.Y., 2003. Supply-chain linkages and operational performance. Int. J. Oper. Prod. Manag. *23* (9), 1084–1099. https://doi.org/10.1108/01443570310491783.

Silva, A., Dionisio, A., Almeida, I., 2020. Enabling cyber-physical systems for industry 4.0 operations: a service science perspective. Int. J. Innov. Technol. Explor. Eng. *9* (8), 838–846. https://doi.org/10.35940/ijitee.H6804.069820.

Silva, A., Dionísio, A., Coelho, L., 2020. Flexible-lean processes optimization: a case study in stone sector. Results Eng. *6* (March), 100129 https://doi.org/10.1016/j.rineng.2020.100129.

Silva, A., Gil, M., 2020. Industrial processes optimization in digital marketplace context: a case study in ornamental stone sector. Results Eng. *7* (April), 100152 https://doi.org/10.1016/j.rineng.2020.100152.

Silva, A., Gil, M.M., Duarte, E., 2020. Service innovation | A service blueprinting for industry 4. 0. Int. J. Sci.: Basic Appl. Res. (IJSBAR) 24535.

Silva, A., & Marques Cardoso, A. (2023). BIM-based Supply Chain in AEC - Threats on the Portuguese Stone sector. In I. 978-972-778-327-4 (Ed.), Proceedings of the 7th Globalstone Congress, Batalha, 2023; ISBN 978-972-778-327-4. ⟨https://repositorio.lneg.pt/bitstream/10400.9/4150/1/GSC2023_PT⟩ Natural Stones-Commercial Names harmonization.pdf.

Silva, A., Pata, A., 2022. Value Creation in Technology Service Ecosystems - Empirical Case Study. In: Machado, J., Soares, F., Trojanowska, J., Ivanov, V., Antosz, K., Ren, Y., Manupati, V.K., Pereira, A. (Eds.), Innovations in Industrial Engeneering II. Springer International Publishing, pp. 26–36. https://doi.org/10.1007/978-3-031-09360-9_3.

Silva, A., Rabadão, C., Capela, C., 2020. Towards Industry 4.0 | A case study of BIM deployment in ornamental stones sector. Int. J. Innov. Technol. Explor. Eng. (IJITEE) *67*, 24535 https://doi.org/ISSN 2307-4531.

Tsai, W., 2002. Social structure of "coopetition" within a multiunit organization: Coordination, competition, and intraorganizational knowledge sharing. Organ. Sci. *13* (2), 179–190. https://doi.org/10.1287/orsc.13.2.179.536.

Vargo, Stephen L., 2023. Conceptual reconciliation for clarity and impact. AMS Rev. *13* (3–4), 169–172. https://doi.org/10.1007/s13162-023-00271-5.

Vargo, Stephen L., Akaka, M.A., Wieland, H., 2020. Rethinking the process of diffusion in innovation: a service-ecosystems and institutional perspective. J. Bus. Res. *116* (December 2018)), 526–534. https://doi.org/10.1016/j.jbusres.2020.01.038.

Vargo, Stephen L., Fehrer, J.A., Wieland, H., Nariswari, A., 2024. The nature and fundamental elements of digital service innovation. J. Serv. Manag. *35* (2), 227–252. https://doi.org/10.1108/JOSM-02-2023-0052.

Vargo, Stephen L., Lusch, R.F., 2004a. The four service marketing myths: remnants of a goods-based, manufacturing model. J. Serv. Res. *6* (4), 324–335. https://doi.org/10.1177/1094670503262946.

Vargo, Stephen L., Lusch, R.F., 2004b. Evolving to a new dominant logic for marketing. J. Mark. *68* (1), 1–17. https://doi.org/10.1509/jmkg.68.1.1.24036.

Vargo, S., Lusch, R., 2016. Institutions and axioms: an extension and update of service-dominant logic. J. Acad. Mark. Sci. *44* (1), 5–23. https://doi.org/10.1007/s11747-015-0456-3.

Vargo, S.L., Lusch, R., 2017. Service-dominant logic 2025. Int. J. Res. Mark. *34* (1), 46–67. https://doi.org/10.1016/j.ijresmar.2016.11.001.

Vargo, Stephen, Lusch, R., 2019. The SAGE Handbook of Service-Dominant Logic. The SAGE Handbook of Service-Dominant Logic. https://doi.org/10.4135/9781526470355.

Vargo, Stephen, L., Wieland, H., O'Brien, M., 2023. Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline. J. Bus. Res. *164*, 113965 https://doi.org/10.1016/j.jbusres.2023.113965.

Vargo, S., Wieland, H., Akaka, M., 2015. Innovation through institutionalization: a service ecosystems perspective. Ind. Mark. Manag. *44* (2013)), 63–72. https://doi.org/10.1016/j.indmarman.2014.10.008.

West, J., Bogers, M., 2017. Open innovation: current status and research opportunities. Innovation *19* (1), 43–50. https://doi.org/10.1080/14479338.2016.1258995.

Wieland, H., Hartmann, N., Vargo, S., 2017. Business models as service strategy. J. Acad. Mark. Sci. *45* (6), 925–943. https://doi.org/10.1007/s11747-017-0531-z.

Wiesner, S., Thoben, K.D., 2017. Requirements for models, methods and tools supporting servitisation of products in manufacturing service ecosystems. Int. J. Comput. Integr. Manuf. *30* (1), 191–201. https://doi.org/10.1080/0951192X.2015.1130243.

Xie, Q., Gao, Y., Xia, N., Zhang, S., Tao, G., 2023. Coopetition and organizational performance outcomes: a meta-analysis of the main and moderator effects. J. Bus. Res. *154* (October 2022), 113363 https://doi.org/10.1016/j.jbusres.2022.113363.

Yazdinejad, A., Zolfaghari, B., Dehghantanha, A., Karimipour, H., Srivastava, G., Parizi, R., 2023. Accurate threat hunting in industrial internet of things edge devices. Digit. Commun. Netw. 9 (Issue 5), 1123–1130. https://doi.org/10.1016/j.dcan.2022.09.010.

Yun, J.J., Zhao, X., Liu, Z., 2024. Regulation architecture of open innovation under digital transformation: case study on telemedicine and for-profit-hospital. J. Open Innov.: Technol., Mark., Complex. *10* (1), 100252 https://doi.org/10.1016/j.joitmc.2024.100252.

applied system innovation

MDPI

Article

Advancing BIM and Sustainability with Coopetition: Evidence from the Portuguese Stone Industry

Agostinho da Silva [1,2,*] and Antonio J. Marques Cardoso [1]

[1] CISE—Electromechatronic Systems Research Centre, University of Beira Interior, 6201-001 Covilhã, Portugal
[2] CIGEST—Centre for Research in Management, Lisbon Business School, 1700-284 Lisboa, Portugal
* Correspondence: agostinho.antunes.silva@ubi.pt

Abstract: The construction industry plays a crucial role in the global economy but faces persistent challenges such as inefficiency, high costs, and significant environmental impact. Building Information Modelling (BIM) has been proposed as a solution to enhance efficiency and sustainability through digital representations of construction projects. However, the full potential of BIM has yet to be realized. A contributing factor to this gap is that construction manufacturing companies, which produce upstream parts and products used downstream in construction, are often overlooked in discussions of BIM's benefits. This study explores the potential of coopetition networks to help manufacturing companies better align with BIM dimensions. Coopetition networks, which integrate competitive and cooperative strategies, present a promising method to enhance the effectiveness of manufacturing companies. Focusing on the Portuguese Ornamental Stone industry, the study employs an experimental pilot network facilitated by the Industrial Internet of Things (IIoT) to assess the effects of competition on labour productivity, on-time delivery, and environmental performance among stone companies. The findings indicate that coopetition networks significantly improve alignment with BIM requirements, enhancing operational efficiency and sustainability. Despite being limited by a small sample size, this research offers valuable insights into the role of manufacturing companies in BIM-enhanced construction projects and the broader applicability of coopetition networks in advancing BIM objectives. These results highlight the potential of coopetition networks as a strategic approach to improving performance in the construction industry.

Keywords: coopetition; construction industry; BIM; ornamental stone; sustainable development goals

check for updates

Citation: Silva, A.d.; Cardoso, A.J.M. Advancing BIM and Sustainability with Coopetition: Evidence from the Portuguese Stone Industry. *Appl. Syst. Innov.* **2024**, *7*, 70. https://doi.org/10.3390/asi7040070

Academic Editors: Mario Di Nardo and Maryam Gallab

Received: 1 June 2024
Revised: 9 August 2024
Accepted: 15 August 2024
Published: 19 August 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The construction industry is a cornerstone of the global economy, with projected growth expected to exceed USD 4.2 trillion over the next 15 years [1]. Despite its significance, this industry faces persistent challenges, including inefficiency, high costs, prolonged timelines, and substantial ecological impacts [2]. These issues have prompted governments and scholars to advocate for adopting Building Information Modelling (BIM) [3], which promises to enhance efficiency and sustainability in construction by creating comprehensive digital representations of physical and functional characteristics [4].

However, despite intense activity surrounding BIM and its numerous potential benefits, its practical impact has yet to be fully realized [5]. One reason for this gap may be that construction manufacturing companies [6], which are responsible for producing upstream parts and products used downstream in construction, are often overlooked in discussions of BIM's potential benefits found in the management literature [7].

This oversight results in a significant gap in understanding how construction manufacturing companies operating upstream in the construction process can align their operations to meet the requirements of various BIM dimensions [8]. Given that a specific construction element produced by a manufacturing company impacts the construction project regarding time, cost, and ecological footprint—representing the fourth, fifth, and sixth BIM

dimensions—it follows that to fully realize BIM's potential, construction manufacturing companies must effectively align their production with these dimensions [9].

A promising approach to addressing current enterprise challenges arising from global digitalization is the concept of coopetition networks [10], which combine competition and cooperation for mutual benefits [11]. Recommended by official entities to respond to the modern challenges faced by SMEs, such as those outlined by the European Union [12], coopetition could be a solution for aligning construction manufacturing company activities with BIM requirements.

Among the various industrial sectors supplying the construction industry, the ornamental stone sector has always been a significant contributor [13]. This sector, primarily composed of SMEs, provides elements for cladding, kitchen tops, and other applications essential for sustainable construction [14]. Can coopetition networks facilitate the alignment of ornamental stone companies with BIM requirements?

To address this question, this study evaluates the potential of coopetition networks to meet BIM requirements within the Portuguese Ornamental Stone industry (OS-PT), a key sector in the national economy [15]. The investigation employs a case study methodology conducted through a coopetition experimental pilot network (CEPN) facilitated by an Industrial Internet of Things (IIoT) artifact to connect the companies involved digitally. The study includes selected companies in the OS-PT sector and aims to determine whether adopting coopetition practices enables these companies to better align with BIM requirements.

Due to cost constraints, the CEPN includes only three OS-PT companies. Despite this limitation, the study's findings provide valuable insights into the role of construction manufacturing companies in BIM-enhanced construction projects and highlight the potential impact of coopetition networks operating upstream in realizing BIM benefits downstream.

2. BIM as a Potential Response to an Efficient Construction Industry

The construction industry has been criticized for generating avoidable waste, reflected in high costs, extended project timelines, and significant ecological footprints [16]. In response, governments and industry practitioners have supported the gradual implementation of BIM to increase transparency [3] and efficiency [6].

BIM has evolved as a successor to CAD in the construction industry [17]. Driven by government directives, the construction industry is now at the forefront of incorporating BIM into its practices, motivated by cost reduction goals, shortened project timelines, and alignment with sustainability principles [18]. This integration signifies a significant shift towards more responsible and efficient design and construction methodologies [19].

BIM represents a paradigm shift in conceptualizing, executing, and managing construction projects. At its core, it provides a digital twin of physical construction [20]. The essence of BIM technology lies in creating a digital representation that mirrors every facet of physical construction [21]. However, this has led to some confusion in the industry regarding the conflation of BIM maturity level with BIM dimensions [22]. BIM maturity refers to the sophistication level at which the supply chain can exchange information, highlighting the collaborative capabilities of the involved parties. In contrast, BIM dimensions encompass the various data types attached to a model, adding depth and insight into the project's lifecycle [23].

Incorporating data dimensions within a BIM context allows for unparalleled comprehension of the construction process [24]. Designers and stakeholders gain a holistic view of the project, including initial design, work stages, delivery methods for each component, budgeting, and maintenance plans. These dimensions foster a more refined management approach [25].

While the first three dimensions (3D BIM) relate to the solid geometry of objects, the fourth dimension (4D BIM) integrates the crucial aspect of time, marking a significant evolution in project management and coordination within the construction industry [25]. By incorporating project timelines directly into BIM models, 4D BIM introduces a dynamic

and interactive approach to planning, allowing for real-time visualization of construction sequences [17].

The fifth dimension (5D BIM) focuses on cost management within construction projects by integrating financial data with each component in the digital model [26]. This holistic approach transforms budgeting into a dynamic, detail-oriented process, enabling immediate visibility and ongoing updates on the financial impacts of design choices and manufacturing changes throughout the project's duration [27].

The sixth dimension (6D BIM) focuses on sustainability by integrating environmental sustainability metrics directly into the building information model [28]. This provides real-time insights into the ecological footprint of materials and processes throughout a project's lifecycle, equipping professionals with the tools to make decisions that adhere to sustainability objectives [29].

Beyond these, BIM includes other dimensions, particularly maintenance and construction safety, allowing for a holistic view of the process from project inception to demolition [9]. However, to realize the full potential of BIM, construction manufacturing companies must effectively address, contribute to, and meet these BIM dimensions.

A fundamental assumption of this study is that some indicators of construction manufacturing companies—low cost, completion on time, and sustainability—are crucial for realizing the benefits of BIM. This assumption is supported by the existing literature, which explicitly indicates the relevance of these performance aspects.

Cost Efficiency: BIM enables precise cost estimation and budget management (5D BIM), directly linking to the performance aspect of low waste [30]. Manufacturing companies that excel in cost management contribute to more accurate financial planning and control, reducing the risk of budget overruns and ensuring financial efficiency throughout the project lifecycle [26]. By integrating cost data into BIM models, these companies help identify cost-saving opportunities and optimize resource allocation, which is essential for achieving overall project cost efficiency [19].

Timely Completion: Integrating project schedules into BIM models (4D BIM) enhances time management by providing the real-time visualization of construction sequences. Companies that adhere to timelines can leverage BIM to synchronize their activities with other stakeholders, minimizing delays and improving coordination [25]. Effective time management by construction manufacturing companies ensures that project milestones are met, contributing to the timely completion of construction projects and enhancing overall project efficiency [31].

Sustainability: The focus on sustainability in BIM (6D BIM) aligns with the performance aspect of environmental responsibility. Construction manufacturing companies that prioritize sustainable practices can integrate environmental data into BIM models, enabling the assessment of the ecological impact of materials and processes [28]. These companies contribute to reducing the ecological footprint of construction projects, ensuring that sustainability goals are met [32]. Their commitment to sustainability enhances the long-term viability of construction projects and supports industry-wide environmental objectives [33].

By focusing on these three performance aspects, manufacturing companies can significantly facilitate the benefits of BIM at the project level. These performance indicators are not only aligned with the core objectives of most construction projects but are also critical for maximizing the potential of BIM dimensions. Therefore, the adequate performance of suppliers in these three areas plays an important role in enhancing project outcomes, ensuring that BIM's benefits in terms of cost, time, and sustainability are fully realized.

3. Literature Review

The concept of "coopetition", initially introduced during the 1980s [34] by Ray Noorda, the founder and CEO of Novell, gained prominence in business strategy through the influential work of Nalebuff and Brandenburger (1997). Their work marked a significant shift in understanding competitive dynamics [35]. Over the years, coopetition has

garnered substantial attention within strategic management, evolving through various interpretations and applications [36].

Despite its widespread discussion, the definition of coopetition remains varied, with interpretations spanning different goals, relationships, and organizational contexts [37]. It has been described as a strategy that encompasses the simultaneous pursuit of cooperation and competition among firms, a hybrid activity within the same business entities, and a complex interplay that affects competitive dynamics among different market players [11].

At the nexus of coopetition and networks, a strategic orientation centred around innovation emerges, essential for firms seeking to bridge competitive gaps and effectively manage market challenges [38]. This orientation emphasizes coopetition's role in navigating competitive terrains and highlights its potential as a catalyst for transformative growth and resilience [10]. Studies show a wide range of findings, underscoring the need for a more unified and in-depth exploration of value co-creation processes in these complex networks [39].

A comprehensive review by Meena, Dhir, and Sushil (2023) reveals that coopetition has been examined through various theoretical lenses, such as Game Theory, Resource-Based View, Paradox Theory, Transaction Cost Theory, and Network Theory [36]. Each perspective, while insightful, often addresses the concept within its specific confines. Regardless of the diversity in definitions, the essence of coopetition converges on the notion of a hybrid relationship where competition and collaboration intertwine to benefit the involved companies [40]. It is particularly relevant in digital supply chains [10].

In the context of manufacturing companies, coopetition is a means to improve efficiency and achieve economies of scale [41]. Specifically, for construction manufacturers, collaboration among competitors holds significant potential, particularly in facilitating the benefits of BIM at the project level [42]. Complex projects require high levels of coordination among various stakeholders, including construction manufacturing companies [43]. Coopetition among these companies can lead to enhanced innovation, better resource utilization, and improved project outcomes. By collaborating on BIM implementation while maintaining competitive drives, companies can share knowledge, reduce costs, and accelerate project timelines [44].

The construction industry faces numerous challenges, such as fragmented supply chains, project delays, and cost overruns [45]. These challenges can be mitigated through effective collaboration and competition among manufacturers, where coopetition becomes highly relevant [11]. By forming coopetitive networks, construction manufacturing companies can integrate their resources and expertise to optimize construction processes [6]. This integration allows for real-time data sharing, improved accuracy in project planning, and more efficient execution of construction activities.

Coopetition in construction manufacturing enhances BIM benefits and fosters a culture of continuous improvement and innovation [42]. When companies cooperate, they can collectively invest in advanced BIM technologies and training programs, leading to higher BIM proficiency across the industry [36]. Simultaneously, the competitive aspect drives each company to strive for excellence, ensuring they remain at the forefront of technological advancements and best practices.

Moreover, coopetition can facilitate the standardization of BIM protocols and practices within the construction industry. Standardization is crucial for ensuring compatibility and interoperability between different BIM systems and tools used by various stakeholders [21]. Through coopetition networks, companies can work together to establish industry-wide standards that streamline BIM adoption and implementation, ultimately leading to more cohesive and successful project outcomes.

The strategic paradigm of coopetition networks represents a powerful approach to harnessing the dual forces of cooperation and competition to foster innovation, enhance competitive advantage, and achieve collective success [11]. This dynamic interplay is particularly intriguing for navigating the complexities of the construction industry and enhancing BIM benefits [27]. Studies have shown that companies can effectively integrate

BIM technologies through coopetition, leading to better project management, reduced errors, and increased efficiency.

4. Methodology

The case study method is invaluable for examining the interface between a phenomenon and its context. It offers a structured approach for event analysis, data collection, and result reporting [46]. This methodology allows researchers to deeply understand the underlying reasons and identify potential future research directions related to the studied instance [47].

Building on the concept of coopetition networks as facilitators of the alignment of ornamental stone companies with BIM requirements, a case study methodology is used to quantitatively assess the contribution of a coopetition network in enhancing BIM dimensions. This quantitative approach provides a structured framework for event analysis, data collection, and result reporting [46], offering a detailed examination of the phenomenon's interface and context. It also aids in understanding the underlying reasons and identifying potential future research directions related to the case study [47].

To facilitate data collection, the CEPN was implemented in the Portuguese ornamental stone sector, involving a series of sequential steps:

Participant Selection: Stone companies meeting specific criteria were identified and selected for participation. Criteria included technological capability, willingness to collaborate, and relevance to the construction industry.

CEPN Implementation: The selected companies were connected using appropriate technology. A process for data collection was established to ensure real-time data collection and analysis.

Metric and KPI Definition: Metrics and KPIs were defined to evaluate the benefits of coopetition networks in meeting BIM dimension requirements. These metrics focused on time response (4D BIM), price (5D BIM), and ecological footprint (6D BIM).

Data Collection and Analysis: Data on the defined KPIs were gathered through the CEPN by monitoring and recording the performance of the coopetition network in real time. The collected data were analysed to evaluate improvements and gain insights into the effectiveness of coopetition networks in enhancing BIM benefits.

Outcome Evaluation: Assessing the extent to which coopetition networks can facilitate the alignment of ornamental stone companies with BIM requirements.

Outcome Evaluation: assessing the extent to which coopetition networks can facilitate the alignment of ornamental stone companies with BIM requirements.

5. Participant Selection

The Ornamental Stone sector, a cornerstone of Portugal's rich cultural heritage and forward-looking innovation, has significantly contributed to iconic stone monuments worldwide since the 15th century [48]. Leveraging Portuguese stone, engineering prowess, and generations of accumulated expertise, the OS-PT sector is deeply woven into the fabric of the nation's identity [49]. As the 21st century progresses, Portugal has solidified its position as a leading producer of stone products, skilfully integrated into the global construction industry, a testament to its competitive edge on the international stage despite the country's modest geographic footprint [50].

Portugal's ornamental stone industry, characterized by its vast and varied stone reserves, plays a crucial role in the global market. The shift towards digital collaborative efforts with customers and architects worldwide underscores a dynamic evolution; the sector's traditional strengths are being repurposed through innovation [15]. This emerging digital engagement, though still developing, is pinpointed as a critical growth avenue for Portuguese stone providers.

According to the Portuguese Stone Federation (2022), the OS-PT sector exports to 116 countries, ranks as the ninth most significant player in the World International Stone Trade, and secures the second position globally regarding international trade per capita.

With exports outstripping imports by 660% and a significant share of exports reaching markets outside Europe, the industry boasts a turnover of EUR 1.230 million. It supports over 16,600 direct jobs, making it a critical employment source, particularly in inland regions [51].

The strategic implementation of the CEPN began by establishing direct and informal communication channels with the managing directors of potential participant companies. Multiple contacts and evaluations with companies revealed three significant operational constraints.

The first constraint was the limited number of companies with technologically connectable production means. To address this issue, 43 of 661 transforming companies were evaluated in person, of which 23 were pre-selected for having production means technologically connectable to a digital platform.

The second constraint was related to the logistical costs for the research team to operationalize data collection for the CEPN. It was observed that the larger the number of companies involved and the longer the data collection period, the higher the costs involved. Given the budget limitations and the "pilot" nature of the experimental project, it was determined that the CEPN should consist of a network of only three companies, with each data collection period not exceeding 60 days.

The third constraint was the companies' discomfort with sharing critical data and information. To address this, a comprehensive confidentiality agreement was drafted to protect sensitive information regarding the companies' operations, clientele, employees, resources, and competitors.

As a result of these trade-offs, three OS-PT companies were formally invited to participate in the study, and the respective confidentiality agreements were signed. To ensure anonymity, the three anonymized companies are designated as "A", "B", and "C".

6. Implementation of the Coopetition Experimental Pilot Network

The emergence of the IoT marks a transformative era, significantly influencing ecosystems through sophisticated sensor technologies that enhance connectivity and data exchange [52]. Building on traditional IoT frameworks, IIoT introduces intelligence to industrial settings, facilitating direct device-to-device communication and supporting the creation of intelligent artefacts that dynamically adapt to user interactions and enhance value co-creation [53]. Empirical evidence highlights the transformative potential of IIoT-based innovations in fostering novel service offerings, such as remote control and predictive maintenance solutions [54]. These capabilities advance operational efficiency and open new avenues for value co-creation within coopetition frameworks, expanding service portfolios and enhancing enterprises' competitive and cooperative capacities [55].

An example in the OS-PT sector is an IIoT artefact developed through the Inovstone4.0 R&D Project [18]. This IIoT system was designed to connect ornamental stone companies with the digital market [49], refining product specifications and promoting value co-creation between providers and customers, thereby improving customization and operational productivity [56].

The current state of Cockpit4.0 epitomizes the IIoT capacity to redefine market dynamics through direct engagement and collaborative efforts.

Although developing IIoT technology was not within the scope of this research, Cockpit4.0, representing the state-of-the-art in the OS-PT [57], was evaluated as a starting point for transforming the operational technology that facilitates coopetition in the CEPN. This required some additional developments to the artefact. To further harness this potential, new functionalities were added to Cockpit4.0, such as enabling secure connections between competitor firms, resulting in an advanced version called Cockpit4.0+ for this research. This new IIoT artefact, specifically designed to connect rival OS-PT firms, brought enhanced technological capabilities and fostered a collaborative industrial environment conducive to a coopetition network.

OPC-UA (Open Platform Communications Unified Architecture) is a crucial protocol for IIoT because it enables secure and reliable communication between diverse industrial devices and systems [53]. It provides a standardized framework that facilitates interoperability and data exchange across different platforms and manufacturers, essential for the seamless integration of various components in an IIoT ecosystem.

OPC-UA allows different devices and systems to communicate and work together, regardless of their underlying technology. This is vital in IIoT environments where equipment from multiple vendors must interact efficiently [58].

Embedding OPC-UA Cockpit4.0+ bridges gaps in connectivity, efficiency, and responsiveness, fostering an ecosystem where firms thrive through collective innovation and adaptive strategies. Cockpit4.0+ integrates technological innovations like artificial intelligence to promote a collaborative industrial environment, ensuring sustainable operations and maintaining SMEs' competitiveness in a dynamic market.

Once Cockpit4.0+ was available, even as a prototype, the implementation of the CEPN began. Three companies recognized as leaders in the OS-PT sector were formally connected (Figure 1) in a real cooperation network. These companies could now operate in some domains, like a single factory linked to BIM architects' stations, regardless of their geographical locations.

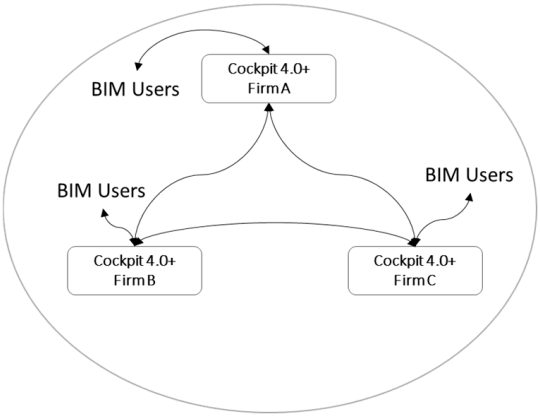


Figure 1. Coopetition experimental pilot network (CEPN).

In each company involved in the CEPN, a Cockpit4.0+ was installed, ensuring secure connectivity between the network companies and capturing potential connections to BIM operators interested in prescribing customized stone on a global scale.

7. Metrics and KPIs Definition

The BIM benefits depend on how each building element meets the requirements of the different BIM dimensions. The 4D BIM requires transparency, accountability, and more effective communication [59] to ensure dynamic on-time delivery. To meet 4D BIM requirements, the stone manufacturers must enhance their scheduling, coordination, and productivity processes, responding positively to the crucial aspect of delivery time [17].

To evaluate this response, the on-time delivery (KPI_{OtD}) indicator can be used, as it measures the OS-PT's ability to consistently meet project deadlines. For this study, KPI_{OtD} is calculated as the percentage of stone parts delivered within the agreed timeframe (Equation (1)). Improvements in KPI_{OtD} directly enhance the effectiveness of 4D BIM by ensuring timely project execution and adherence to schedules.

$$KPI_{OtD}\ (\%) = \sum_1^n \left(\frac{parts_delivered_on_time_{(daily)}}{parts_delivered\ _{(daily)}} \right) \quad (1)$$

A 5D BIM integrates cost data with the 3D model, enabling comprehensive budget and financial management throughout the project lifecycle [27]. BIM's benefits for construction

require that components meet the necessary quality at the lowest cost. Consequently, stone manufacturing companies must respond positively in terms of component cost. For OS-PT to be aligned with 5D BIM, their manufacturing processes must optimize resources to enhance efficiency, using both human and technological resources better to lower waste and costs.

According to the literature on lean management, one way to measure industry efficiency is through labour productivity, which relates output to the labour involved [5]. Therefore, for this study, the indicator for labour productivity (KPI_{LP}) has been selected to evaluate the number of stone parts a worker completes within a specified timeframe, indicating the efficiency of labour use (Equation (2)). By enhancing labour productivity, stone companies can better meet the requirements of 5D BIM.

$$\mathrm{KPI_{LP}}\ (\%) = \sum_1^n \left(\frac{parts_produced_{(daily)}}{workers_involved_{(daily)}} \right) \quad (2)$$

The 6D BIM focuses on sustainability by incorporating environmental data into the BIM model to manage and reduce the ecological footprint of construction projects [29]. This requires manufacturers to use raw materials and processes efficiently to minimize the environmental impact of building materials [60].

To evaluate how a stone company can meet this requirement, the CO2 equivalent (CO2-eq) factor must be considered [61]. This indicator converts the energy consumed into equivalent carbon dioxide emissions, providing a standardized measure of environmental impact..The integration of power networks within the EU makes calculating the CO2 equivalent per country challenging. In Portugal, for example, meeting energy demand during critical periods often requires importing energy produced in other European countries. Therefore, the average European CO2 equivalent factor should be adopted for this case study.

According to the European Electricity Review (2023), the carbon intensity of electricity in Europe varies significantly among different EU member states due to their diverse energy mixes [62]. For instance, countries like Sweden and France have much lower carbon intensities (below 50 g CO_2/kWh) due to their heavy reliance on nuclear and renewable energy sources [62]. In contrast, countries like Poland and Estonia have higher carbon intensities (over 600 g CO_2/kWh) due to their dependence on coal and other fossil fuels. As of 2022, the EU's average carbon intensity of electricity generation was 276 g of CO_2 per kilowatt-hour (g CO_2/kWh).

Equation (3) can be used to evaluate the CO2 equivalent ($KPI_{CO2\text{-}eq}$) for producing stone parts, reflecting the energy consumed per part produced.

$$\mathrm{KPI_{CO2\text{-}eq}(KgCO2/part)} = \sum_1^n \left(\frac{energy_consumed_{(daily)}}{parts_produced_{(daily)}} \right) \times 0.276 \quad (3)$$

Reductions in $KPI_{CO2\text{-}eq}$ directly impact the construction industry's CO2 emissions and contribute to the Sustainable Development Goals (SDGs), particularly SDG 11: Sustainable Cities and Communities, by promoting environmentally responsible practices and reducing urban carbon footprints [63].

8. Measuring the Impact of Coopetition vs. No Coopetition

This study evaluates coopetition against scenarios where such interactions are absent (no coopetition). The objective is to understand how coopetition influences the KPIs mentioned above in a manufacturing context. The independent variables considered include Parts Delivered, Parts Delivered On Time, Parts Shipped, Labour Hours Involved, Energy Consumed, and Parts Produced. These variables reflect the companies' operational efficiency, productivity, and sustainability.

To distinguish between cooperative and non-coopetition scenarios, the study employs a comparative analysis of company outputs during periods of active cooperation and periods when companies operated independently (no cooperation).

This approach evaluated the transition from current practices (CB.P) to a new concept of practices, referred to as coopetition network practices (CN.P), where companies, facilitated by the Cockpit4.0+, share manufacturing resources and raw material stocks to capture market opportunities from BIM users.

The CN.P phase involved structured collaborations among companies, sharing resources, knowledge, and logistics while maintaining competitive aspects. Current practices (CB.P) refer to the no-coopetition phase, a period when companies operate without such collaborative interactions, relying solely on their internal capabilities and strategies.

The independent variables were measured as follows:

- Parts Delivered: The total number of parts delivered to customers during the observation period.
- Parts Delivered On Time: The percentage of parts delivered within the agreed-upon time frame, reflecting the companies' ability to meet deadlines.
- Parts Shipped: The total number of parts shipped out, indicating the companies' logistical and production capabilities.
- Labour Hours Involved (h): The total labour hours expended in production provide insight into workforce efficiency and productivity.
- Energy Consumed (kWh): The total energy consumed during production, which is critical for assessing sustainability and energy efficiency.
- Parts Produced: The total number of parts manufactured during the period, reflecting overall production output.

The study acknowledges that the outputs of the companies could be influenced by other factors, such as time lapses or learning effects. To isolate the impact of coopetition, these potential confounding factors were controlled by comparing performance metrics during similar time periods and by normalizing data to account for seasonal variations or other external influences. This approach helps ensure that the observed differences in performance metrics can be more confidently attributed to the presence or absence of co-opetition.

Coopetition, as a strategic approach, can be considered a latent (hidden) variable that influences the observed outputs. This study operationalizes coopetition through structured interactions between companies, such as joint resource utilization, shared logistics, and coordinated production schedules. By comparing the independent variables under co-opetition and non-coopetition scenarios, the study aims to reveal the underlying effects of coopetition on operational performance.

To strengthen the analysis, additional qualitative insights were gathered from company management and operational staff to understand the nature and extent of competition during the study period. This helped contextualize the quantitative findings and provided a clearer picture of how coopetition practices were implemented and their perceived impact on company performance.

9. Data Collection and Analysis

A data collection strategy was implemented across two fifty-four-day intervals to assess how coopetition networks influence the selected KPIs.

The first 54-day period, conducted in June and July 2023, was focused on capturing current best practices at the anonymized companies. This baseline phase documented each company's reliance on internal resources for production and delivery, providing essential reference data for subsequent comparisons. Table 1 presents a summary of the average data collected under CB.P.

Table 1. Summary of average data collected under CB.P.

Data ID	Description	Current Practices (CB.P)	Data (Average Daily)
Data 1	Parts Delivered	parts_delivered	339
Data 2	Parts Delivered On Time	parts_delivered_on_time	240
Data 3	Parts Shipped	parts_shipped	338.5
Data 4	Labours Involved (h)	labour_involved	49.3
Data 5	Energy Consumed (kWh)	energy consumed producing parts	4692
Data 6	Parts Produced	parts_produced	369.9

The second 54-day period, concluding in November 2023, assessed the effects of integrating the same three OS-PT firms into a CEPN. During this period, the three Cockpit4.0+ systems installed in the companies shared real-time information about the availability of manufacturing resources and raw material stocks. Table 2 presents a summary of the average data collected under CN.P.

Table 2. Summary of average data collected under CN.P.

Data ID	Description	Coopetition Practices (CN.P)	Data (Average Daily)
Data 7	Parts Delivered	parts_delivered	454
Data 8	Parts Delivered On Time	parts_delivered_on_time	358
Data 9	Parts Shipped	parts_shipped	415.8
Data 10	Labours Involved (h)	labour_involved	49.3
Data 11	Energy Consumed (kWh)	energy consumed producing parts	4071
Data 14	Parts Produced	parts_produced	416

Data management and privacy were maintained throughout the study in compliance with confidentiality agreements. All data were anonymized and referred to only by company labels. Data collection, recording, and exportation procedures were followed, with results exported to Excel files as detailed in the methodology section. This ensured a secure and consistent approach to data handling, enabling detailed analysis while safeguarding the privacy and proprietary information of the participating companies.

Table 3 shows the assessment of KPIs for both CB.P and CN.P. It illustrates the quantitative gains achieved through the implementation of coopetition practices.

Table 3. Assessment of KPIs for CB.P and CN.P.

Key Performance Indicators (KPIs)	CB.P	CN.P	Quantitative Gain
KPI—On-Time Delivery (parts/parts)	0.671	0.775	15.6%
KPI—Labour Productivity (parts/worker)	6.84	8.72	27.38%
KPI—CO_2-eq ($KgCO_2$/part)	3.41	2.68	21.8%

Based on these data, the following section focuses on interpreting the results to determine whether a coopetition network can positively impact stone companies' response to BIM requirements. This interpretation will draw conclusions about the effectiveness of coopetition networks as facilitators in aligning ornamental stone companies with BIM requirements.

10. Outcomes Evaluation

10.1. Meeting the 4D BIM Requirements through Coopetition Networks

The 4D BIM integrates the crucial aspect of time, significantly advancing project management and coordination within the construction industry. By incorporating detailed

scheduling and time-related data into the BIM model, 4D BIM enables real-time visualization of construction sequences, improves planning accuracy, and enhances the ability to foresee and mitigate potential delays. This dynamic approach ensures that projects stay on schedule, fostering greater transparency, accountability, and communication among all stakeholders.

To evaluate how coopetition networks help manufacturing companies meet the requirements of 4D BIM, the KPI_{OtD} was assessed to determine the manufacturers' gains when they evolve from CB.P to CN.P. From the data collected, under CB.P, the KPI_{OtD} was recorded at 67.1%, with 240 out of 339 stone parts delivered as scheduled. Conversely, CN.P significantly increased the KPI_{OtD} to 77.5%, with 358 out of 454 parts delivered on time.

Examining the on-time delivery trend during the observation periods, Figure 2 depicts the percentage of deliveries made on time each day, offering insights into the consistency and reliability of delivery services over the observed period.

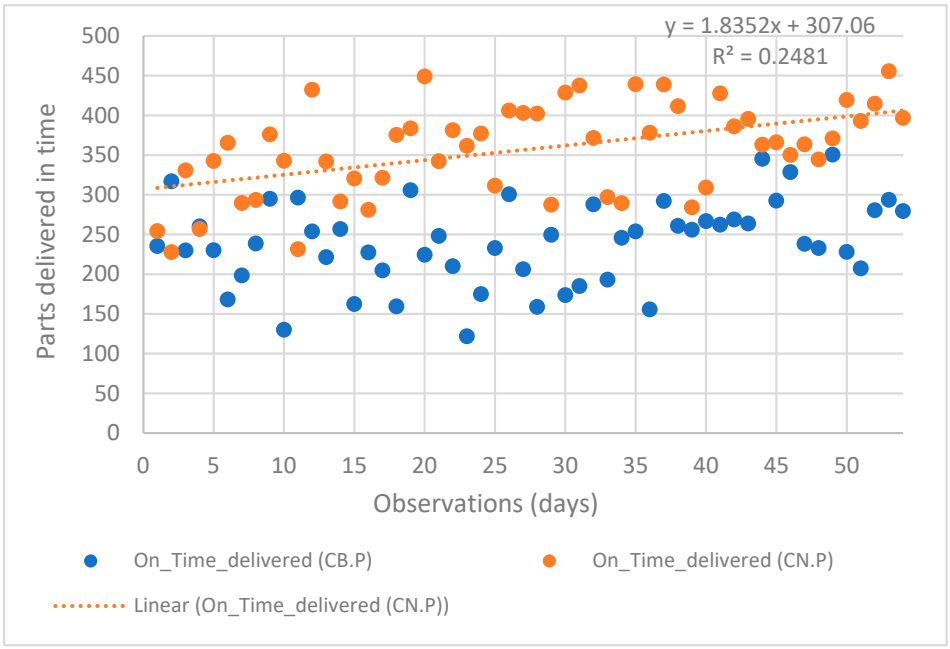


Figure 2. Trend in on-time delivery over 54 daily observations.

The trend in KPI_{OtD} over 54 daily observations is described by the linear equation shown in Figure 2, representing the number of stone parts delivered on time, and x represents the day number. The positive slope of 1.8352 indicates a gradual increase in the number of parts delivered daily on time.

From these results, the companies involved in the CEPN experienced substantial improvements in on-time delivery performance by transitioning to CN.P. The increase from 67.1% to 77.5% demonstrates the potential of coopetition networks in enhancing operational response in time, which is a critical component of the 4D BIM dimension. Despite these positive gains, the coefficient of determination (R^2 = 0.2481) suggests that this linear model can explain approximately 24.81% of the variability in on-time delivery, suggesting a moderate but not linear solid relationship between the days and the on-time delivery of parts.

Although these findings are promising, a statistical test is needed to evaluate whether CN.P makes a significant difference compared to CB.P. A *t*-test is an appropriate method for determining if there is a significant difference between the means of two groups. It assesses whether the observed differences in the sample data can be generalized to the population. The test produces a *p*-value, indicating the probability that the observed differences occurred by chance. A *p*-value less than a chosen significance level (commonly 0.05) suggests that the differences are statistically significant.

In this analysis, considering that the two datasets, CB.P and CN.P, come from the same universe and are paired, a paired *t*-test was used. The *t*-test applied to the datasets CB.P and CN.P resulted in a *p*-value of 23.92×10^{-15}.

This low *p*-value indicates that the probability of observing the difference in means by random chance is exceedingly small, suggesting a highly significant difference between the on-time delivery performance of CB.P and CN.P. Therefore, it can be concluded that the transition to CN.P has resulted in statistically significant improvements in on-time delivery performance.

Under CB.P, the regression model is statistically significant (Significance F = 0.002502), indicating that the relationship between on-time delivery and KPI_{OtD} is meaningful. In contrast, under CN.P, the regression model is not statistically significant (Significance F = 0.612009), suggesting that the relationship between on-time delivery and KPI_{OtD} under coopetition practices is not meaningful. This indicates that the performance of KPI_{OtD} under coopetition practices requires ongoing monitoring, with necessary adjustments to ensure that the shift from current best practices results in actual performance improvements. To fully realize the potential benefits of coopetition, it may be necessary to revisit and refine network practices by enhancing communication, setting clearer goals, and offering better incentives for cooperation.

10.2. Meeting the 5D BIM Requirements through Coopetition Networks

The 5D BIM dimension integrates cost data with the 3D model, enabling comprehensive budget and financial management throughout the project lifecycle. This integration allows for more accurate cost estimation, efficient resource allocation, and continuous cost monitoring. By providing a detailed financial overview linked to the 3D model, 5D BIM helps stakeholders make informed decisions, identify potential cost overruns early, and implement cost-saving measures effectively.

To evaluate how coopetition networks help manufacturing companies meet the requirements of 5D BIM, the KPI_{LP} was assessed to determine the gains from CB.P to CN.P.

Under CB.P, employing an average workforce of 49.9, the OS-PT companies managed a daily shipment of 338.5 stone parts, establishing a labour productivity rate of 6.84 parts per worker. Implementing CN.P enhanced daily output to 415.8 stone parts while maintaining the same workforce size, boosting the KPI_{LP} to 8.72 parts per worker. This significant increase showcases the positive impact of competition on labour efficiency.

To examine the averages more closely, Figure 3 illustrates daily KPI_{LP} over the 54 observation days, highlighting in green the consistently higher productivity under CN.P. This provides clear positive insights into the potential contribution of coopetition networks to improving the benefits of BIM.

The improvement in the KPI_{LP} from 6.84 to 8.72 highlights the ability of coopetition networks to enhance labour productivity. This improvement suggests that stone companies can better meet the requirements of 5D BIM. Increasing productivity makes projects more likely to be completed within budget, enhancing project outcomes and greater market competitiveness.

A paired *t*-test was conducted to evaluate the difference in labour productivity between the two datasets, CB.P and CN.P. Since both datasets are derived from the same universe, they are naturally paired. The *t*-test yielded a *p*-value of 1.7729×10^{-9}, indicating that the transition to CN.P has led to statistically significant improvements in labour productivity.

Under CB.P, the ANOVA Significance F value of 7.4×10^{-23} indicates that the model is highly statistically significant, meaning Labour Productivity under current best practices has a solid and meaningful relationship with KPI_{LP}. In contrast, under CN.P, the ANOVA Significance F value of 0.700662 shows that the model is not statistically significant, suggesting that Labour Productivity under coopetition practices does not have a meaningful relationship with KPI_{LP}. Given these findings, the performance of KPI_{LP} under coopetition practices should be continuously monitored, and adjustments should be made to ensure that the transition from current best practices results in actual performance improvements.

To achieve the intended benefits of coopetition, a thorough reassessment and refinement of these practices may be necessary.

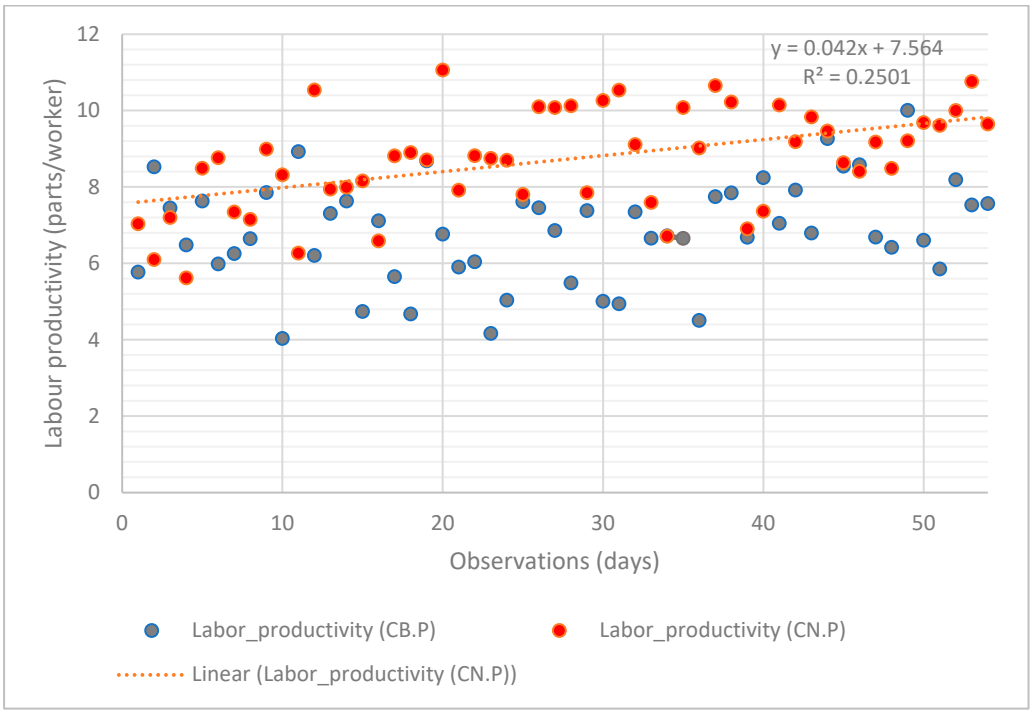


Figure 3. Daily labour productivity across 54 observations.

10.3. Meeting the 6D BIM Requirements through Coopetition Networks

The 6D BIM dimension emphasizes sustainability by integrating environmental data into the BIM process. This integration aims to manage and reduce the ecological footprint of construction projects, promote efficient resource use, minimize waste, and help achieve sustainability goals throughout the project lifecycle. By embedding environmental metrics into the BIM model, 6D BIM provides stakeholders with the tools to analyse and optimize the environmental performance of building materials and processes, ensuring that sustainability considerations are integral to decision-making.

Under the CB.P, the OS-PT companies recorded an energy consumption of 4692 kWh per day, producing a $KPI_{CO2\text{-}Eq}$ of 3.41 kg CO2 per part. With the implementation of CN.P, energy consumption decreased to 4071 kWh per day, reducing the $KPI_{CO2\text{-}Eq}$ to 2.68 kg CO2 per part produced. This represents an average 21.8% reduction in carbon emissions per part.

The analysis of the 54 observation days of CO2 equivalent emissions, as depicted in Figure 4, shows a reduction in emissions under CN.P, illustrated in green. This demonstrates the effectiveness of coopetition networks in enhancing sustainability performance and contributing to the goals of 6D BIM.

A *t*-test was conducted on the emissions data to assess the significance of these improvements. The *t*-test yielded a *p*-value of 7.96775×10^{-8}.

This result suggests a statistically significant difference in environmental performance between CB.P and CN.P. Therefore, it can be concluded that the transition to coopetition networks has resulted in a significant improvement in sustainability, as evidenced by the reduction in carbon emissions per part.

Under CB.P, the ANOVA Significance F value (2.15×10^{-8}) indicates that the model is highly statistically significant, meaning the relationship between CO2 equivalent under current best practices and $KPI_{CO2\text{-}Eq}$ is meaningful. In contrast, under CN.P, the ANOVA Significance F value (0.150532) shows that the model is not statistically significant, indicating that the relationship between CO2 equivalent under coopetition practices and

$KPI_{CO2\text{-}Eq}$ is not meaningful. The transition from current best practices to coopetition network practices significantly reduces the impact of CO2 equivalent on $KPI_{CO2\text{-}Eq}$.

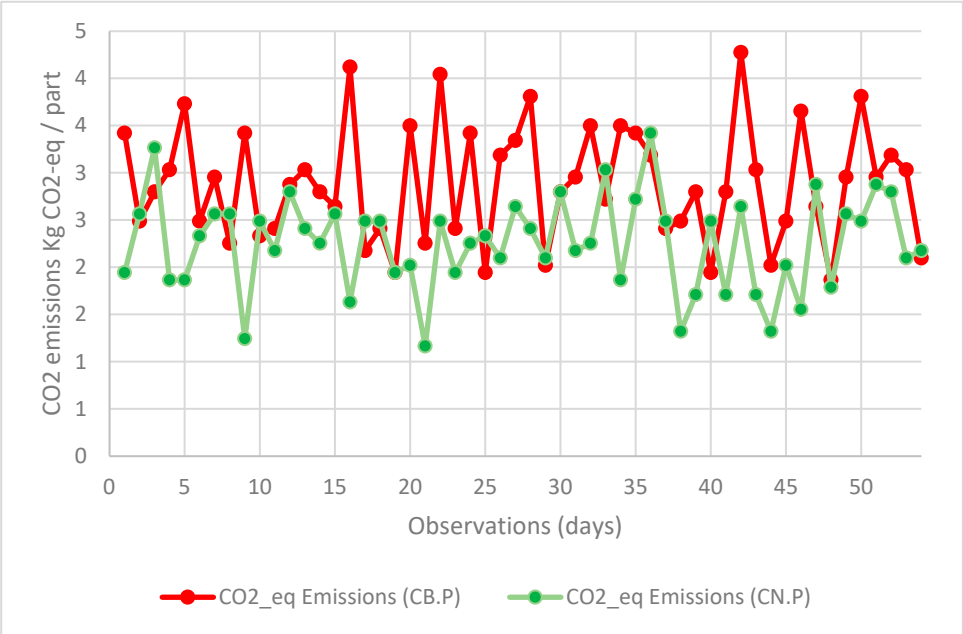


Figure 4. Daily CO2_eq emissions across 54 observation days.

11. Conclusions

The findings reveal that coopetition networks have a significant positive impact on OS-PT companies in terms of their labour productivity, on-time delivery performance, and environmental performance, showing that coopetition networks facilitate the alignment of ornamental stone companies with BIM requirements:

On-time delivery: Coopetition network practices improved on-time delivery rates from 67.1% to 77.5%, reflecting enhanced operational efficiency and response times, which are critical for the 4D BIM dimension. The *t*-test yielded a *p*-value of 223.92×10^{-15}, indicating a highly significant improvement and reinforcing the role of coopetition networks in enhancing project execution.

However, the regression analysis under CB.P shows a statistically significant relationship between on-time delivery and KPI_{OtD}, highlighting that on-time delivery directly influences project performance. In contrast, under CN.P, the regression model is not statistically significant, suggesting that despite the improvement in delivery rates, the relationship between on-time delivery and KPI_{OtD} under coopetition practices could be stronger and more meaningful. This indicates that to fully realize the potential benefits of coopetition, it may be necessary to revisit and refine network practices by enhancing communication, setting more precise goals, and offering better incentives for cooperation.

Labor Productivity: The transition to coopetition network practices increased labour productivity from 6.84 to 8.72, demonstrating enhanced manufacturing efficiency. This potentially leads to reduced costs as required by 5D BIM. The *p*-value of 1.77297×10^{-9} confirms that this improvement is statistically significant, with a very low probability that the observed difference is due to random chance.

However, the correlation analysis presents a more nuanced view. Under CB.P, the ANOVA Significance F value of 7.4×10^{-23} indicates that the relationship between labour productivity and KPI_{LP} is highly statistically significant, meaning that labour productivity under current best practices has a solid and meaningful impact on KPI_{LP}. In contrast, under CN.P, the Significance F value of 0.700662 shows that the relationship between labour productivity and KPI_{LP} is not statistically significant, suggesting that despite the observed improvement in labour productivity, it does not translate into a meaningful

impact on KPILP under coopetition practices. Given these findings, while the transition to coopetition practices has led to an increase in labour productivity, the performance of KPI_{LP} under coopetition practices should be continuously monitored, and adjustments should be made as necessary to ensure that the transition from current best practices results in actual performance improvements.

Environmental Performance: Regarding sustainability, adopting coopetition practices reduced energy consumption from 4692 kWh to 4071 kWh daily. This led to a decrease in the KPICO2-Eq from 3.41 kg CO2 to 2.68 kg CO2 per part produced, representing a 21.8% reduction in carbon emissions, aligning with 6D BIM requirements. The *p*-value of 7.96775×10^{-8} confirms that this reduction in carbon emissions is statistically significant.

Under CB.P, the ANOVA Significance F indicates that the relationship between CO2 equivalent and $KPI_{CO2\text{-}Eq}$ is highly statistically significant, meaning that CO2 equivalent under current best practices has a strong and meaningful impact on $KPI_{CO2\text{-}Eq}$. In contrast, under CN.P, the relationship between CO2 equivalent and $KPI_{CO2\text{-}Eq}$ is not statistically significant, indicating that despite the observed reduction in carbon emissions, the impact on $KPI_{CO2\text{-}Eq}$ under coopetition practices is not as meaningful.

This suggests that while the transition to coopetition practices has led to a significant reduction in carbon emissions, the $KPI_{CO2\text{-}Eq}$ under coopetition practices should be closely monitored, and adjustments should be made to ensure that the shift from current best practices continues to drive meaningful environmental performance.

These findings contribute to the coopetition literature by demonstrating how coopetition networks can drive significant operational improvements in the construction industry, specifically within the Portuguese Ornamental Stone industry. The study provides empirical evidence of how coopetition networks facilitate alignment with BIM requirements, showcasing their potential to enhance the competitive advantage of construction manufacturing companies. By integrating BIM dimensions upstream, coopetition networks help companies achieve better project outcomes in terms of efficiency, sustainability, and overall performance.

Furthermore, this research highlights the strategic value of coopetition as a mechanism for fostering innovation and sustainability in industries where traditional competitive strategies may fall short. The study also underscores the importance of cooperation among competitors as a means of achieving common goals, such as improved BIM compliance, which can lead to broader industry benefits.

Despite the limitation of involving only three OS-PT companies due to cost constraints, the findings underscore the potential of coopetition networks as a viable strategy for achieving BIM objectives. Further research with a larger sample size and across different sectors is recommended to validate these findings and explore the broader applicability of coopetition networks in meeting BIM requirements.

Overall, this study contributes to the growing evidence supporting coopetition networks as a powerful strategy for enhancing efficiency and sustainability in the construction industry.

Author Contributions: Conceptualization, A.d.S. and A.J.M.C.; methodology, A.d.S. and A.J.M.C.; software, A.d.S.; validation, A.d.S. and A.J.M.C.; formal analysis, A.d.S. and A.J.M.C.; investigation, A.d.S. and A.J.M.C.; resources, A.d.S. and A.J.M.C.; data curation, A.d.S. and A.J.M.C.; writing—original draft preparation, A.d.S.; writing—review and editing, A.d.S. and A.J.M.C.; visualization, A.d.S. and A.J.M.C.; supervision, A.J.M.C.; project administration, A.d.S.; funding acquisition, A.d.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Fearnley, N.; Robinson, G.; Leonard, J. Global Construction Futures. 2023. Available online: https://www.oxfordeconomics.com/resource/global-construction-futures/ (accessed on 15 May 2024).
2. Kulinan, A.S.; Park, M.; Aung, P.P.W.; Cha, G.; Park, S. Advancing construction site workforce safety monitoring through BIM and computer vision integration. *Autom. Constr.* **2024**, *158*, 105227. [CrossRef]
3. HM Government Digital Built Britain Level 3 Building Information Modelling—Strategic Plan. In *Cabinet Office (Vince, H.)*; 2015.
4. Altaf, M.; Alalaoul, W.S.; Musarat, M.A.; Abdelaziz, A.A.; Thaheem, M.J. Optimisation of energy and life cycle costs via building envelope: A BIM approaches. *Environ. Dev. Sustain.* **2023**, *26*, 7105–7128. [CrossRef]
5. Polat, F.; Demirkesen, S. Measuring the impact of lean implementation on BIM and project success: Case of construction firms. *Eng. Constr. Archit. Manag.* **2024**. [CrossRef]
6. Diaz Schery, C.A.; Caiado, R.G.G.; Aguilar Vargas, S.; Rodriguez Vignon, Y. Paths to BIM-based digital transformation: A bibliometric and systematic review of critical factors. *Eng. Constr. Archit. Manag.* **2024**. [CrossRef]
7. Wang, S.; Chong, H.-Y.; Zhang, W. The impact of BIM-based integration management on megaproject performance in China. *Alex. Eng. J.* **2024**, *94*, 34–43. [CrossRef]
8. Nath, T.; Attarzadeh, M.; Tiong, R.L.K.; Chidambaram, C.; Yu, Z. Productivity improvement of precast shop drawings generation through BIM-based process re-engineering. *Autom. Constr.* **2015**, *54*, 54–68. [CrossRef]
9. Chowdhury, M.; Hosseini, M.R.; Edwards, D.J.; Martek, I.; Shuchi, S. Comprehensive analysis of BIM adoption: From narrow focus to holistic understanding. *Autom. Constr.* **2024**, *160*, 105301. [CrossRef]
10. Rouyre, A.; Fernandez, A.-S.; Bruyaka, O. Big problems require large collective actions: Managing multilateral coopetition in strategic innovation networks. *Technovation* **2024**, *132*, 102968. [CrossRef]
11. Bouncken, R.; Kumar, A.; Connell, J.; Bhattacharyya, A.; He, K. Coopetition for corporate responsibility and sustainability: Does it influence firm performance? *Int. J. Entrep. Behav. Res.* **2024**, *30*, 128–154. [CrossRef]
12. European Commission. Farm to Fork Strategy. European Green Deal, DG SANTE/Unit 'Food Information and Composition, Food Waste', 23. 2020. Available online: https://ec.europa.eu/food/sites/food/files/safety/docs/f2f_action-plan_2020_strategy-info_en.pdf (accessed on 27 May 2024).
13. Galetakis, M.; Soultana, A. A review on the utilisation of quarry and ornamental stone industry fine by-products in the construction sector. *Constr. Build. Mater.* **2016**, *102*, 769–781. [CrossRef]
14. Rebello, T.A.; Zulcão, R.; Calmon, J.L.; Gonçalves, R.F. Comparative life cycle assessment of ornamental stone processing waste recycling, sand, clay and limestone filler. *Waste Manag. Res.* **2019**, *37*, 186–195. [CrossRef] [PubMed]
15. Silva, A.; Pata, A. Value Creation in Technology Service Ecosystems—Empirical Case Study. In *Innovations in Industrial Engeneering II*; Machado, J., Soares, F., Trojanowska, J., Ivanov, V., Antosz, K., Ren, Y., Manupati, V.K., Pereira, A., Eds.; Springer: Cham, Switzerland, 2022; pp. 26–36.
16. Blanco, F.G.B.; Chen, H. The Implementation of Building Information Modelling in the United Kingdom by the Transport Industry. *Procedia-Soc. Behav. Sci.* **2014**, *138*, 510–520. [CrossRef]
17. Abdumutalibovich, K.A.; Lutfillaevna, B.M. The Role of Bim Technologies in the Information System of Education. *Eur. J. Contemp. Bus. Law Technol. Cyber Law Blockchain Leg. Innov.* **2023**, *1*, 9–13. [CrossRef]
18. Silva, A.; Rabadão, C.; Capela, C. Towards Industry 4.0 | A case study of BIM deployment in ornamental stones sector. *Int. J. Innov. Technol. Explor. Eng.* **2020**, *67*, 24535.
19. Jalaei, F.; Jrade, A. Integrating building information modeling (BIM) and LEED system at the conceptual design stage of sustainable buildings. *Sustain. Cities Soc.* **2015**, *18*, 95–107. [CrossRef]
20. Vilas-Boas, J.; Mirnoori, V.; Razy, A.; Silva, A. Outlining a New Collaborative Business Model as a Result of the Green Building Information Modelling Impact in the AEC Supply Chain. In *PRO-VE 2019*; IFIP Advances in Information and Communication Technologyvol; Springer: Cham, Switzerland, 2019; Volume 568, pp. 405–417. [CrossRef]
21. Hadavi, A.; Alizadehsalehi, S. From BIM to metaverse for AEC industry. *Autom. Constr.* **2024**, *160*, 105248. [CrossRef]
22. Chen, Z.-S.; Wang, Z.-R.; Deveci, M.; Ding, W.; Pedrycz, W.; Skibniewski, M.J. Optimization-based probabilistic decision support for assessing building information modelling (BIM) maturity considering multiple objectives. *Inf. Fusion* **2024**, *102*, 102026. [CrossRef]
23. Cheung, F.K.T.; Rihan, J.; Tah, J.; Duce, D.; Kurul, E. Early stage multi-level cost estimation for schematic BIM models. *Autom. Constr.* **2012**, *27*, 67–77. [CrossRef]
24. Raut, R.D.; Kumar, S.; Narwane, V.S.; Gardas, B.B.; Priyadarshinee, P.; Narkhede, B.E. Linking big data analytics and operational sustainability practices for sustainable business management. *J. Clean. Prod.* **2019**, *224*, 10–24. [CrossRef]
25. Ridho Alfarizi, M.; Irfan Rifai, A.; Indrastuti, I.; Prasetijo, J. Bibliometric Analysis of Cost and Time Management In Handling Avalanches on National Roads In Mountainous Areas Using BIM. *Asian J. Soc. Humanit.* **2024**, *2*, 1952–1966. [CrossRef]
26. Hakimi, O.; Liu, H.; Abudayyeh, O. Digital twin-enabled smart facility management: A bibliometric review. *Front. Eng. Manag.* **2024**, *11*, 32–49. [CrossRef]
27. Shao, S.; Cao, D. Contagion of BIM Implementation Practices in Interproject Networks: An Empirical Study in China. *J. Manag. Eng.* **2024**, *40*, 05023009. [CrossRef]
28. Waqar, A.; Qureshi, A.H.; Alaloul, W.S. Barriers to Building Information Modeling (BIM) Deployment in Small Construction Projects: Malaysian Construction Industry. *Sustainability* **2023**, *15*, 2477. [CrossRef]

29. Wijeratne, P.U.; Gunarathna, C.; Yang, R.J.; Wu, P.; Hampson, K.; Shemery, A. BIM enabler for facilities management: A review of 33 cases. *Int. J. Constr. Manag.* **2024**, *24*, 251–260. [CrossRef]
30. Holmström, J.; Partanen, J. Digital manufacturing-driven transformations of service supply chains for complex products. *Supply Chain. Manag.* **2014**, *19*, 421–430. [CrossRef]
31. Yan, J.; Lu, Q.; Tang, J.; Chen, L.; Hong, J.; Broyd, T. Digital Tools for Revealing and Reducing Carbon Footprint in Infrastructure, Building, and City Scopes. *Buildings* **2022**, *12*, 1097. [CrossRef]
32. Li, X.; Zhao, C. Did innovative city constructions reduce carbon emissions? A quasi-natural experiment in China. *Environ. Dev. Sustain.* **2023**, *26*, 6315–6340. [CrossRef]
33. Smith, P. BIM & the 5D Project Cost Manager. *Procedia-Soc. Behav. Sci.* **2014**, *119*, 475–484. [CrossRef]
34. Moore, J.F. The rise of a new corporate form. *Wash. Q.* **1998**, *21*, 167–181. [CrossRef]
35. Nalebuff, B.J.; Brandenburger, A.M. Co-opetition: Competitive and cooperative business strategies for the digital economy. *Strateg. Leadersh.* **1997**, *25*, 28–33. [CrossRef]
36. Meena, A.; Dhir, S.; Sushil, S. A review of coopetition and future research agenda. *J. Bus. Ind. Mark.* **2023**, *38*, 118–136. [CrossRef]
37. Ramírez-López, C.; Till, K.; Boyd, A.; Bennet, M.; Piscione, J.; Bradley, S.; Giuliano, P.; Leduc, C.; Jones, B. Coopetition: Cooperation among competitors to enhance applied research and drive innovation in elite sport. *Br. J. Sports Med.* **2021**, *55*, 522–523. [CrossRef]
38. Corbo, L.; Kraus, S.; Vlačić, B.; Dabić, M.; Caputo, A.; Pellegrini, M.M. Coopetition and innovation: A review and research agenda. *Technovation* **2023**, *122*, 102624. [CrossRef]
39. Gernsheimer, O.; Kanbach, D.K.; Gast, J. Coopetition research—A systematic literature review on recent accomplishments and trajectories. *Ind. Mark. Manag.* **2021**, *96*, 113–134. [CrossRef]
40. Estrada, I.; Dong, J. Learning from experience? Technological investments and the impact of coopetition experience on firm profitability. *Long Range Plann.* **2020**, *53*, 101866. [CrossRef]
41. Klimas, P.; Ahmadian, A.A.; Soltani, M.; Shahbazi, M.; Hamidizadeh, A. Coopetition, Where Do You Come From? Identification, Categorization, and Configuration of Theoretical Roots of Coopetition. *SAGE Open* **2023**, *13*, 21582440221085003. [CrossRef]
42. Xie, Q.; Gao, Y.; Xia, N.; Zhang, S.; Tao, G. Coopetition and organizational performance outcomes: A meta-analysis of the main and moderator effects. *J. Bus. Res.* **2023**, *154*, 113363. [CrossRef]
43. Lindström, T.; Polsa, P.; Pellegrin-Boucher, E.; Le Roy, F.; Gurău', C.; Filieri, R.; Bouncken, R.B.; Gast, J.; Kraus, S.; Bogers, M.; et al. Destination networking: Co-opetition in peripheral surroundings. *Ind. Mark. Manag.* **2016**, *33*, 427–448. [CrossRef]
44. Wang, M.-C.; Chen, J.-S. Driving coopetition strategy to service innovation: The moderating role of coopetition recognition. *Rev. Manag. Sci.* **2022**, *16*, 1471–1501. [CrossRef]
45. Vilas-Boas, J.; Simões, J. *Innovative Enterprise Architectures for Deploying Product-Service Systems in SME*; Camarinha-Matos, L.M., Afsarmanesh, H., Rezgui, Y., Eds.; Springer International Publishing: New York, NY, USA, 2018; pp. 637–649. [CrossRef]
46. Hsu, Y. Integrating Service Science and Information System Technology: A Case Study. *Int. J. Organ. Innov.* **2016**, *9*, 158–173. [CrossRef]
47. Hollweck, T.; Robert, K.Y. Case Study Research Design and Methods (5th ed.). *Can. J. Progr. Eval.* **2015**, *30*, 108–110. [CrossRef]
48. Carvalho, J.; Lopes, C.; Mateus, A.; Martins, L.; Goulão, M. Planning the future exploitation of ornamental stones in Portugal using a weighed multi-dimensional approach. *Resour. Policy* **2018**, *59*, 298–317. [CrossRef]
49. Silva, A.; Gil, M.M.; Duarte, E. Service Innovation: A Service Blueprinting for Industry 4.0. *Int. J. Sci. Basic Appl. Res.* **2020**, *52*, 33–49.
50. da Silva, A.; Cardoso, A.J.M. Coopetition with the Industrial IoT: A Service-Dominant Logic Approach. *Appl. Syst. Innov.* **2024**, *7*, 47. [CrossRef]
51. Silva, A.; Marques Cardoso, A. BIM-based Supply Chain in AEC—Threats on the Portuguese Stone sector. In Proceedings of the 7th Globalstone Congress, Batalha, Portugal, 18–23 June 2023.
52. Ng, I.; Wakenshaw, S. The Internet-of-Things: Review and research directions. *Int. J. Res. Mark.* **2017**, *34*, 3–21. [CrossRef]
53. Hoppe, S. OPC Unified Architecture-Interoperability for Industrie 4.0 and the Internet of Things. 2023. Available online: https://opcfoundation.org/wp-content/uploads/2023/05/OPC-UA-Interoperability-For-Industrie4-and-IoT-EN.pdf (accessed on 15 May 2024).
54. Pereira, T.; Barreto, L.; Amaral, A. Network and information security challenges within Industry 4.0 paradigm. *Procedia Manuf.* **2017**, *13*, 1253–1260. [CrossRef]
55. Latif, G.; Brahim, G.B.; Abdelhamid, S.E.; Alghazo, R.; Alhabib, G.; Alnujaidi, K. Learning at Your Fingertips: An Innovative IoT-Based AI-Powered Braille Learning System. *Appl. Syst. Innov.* **2023**, *6*, 91. [CrossRef]
56. Silva, A.; Dionisio, A.; Almeida, I. Enabling Cyber-Physical Systems for Industry 4.0 operations: A Service Science Perspective. *Int. J. Innov. Technol. Explor. Eng.* **2020**, *9*, 838–846. [CrossRef]
57. Silva, A.; Dionísio, A.; Coelho, L. Improving Industry 4.0 through service science. *Int. J. Serv. Sci.* **2020**, *7*, 58. [CrossRef]
58. Bartelt, M.; Kuhlenk, B. Automated production of individualized products for teaching I4.0 concepts. *Procedia Manuf.* **2020**, *45*, 337–342. [CrossRef]
59. Yilmaz, G.; Akcamete, A.; Demirors, O. BIM-CAREM: Assessing the BIM capabilities of design, construction and facilities management processes in the construction industry. *Comput. Ind.* **2023**, *147*, 103861. [CrossRef]
60. Li, M.; Lu, K.; Wang, H.; Wang, S. Integrating BIM with greenhouse-gas emissions in AEC: A scientometric review. *E3S Web Conf.* **2020**, *143*, 01008. [CrossRef]

61. OECD. *Rethinking Innovation for a Sustainable Ocean Economy*; OECD Publishing: Paris, France, 2019. [CrossRef]
62. Jones, D. European Electricity Review 2023 (Issue January). Available online: https://ember-climate.org/app/uploads/2023/01/Report-European-Electricity-Review-2023.pdf (accessed on 22 May 2024).
63. Fonseca, L.; Carvalho, F. The Reporting of SDGs by Quality, Environmental, and Occupational Health and Safety-Certified Organizations. *Sustainability* **2019**, *11*, 5797. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

systems

MDPI

Article

Coopetition Networks for Small and Medium Enterprises: A Lifecycle Model Grounded in Service-Dominant Logic

Agostinho Da Silva [1,2,*] and Antonio J. Marques Cardoso [1]

[1] CISE—Electromechatronic Systems Research Centre, University of Beira Interior, 6201-001 Covilhã, Portugal; ajmcardoso@ieee.org
[2] CIGEST—Centre for Research in Management, Lisbon Business School, 1000-002 Lisboa, Portugal
* Correspondence: a.silva@zipor.com

Abstract: Small and medium enterprises (SMEs) are vital to the European economy, but sustaining coopetition networks—collaborative arrangements between competitors—remains challenging. In this study, this gap is addressed by developing a reference model and methodology for coopetition networks explicitly designed for SMEs and grounded in the service-dominant (S-D) logic framework. The model provides a structured approach for managing coopetition across the entire network lifecycle, from initiation to dissolution, emphasizing value co-creation and resource integration. A proof of concept (PoC) was implemented in the Portuguese ornamental stone sector to validate the model, revealing significant improvements in manufacturing effectiveness and demonstrating the model's practical applicability. The results underscore the potential of coopetition networks to boost SMEs' competitiveness and performance while identifying key trade-offs and risks, such as knowledge sharing and market cannibalization. Although the model addresses critical challenges, in this study, limitations are acknowledged and areas for future research are suggested, particularly in relation to the long-term sustainability of coopetition and the influence of interpersonal dynamics.

Keywords: coopetition; instantiation; networks; service-dominant logic; service ecosystems

check for updates

Citation: Da Silva, A.; Cardoso, A.J.M. Coopetition Networks for Small and Medium Enterprises: A Lifecycle Model Grounded in Service-Dominant Logic. *Systems* **2024**, *12*, 461. https://doi.org/10.3390/systems12110461

Academic Editor: Mitsuru Kodama

Received: 15 September 2024
Revised: 10 October 2024
Accepted: 27 October 2024
Published: 31 October 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Small and medium-sized enterprises (SMEs) are a cornerstone of the European economy, representing 99.8% of all non-financial businesses and over 65% of employment in the EU27 [1]. As the global economy transitions toward increasingly digital supply chains, coopetition—where competitors collaborate—has become a crucial strategy for business survival and growth [2]. Although coopetition has gained traction in academic research and policy discussions, its potential to enhance firm performance, particularly in the SME context, remains significantly underexplored [3]. Addressing this gap, in the present paper, a lifecycle model is proposed for coopetition networks explicitly tailored for SMEs, grounded in the service-dominant (S-D) logic framework [4], which emphasizes reciprocal value creation rather than transactional exchanges.

The current literature adopts various theoretical perspectives—game theory, resource-based view, paradox theory, transaction cost theory, and network theory—to examine coopetition, illuminating its economic, strategic, and organizational dimensions [5]. However, despite these insights, approximately 85% of coopetition networks fail to achieve long-term success [6], indicating the fragility of such networks. The high failure rate, especially within the SME sector, underscores the urgent need for a model that can accommodate the unique challenges faced by smaller firms, which often lack the dominant "keystone" players found in larger enterprises [7].

In this study, the aim is to develop a comprehensive model to effectively guide SMEs in designing and sustaining coopetition networks. The research seeks to understand how coopetition networks can be structured to enhance value creation for SMEs, identify the

specific challenges SMEs face in forming and maintaining these networks, and explore how applying the S-D logic framework can foster network sustainability and mutual value creation. By answering these guiding questions, in this paper, the intention is to bridge the gaps in the existing literature and provide a practical, adaptable coopetition framework for SMEs.

To achieve this, the methodology starts with a literature review that positions coopetition networks within the S-D logic framework, conceptualizing these networks as dynamic ecosystems that evolve from initiation to dissolution. The theoretical foundation will emphasize how coopetition can create reciprocal value, improving SMEs' operational and strategic capabilities. Building on this foundation, in this paper, a reference model is introduced that addresses common SME challenges, such as limited resources and the need for flexible collaboration, offering a practical blueprint for implementing and sustaining coopetition networks.

The empirical validation of the model involves a two-phase approach. First, a preliminary survey is conducted within the Portuguese ornamental stone industry, involving a sample representing 16.2% of the sector. This survey assessed the acceptance of the proposed reference model using a hypothetical scenario in which companies collaborated within a network while maintaining commercial confidentiality. The second phase involves a proof of concept (PoC) implemented in three SMEs with ERP-connected machines interfacing with building information modeling (BIM) systems. The PoC will compare performance metrics under traditional operations versus a coopetition framework, ensuring that sensitive information is protected through confidentiality agreements.

2. Coopetition Frameworks for SMEs: A Critical Review

The recent literature provides a wide range of frameworks that examine coopetition from multiple perspectives, including economic, strategic, and digital transformation viewpoints [8]. However, when applying these frameworks to SMEs, significant challenges and limitations emerge due to their unique characteristics, such as resource constraints, limited market influence, and less established networks than larger firms [9].

Several theoretical approaches have been utilized to understand coopetition, including game theory, which focuses on strategic decision-making among competitors [10], and resource-based view, which emphasizes leveraging internal resources for competitive advantage [5]. While these frameworks offer valuable insights, they often need to address the dynamic nature of inter-organizational collaboration, especially for SMEs that operate in rapidly evolving digital environments. Network Theory adds another dimension by examining the structure and interconnectedness of firms [11]. However, it needs to adequately explain how SMEs can sustain collaboration without dominant network leaders or keystone players [12].

2.1. Digital Transformation and Its Impact on Coopetition

The shift towards digital transformation has intensified the need for flexible, adaptable coopetition models that can accommodate rapid changes in technology and market conditions [13]. Recent studies have highlighted the role of digital platforms in enabling real-time collaboration, data sharing, and co-innovation, which are essential for sustaining coopetition [2]. While some frameworks incorporate digital elements, they focus on large enterprises with the resources and capabilities to invest in advanced technology solutions [14]. For SMEs, adopting digital tools is often constrained by financial and technical limitations, indicating a gap in the existing models that need to fully account for the barriers and enablers of digital transformation in the SME context [15].

The research has shown that coopetition manifests differently across sectors, reflecting varying levels of market maturity, regulatory environments, and technological advancements [16]. For example, the healthcare and pharmaceutical sectors often employ coopetition to facilitate joint research and development while maintaining competitive boundaries [17]. In contrast, the technology and manufacturing sectors leverage coopetition

for supply chain integration and process innovation [3]. However, studies focusing on SMEs within these sectors are limited, often providing fragmented insights rather than comprehensive frameworks that can be generalized across industries [18].

2.2. Limitations of Existing Frameworks for SMEs

The existing coopetition frameworks face several limitations when applied to SMEs [11]. Firstly, many models assume the presence of a leading firm that orchestrates the network, which is often different for SMEs [18]. Secondly, existing approaches need to adequately consider the lifecycle of coopetition networks, often focusing on initiation or early growth phases without addressing the long-term sustainability and evolution of these networks [19]. Thirdly, S-D logic needs to be more integrated in coopetition frameworks [20], which can offer a more nuanced understanding of value co-creation, especially in ecosystems where transactional relationships are less prominent [21].

Building on the critical review of the existing frameworks, in this paper, a lifecycle model is introduced, grounded in S-D logic, specifically tailored for SMEs. The proposed model aims to fill the gaps identified in the literature by providing a comprehensive framework that addresses the initiation and growth phases of coopetition and its long-term sustainability. It emphasizes reciprocal value creation and the dynamic nature of resource exchange within digital and traditional contexts, offering a more adaptable approach for SMEs in sectors undergoing digital transformation.

3. A Service Dominant Logic View for Coopetition

Vargo and Lusch (2004) revolutionized the understanding of "service" by defining it as the application of competencies for the benefit of others, a perspective that forms the cornerstone of this approach to coopetition networks [4].

Building on this paradigm, the S-D logic literature further elaborates that value is always co-created with the beneficiary [22]. This perspective emphasizes the importance of resource integration and service exchange, coordinated and constrained by institutions and institutional arrangements, as central to value co-creation in ecosystems [23].

Anchored on this service ecosystem's view, to S-D logic, networks are formed through the spontaneous creation of spatial and temporal structures [24]. These structures emerge from the interactions of social and economic actors influenced by institutions and technology [25]. These networks are characterized by adaptive interactions among actors, who are driven by the intrinsic goal of creating value and maintaining the viability of the ecosystem [26]. S-D logic views value creation as a mutual and adaptive service provision process, self-adjustable and interconnected within a framework of shared institutions and institutional arrangements [27]. This conceptual framework leads to understanding service ecosystems, where value is co-created in a dynamic and interconnected environment [28].

Traditionally perceived as merely physical devices, the role of technology in ecosystems has undergone a significant reevaluation in recent years. Hunt (2000) emphasizes the social dimensions of technology [29]. He argues that social groups play a crucial role in shaping technology and, more broadly, constructing value perceptions. Complementing this view, Arthur (2009) challenges the conventional view by describing technology as a physical tool and an assemblage of practices and components aimed at fulfilling human purposes and technological advancement as the recombination of helpful knowledge [30]. These insights shed light on how technology, as a component of ecosystems, is not just a tool but a dynamic element shaped by and shaping social practices and value creation.

The service literature increasingly recognizes the critical role of technology in enhancing and transforming networks [21]. This transformation extends to creating technology-supported ecosystems, where technology is central in facilitating and exploring new avenues for value creation within networks [31]. Understanding this dynamic role of technology is crucial for coopetition networks, where technological integration can significantly influence the mechanisms of value creation and collaboration among competing firms.

The literature on coopetition networks consistently acknowledges the role of technology in fostering innovation within these networks. Rusko (2014) identifies technology-based strategic networks as vital for coopetition innovation [32]. Similarly, Bicen et al. (2021) emphasize technology's role as a facilitator of interaction among network members [17], enabling the formation of shared understandings [31].

This collective viewpoint aligns closely with the S-D logic perspective, where technology is seen not only as an enabler (operand) but also as a starter (operant) in service ecosystems, contributing to resource integration and value creation [33]. In the context of coopetition networks, this dual role of technology is crucial in enabling and enhancing collaborative yet competitive interactions among firms.

4. Constructs for Coopetition Networks for Value Co-Creation

Reference models are abstract representations of domain knowledge, capturing prescriptive and descriptive design knowledge pertinent to sociotechnical problems [34]. Hevner (2004) underscores the importance of substantial academic knowledge in creating relevant reference models, which are instrumental in addressing complex real-world problems [35]. In the context of coopetition networks, the performative nature of S-D logic is particularly relevant, providing a robust framework for addressing real-world problems, especially those involving service objects, technology systems, organizations, and people collaboratively creating value [36]. In coopetition networks, this approach facilitates the understanding and shaping of evolving value propositions among a broad system of interacting actors.

4.1. Enabling Coopetition

Orlikowski (1992) offers a nuanced understanding of the interaction between technology and organizations [37]. She posits that technology both influences and is influenced by institutional factors and the practices of social and economic actors. At the same time, S-D logic conceptualizes a service ecosystem as a self-contained, self-adjusting system. This system comprises resource-integrating actors interconnected by shared institutional logic, facilitating mutual value creation through service exchange [38]. This perspective emphasizes the role of institutions in value creation, drawing attention to how technology, as an operant resource, actively interacts with other resources to co-create value and innovate services [21].

Building upon the convergence of technology's role as established in S-D logic, reference models for coopetition networks can designed for practical applications. Supported by the foundational principles of S-D logic, this reference model must integrate the crucial role of technology, reflecting its importance in service ecosystems. Transporting this service ecosystem perspective to networks allows the synthesis of diverse viewpoints into a cohesive framework emphasizing the integration and application of resources as central to value creation, driving interactions and exchanges in coopetition networks.

4.2. Actors and Resources in Coopetition

Embracing the S-D logic perspective, it is recognized that all economic and social actors function as resource integrators [39]. Under this view, service ecosystems comprise a variety of actors, such as customers, providers, and competitors. These actors apply specialized competencies through deeds, processes, and performances and integrate multiple resources, including market-facing, technological, financial, and public resources, thereby creating value [40] to co-create mutual benefits, establishing economic relations based on service exchange [41]. In these ecosystems, technology is a resource that plays a crucial role in these exchanges. It is an integral element, enabling individuals and organizations to participate in the value-creation process and function as resource integrators within these networks [42].

Transposing this perspective to coopetition networks, the traditional roles of providers and competitors often converge, leading to a unique dynamic where providers can also become competitors and vice versa [10]. Within these networks, firms, customers, and

other actors engage in economic exchanges, each acting as resource-integrating, service-providing entities. This collaboration is driven by a shared value co-creation goal [43]. Arguably, actors in coopetition networks integrate resources in a manner that can be characterized by a loosely coupled architecture that facilitates the formation of service and information flow frameworks, thereby creating value networks [44]. Value creation within these networks occurs through dynamic interactions among multiple entities. Actors continuously configure resources to initiate and sustain interactions that lead to the creation of value [45].

Expanding upon the S-D logic's classification of resources, the service literature recognizes any potentially useful entity, tangible or intangible, as a resource. This encompasses aspects like ephemerality and the cost of usufruct, especially pertinent in coopetition networks [46]. Building on this S-D logic understanding can identify the actor and resources' constructs for coopetition networks for value co-creation, as follows:

Construct #1 (actors as resource integrators)—The first construct posits that actors in cooperation networks function as resource integrators. They actively engage with available resources to create value for themselves and others, fostering new and improved ways of value creation [22]. Systemic mechanisms underpin this process of resource integration. These mechanisms facilitate service exchanges, ensuring that all actors in the ecosystem can act as resource integrators. This is achieved through reconfiguring access rights and forming mutually agreed-upon value propositions [43].

Construct #2 (technology as operant and operand resource)—The second construct explores the dual role of technology in coopetition networks. Technology serves both as a facilitator or enabler (operand) and as an initiator or actor (operant) [47,48]. As an operant resource, technology initiates and drives new forms of interaction and value creation. As an operand resource, it facilitates and supports these processes, enabling actors to engage more effectively in coopetition networks [49]. This positioning of technology allows actors, such as rival firms and individual customers, to extend and reconfigure their patterns of resource integration. It enables them to access resources across rival firms in a mutually beneficial manner, thereby facilitating value creation in the network [33]. This strategic use of technology can be instrumental in alleviating the inherent tensions in coopetition networks, as it fosters a more collaborative, transparent, and integrated approach to resource sharing [50].

4.3. Service-Exchange in Coopetition Networks

In the realm of S-D logic, the service exchange among actors is fundamental to the emergence of value [20]. This perspective is echoed broadly in the service literature, emphasizing the centrality of service exchange and resource integration in economic exchanges [51]. This view is central to this reference model. Value co-creation occurs within networks of relationships and resources, a dynamic process involving resource integration, application, and transformation [52].

Understanding how economic actors engage in value co-creation necessitates focusing on the knowledge mechanisms and processes involved in resource integration [53]. Maglio and Spohrer (2007) underscore the significance of the rights nature of resources, pointing out the crucial distinction between resources capable of entering contracts or agreements and those that cannot [54]. This distinction is crucial as only people and firms, as imputable actors, can legally bind themselves in such ways. They further argue that specific configurations of resources can actively initiate interactions, adding a dynamic layer to how resources are utilized in economic exchanges [55]. In scenarios where complex resource configurations lead to initiating actions, people and technology collaboratively compute and adjust to the evolving value of knowledge, reflecting the dynamic nature of service ecosystems [47].

As envisioned in S-D logic, the service process is inherently interactive and collaborative, involving multiple economic actors [27]. This perspective aligns with the broader

view that all social and economic actors are resource integrators [42]. Successful value co-creation hinges on the ability of these actors to engage in meaningful interactions.

The efficacy of these interactions, and thus the value co-created, is contingent upon each actor's capability to exchange and apply service information in relevant and beneficial ways within their respective realities [56]. Building on this foundational understanding of service exchange among rivals can be identified as the second set of constructs for coopetition networks for value co-creation, as follows:

Construct #3 (interactions among rivals)—In coopetition networks, rival interactions are critical in value co-creation [57]. Integrating technology, both as operant and operand resources, is instrumental in simultaneously facilitating cooperation and competition among rivals [11]. Reliable technology serves as a guide and enabler in formulating proposals between competitors. It allows rivals to rely more on objective, technology-driven processes rather than direct interactions with competitors, thereby increasing the likelihood of mutual acceptance of proposals and reducing direct competitive friction. This indirect approach facilitated by technology enhances the probability of acceptance and successful collaboration among rivals, leading to more effective and efficient value co-creation.

Construct #4 (service-exchange intensity)—In coopetition networks, the intensity of service exchange is essential to enhancing the co-creation of value. Integrating competitors' resources, facilitated by operant and operand technology, can amplify this intensity [58]. This heightened level of resource integration aligns with the broader value creation process, as conceptualized in S-D logic. Value creation in this context arises from intricate value configurations constantly refined and enhanced through the interactions among rival actors [24].

Within service ecosystems, the interplay among actors at multiple levels significantly enhances the value co-created. Increasing interactions in coopetition networks within and across different aggregation levels contribute to a more dynamic and enriched value co-creation process [59].

4.4. Coopetition Networks as a Particular Case of Service Ecosystems

In service ecosystems, institutions are humanly devised rules, norms, and beliefs [60]. These elements enable and constrain actions, thereby making social life predictable and meaningful, as described by Scott (2008) and further elaborated by Vargo and Lusch (2016) [45,61].

Building upon this foundational understanding, the S-D logic literature has evolved to adopt a dynamic perspective that focuses on how institutions shape value creation through service exchange, offering insights into ecosystems' structural intricacies beyond dyadic or micro-level interactions [23]. According to the S-D logic, this institutional view is crucial for comprehending how value is co-created in service ecosystems, as it provides a lens to understand the broader, systemic interactions and constraints that shape economic and social exchanges.

Establishing a bridge between technology and knowledge, in a broader sense, technology is often applied to enhance and utilize valuable knowledge [62], further positing that knowledge itself forms a part of the institutional structure of society, an idea echoed in S-D logic [23]. Moreover, drawing from Simon's (1988) concept of design as resource reconfiguration to address problems [63], technology resources can be viewed as assemblages of practices and components to fulfil human purposes [30]. Social technologies are often conceptualized as institutions [64]. Orlikowski (2000) provides a nuanced view of this interplay, describing how technology and actors collaboratively affect, transform, and maintain institutions [65]. Drawing on Giddens' (1984) structuration theory, this perspective positions technology as both a product and an enabler of human action [66]. This conceptualization of technology as an institutional phenomenon aligns with the S-D logic perspective on institutions within service ecosystems [67], from which it may be argued that in the context of coopetition networks, technology can facilitate institutionalization, enabling interactions among rivals while also helping to manage and constrain potential

tensions. Building on this foundational understanding of the service ecosystem can be identified two additional constructs for coopetition networks for value co-creation:

Construct #5 (technology as institutionalization mechanism)—This construct explores the role of technology as a mechanism for institutionalization within coopetition networks. This involves viewing and using technology as both an operand (enabler) and operant (initiator) resource in the process of value creation [28,47]. Drawing from Simon's (1988) concept of designed artefacts, technology systems are not just tools but repositories of embedded knowledge and skills, as discussed by Wanda J. Orlikowski (1992). In this capacity, technology acts as an institutionalization mechanism, facilitating the endogenous generation of new institutions. This is crucial for shaping the context in which resource integration and service exchange occur, enabling effective coopetition and value co-creation in ecosystems [68].

Construct #6 (institutionalized networks)—Institutions are crucial in coopetition networks as coordination mechanisms. Here, operant and operand technology facilitate rival interaction and act as mechanisms for institutionalization within service ecosystems [23]. Once institutionalized, the coopetition networks are guided by sets of institutions or institutional arrangements that shape the thinking and behaviour of the actors by providing a framework of value assumptions, cognitive frames, rules, and routines, thereby establishing nested and interlocking service ecosystems. Within this framework, operant and operand technology are not just tools but are conceptualized as repositories of potentially helpful knowledge. This knowledge is instrumental for future interactions within service ecosystems, facilitating the exchange and innovation [46]. This perspective on institutionalized networks is particularly relevant in dynamic and changing industries. Innovations, characterized by loosely coupled systems, enable rapid adaptation and evolution of behaviour patterns, often keeping pace with or outstripping the rate of technological advancements [69].

5. Methodological Approach

In this section, the research methodology used in this study is outlined, emphasizing the steps followed to develop, implement, and evaluate the proposed coopetition network model. The methodology was designed to balance technical aspects with scientific rigor, ensuring this study's approach is robust and suitable for a scientific publication. The research procedure includes three main phases, the theoretical framework development, model instantiation, and empirical evaluation.

The first phase involved developing a theoretical foundation for the coopetition model. A comprehensive literature review covered existing coopetition frameworks, S-D logic, and their applications in various sectors. This review helped identify gaps in current models, especially in the context of SMEs and digital transformation. Key theoretical concepts were then integrated to form the basis of the proposed model, emphasizing value co-creation and service exchange. The S-D logic framework was chosen to guide the model, as it shifts the focus from transactional exchanges to reciprocal value creation within dynamic ecosystems, which is particularly relevant for SMEs operating in resource-constrained environments.

The second phase of the research focused on instantiating the proposed coopetition network model across its lifecycle stages, as follows: initiation, operation, metamorphosis, and dissolution. Each stage was defined with specific activities and objectives based on the literature review and feedback from industry experts. This instantiation aimed to provide actionable guidelines for implementing coopetition networks, with particular attention to SMEs facing digital transformation challenges.

Initiation Stage: This stage involved setting up the basic structure of the coopetition network, including identifying potential partners, defining common objectives, and establishing governance protocols. Emphasis was placed on creating trust and transparency among network participants.

Operation Stage: The network transitioned to active collaboration, focusing on shared resource utilization, joint problem-solving, and real-time data exchange. This stage utilized

digital tools (e.g., Internet of Things, ERP systems, and BIM integration) to facilitate service exchange and enhance network effectiveness.

Metamorphosis Stage: The network adapted to environmental changes, such as shifts in market conditions or technological advancements. Strategies for scaling the network or integrating new partners were explored, ensuring flexibility and resilience.

Dissolution Stage: This final stage covered network disbanding or reconfiguration. It included procedures for the orderly exit of partners, redistribution of shared resources, and retention of valuable knowledge.

The model instantiation was designed to provide a practical, adaptable framework for SMEs to navigate these stages effectively.

The third phase aimed to evaluate the model's applicability and effectiveness empirically. This phase consisted of two main components: a preliminary survey and a PoC.

A preliminary survey, conducted among SMEs in the Portuguese ornamental stone sector, aimed to assess the initial acceptance and perceived usefulness of the proposed coopetition model. The survey covered 16.2% of the industry, providing insights into the readiness of SMEs to adopt digital coopetition practices. These data helped refine the model by incorporating feedback on specific barriers and enablers experienced by SMEs.

A proof of concept (PoC) was implemented with three DL#4 companies, representing 20% of the DL#4 SMEs in the sector. These firms were selected based on their digital maturity, enabling a controlled evaluation of the coopetition model's impact. The PoC involved a structured comparison of KPIs for two 54-day periods: the state-of-the-art (SoA) practices phase and the coopetition network for value co-creation (CNVC) phase. The transition from SoA to CNVC practices highlighted the impact of coopetition on efficiency, collaboration, and value co-creation.

Data were collected using quantitative metrics (e.g., production data, survey responses). Quantitative data included daily production figures, network interaction frequency, and resource utilization rates.

A key component of a reference model is its lifecycle, which delineates the various stages a coopetition network undergoes from inception to dissolution. Figure 1 illustrates this lifecycle, providing a visual representation of each stage.

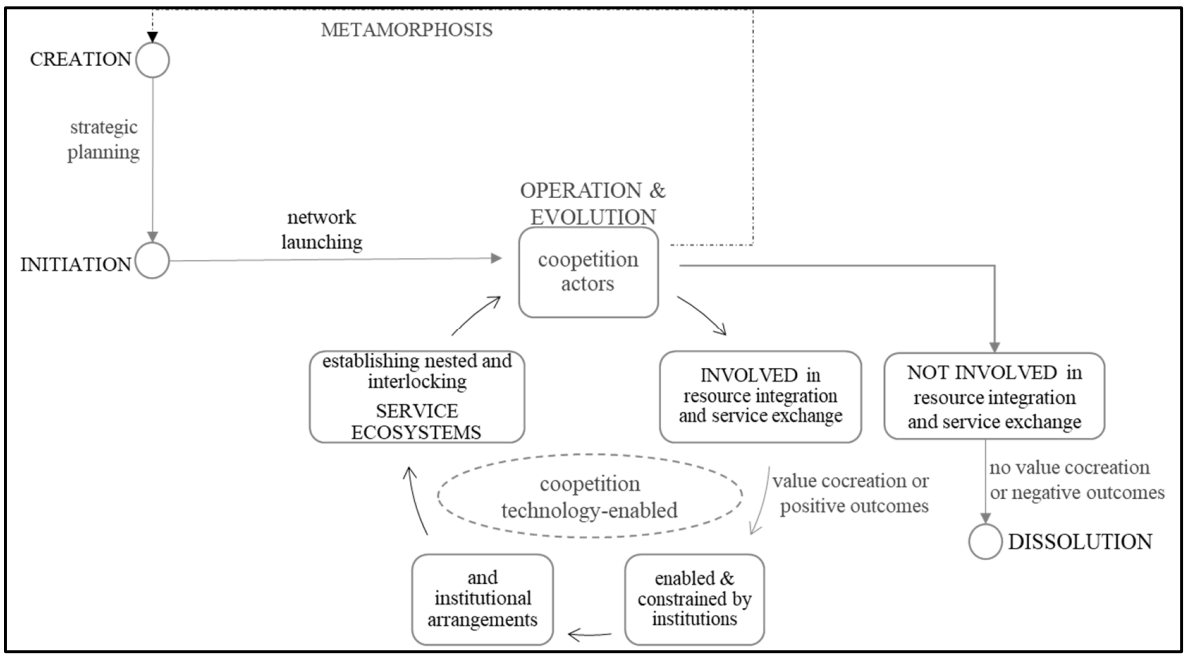


Figure 1. Coopetition network lifecycle: a service ecosystems perspective.

The creation stage encompassed strategic planning, governance establishment, and the development of a common ontology. It also involved setting up the necessary technology

and network infrastructure. The initiation phase included the installation of a network infrastructure and motivator teams, launching the coopetition network, and undertaking activities like actor recruitment and conformity checking. In the operation stage, technology facilitated the integration of resources and service exchange among rivals. This stage was characterized by forming service ecosystems driven by the actors' interactions within the network. The metamorphosis stage was prompted by significant changes within the network, necessitating a strategic overhaul and potentially leading to the network's relaunch. The dissolution stage was when the network ceased to create value or when the value generated fell short of the actors' expectations, leading to disengagement and the eventual collapse of the service ecosystem—the actors rapidly quit involvement in resource integration and service exchange, resulting in the service ecosystem death and consequent coopetition network closure.

Linking value co-creation to resource integrators (actors) to service exchange [70], a coopetition network can be viewed as a relatively self-contained, self-adjusting system of resource-integrating rivals and customers connected by technology that ensures institutional arrangements for mutual value creation through service exchange [23].

6. Coopetition Networks Instantiation

Instantiation refers to the process of creating a specific occurrence or realization of an abstract concept. It involves developing a concrete instance or application based on a theoretical reference model or architecture. In the case of this research, the instantiation process is applied to coopetition networks. This process involved characterizing new technology-based networks by leveraging the lifecycle outlined above and considering the unique aspects of coopetition. The instantiation process for coopetition networks encompassed a systematic set of steps. These steps were designed to specify and generate a customized version of the coopetition networks for value co-creation, fully describing its components. Collectively, these components constituted an instance of the reference model, operationalizing the theoretical framework within a practical context.

6.1. Initiation Stage

The initiation stage of coopetition networks for value co-creation is the starting phase. It can be subdivided into creation and initiation phases, each with distinct objectives and activities (Figure 2).

The creation phase primarily focuses on strategic planning, starting with evaluating the environmental context. This step is essential for preparing and facilitating all subsequent operational activities. Key aspects, such as technology requirements, play a vital role at this stage, particularly in establishing a standard ontology for the network. This process includes defining governance structures, determining common ontologies, and setting technology standards and requirements, such as cybersecurity, interoperability, and maintenance protocols. The final steps in this phase involve addressing the network system's enabling requirements. This includes setting up the necessary infrastructure, hosting arrangements, and forming teams responsible for recruiting actors and motivating participation in the network.

The initiation phase is crucial in developing coopetition networks for value co-creation, focusing on network launching, infrastructure setup, and forming motivator teams for actor recruitment and conformity checking. A critical trigger for launching a coopetition network is the establishment of clear and shared expectations among the rival actors [71].

This phase ensures that the management principles and the common ontology, previously established in the creation phase, are well-understood and committed to by all participating actors. Moreover, the network's initiation involves the network motivator team setting up the necessary technology-enabling infrastructure. This setup is a foundational step that precedes the actual launching of the coopetition network. Following the network launch, the focus shifts to recruiting actors and checking their compliance with essential requirements. This process includes thorough interoperability and cybersecurity

assessments to ensure that each actor's technology aligns with the network's standards and is fully compliant.

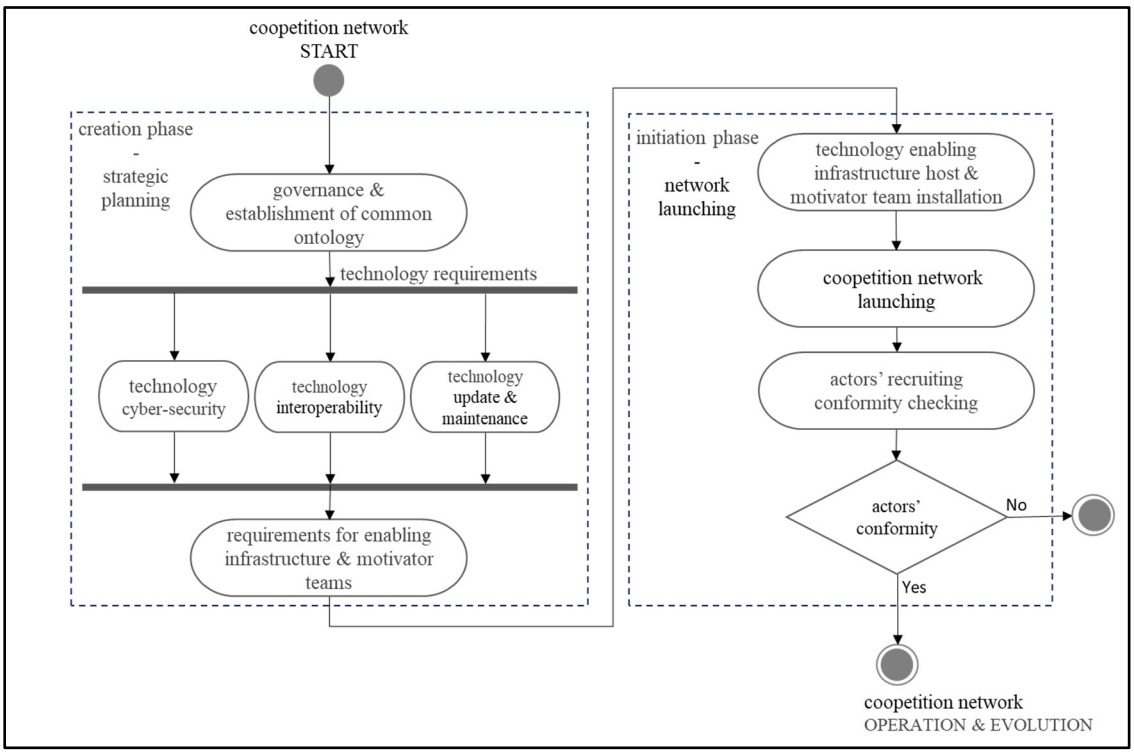


Figure 2. The initiation stage of the coopetition networks for value co-creation.

6.2. Operation Stage

The operation stage marks the emergence and evolution of coopetition networks for value co-creation, where resources are recruited and integrated for service exchange among rivals. Operating within the S-D logic framework, these networks are shaped by institutions and institutional arrangements [72], forming interconnected service ecosystems where value is co-created through collaborative efforts and resource integration (Figure 3) [73].

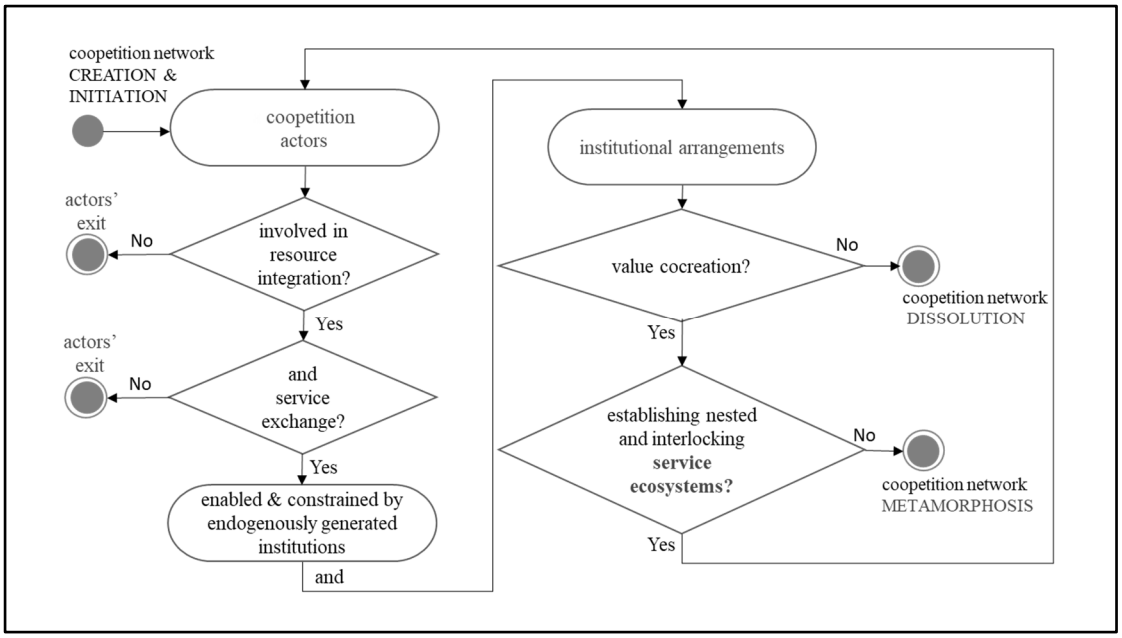


Figure 3. The operation and evolution stage of the coopetition networks for value co-creation.

At the micro-level, actors, such as rival firms, engage with technology and resources, gaining the ability to integrate their skills, knowledge, operand resources, and various assets into the network. These actors participate in multi-level interactions, engaging in service exchange that is influenced by the institutions and institutional arrangements developed at the meso-level [74]. The network activities thus represent a continuous process of adaptation, where actors adjust their roles, strategies, and resource configurations in response to the evolving dynamics of the service ecosystem.

At the meso-level, behavioral patterns emerge as institutions—humanly devised rules, norms, and shared meanings that guide interactions among the actors [75]. These institutions coordinate the actions of participants, creating a service ecosystem where resource integration and service exchange occur among multiple rivals. However, organizational routines play a crucial role in shaping the network's behavior alongside institutions.

Building on the insights from Nelson and Winter's (1982) evolutionary economics, organizational routines are considered regular, patterned activities that extend beyond individual firms and manifest across the network [76]. These routines help establish common practices and expectations, facilitating the coordination of cooperative and competitive behaviors within the coopetition network. Network routines emerge as actors collectively adopt service exchange, resource sharing, and joint problem-solving processes, thereby bringing institutional rules into practice [77].

The relationship between institutions and organizational routines is dynamic. Institutions provide the structural framework of rules and norms, while routines serve as the mechanisms that operationalize these rules in daily interactions. For instance, institutions may set norms for data sharing or competitive behavior. At the same time, routines determine how firms implement these norms in specific actions, resulting in an ongoing feedback loop where changes in network activities lead to the adaptation of existing routines or the emergence of new ones. This co-evolutionary process aligns with the principles of evolutionary economics, where routines carry organizational knowledge that evolves in response to environmental changes.

In coopetition networks, routines are co-created by multiple participants, making them inherently more adaptive than traditional routines confined to individual organizations, as they must accommodate diverse cultures, objectives, and resource capabilities. The process of resource integration is further guided by the principles of service-dominant logic, which highlight the primacy of service in exchanges, the collaborative nature of value creation, the role of actors as resource integrators, the subjective determination of value by the beneficiary, and the coordination of value co-creation through institutions and routines. As illustrated in Figure 3, the Operation Stage is a dynamic process where institutions and routines interact to shape the evolution of coopetition networks, enabling actors to adapt to changing conditions and continually seek new opportunities for value co-creation.

6.3. Metamorphosis Stage

The metamorphosis stage represents a crucial phase in evolving coopetition networks for value co-creation. Coopetition networks undergo strategic adaptations during this stage, to respond effectively to evolving market conditions and maintain competitiveness (Figure 4).

Among other reasons behind a coopetition network starting a metamorphosis stage, the reasons may comprise the following: (1) Network reshaping: A coopetition network undergoes a transformation or reshaping process. This transformation is triggered when the existing institutions and institutional arrangements within the network cannot establish the desired nested and interlocking service ecosystems; (2) Identifying the need for change: The network's leadership and stakeholders recognize the need for change. This recognition may stem from challenges in achieving the intended service ecosystems, changes in market dynamics, or other factors affecting the network's performance; (3) Strategic planning: A new strategic plan addresses the identified issues and challenges. This plan outlines the changes, improvements, or innovations needed to enhance the network's competitiveness

and value creation capabilities; (4) Improving key components: The strategic plan may focus on various aspects, including technology enhancements, governance adjustments, ontology refinement, and other relevant issues. These improvements aim to boost the network's capacity to create value through service ecosystems; (5) Reactivation of network infrastructure: Once the strategic planning phase is completed, the network-enabling infrastructure is reactivated. This involves implementing the technological, structural, and organizational changes outlined in the strategic plan; (6) Re-launching: The network undergoes a re-launching phase with the updated infrastructure. This phase signifies the network's readiness to operate under the new strategic framework; (7) (Re)Initiation Steps: The (re)initiation steps are carried out to ensure that all actors and stakeholders are aligned with the revised plan. This may involve recruiting new participants, reaffirming commitments, and conducting interoperability and cybersecurity checks to ensure compliance with the updated technology requirements. In summary, the metamorphosis stage is a pivotal phase in the life of a coopetition network for value co-creation. It involves adapting the network's strategy, technology, governance, and ontology to respond effectively to changing market conditions and trends. By embracing these adaptations, the network aims to remain competitive and continue its mission of value creation through service ecosystems.

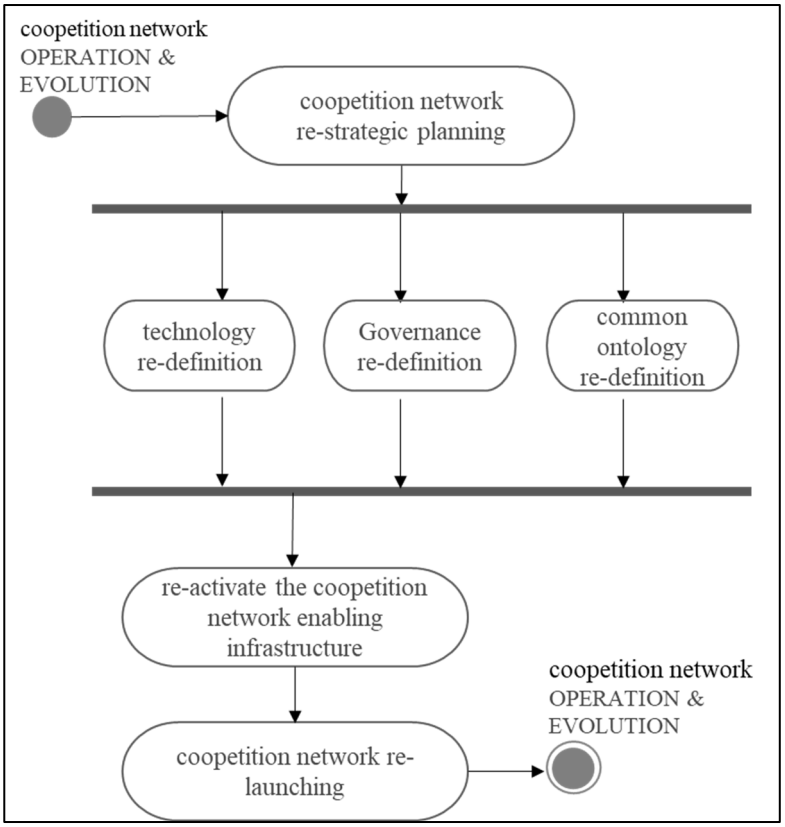


Figure 4. Metamorphosis stage of the coopetition networks for value co-creation.

6.4. Dissolution Stage

The dissolution stage, as illustrated in Figure 5, represents the coopetition network's closure when its activities end. This stage is typically triggered when the network's value creation falls below the actors' expectations, leading to a situation where the benefits of continued participation do not justify the associated costs or efforts. When the network fails to deliver adequate results or meet the evolving needs of the actors, participants may choose to withdraw from resource integration and service exchange activities. This withdrawal initiates a process of decline, resulting in the service ecosystem's gradual dissolution and the coopetition network's eventual closure.

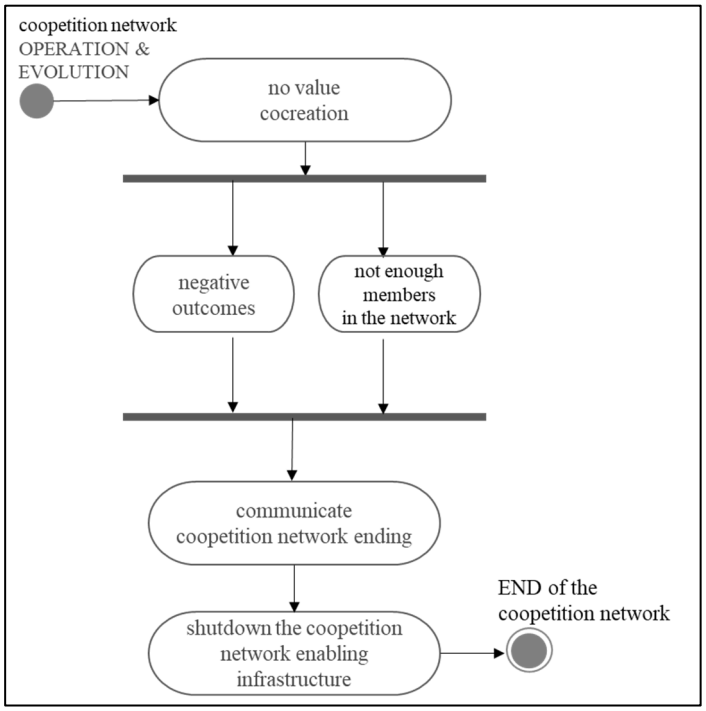


Figure 5. Dissolution stage of the coopetition for value co-creation.

During the dissolution process, the primary focus shifts to concluding all affairs and contractual obligations with participants, including customers and partners. This involves systematically shutting down the coopetition-enabling infrastructure, such as shared digital platforms or communication channels, and formally announcing the network's closure to all stakeholders. The aim is to manage the exit process in an orderly manner, ensuring that any remaining shared resources are redistributed or decommissioned, intellectual property and proprietary knowledge are appropriately safeguarded, and legal or financial obligations are settled. The dissolution marks the final phase of the network's lifecycle, closing the chapter on the cooperative efforts and signaling the end of the service ecosystem's operational activities.

The decision to dissolve a coopetition network is often driven by factors such as diminishing returns from collaboration, shifts in market conditions that render the network's objectives less relevant, changes in the strategic priorities of key actors, or the emergence of new technological or competitive disruptions that alter the landscape. In some cases, the dissolution may also be prompted by internal conflicts or disagreements that cannot be resolved through negotiation, making continued collaboration untenable. Whatever the specific triggers, the dissolution stage represents a critical point where the focus is on minimizing potential disruptions and losses associated with the network's closure while learning from the experience to inform future coopetition ventures.

7. Coopetition Networks for Value Co-Creation Evaluation

The ornamental stone sector, a pillar of Portugal's esteemed cultural heritage and progressive innovation, has played a crucial role in creating iconic stone monuments worldwide since the 15th century [78]. Recent figures from the Portuguese Stone Federation (2022) highlight the sector's notable economic influence; exporting to 116 countries, it is ranked as the ninth largest in the World International Stone Trade. It holds the second position globally for international trade per capita [79]. With exports exceeding imports by 660% and a substantial portion of these exports destined for markets outside Europe, the industry generates a turnover of EUR 1.230 million. It provides over 16,600 direct jobs, serving as a vital source of employment, especially in inland regions [55].

7.1. Preliminary Survey

To assess the acceptance level of the coopetition network reference model among Portuguese ornamental stone companies, a survey was conducted across a sample representing 16.2% of the industry. These SMEs are recognized for their substantial contributions to the economy and innovations in digital technologies [55]. Based on on-site visits, each participating company was assigned a digital level (DL) for this study, as follows:

DL#0: no digital machines are used; DL#1: at least one computerized machine on the manufacturing floor; DL#2: all machines are computerized; DL#3: all machines are computerized and connected to the SME management system; DL#4: all machines are connected and can interface with building information modelling (BIM) architects' stations.

The evaluation thoroughly assessed each company's digital production equipment, management practices, integration processes with production, and participation in digital marketplaces. The survey was organized into the following three essential actions: (1) Introduction—emphasizing the industry's transition to BIM platforms and the imperative for stone companies to scale up, offer competitive pricing, and ensure rapid delivery. (2) Hypothesis—presenting a theoretical scenario where companies join a network technology that facilitates market search collaboration with competitors while maintaining commercial confidentiality. (3) Question—inquiring if companies would be willing to collaborate with competitors under the proposed "network technology" framework. The survey, conducted throughout 2023, assessed the willingness of companies at various DLs to join such networks under a proposed "network technology" that ensures market search collaboration with competitors while maintaining commercial confidentiality.

Figure 6 provides a detailed breakdown of responses across different digital levels. The results indicate that 64.9% of respondents were strongly inclined to join collaboration networks, signifying a general acceptance of the reference model. This widespread acceptance underscores the industry's recognition of the potential benefits of such collaborations in enhancing scale, competitive pricing, and rapid delivery.

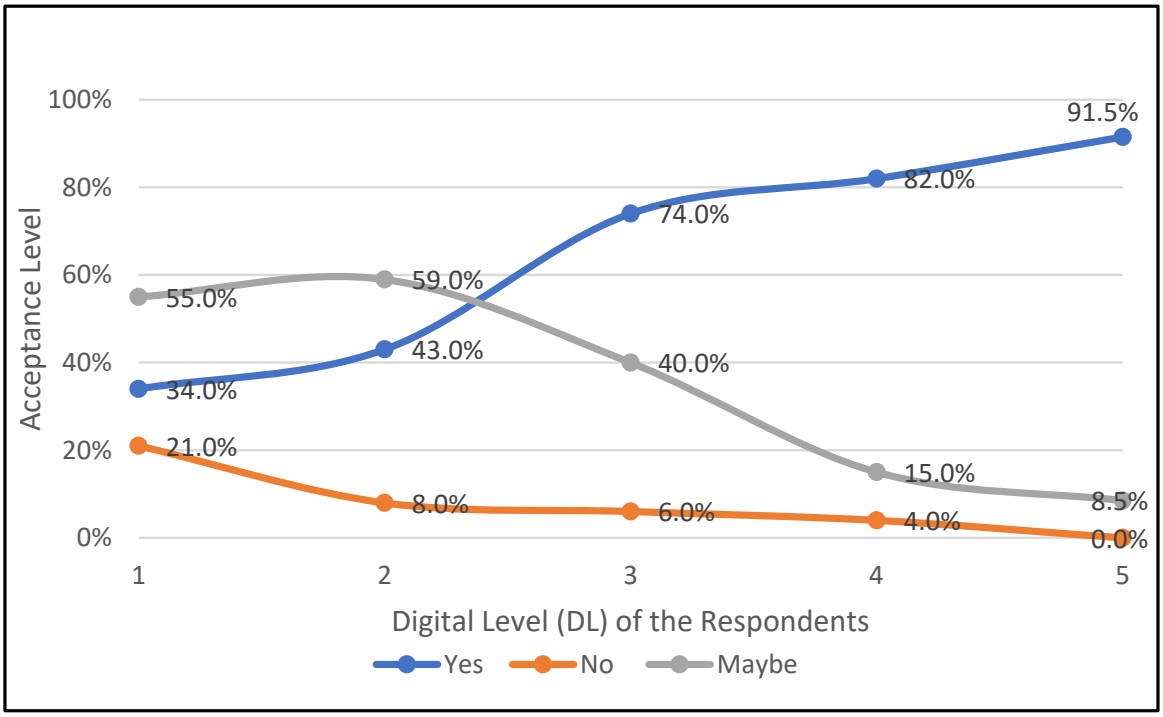


Figure 6. Functional acceptance of coopetition networks for value co-creation.

A detailed analysis of the findings reveals a strong correlation between a company's digital maturity and its inclination to participate in coopetition networks. Companies with higher digital maturity levels (DL#3 and DL#4) exhibited a notably higher acceptance rate

of 86.8%, highlighting the crucial role of digital advancement in promoting openness to collaborative innovations. These digitally advanced companies, equipped with integrated computerized systems and BIM capabilities, are more adept at leveraging technological networks for value co-creation. In contrast, only 7.8% of respondents were reluctant to join the proposed networks, indicating minimal rejection of the hypothesis. This low rejection rate further underscores the broad recognition of the strategic benefits that coopetition networks can offer. This favorable initial assessment of coopetition networks for value co-creation, particularly among DL#4 respondents, paves the way for advancing to the proof of concept (PoC) stage.

7.2. Proof-of-Concept (PoC)

The previously described instantiation methodology was utilized to implement the proof of concept (PoC) for coopetition networks for value co-creation. While the original plan aimed to include a broader range of companies, acceptance rates among SMEs at digital maturity levels DL#0, DL#1, and DL#2 were notably low. These companies faced significant challenges related to digital readiness and integration, indicating the need for further development of a digital mindset before they could participate in a coopetition network. As a result, the PoC was strategically executed for companies at digital maturity level DL#4, which had the necessary technological infrastructure and digital mindset for effective network integration.

The PoC was conducted with three DL#4 companies, representing 20% of the total population of fifteen DL#4 SMEs in the Portuguese ornamental stone sector. These companies, equipped with ERP-connected machines interfacing with BIM architects' stations, were selected due to their advanced digital capabilities, which allowed for a controlled assessment of the proposed coopetition model under optimal conditions. The setup aimed to exemplify best practices in the industry, providing insights into how coopetition could function in a highly digitally mature environment. To safeguard sensitive information throughout the PoC, a comprehensive confidentiality agreement was established with the participating companies.

For evaluating the potential of coopetition networks for value co-creation, among the numerous indicators recommended by the management and manufacturing literature [80], effectiveness was chosen as the key performance indicator (KPI_{EFECT}) [81]. Given that this is a proof of concept, this single KPI was selected due to its relevance in incorporating the element of time. BIM has changed project management and coordination in the construction industry [82]. To meet the competition requirements as imposed by BIM, stone providers must improve their production effectiveness [83]. Thus, KPI_{EFECT} was selected to assess how stone manufacturers adapt to global BIM procurement requirements. The KPI_{EFECT} metric measures effectiveness by calculating the ratio of daily good parts produced (GPP) to the number of production hours (PT) utilized (Equation (1)), as follows:

$$KPI_{EFECT}\ (\text{good partes/hour}) = \sum_{1}^{n}\left(\frac{GPP_{(daily)}}{PT_{(daily)}}\right) \quad (1)$$

Improvements in KPI_{EFECT} indicate increased production effectiveness, allowing firms to offer stone parts at more competitive prices.

This PoC employed a comprehensive data collection strategy over two separate fifty-four-day periods to evaluate the transition from state-of-the-art (SoA) practices to a coopetition network for value co-creation (CNVC) practices. The comparative analysis highlights the potential of coopetition networks to enhance performance efficiency. It demonstrates how these networks' shared resources and collaborative efforts can lead to superior operational outcomes. By improving the KPI_{EFECT}, firms can better align with BIM requirements, co-creating value through enhanced project execution and timely delivery. This underscores the strategic advantage of adopting coopetition networks to drive value co-creation and operational excellence in the construction sector.

To collect data for assessing KPI_{EFECT}, an Internet of Things (IoT) prototype was deployed with two ornamental stone producers [75]. This PoC aimed to showcase the benefits of coopetition networks for value co-creation. The implementation allowed these SMEs to experience enhanced digital connectivity and collaboration within their operations. Figure 7 illustrates the digital connectivity and operational synergies achieved through the network.

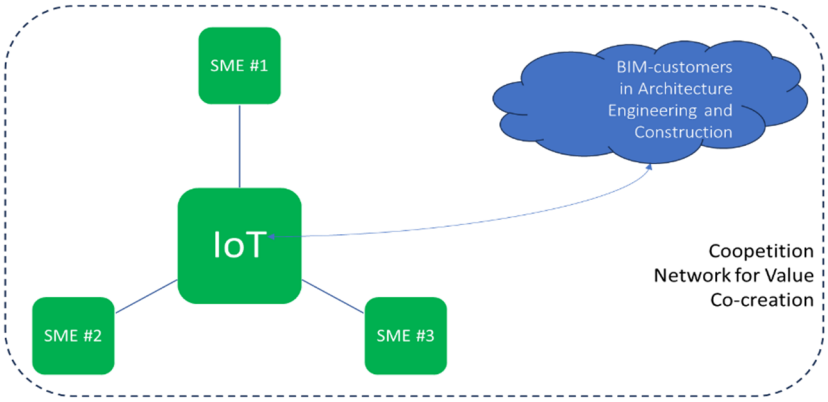


Figure 7. The IoT-enabled coopetition networks for value co-creation.

This PoC utilized a structured data collection approach over two 54-day periods to assess the shift from SoA to CNVC. This framework facilitated a detailed analysis of KPI_{EFECT} before and after the implementation of the competition network for value co-creation.

The first phase aimed to document operational metrics under the SoA conditions. During this period, each company operated independently, managing its production and delivery processes without any collaborative interactions. This phase established a baseline of traditional practices, serving as a reference point for later comparisons.

The second phase marked the transition to CNVC practices, where companies engaged in an IoT-enabled network. The CNVC practices blend competition and cooperation among companies, fostering an environment of shared resources and technological collaboration. Using IoT technology, companies could enhance their operational efficiencies and innovate together. In this phase, companies were encouraged to leverage each other's strengths and technological capabilities within a secure and adaptable framework. The structured sharing and secure communication practices fostered an environment conducive to collective innovation and operational improvement. The following practices were implemented: (1) SMEs confidentially shared and accessed each other's resources, such as stock and machinery, enabling more efficient use of assets and mutual support within the network; (2) companies had the flexibility to join or leave the network at any time, maintaining their autonomy while participating in the collaborative ecosystem; (3) all interactions and data exchanges were conducted using secure OPC-UA protocols [84], ensuring confidentiality and protection of proprietary information; (5) companies provided and gained access to resources based on a reciprocal model, fostering cooperation while preserving competitive integrity; and, (6) the network was designed to integrate with BIM systems used by architects seamlessly [85], enhancing coordination across different stages of production and delivery.

Adherence to confidentiality agreements was critical throughout this phase. All data were stored and handled to ensure privacy and security, facilitating a robust evaluation of CNVC's impact on operational efficiencies.

Data were collected and managed, focusing on privacy and security compliance. All data were anonymized and referenced only by company labels. Collection, recording, and export procedures were meticulously followed, with results stored in Excel files for secure and consistent handling. This approach enabled a detailed analysis while safeguarding the privacy and proprietary information of the participating companies.

In this study, the tangible benefits of coopetition practices within SMEs were highlighted by contrasting operational metrics between the SoA and CNVC phases. Table 1 summarizes the collected data.

Table 1. Summary of data collected during the proof of concept.

Data	Description	Daily Average (SoA)	Daily Average (CNVC)
Data 1	Good Parts Produced (good parts)	299.2	415.8
Data 2	Production Time (hours/day)	13.3	13.3
KPI_{EFECT}	Efficiency (good parts/hour)	22.48	31.20

Under the SoA conditions, the KPI_{EFECT} was 22.48 good parts per hour. During the CNVC phase, this efficiency significantly increased to 31.20 good parts per hour, representing a substantial gain of 38.8%.

8. Discussion of PoC Results and Broader Implications

The PoC demonstrated substantial improvements in operational efficiency for the participating DL#4 companies in the Portuguese ornamental stone sector. The 38.8% increase in the KPI_{EFECT}, from 22.48 to 31.20 good parts per hour, highlights the potential of coopetition networks to significantly enhance production processes by enabling resource sharing, collaboration, and mutual support. These improvements suggest that coopetition can be an effective strategy for SMEs, particularly those with advanced digital capabilities.

Figure 8 shows a moderate positive correlation between the degree of coopetition network integration and operational effectiveness (Pearson's r = 0.499), indicating that increased participation in coopetition networks is associated with higher production efficiency. The trend line shows that each unit increase in network integration corresponds to an increase of approximately 0.1503 good parts per hour, starting from a baseline of 27.5 good parts per hour. However, the fact that coopetition networks account for only about 24.9% of the variability in effectiveness implies that other factors also play a significant role in determining performance outcomes.

While the results validate the potential benefits of coopetition for digitally mature SMEs, a critical analysis is necessary to understand the sustainability, generalizability, and broader implications of these findings across different contexts.

The observed efficiency improvements are promising, but their long-term sustainability requires careful consideration. The PoC was conducted in a controlled environment with companies already equipped with advanced digital infrastructure and a collaborative mindset. As the network grows and includes more diverse participants, factors such as fluctuating market conditions, technological changes, and coopetition dynamics shifts could impact the coopetition model's continued success. To maintain efficiency gains, ongoing investments in digital infrastructure, skills development, and process innovation will likely be needed, especially as companies at varying levels of digital maturity join the network. Future research should focus on longitudinal studies to track these efficiency gains' persistence over time and develop strategies for adapting the coopetition model in response to evolving business environments.

One of the limitations of this PoC is its exclusion of SMEs at lower digital maturity levels (DL#0 to DL#2), which could potentially derive even greater benefits from participating in a coopetition network. The current focus on DL#4 companies was intended to assess the model's feasibility under ideal conditions, but it needs to account for the challenges that less digitally advanced firms may face, such as difficulties in integration, data sharing, or adopting new technologies. These firms may encounter barriers to realizing similar efficiency gains due to limited resources, expertise, or digital capabilities. To make the

coopetition model more inclusive, future efforts should explore strategies for gradually onboarding companies with lower digital maturity. This could involve providing targeted training programs, digital upskilling initiatives, or phased integration processes that allow these firms to enhance their digital competencies progressively while engaging in collaborative practices.

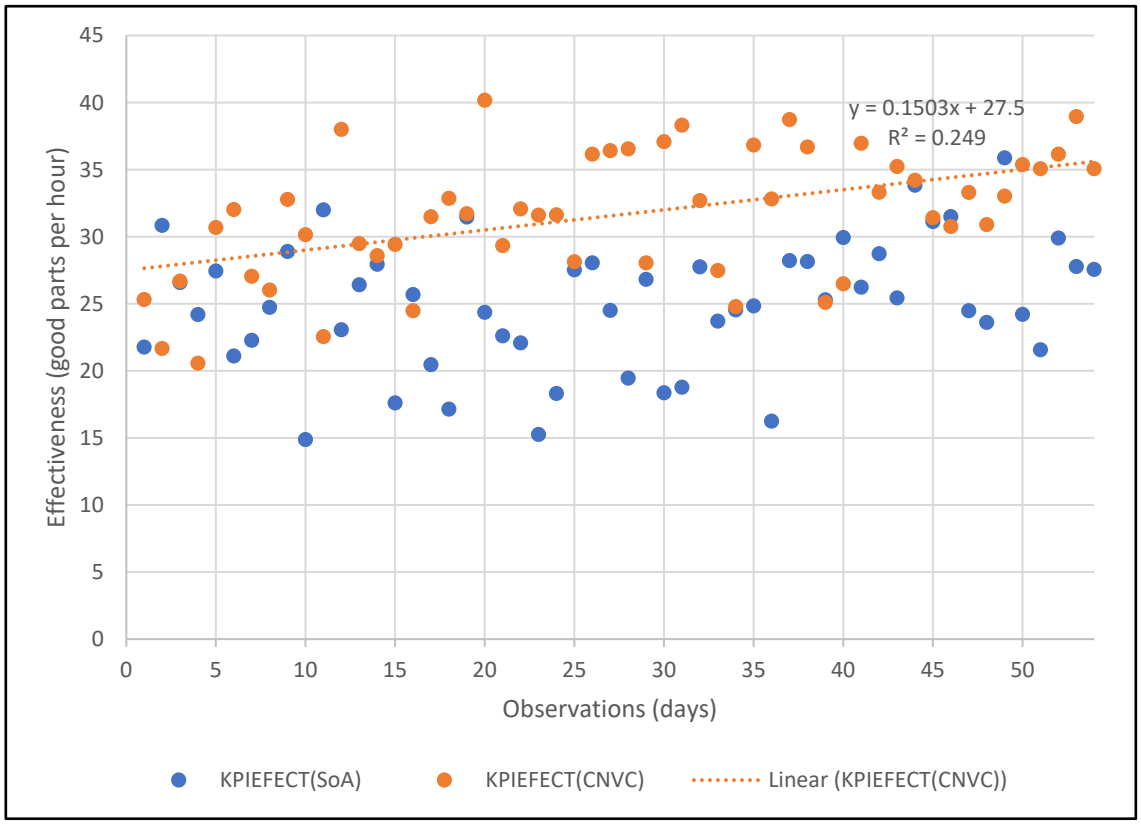


Figure 8. Impact trend of coopetition networks on performance efficiency (good parts per hour).

8.1. Cross-Industry Generalizability of the Coopetition Model

The PoC was conducted within the ornamental stone industry, characterized by a high degree of customization, reliance on natural resources, and integration with architectural design processes through BIM. While the coopetition model proved effective in this sector, applying it to other industries requires careful consideration of sector-specific factors. For instance, industries such as manufacturing, healthcare, or retail may face unique challenges related to regulatory compliance, competitive dynamics, or supply chain complexity, which could affect the feasibility and impact of coopetition networks.

To enhance the cross-industry applicability of the model, future studies should implement the coopetition framework in various sectors to examine how different industry characteristics influence outcomes. This approach would help identify the necessary adaptations to optimize the model for different contexts. Moreover, comparisons between industries can offer insights into the underlying mechanisms that drive coopetition success, helping to generalize the model's core principles while allowing for customization based on sector-specific needs.

While the PoC findings indicate that coopetition networks can drive significant operational improvements, several challenges must be addressed for widespread adoption. One major challenge is ensuring the secure sharing of sensitive information, especially among direct competitors. The PoC's use of secure OPC-UA protocols and confidentiality agreements provided a controlled environment for managing these risks, but scaling these practices across larger or more complex networks could prove challenging. The success

of coopetition initiatives will depend on establishing robust data security measures and building trust among participants.

Additionally, the effectiveness of coopetition networks hinges on the willingness of firms to engage in reciprocal collaboration, which may vary based on organizational culture, past experiences, or strategic priorities. Some SMEs may resist fully embracing collaborative practices if they perceive the risks to outweigh the benefits. Overcoming this resistance will require demonstrating the tangible value of coopetition and fostering a cultural shift towards collective value creation. This can be achieved through case studies, pilot programs, and incentives that illustrate the benefits of collaboration.

8.2. Implications for Digital Transformation and Policy

The findings from this PoC underscore the potential of coopetition networks to accelerate digital transformation, especially in sectors where SMEs are prevalent. The case of the ornamental stone industry shows that embracing digital connectivity and collaborative practices can lead to substantial performance improvements, aligning with broader industry trends toward digitization and Industry 4.0. Policymakers can support this transition by incentivizing SMEs to adopt digital technologies, fostering ecosystems that encourage collaboration, and developing regulatory frameworks that facilitate secure data sharing and network integration. These policy measures can help lower the barriers to coopetition and promote the digitalization of traditionally underserved sectors.

8.3. Potential Trade-Offs and Risks of Adopting the Coopetition Model

While the coopetition model offers benefits for boosting efficiency and value co-creation, it also presents trade-offs that can affect long-term competitiveness. Key risks include unintended knowledge sharing, market cannibalization, and dependency on external partners.

Unintended knowledge sharing is a concern, as even with secure protocols, collaboration may lead to the unintentional transfer of proprietary information, potentially weakening a firm's competitive advantage. To reduce this risk, SMEs should set clear information-sharing boundaries and focus collaboration on less sensitive areas.

Market cannibalization may occur if partners compete for the same customers, particularly in industries with limited differentiation. To avoid this, SMEs should choose partners whose strengths complement their own and pursue joint initiatives that open new market opportunities.

Dependence on shared resources can undermine a firm's internal capabilities, making it challenging to innovate independently. To maintain competitiveness, firms should balance coopetition activities with efforts to develop internal competencies and invest in R&D.

Strategic misalignment and conflicts of interest can also pose risks, as differences in priorities or goals may hinder collaboration. Clear governance structures and shared objectives can help align expectations and resolve conflicts.

Finally, legal and regulatory risks may arise, especially in industries with strict competition laws. SMEs should seek legal guidance to ensure compliance with relevant regulations.

Adopting a dual strategy that combines coopetition with traditional competitive approaches can help SMEs maximize the benefits of collaboration while maintaining a solid market position.

8.4. Long-Term Implications for Scalability and Generalizability

The PoC results demonstrated significant short-term efficiency gains. However, deeper exploration is needed to understand the long-term implications of scaling the coopetition model and its generalizability across different sectors. As the network expands to include a broader range of SMEs, challenges such as varying digital maturity levels, differences in organizational culture, and resource disparities could arise. To scale the model successfully,

it will be essential to implement robust governance mechanisms, standardize procedures, and ensure that participating firms can adapt to evolving business environments.

While the 38.8% increase in efficiency is promising, the sustainability of these gains in the long term is still being determined. Factors such as changing market conditions, technological advancements, and shifts in collaboration dynamics could affect continued benefits. Ongoing investments in digital infrastructure, skills development, and process improvements will be needed to maintain performance over time. Longitudinal studies should explore how coopetition networks evolve and adapt, providing insights for refining the model's applicability across different contexts.

Generalizing the model to other industries requires the careful consideration of sector-specific factors like regulatory requirements and supply chain complexity. For instance, industries such as healthcare or manufacturing may face unique challenges or opportunities that impact the model's effectiveness. Testing the model in various sectors will help identify necessary adaptations for optimizing its use in different business environments.

Additionally, long-term reliance on coopetition should be balanced with efforts to maintain unique competitive advantages. While collaboration can drive operational improvements, firms should continue investing in innovation and internal competencies to avoid overdependence on shared resources. Integrating coopetition with traditional competitive strategies ensures the model supports sustained growth without compromising a firm's ability to innovate independently.

The findings also imply that policy measures and support programs can play a role in enhancing the model's scalability. Providing incentives for digital transformation, collaborative R&D, and skills development can help a broader range of SMEs adopt the model, ensuring its relevance and applicability in diverse settings.

9. Conclusions

In this study, a significant gap is addressed in the coopetition literature by developing a reference model specifically tailored for SMEs, grounded in the S-D logic. While coopetition has been extensively studied in large enterprises, its potential to enhance performance in SMEs still needs to be explored. The unique challenges SMEs face—such as limited resources and the absence of dominant network players—make sustaining coopetition particularly difficult. This research aims to fill this gap by shifting the focus from transactional interactions to service-based exchanges, enabling SMEs to overcome resource constraints and collaborate more effectively. The proposed model covers the entire lifecycle of coopetition networks, from initiation to dissolution, providing actionable guidelines to help SMEs navigate these collaborative ventures.

The practical application of this study was validated through a PoC within the Portuguese ornamental stone sector, chosen for its relevance in demonstrating the potential benefits of coopetition. The PoC showed a 92.3% approval rate from participants, confirming the model's practical utility. Moreover, the 38.8% increase in the effectiveness KPI (from 22.48 to 31.20 good parts per hour) demonstrated the model's ability to enhance operational performance, validating its real-world applicability and showcasing how coopetition networks can drive tangible benefits for SMEs.

The theoretical implications of this study lie in its extension of S-D logic to the context of coopetition networks, positioning technology not merely as a tool but as an enabler of service exchange. This approach deepens the understanding of coopetition networks as dynamic service ecosystems, enriching the discourse on value co-creation within SME contexts. By framing technology as a catalyst for integrating resources and facilitating mutual value creation, this study contributes to the literature by providing a nuanced view of how digital transformation can be leveraged to enhance collaborative interactions. Additionally, integrating organizational routines and institutions into the model offers new insights into the co-evolution of network behaviors, highlighting how these elements interact to shape the development of service ecosystems over time.

From a managerial perspective, in this study, practical guidance is provided for SME managers seeking to implement and sustain coopetition networks. The model offers a structured approach to navigating the complexities of multi-actor collaboration, emphasizing the importance of aligning shared goals, establishing governance mechanisms, and building trust among participants. The findings suggest that SMEs can benefit from adopting a dual approach that combines coopetition with traditional competitive strategies, ensuring that collaboration enhances rather than dilutes competitive differentiation. Furthermore, the potential risks are identified in this study, such as unintended knowledge sharing and market cannibalization. It proposes strategies to mitigate these risks by establishing clear boundaries for information exchange and selecting partners with complementary strengths. Policymakers can also draw on these insights to design support programs that incentivize digital transformation, facilitate secure data sharing, and promote collaborative R&D initiatives.

However, this study has limitations that future research should address. The focus on DL#4 companies presents challenges in generalizing the results, as SMEs with lower technological capabilities (DL#0 to DL#2) were not considered. While this focus was necessary to validate the model under optimal conditions, the findings may not fully capture the experiences and challenges less digitally mature SMEs face. Expanding the scope to include a more diverse range of companies, considering variations in digital maturity, size, and industry, would provide a more comprehensive evaluation of the model's applicability. Additionally, the emphasis in this study on short-term gains in production efficiency leaves the long-term sustainability of these improvements to be explored. Future research should involve longitudinal studies to monitor the persistence of efficiency gains, assess the impact of coopetition networks on innovation and competitiveness, and explore how changes in market conditions or collaborative dynamics influence the model's effectiveness over time.

The complex dynamics of human relationships within coopetition networks were not thoroughly examined in this study, although they can significantly influence network sustainability. Future studies should investigate the role of interpersonal and inter-organizational relationships in shaping long-term success and address the economic implications of adopting coopetition networks, including associated costs and trade-offs. Moreover, the potential risks were highlighted in this study, such as strategic misalignment and regulatory challenges, calling for further exploration of strategies to manage these risks effectively and optimize collaborative approaches.

In conclusion, this study contributes to the coopetition literature by offering a reference model for SMEs that integrates theoretical insights from S-D logic and practical guidance from empirical evaluation. The proposed model demonstrates significant potential to improve SME performance through strategic collaboration, addressing theoretical and managerial aspects. While the findings provide a solid foundation for enhancing SME competitiveness in the digitalized, network-based business landscape, they also lay the groundwork for future research to build on these insights and explore emerging opportunities in coopetition.

Author Contributions: Conceptualization, A.D.S. and A.J.M.C.; methodology, A.D.S.; software, A.D.S.; validation, A.D.S. and A.J.M.C.; formal analysis, A.D.S.; investigation, A.D.S.; resources, A.D.S.; data curation, A.D.S.; writing—original draft preparation, A.D.S.; writing—review and editing, A.D.S.; visualization, A.D.S.; supervision, A.D.S.; project administration, A.D.S.; funding acquisition, A.D.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Stone by Portugal, Portaria n.º 43-A/19 January 2022 (Agenda C5-Aviso N.º 02/C05-i01/2022), funded by the Plano de Recuperação e Resiliência, Agendas para A Inovação Empresarial. And The APC was funded by Ensinus Estudos Superiores, SA.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Muller, P.; Devnani, S.; Ladher, R.; Cannings, J.; Murphy, E.; Robin, N.; Illán, S.R.; Aranda, F.; Gorgels, S.; Priem, M.; et al. *Annual Report on European SMEs 2020/2021—Digitalisation of SMEs—Background Document*; Hope, K., Ed.; Publications Office of the European Union: Luxembourg, 2021. [CrossRef]
2. Di Bella, L.; Katsinis, A.; Lagüera-González, J.; Odenthal, L.; Hell, M.; Lozar, B. *Annual Report on European SMEs 2022/2023*; Publications Office of the European Union: Luxembourg, 2023.
3. Bouncken, R.; Kumar, A.; Connell, J.; Bhattacharyya, A.; He, K. Coopetition for corporate responsibility and sustainability: Does it influence firm performance? *Int. J. Entrep. Behav. Res.* **2024**, *30*, 128–154. [CrossRef]
4. Vargo, S.L.; Lusch, R.F. Evolving to a New Dominant Logic for Marketing. *J. Mark.* **2004**, *68*, 1–17. [CrossRef]
5. Meena, A.; Dhir, S.; Sushil, S. A review of coopetition and future research agenda. *J. Bus. Ind. Mark.* **2023**, *38*, 118–136. [CrossRef]
6. Reeves, M.; Lotan, H.; Legrand, J.; Jacobides, M.G. How Business Ecosystems Rise (and Often Fall). In *Business Ecosystems*; De Gruyter: Berlin, Germany, 2022; pp. 27–34.
7. Destefanis, S.; Maietta, O.W.; Mazzotta, F.; Parisi, L. Firm survival and innovation: Direct and indirect effects of knowledge for SMEs. *Econ. Innov. New Technol.* **2024**, *33*, 926–954. [CrossRef]
8. da Silva, A.; Cardoso, A.J.M. A Comprehensive Service Blueprint for Enhancing Coopetition Networks BT. In Proceedings of the Third International Conference on Innovations in Computing Research (ICR'24), Athens, Greece, 12–14 August 2024; pp. 322–333.
9. Crick, J. The dark side of coopetition: When collaborating with competitors is harmful for company performance. *J. Bus. Ind. Mark.* **2019**, *35*, 318–337. [CrossRef]
10. Rouyre, A.; Fernandez, A.-S.; Bruyaka, O. Big problems require large collective actions: Managing multilateral coopetition in strategic innovation networks. *Technovation* **2024**, *132*, 102968. [CrossRef]
11. Manzhynski, S.; Biedenbach, G. The knotted paradox of coopetition for sustainability: Investigating the interplay between core paradox properties. *Ind. Mark. Manag.* **2023**, *110*, 31–45. [CrossRef]
12. Corbo, L.; Kraus, S.; Vlačić, B.; Dabić, M.; Caputo, A.; Pellegrini, M.M. Coopetition and innovation: A review and research agenda. *Technovation* **2023**, *122*, 102624. [CrossRef]
13. Amaral, A.; Peças, P. SMEs and Industry 4.0: Two case studies of digitalization for a smoother integration. *Comput. Ind.* **2021**, *125*, 103333. [CrossRef]
14. Gillani, F.; Chatha, K.A.; Jajja, S.S.; Cao, D.; Ma, X. Unpacking Digital Transformation: Identifying key enablers, transition stages and digital archetypes. *Technol. Forecast. Soc. Chang.* **2024**, *203*, 123335. [CrossRef]
15. da Silva, A.; Cardoso, A.J.M. Value Creation in Technology-Driven Ecosystems: Role of Coopetition in Industrial Networks. *J. Theor. Appl. Electron. Commer. Res.* **2024**, *19*, 2343–2359. [CrossRef]
16. Xie, Q.; Gao, Y.; Xia, N.; Zhang, S.; Tao, G. Coopetition and organizational performance outcomes: A meta-analysis of the main and moderator effects. *J. Bus. Res.* **2023**, *154*, 113363. [CrossRef]
17. Bicen, P.; Hunt, S.; Madhavaram, S. Coopetitive innovation alliance performance: Alliance competence, alliance's market orientation, and relational governance. *J. Bus. Res.* **2021**, *123*, 23–31. [CrossRef]
18. Mwesiumo, D.; Harun, M.; Hogset, H. Unravelling the black box between coopetition and firms' sustainability performance. *Ind. Mark. Manag.* **2023**, *114*, 110–124. [CrossRef]
19. Klimas, P.; Ahmadian, A.A.; Soltani, M.; Shahbazi, M.; Hamidizadeh, A. Coopetition, Where Do You Come from? Identification, Categorization, and Configuration of Theoretical Roots of Coopetition. *SAGE Open* **2023**, *13*, 215824402210850. [CrossRef]
20. Elo, J.; Lumivalo, J.; Tuunanen, T.; Vargo, S.L. Enabling Value Co-Creation in Partner Collaboration Ecosystems: An Institutional Work Perspective. In Proceedings of the 57th Annual Hawaii International Conference on System Sciences (HICSS 2024), Honolulu, HI, USA, 3–6 January 2024; Available online: https://www.sdlogic.net/pdf/post2018/24_0031.pdf (accessed on 17 October 2024).
21. Vargo, S.L.; Fehrer, J.A.; Wieland, H.; Nariswari, A. The nature and fundamental elements of digital service innovation. *J. Serv. Manag.* **2024**, *35*, 227–252. [CrossRef]
22. Lusch, R.; Vargo, S. Service-dominant logic: Continuing the evolution. *J. Acad. Mark. Sci.* **2007**, *36*, 1–10. [CrossRef]
23. Vargo, S.; Lusch, R. Institutions and axioms: An extension and update of service-dominant logic. *J. Acad. Mark. Sci.* **2016**, *44*, 5–23. [CrossRef]
24. Vargo, S.L.; Lusch, R.F. Advancing Service Science with Service-Dominant Logic. In *Handbook of Service Science*; Springer: New York, NY, USA, 2010. [CrossRef]
25. Lusch, R.; Nambisan, S. Service Innovation: A Service-Dominant Logic Perspective. *MIS Q.* **2015**, *39*, 155–175. [CrossRef]
26. Lusch, R.F.; Vargo, S.L.; Tanniru, M. Service, value networks and learning. *J. Acad. Mark. Sci.* **2010**, *38*, 19–31. [CrossRef]
27. Vargo, S.; Akaka, M. Value Cocreation and Service Systems (Re)Formation: A Service Ecosystems View. *Serv. Sci.* **2012**, *4*, 207–217. [CrossRef]
28. Vargo, S.L.; Lusch, R. Service-dominant logic 2025. *Int. J. Res. Mark.* **2017**, *34*, 46–67. [CrossRef]
29. Hunt, S.D. *A General Theory of Competition: Resources, Competences, Productivity, Economic Growth*; Sage Publications: Thousand Oaks, CA, USA, 2000; Volume 16, pp. 385–393.
30. Arthur, W.B. *The Nature of Technology*; Penguin Books Ltd., Registered Offices: London, UK, 2009.
31. Shen, L.; Qin, C.; Luo, C. A Grounded Theory Approach to Brand Value Networks: The Prosumption Logic Standpoint. *Am. J. Ind. Bus. Manag.* **2020**, *10*, 841–860. [CrossRef]

32. Rusko, R. Mapping the perspectives of coopetition and technology-based strategic networks: A case of smartphones. *Ind. Mark. Manag.* **2014**, *43*, 801–812. [CrossRef]
33. Sklyar, A.; Kowalkowski, C.; Sörhammar, D.; Tronvoll, B. Resource integration through digitalization: A service ecosystem perspective. *J. Mark. Manag.* **2019**, *35*, 974–991. [CrossRef]
34. Geissdoerfer, M.; Vladimirova, D.; Evans, S. Sustainable business model innovation: A review. *J. Clean. Prod.* **2018**, *198*, 401–416. [CrossRef]
35. Hevner, A.; March, S.; Park, J.; Ram, S. Design Science in Information Systems Research. *MIS Q.* **2004**, *28*, 75. [CrossRef]
36. vom Brocke, J.; Hevner, A.; Maedche, A. Introduction to Design Science Research. In *Design Science Research. Cases*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 1–13.
37. Silva, A.; Pata, A. Value Creation in Technology Service Ecosystems—An Empirical Case Study. In *Innovations in Industrial Engineering II*; Lecture Notes in Mechanical Engineering; Springer: Cham, Switzerland, 2023; pp. 26–36. [CrossRef]
38. Jaakkola, E.; Vargo, S.L. Assessing and enhancing the impact potential of marketing articles. *AMS Rev.* **2021**, *11*, 407–415. [CrossRef]
39. Lusch, R.; Vargo, S.; Gustafsson, A. Fostering a trans-disciplinary perspectives of service ecosystems. *J. Bus. Res.* **2016**, *69*, 2957–2963. [CrossRef]
40. Wieland, H.; Hartmann, N.; Vargo, S. Business models as service strategy. *J. Acad. Mark. Sci.* **2017**, *45*, 925–943. [CrossRef]
41. Vargo, S.L.; Akaka, M.A. Service-Dominant Logic as a Foundation for Service Science: Clarifications. *Serv. Sci.* **2009**, *1*, 32–41. [CrossRef]
42. Vargo, S.L.; Akaka, M.A.; Wieland, H. Rethinking the process of diffusion in innovation: A service-ecosystems and institutional perspective. *J. Bus. Res.* **2020**, *116*, 526–534. [CrossRef]
43. Vargo, S.L.; Lusch, R.F. Inversions of service-dominant logic. *Mark. Theory* **2014**, *14*, 239–248. [CrossRef]
44. Zott, C.; Amit, R. The fit between product market strategy and business model: Implications for firm performance. *Strateg. Manag. J.* **2008**, *29*, 1–26. [CrossRef]
45. Kleinaltenkamp, M.; Kleinaltenkamp, M.J.; Karpen, I.O. Resource entanglement and indeterminacy: Advancing the service-dominant logic through the philosophy of Karen Barad. *Mark. Theory* **2023**. [CrossRef]
46. Jaakkola, E.; Kaartemo, V.; Siltaloppi, J.; Vargo, S.L. Advancing service-dominant logic with systems thinking. *J. Bus. Res.* **2024**, *117*, 114592. [CrossRef]
47. Barile, S.; Piciocchi, P.; Bassano, C.; Spohrer, J.; Pietronudo, M.C. Re-defining the role of artificial intelligence (AI) in wiser service systems. *Adv. Intell. Syst. Comput.* **2019**, *787*, 159–170. [CrossRef]
48. Pakkala, D.; Koivusaari, J.; Pääkkönen, P.; Spohrer, J. An Experimental Case Study on Edge Computing Based Cyber-Physical Digital Service Provisioning with Mobile Robotics. In Proceedings of the 53rd Hawaii International Conference on System Sciences, Maui, HI, USA, 7–10 January 2020; pp. 1165–1174. [CrossRef]
49. Nambisan, S. Information Technology and Product/Service Innovation: A Brief Assessment and Some Suggestions for Future Research. *J. Assoc. Inf. Syst.* **2013**, *14*, 215–226. [CrossRef]
50. Raza-Ullah, T.; Bengtsson, M.; Kock, S. The coopetition paradox and tension in coopetition at multiple levels. *Ind. Mark. Manag.* **2014**, *43*, 189–198. [CrossRef]
51. Breidbach, C.; Maglio, P. Technology-enabled value co-creation: An empirical analysis of actors, resources, and practices. *Ind. Mark. Manag.* **2016**, *56*, 73–85. [CrossRef]
52. Imschloss, M.; Schwemmle, M. Value creation in post-pandemic retailing: A conceptual framework and implications. *J. Bus. Econ.* **2024**, *94*, 851–889. [CrossRef]
53. Legner, C.; Pentek, T.; Otto, B. Accumulating Design Knowledge with Reference Models: Insights from 12 Years' Research into Data Management. *J. Assoc. Inf. Syst.* **2020**, *21*, 735–770. [CrossRef]
54. Spohrer, J.; Maglio, P.; Bailey, J.; Gruhl, D. Steps Toward a Science of Service Systems. *IEEE Comput. Soc.* **2007**, *40*, 71–77. [CrossRef]
55. Silva, A.; Dionísio, A.; Coelho, L. Flexible-lean processes optimization: A case study in stone sector. *Results Eng.* **2020**, *6*, 100129. [CrossRef]
56. van Schaik, M.E.; Pichon, S.A.S.; Toeters, M.J.; Bottenberg, E.; Gonzalez, J.F.; Kuhlmann, J.-C. Weaving Together Disciplines: Service Blueprinting for Multidisciplinary E-Textile Design. *Eng. Proc.* **2024**, *52*, 16. [CrossRef]
57. Saccetti, S.; Tortia, E. The extended governance of cooperative firms: Inter-firm coordination and consistency of values. *Ann. Public Coop. Econ.* **2016**, *87*, 93–116. [CrossRef]
58. Ng, I.; Wakenshaw, S. The Internet-of-Things: Review and research directions. *Int. J. Res. Mark.* **2017**, *34*, 3–21. [CrossRef]
59. Vargo, S.L.; Wieland, H.; O'Brien, M. Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline. *J. Bus. Res.* **2023**, *164*, 113965. [CrossRef]
60. North, D.C. *Institutions, Institutional Change and Economic Performance*; Cambridge University Press: Cambridge, UK, 1990.
61. Scott, W. *Institutions and Organizations-Ideas, Interests, and Identities*; SAGE Publications, Inc.: Thousand Oak, CA, USA, 2013.
62. Mokyr, J. *The Gifts of Athena*; Princeton University Press: Princeton, NJ, USA, 2002.
63. Simon, H.A. The Science of Design: Creating the Artificial. *Des. Issues* **1988**, *4*, 67. [CrossRef]
64. Nelson, R.R.; Nelson, K. Technology, institutions, and innovation systems. *Res. Policy* **2002**, *31*, 265–272. [CrossRef]
65. Orlikowski, W.J. Using technology and constituting structures: A practice lens for studying technology in organizations. *Organ. Sci.* **2000**, *11*, 404–428. [CrossRef]

66. Orlikowski, W.J. The Duality of Technology: Rethinking the Concept of Technology in Organizations. *Organ. Sci.* **1992**, *3*, 398–427. [CrossRef]
67. Vargo, S.; Wieland, H.; Akaka, M. Innovation through institutionalization: A service ecosystems perspective. *Ind. Mark. Manag.* **2015**, *44*, 63–72. [CrossRef]
68. Akaka, M.; Schau, H.; Vargo, S. How Practice Diffusion Drives IoT Technology Adoption and Institutionalization of Solutions in Service Ecosystems. In Proceedings of the Annual Hawaii International Conference on System Sciences, Maui, HI, USA, 3–6 January 2023; pp. 1427–1435. [CrossRef]
69. Akaka, M.A.; Vargo, S.L. Technology as an operant resource in service (eco)systems. *Inf. Syst. e-Bus. Manag.* **2014**, *12*, 367–384. [CrossRef]
70. Mustak, M.; Plé, L. A critical analysis of service ecosystems research: Rethinking its premises to move forward. *J. Serv. Mark.* **2020**, *34*, 399–413. [CrossRef]
71. Chen, M.; Lv, C.; Wang, X.; Li, L.; Yang, P. A Critical Review of Studies on Coopetition in Educational Settings. *Sustainability* **2023**, *15*, 8370. [CrossRef]
72. Chandler, J.D.; Danatzis, I.; Wernicke, C.; Akaka, M.A.; Reynolds, D. How Does Innovation Emerge in a Service Ecosystem? *J. Serv. Res.* **2019**, *22*, 75–89. [CrossRef]
73. Razmdoost, K.; Alinaghian, L.; Chandler, J.D.; Mele, C. Service ecosystem boundary and boundary work. *J. Bus. Res.* **2023**, *156*, 113489. [CrossRef]
74. Friend, S.B.; Malshe, A.; Fisher, G.J. What drives customer Re-engagement? The foundational role of the sales-service interplay in episodic value co-creation. *Ind. Mark. Manag.* **2020**, *84*, 271–286. [CrossRef]
75. Mosch, P.; Majocco, P.; Obermaier, R. Contrasting value creation strategies of industrial-IoT-platforms—A multiple case study. *Int. J. Prod. Econ.* **2023**, *263*, 108937. [CrossRef]
76. Ulen, T.S. An Evolutionary Theory of Economic Change. By Richard R. Nelson and Sidney G. Winter. *Bus. Hist. Rev.* **1983**, *57*, 576–578. [CrossRef]
77. Lissillour, R.; Cui, Y.; Guesmi, K.; Chen, W.; Chen, Q. Value network and firm performance: The role of knowledge distance and environmental uncertainty. *J. Knowl. Manag.* **2024**, *28*, 44–68. [CrossRef]
78. Carvalho, J.M.F.; Lisboa, J.V. Ornamental stone potential areas for land use planning: A case study in a limestone massif from Portugal. *Environ. Earth Sci.* **2018**, *77*, 206. [CrossRef]
79. Silva, A.; Cardoso, A.M. BIM-based Supply Chain in AEC-Threats on the Portuguese Stone sector. In Proceedings of the 7th Globalstone Congress, Batalha, Portugal, 18–23 June 2023; ISBN 978-972-778-327-4. Available online: https://dspace.uevora.pt/rdpc/handle/10174/36970?mode=full9 (accessed on 5 July 2024).
80. Slavic, D.; Marjanovic, U.; Medic, N.; Simeunovic, N.; Rakic, S. The Evaluation of Industry 5.0 Concepts: Social Network Analysis Approach. *Appl. Sci.* **2024**, *14*, 1291. [CrossRef]
81. Briglauer, W.; Grajek, M. Effectiveness and efficiency of state aid for new broadband networks: Evidence from OECD member states. *Econ. Innov. New Technol.* **2024**, *33*, 672–700. [CrossRef]
82. Abdumutalibovich, K.A.; Lutfillaevna, B.M. The Role of Bim Technologies in the Information System of Education. *Eur. J. Contemp. Bus. Law Technol. Cyber Law Blockchain Leg. Innov.* **2023**, *1*, 9–13. [CrossRef]
83. Aliyari, M.; Ayele, Y.Z. Application of Artificial Neural Networks for Power Load Prediction in Critical Infrastructure: A Comparative Case Study. *Appl. Syst. Innov.* **2023**, *6*, 115. [CrossRef]
84. Hoppe, S. OPC Unified Architecture-Interoperability for Industrie 4.0 and the Internet of Things. 2023. Available online: https://opcfoundation.org/wp-content/uploads/2023/05/OPC-UA-Interoperability-For-Industrie4-and-IoT-EN.pdf (accessed on 5 July 2024).
85. Wijeratne, P.U.; Gunarathna, C.; Yang, R.J.; Wu, P.; Hampson, K.; Shemery, A. BIM enabler for facilities management: A review of 33 cases. *Int. J. Constr. Manag.* **2024**, *24*, 251–260. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

administrative sciences

MDPI

Article

Harnessing Technology to Drive Coopetition and Value Co-Creation: A Service-Dominant Perspective

Agostinho Antunes da Silva [1,2,*] and Antonio J. Marques Cardoso [1]

[1] CISE-Electromechatronic Systems Research Centre, University of Beira Interior, 6200-001 Covilhã, Portugal; ajmcardoso@ieee.org
[2] CIGEST-Centre for Research in Management, Lisbon Business School, 1000-002 Lisboa, Portugal
* Correspondence: a.silva@zipor.com

Abstract: Coopetition, the strategic blend of competition and collaboration, has emerged as a critical strategy for firms navigating today's interconnected and resource-constrained global economy. While coopetition networks offer substantial benefits, such as fostering innovation, market expansion, and scalability, they are fraught with challenges like resource-sharing risks, trust deficits, and the inherent tension between collaboration and competition. Despite these hurdles, the transformative potential of technology in enabling and enhancing coopetition networks remains underexplored. This study addresses this gap by integrating Service-Dominant Logic (S-D Logic) and institutional work to propose a comprehensive framework for technology-driven coopetition networks. It identifies seven systemic building blocks—coopetition actors, resource integration, service exchange, institutions, nested ecosystems, operand technologies, and operant technologies—that facilitate sustainable value co-creation. These components enable firms to navigate dynamic market conditions by fostering trust, collaboration, and innovation. This research emphasizes technology's pivotal role as a transformative enabler and strategic driver, enabling real-time interaction, seamless resource integration, and institutional alignment. Institutional work is highlighted as essential for managing regulatory, normative, and cognitive dimensions to ensure the Adaptability and longevity of coopetition ecosystems. By providing actionable insights into the design and management of resilient, technology-driven coopetition networks, this study offers a roadmap for sustainable and equitable value distribution. It contributes to the evolving discourse on strategic business networks, empowering organizations to harness the power of coopetition in an increasingly complex global marketplace.

Keywords: coopetition networks; service-dominant logic; value co-creation; innovation; institutional work

check for updates

Received: 29 December 2024
Revised: 6 February 2025
Accepted: 10 February 2025
Published: 14 February 2025

Citation: da Silva, A. A., & Cardoso, A. J. M. (2025). Harnessing Technology to Drive Coopetition and Value Co-Creation: A Service-Dominant Perspective. *Administrative Sciences*, *15*(2), 64. https://doi.org/10.3390/admsci15020064

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

In today's globalized economy, firms operate in an increasingly complex landscape characterized by resource asymmetry, rapid market evolution, and intensified competition. As industries become more interconnected, businesses—micro- and medium-sized enterprises (SMEs)—seek strategies to enhance competitiveness, expand market reach, and scale operations. One of the most effective strategic responses to these challenges is coopetition, a paradoxical interplay between collaboration and competition that allows firms to leverage shared resources while maintaining their competitive edge (Meena et al., 2023; Rouyre et al., 2024). However, while coopetition presents significant advantages, it also introduces challenges such as resource-sharing risks, opportunistic behaviours, and

fragile trust structures, which, if not properly managed, can destabilize networks and hinder long-term value creation (Crick, 2019; Reeves et al., 2022).

Despite the growing recognition of coopetition's strategic value, research remains fragmented and inconclusive regarding how value is created, distributed, and sustained within these networks (Klimas et al., 2023). Many existing theoretical perspectives—ranging from Game Theory and the Resource-Based View (RBV) to Paradox Theory, Transaction Cost Theory, and Network Theory—offer valuable insights into the mechanisms of coopetition (Corbo et al., 2023). However, these frameworks often fail to capture modern coopetition ecosystems' dynamic, multi-actor, and technology-driven nature, leaving critical gaps in understanding how firms effectively co-create value while balancing competitive and collaborative forces (Xie et al., 2023). Addressing these gaps requires an integrative conceptual approach considering the institutional and technological enablers shaping coopetition networks.

Technology fundamentally transforms coopetition dynamics by enabling real-time interactions, optimizing resource integration, and reshaping competitive landscapes (da Silva & Cardoso, 2024). IoT platforms, AI-driven coordination, and data analytics are key enablers of value co-creation, yet the precise mechanisms through which technology sustains and enhances coopetition remain underexplored (R. Bouncken et al., 2024). This study seeks to address this gap by developing a conceptual framework that examines the interaction between technology and institutional work, proposing a structured model for sustainable value co-creation in coopetition networks.

To structure this analysis, this study adopts Service-Dominant (S-D) Logic as its theoretical foundation (Vargo & Lusch, 2004). Unlike traditional Goods-Dominant Logic (Joiner & Lusch, 2016), which views value creation as a static, transactional exchange, S-D Logic reconceptualizes value as a dynamic, co-created process shaped through service exchange, resource integration, and institutional interactions (Vargo et al., 2024). This perspective is potentially relevant to coopetition networks as it (1) shifts the focus to service-based value co-creation (Vargo & Lusch, 2017), (2) emphasizes ecosystems where actors co-create value by integrating both tangible and intangible resources to generate mutual benefits (Jaakkola & Vargo, 2021), and (3) aligns with technology's role in shaping modern service interactions, business networks, and digital transformation strategies (Vargo et al., 2024). Moreover, S-D Logic provides an institutional lens, allowing for an in-depth analysis of how governance structures, shared norms, and institutional work stabilize coopetition relationships (Vargo et al., 2023a). By incorporating S-D Logic and technological enablers, this study offers a holistic framework for understanding the interplay between actors, institutions, and technology in coopetition ecosystems.

This study develops a conceptual framework for technology-enabled coopetition networks, focusing on value co-creation by addressing three key research questions: (1) How can technology facilitate coopetition within networks? (2) What institutional and technological configurations optimize value co-creation? (3) How can coopetition networks ensure sustainable and equitable value distribution? This research advances the theoretical understanding of coopetition networks by answering these questions while providing a structured foundation for future empirical validation.

This research begins by exploring the interplay between cooperation and competition, examining how firms navigate this duality to drive innovation and strategic positioning. An analysis of value co-creation mechanisms follows this, tracing the shift from coproduction to co-creation and positioning S-D Logic as a key perspective for understanding coopetition ecosystems. Next, this study examines how institutional work and technological advancements shape the sustainability and governance of coopetition networks, identifying technology's role in service ecosystems and addressing gaps in existing theoretical approaches. It then develops the systemic and institutional foundations for

technology-enabled coopetition networks, integrating insights from S-D Logic and digital transformation. Finally, it summarizes theoretical contributions, acknowledges limitations, and outlines future empirical research to validate and refine the proposed framework.

This study provides a comprehensive foundation for understanding how firms can strategically leverage coopetition by integrating S-D Logic's institutional perspective with technology-enabled networks. The proposed framework serves as a guiding model for balancing competition and collaboration, enabling firms to harness technology and institutional structures to drive sustainable and scalable value co-creation, focusing on real-world applications for SMEs.

2. Literature Review

The concept of coopetition has evolved significantly since its early conceptualization by Ray Noorda, the founder of Novell, in the 1980s. Initially recognized as a practical business strategy, coopetition gained a theoretical foundation through the work of Nalebuff and Brandenburger (1997), who, drawing on Game Theory, highlighted its transformative potential in reshaping competitive dynamics (Nalebuff & Brandenburger, 1997). By balancing collaborative engagement with competitive intent, coopetition enables firms to foster innovation, share resources, and create mutual value, even among direct competitors (Manzhynski & Biedenbach, 2023).

At its core, coopetition leverages synergies that allow firms to pursue shared objectives while maintaining strategic independence (Gnyawali & Song, 2016). By blending competitive and cooperative interactions, firms can mitigate risks, optimize resources, and unlock opportunities that would be unattainable in purely competitive or cooperative relationships (Bicen et al., 2021). This duality has made coopetition a critical driver of competitive advantage and innovation, particularly in technology-driven and rapidly evolving business ecosystems (Chen et al., 2023).

Over time, coopetition research has expanded across various disciplines and industries, reflecting its relevance in technology, manufacturing, and SMEs (Meena et al., 2023). Scholars have explored its strategic benefits and inherent challenges, particularly in contexts where firms must navigate trust dynamics, resource dependencies, and institutional constraints (Xie et al., 2023).

2.1. Theoretical Foundations of Coopetition

Coopetition's unique ability to balance collaboration and competition makes it a powerful driver of innovation and competitive resilience, particularly in environments characterized by resource asymmetry, technological disruption, and global interconnectivity (Rouyre et al., 2024). By engaging in cooperative and competitive interactions, firms can mitigate market uncertainties, leverage shared resources, and foster strategic growth (Garay-Rondero et al., 2020). However, despite its acknowledged strategic benefits, the mechanisms underpinning value creation in coopetition remain inconsistently conceptualized across research (Gernsheimer et al., 2021).

These inconsistencies stem from contextual factors such as trust, resource complementarities, and network dynamics, which shape coopetition outcomes in unpredictable ways (Meena et al., 2023). While several theoretical frameworks have been applied to explain coopetition, they often offer fragmented perspectives, emphasizing specific aspects while overlooking the broader systemic foundations that enable sustained value creation across networks (R. B. Bouncken et al., 2015).

Various theoretical perspectives offer distinct insights into the benefits and complexities of coopetition. Game Theory views coopetition as a strategic interaction, where firms balance cooperation and competition to optimize collective and individual gains. However,

information asymmetry and trust deficits often challenge its real-world applicability, which can hinder effective decision-making (Xie et al., 2023).

The Resource-Based View frames coopetition as a resource access and co-development strategy, emphasizing how firms enhance innovation and market reach by leveraging shared and proprietary resources (Gernsheimer et al., 2021). Similarly, Paradox Theory highlights the dynamic tension between collaboration and competition, viewing coopetition as an ongoing process of navigating contradictions to create strategic synergies (Corbo et al., 2023).

From an economic perspective, Transaction Cost Theory (TCT) focuses on minimizing transaction costs and safeguarding competitive interests through effective governance mechanisms, ensuring that firms manage risk while maintaining cooperative relationships (Spiller, 2010; Xie et al., 2023). Lastly, Network Theory underscores the significance of strategic positioning within business networks, demonstrating how firms access critical resources, manage interdependencies, and enhance value creation through network structures (Burga & Rezania, 2017).

While these frameworks provide valuable insights, their scope and focus vary. Game Theory optimizes strategic interactions, RBV and Network Theory emphasize resource and network dynamics, Paradox Theory addresses coopetition's inherent tensions, and TCT focuses on transactional efficiency and competitive safeguarding (Meena et al., 2023). However, a crucial research gap remains—existing frameworks fail to fully capture the systemic mechanisms of value co-creation in technology-driven coopetition networks.

As firms increasingly leverage emerging technologies, there is a pressing need to explore how technological innovations interact with institutional structures to shape coopetition outcomes. Addressing this gap is essential for developing a systemic understanding of value co-creation, providing the conceptual foundations for sustainable and scalable coopetition networks in technology-driven environments.

2.2. Value Creation Mechanisms in Coopetition Networks (Research Gap 1)

Traditional frameworks often conceptualize value creation in coopetition networks as a linear and static process primarily grounded in internal resources, market positions, or discrete strategic interactions (R. Bouncken et al., 2024). These approaches implicitly assume that value is an inherent characteristic of goods or services, flowing unidirectionally from producer to consumer (Amit & Zott, 2001). However, this goods-centric perspective fails to capture modern coopetition's fluid, interconnected, and evolving nature, where the boundaries between competition and collaboration are increasingly blurred (Xie et al., 2023).

Existing value creation models struggle to explain the dynamic and adaptive processes that define coopetition networks. Three key limitations stand out: (1) Traditional theories focus on firm-specific resources but overlook the interdependencies and complementarities that drive value creation in coopetition settings (Meena et al., 2023). In reality, value emerges through integrating shared and distinct resources contributed by multiple actors. (2) Static models assume fixed roles and contributions, yet coopetition networks require continuous renegotiation of positions, resources, and strategies as market conditions evolve (Xie et al., 2023). This limitation is especially problematic in industries driven by rapid technological change, and (3) conventional frameworks treat value as a predetermined result rather than a dynamic, iterative process of co-creation, negotiation, and distribution within networks (R. Bouncken et al., 2024). This narrow view obscures value creation's emergent and evolving nature in complex coopetition ecosystems.

To address these limitations, a relational and dynamic perspective must consider the continuous interplay between competition and collaboration in coopetition networks

(Vargo et al., 2024). This perspective is built on three core principles: Value as co-created, coopetition networks as adaptive ecosystems, and technology as a facilitator of value co-creation. This perspective provides a more comprehensive understanding of coopetition networks by shifting the focus from value as a static outcome to value as a dynamic and co-created process.

2.3. The Role of Technology in Coopetition Networks (Research Gap 2)

Traditional theoretical frameworks often fail to account for the complexity and interconnectivity that define technology-driven coopetition networks (Corbo et al., 2023). Technology serves a dual role in these networks: (1) As an operant resource, technology is a dynamic agent that drives innovation, coordination, and value co-creation (Kaartemo et al., 2017). (2) An operand resource is an enabler, providing infrastructure, tools, and digital platforms that facilitate interactions (Greer et al., 2016).

This duality underscores technology's multifaceted role in shaping coopetition dynamics, influencing how firms compete, collaborate, and integrate resources within evolving business ecosystems.

Conventional coopetition theories often emphasize static and linear interaction models, overlooking how technology fosters real-time, adaptive exchanges (Klimas et al., 2023). These models fail to address the following factors: (1) the networked and dynamic nature of digital interactions, where technology enables firms to adjust their strategies and collaborations constantly; (2) the role of technology in sustaining long-term coopetition, ensuring trust, transparency, and efficiency through data-driven decision-making and automation; and (3) technology's function in creating interconnected value ecosystems, where multiple actors co-create, distribute, and evolve value (Meena et al., 2023).

By embracing this technology-integrated perspective, research can provide a more accurate and comprehensive understanding of how firms build, sustain, and optimize coopetition networks in the digital economy.

2.4. Reframing Coopetition Through Service-Dominant Logic: A Shift Toward Value Co-Creation

S-D Logic fundamentally redefines goods as facilitators of service delivery, shifting the focus from ownership and production to specialized competencies that create service experiences (Vargo & Lusch, 2010). This perspective places service exchange and value co-creation at the heart of economic activity, challenging static, transactional views of value creation (Greer et al., 2016).

Within this framework, value is not intrinsic to products but emerges relationally, co-created through interactions among multiple actors in a shared system of resource integration and service exchange (M. A. Akaka & Vargo, 2014). This shift underscores the importance of understanding how firms, customers, and other stakeholders dynamically collaborate to create value within coopetition networks (Vargo et al., 2020).

The transition from coproduction to co-creation, and ultimately to value co-creation in service ecosystems, highlights coopetition networks' adaptive and systemic nature (Lusch & Vargo, 2014). This framework is defined by two key characteristics: (1) Value as an iterative and dynamic process—value is continuously derived, assessed, and redefined through real-time interactions among network actors, reflecting the fluid nature of markets (Bettencourt et al., 2014). (2) Ecosystems as complex adaptive systems—coopetition networks function as complex adaptive systems, where economic and social structures evolve dynamically, shaped by the collective actions of participating actors (Elo et al., 2024). By embracing S-D Logic, firms engaged in coopetition can better understand how value emerges through collaboration and competition, using these dynamics to drive innovation, Adaptability, and long-term sustainability.

3. Methodology

This study employs an integrative conceptual approach (Vargo & Koskela-Huotari, 2020) to construct a theoretical framework for understanding value co-creation within technology-enabled coopetition networks (TECNs). Conceptual research is a key tool for advancing theoretical development by synthesizing and integrating existing knowledge rather than relying on empirical data (Jaakkola, 2020). Given the complex and dynamic nature of coopetition, this methodology enables systematic exploration of underlying value co-creation mechanisms that empirical studies may not yet fully capture (Clemens et al., 2025).

3.1. A Conceptual Approach

Empirical research is valuable for hypothesis testing but often requires a well-established theoretical foundation. Since the mechanisms of technology-driven coopetition remain underexplored, a conceptual approach serves as a necessary first step in developing a structured framework that future empirical research can validate (Jaakkola, 2020).

This study begins with a focal phenomenon that is observable but not adequately addressed in existing research: In today's globalized economy, firms operate in an increasingly complex landscape characterized by resource asymmetry, rapid market evolution, and intensified competition. A critical aspect of this landscape is the role of technology in facilitating and sustaining coopetition while ensuring sustainable value co-creation. While previous studies have examined coopetition through Game Theory, the Resource-Based View, and Transaction Cost Theory (Meena et al., 2023), they often neglect the value of co-creation mechanisms and the digital nature of modern coopetition ecosystems (Corbo et al., 2023). The rapid transformation of business ecosystems through technology and globalization necessitates a new theoretical lens integrating institutional and service-based perspectives to understand coopetition dynamics better (Xie et al., 2023).

To address this gap, this study synthesizes insights from S-D Logic, which shifts the focus from goods-based competition to service-based value co-creation. This perspective aligns with modern coopetition's interactive and technology-mediated nature (Vargo et al., 2024; Vargo & Lusch, 2004). S-D Logic provides a conceptual foundation for understanding how firms integrate resources and co-create value in dynamic and digitally enabled networks (Clemens et al., 2025).

Viewing coopetition through this theoretical lens, this study develops a novel conceptual model that (1) clarifies how technology facilitates coopetition, (2) identifies institutional and technological configurations that optimize value co-creation, and (3) explores sustainable and equitable value distribution in coopetition networks.

Through this integrative conceptual approach, this research advances theoretical understanding while providing practical insights for firms navigating coopetition in digital ecosystems. It lays the groundwork for future empirical validation, ensuring the proposed model can be tested and refined through real-world applications.

3.2. Research Approach

This study follows a systematic conceptual approach, progressing through four key phases to develop a theoretical framework for developing future TECNs. It begins by identifying critical gaps in the existing literature, particularly the limited understanding of value co-creation mechanisms within coopetition networks and the underexplored role of technology in sustaining these interactions. Addressing these gaps, this research integrates S-D Logic and digital transformation research perspectives, synthesizing these theoretical foundations to construct a service-centric view of coopetition. This integration informs the next phase, where this study develops a structured framework outlining the key constructs

and building blocks necessary for designing and optimizing TECNs. While the framework provides a strong theoretical foundation, it also serves as a basis for future empirical validation through case studies, surveys, or network analyses, ensuring its applicability in real-world settings.

3.3. Theoretical Choices and Transparency

A structured and systematic literature review was conducted to identify and integrate the most relevant frameworks for understanding value co-creation within technology-enabled coopetition networks (TECNs) to establish a solid theoretical foundation for this study. Given the complex, multi-actor nature of coopetition and the increasing role of digital transformation in shaping business interactions, it was crucial to adopt a comprehensive and interdisciplinary approach to selecting the appropriate theories.

This process unfolded in three key phases: identifying relevant theories, ensuring comprehensive coverage, and applying selection criteria to refine the theoretical model. The goal was to construct a framework that captures coopetition's strategic, institutional, and technological dimensions, ensuring that it aligns with the dynamic and digitally driven business landscape.

3.3.1. Identifying Relevant Theories

To construct a robust theoretical foundation, this study conducted an extensive literature review spanning multiple disciplines, including strategic management, organizational theory, institutional economics, and digital transformation research. The objective was to identify foundational theories that have historically shaped coopetition research and contemporary perspectives that reflect the evolving nature of digital ecosystems. By integrating insights from these diverse fields, this study aimed to develop a comprehensive framework that captures the complexities of value co-creation in TECNs.

The review revealed several established theories, each offering distinct insights into coopetition's strategic, institutional, and technological dimensions. Among these, Game Theory provided a foundation for understanding coopetition as a strategic interaction, where firms carefully balance collaboration and competition to maximize their individual and collective benefits. Meanwhile, the Resource-Based View emphasized resource access and co-development, highlighting how firms leverage shared and proprietary assets to achieve competitive advantage and foster innovation.

From a governance perspective, Transaction Cost Theory addresses the mechanisms firms use to minimize risks and manage cooperation costs, ensuring that competitive tensions do not undermine collaboration. Similarly, Network Theory explored interfirm relationships and strategic positioning, explaining how firms navigate dependencies, partnerships, and access to critical resources within coopetition ecosystems.

This study also examined Paradox Theory, which provided a lens for understanding the inherent contradictions of coopetition, where firms must simultaneously compete and collaborate while managing conflicting strategic objectives. In contrast, S-D Logic introduced a dynamic and interactive view of value creation, shifting the focus from static transactions to co-created value, where firms integrate resources, technology, and institutional structures to generate sustainable benefits.

Additionally, Institutional Theory played a key role in explaining the governance structures, trust mechanisms, and regulatory frameworks that stabilize coopetition networks (Elo et al., 2024). It emphasized the influence of formal rules, industry norms, and shared expectations in shaping long-term collaborative strategies. Finally, Technology Research provided crucial insights into the impact of digital transformation on coopetition

dynamics, examining how AI, blockchain, data analytics, and cloud computing enable firms to enhance efficiency, transparency, and strategic coordination in digital ecosystems.

While these theories contribute valuable perspectives, no single framework fully captures the multi-dimensional nature of technology-driven coopetition. Given the need for a holistic and integrated approach, this study proceeded with a refined selection process to identify the most relevant theoretical foundations. The final framework needed to account for institutional structures, strategic governance, and technological enablers, ensuring a comprehensive understanding of how value is co-created in TECNs.

3.3.2. Ensuring Comprehensive Coverage

To develop a well-founded theoretical framework, this study undertook a systematic and structured literature review to ensure that the selection of theoretical perspectives was comprehensive and methodologically sound. The process began with an extensive search across leading academic databases, including Web of Science, Scopus, and Google Scholar, to identify key works that explore coopetition, value co-creation, digital transformation, and service ecosystems. Given the interdisciplinary nature of this study, it was essential to include insights from strategic management, organizational theory, institutional economics, and digital transformation research to capture a holistic view of the mechanisms driving value co-creation in TECNs.

To maintain academic rigour, the search was restricted to peer-reviewed journal articles, books, and high-impact conference proceedings, ensuring that only established and high-quality research informed the theoretical foundation. Key search terms such as "coopetition theory", "value co-creation in networks", "digital transformation and competition", and "service ecosystems" were used to identify relevant literature, ensuring that this study captured both well-established theories and emerging perspectives.

Beyond direct keyword searches, this study employed citation tracking and snowballing techniques to refine the literature selection further. By tracing highly cited and influential research, this study was able to incorporate both seminal works that shaped coopetition theory and contemporary studies addressing the role of technology in modern business ecosystems. This iterative approach allowed for progressive refinement of theoretical perspectives, ensuring that the frameworks included in this study were historically significant and highly relevant to contemporary digital coopetition dynamics.

3.3.3. Selection Criteria for Theoretical Frameworks

Following identifying a broad range of theoretical perspectives, a systematic selection process was undertaken to determine which frameworks would serve as the primary theoretical foundation for this study. The goal was to ensure that the chosen theories aligned with the core themes of technology-driven coopetition and value co-creation while addressing the institutional and governance structures that sustain collaborative business ecosystems. To achieve this, each theoretical framework was assessed based on five key criteria.

The first and most essential criterion was relevance to technology-enabled coopetition. Given this study's focus on digital transformation and its impact on business interactions, priority was given to theories that explicitly explore how emerging technologies influence coopetition networks. The selected frameworks needed to account for the role of digital platforms, AI, blockchain, and data-driven decision-making in shaping collaborative and competitive dynamics.

The second criterion was the theory's focus on value co-creation. Since this study investigates how firms collaboratively generate and distribute value, preference was given to frameworks that define value as co-created rather than as a static or transactional

outcome. Traditional perspectives often view value creation as firm-centric, whereas a service-oriented, interactive approach was necessary to capture modern coopetition's fluid, networked, and technology-mediated nature.

Another essential factor was the ability to address multi-actor dynamics. Coopetition does not occur in isolation; it is embedded in complex ecosystems where multiple stakeholders—ranging from firms and suppliers to regulatory bodies and consumers—interact continuously. Theories that provided insights into network-level interactions, evolving business relationships, and shared ecosystems were prioritized, as they offered a more nuanced and realistic depiction of coopetition in digital environments.

This study also sought theories that integrated institutional and governance mechanisms, recognizing that sustainable coopetition requires structured governance, regulatory frameworks, and trust mechanisms to manage competitive tensions effectively. Theories incorporating legal structures, industry norms, cognitive models, and trust-building processes were particularly valuable in understanding how firms maintain long-term coopetition without opportunistic behaviours destabilizing the network.

Finally, a critical evaluation of alternative theories was conducted. While Game Theory, Resource-Based View, and Transaction Cost Theory have traditionally been used to explain strategic decision-making, resource control, and cost minimization, they were found to be insufficient for capturing the full complexity of modern coopetition networks. These frameworks (Corbo et al., 2023), while helpful in understanding competitive positioning and risk management, do not fully explain the technology-driven, multi-actor, and evolving nature of contemporary coopetition ecosystems. Therefore, their exclusion was not due to irrelevance but rather a necessity for a more integrative, service-oriented, and institutionally grounded perspective.

By applying these carefully structured selection criteria, this study ensures that its theoretical foundation is methodologically rigorous, conceptually robust, and practically relevant. The resulting framework provides a holistic understanding of how technology, governance, and strategic interactions converge to enable sustainable value co-creation in TECNs, setting the stage for future empirical validation and real-world application.

3.3.4. Final Theoretical Choices and Justification

Following a rigorous selection process, this study identifies three key theoretical perspectives as the foundation for understanding value co-creation in TECNs: S-D Logic, Institutional Theory, and Technology Research. These frameworks were chosen for their ability to capture the interplay between competition, collaboration, governance, and digital transformation in coopetition ecosystems.

S-D Logic provides a service-based perspective, emphasizing that value is co-created through interactions and resource integration rather than being a static outcome of firm-centric transactions. This aligns with technology-enabled coopetition, where firms leverage digital platforms to collaborate, innovate, and share resources in real time.

Institutional Theory highlights the governance structures, trust mechanisms, and regulatory frameworks that stabilize coopetition. It explains how formal contracts, industry norms, and cognitive models shape long-term collaborative relationships, ensuring stability in digital business ecosystems.

Technology Research focuses on the role of digital transformation as an enabler of coopetition. Emerging technologies like AI, blockchain, and data analytics enhance coordination, transparency, and efficiency, allowing firms to balance competitive and cooperative interactions more effectively.

These three perspectives complement one another, forming a comprehensive and integrative framework: S-D Logic explains how firms co-create value, Institutional Theory

provides a governance lens, and Technology Research highlights the role of digital enablers. By explicitly detailing the selection and justification process, this study ensures transparency and methodological rigour, offering a structured foundation for future empirical research and practical applications in digital coopetition ecosystems.

3.4. Research Strategy and Theoretical Coherence

To ensure conceptual rigour and coherence, this study follows a structured synthesis approach that unfolds in three interrelated phases. It begins by embedding value co-creation within coopetition networks, examining the role of institutions and S-D Logic in shaping collaborative dynamics. This phase establishes the foundational link between coopetition and service exchange, positioning institutions as key enablers of sustainable value co-creation.

Next, this study systematically maps theoretical intersections, exploring the interplay between technology, institutional work, and service exchange. By aligning these elements within the S-D Logic framework, this research highlights how digital transformation and governance structures shape the evolution of coopetition networks.

Building on these insights, the final phase develops a coherent theoretical framework, structuring the key constructs that explain how institutions and technology interact to sustain coopetition and foster long-term value co-creation. This study refines its conceptual model through this iterative process, ensuring logical consistency and alignment with existing research. By systematically mapping the relationships between coopetition, technology, and institutional work, this study constructs a robust framework that serves as both a theoretical lens and a practical guide for understanding how technology-driven coopetition networks function and evolve.

This study establishes a structured and theoretically grounded framework for understanding TECNs by adopting an integrative conceptual approach. This framework is a foundation for future empirical research, offering valuable insights into the interplay between technology, institutional work, and value co-creation in dynamic business ecosystems. As firms continue to navigate the complexities of digital transformation, future studies should build on this model through empirical validation, ensuring its applicability and effectiveness in real-world coopetition networks.

4. Institutional and Technological Foundations of Value Co-Creation in Coopetition Networks

The concept of service as a foundation of economic exchange has long been recognized, but the introduction of S-D Logic by Vargo and Lusch (2004) marked a paradigm shift in contemporary economic thought (Vargo & Lusch, 2004). Unlike traditional goods-centric frameworks, S-D Logic prioritizes operant resources—intangible assets such as knowledge, skills, and relationships—over operand resources, the tangible goods traditionally regarded as primary value drivers (Vargo & Lusch, 2008). In this perspective, goods are merely facilitators of service delivery, and value emerges through applying specialized competencies in dynamic exchanges (Lusch et al., 2010).

By redefining value as a dynamic and relational process, S-D Logic offers a conceptual foundation well suited for coopetition networks, where firms compete and collaborate. This framework challenges static perspectives of value creation, emphasizing that value is co-created through interactions within a shared institutional structure (Greer et al., 2016). Given coopetition's interconnected and evolving nature, institutional mechanisms are crucial in stabilizing relationships, facilitating trust, and governing value co-creation processes within these networks.

4.1. From Labour Theory to Value Co-Creation

Traditional economic theories, such as those of Adam Smith (1776, cited in (Parayitam & Guru-Gharana, 2010)) and David Ricardo (1817, cited in (Dome, 2003)), conceptualized value through the labour theory of value, emphasizing tangible production efforts as the foundation of economic exchange. Over time, however, economic thought has evolved to recognize value co-creation as a collective and interactive process involving multiple stakeholders—including suppliers, partners, allies, and customers (Normann & Ramirez, 1993). This shift from coproduction to co-creation and, ultimately, to value co-creation within service ecosystems reflects the growing complexity and dynamism of modern economic interactions (Vargo & Lusch, 2014).

From an S-D Logic perspective, value creation is not a static transaction but an ongoing, interactive process within service ecosystems, which are complex adaptive systems composed of interdependent actors and resources (Elo et al., 2024). These ecosystems function through value propositions, shifting the focus from fixed value delivery to value-in-use, where value is realized by applying resources within specific contexts (Siltaloppi & Vargo, 2017). This perspective underscores value creation's relational and dynamic nature, emphasizing that firms must engage in continuous resource integration and institutional alignment to sustain coopetition networks.

4.2. Relevance to Coopetition Networks

The S-D Logic framework provides a compelling lens for understanding value co-creation in coopetition networks. It emphasizes dynamic resource integration and continuous interaction among service ecosystem actors (Wieland et al., 2017). This perspective aligns with coopetition's fluid and evolving nature, where businesses must balance competition and collaboration to sustain long-term value creation (R. Bouncken et al., 2024).

By embedding S-D Logic within coopetition research, this study establishes connections with key strategic theories that further explain how firms leverage and reconfigure resources: the Resource-Based View highlights the importance of both shared and firm-specific resources in sustaining competitive advantage (Peteraf, 1993), the Competency Core Theory underscores the development and integration of unique capabilities for long-term success (Corbo et al., 2023), and the Corporate Core Competencies Theory focuses on how firms strategically recombine competencies to drive innovation and differentiation (Meena et al., 2023).

Through this integration, the study of coopetition shifts the focus from transactional and static competitive advantages to a more interactive and adaptive understanding of value co-creation. This perspective is particularly relevant in networks, where firms must continuously adapt to market shifts, competitive pressures, and emerging collaborative opportunities (Rouyre et al., 2024). By framing coopetition as an ongoing process shaped by institutional and technological environments, S-D Logic offers a more holistic view of how firms navigate the complexities of digital transformation and ecosystem-driven competition to sustain value co-creation.

4.3. The Role of Technology in Networks: Knowledge, Institutions, and Value Creation

Technology is more than just physical tools and devices—it encompasses a system of practices, processes, and knowledge recombination aimed at serving human purposes (Arthur, 2009). This broader perspective recognizes technology as tangible tools and the methods and processes that drive technological advancement.

Scholars such as Hughes (1989, cited in (Fullerton et al., 2014)) and Mokyr (2004) conceptualize technology as both an organizational framework for problem-solving and a repository of practical knowledge (Akwei et al., 2010). This perspective links technology to

broader constructs such as knowledge, competencies, and capabilities, emphasizing that technological progress arises from the interconnected integration of resources to address challenges (Hunt, 2000).

Understanding technology as a dynamic system of knowledge and institutional processes (Elo et al., 2024) clarifies its role in value co-creation within coopetition networks (M. Akaka et al., 2023). Technology facilitates interactions and knowledge exchange and shapes the institutional structures that govern coopetition ecosystems, influencing how firms leverage, share, and protect resources in competitive environments (Vargo et al., 2023b).

4.4. Social Construction of Technology and Value Perception

The social construction of the technology framework emphasizes that technology's development, adoption, and perceived value are shaped by social groups and institutional contexts rather than being inherently determined by its functionality (Klein & Kleinman, 2002). Hunt (2000) reinforces this idea, arguing that technology's meaning and utility emerge through interaction with societal norms and shared practices (Hargadon & Douglas, 2001). This perspective challenges technological determinism, which assumes that technologies inherently possess value, instead highlighting the role of institutional arrangements in shaping how technologies are understood and integrated into business ecosystems (Munir & Phillips, 2005).

Building on this, M. Akaka et al. (2013) apply this framework to service ecosystems, illustrating how technology shapes and is shaped by institutional structures that govern its use (M. Akaka et al., 2013). The concept of interpretive flexibility further underscores this perspective, suggesting that different actors assign diverse meanings to the same technology based on their institutional and strategic contexts (Pinch & Bijker, 1984). These varying interpretations influence how technology is evaluated, integrated, and utilized within coopetition networks, reinforcing technological value construction's fluid and evolving nature.

4.5. Technology as a Key Enabler in Coopetition Networks

Technology does not generate value in isolation; instead, it is socially and institutionally constructed (Hunt, 2000), emerging through its integration with other resources and the broader coopetition ecosystem (Chesbrough & Rosenbloom, 2002). Institutional mechanisms are fundamental in shaping how technology is perceived, adopted, and evolves within coopetition networks, influencing its trajectory across three key stages (Vargo & Lusch, 2016).

In the designing phase of the networks, institutional norms, regulatory frameworks, and industry practices define how new technologies are framed and integrated, shaping their perceived utility and strategic application (Vargo et al., 2023a). As technologies gain traction, they move into the stabilization phase, where dominant interpretations and standardized applications emerge through repeated network interactions and institutional alignment. Over time, however, technology is not static; in the evolution phase, it adapts and transforms as new knowledge, resources, and institutional structures reshape its role, allowing firms to respond to shifting market dynamics and competitive pressures (Vargo et al., 2024).

This perspective underscores technology's iterative and co-evolutionary nature, where its role within coopetition networks is continuously redefined through social, institutional, and technological interactions (Moore, 1993). Rather than being a fixed or deterministic force, technology is shaped by evolving institutional ecosystems, adapting to coopetition networks' changing needs and structures.

Beyond its structural role, technology is instrumental in balancing collaboration and competition within coopetition networks. Traditional perspectives on value creation often assume a linear and static process, focusing on internal resources and transactional exchanges (R. Bouncken et al., 2024). However, modern coopetition networks are far more dynamic, involving continuous interactions among multiple actors who integrate distinct and shared resources in an evolving landscape (Xie et al., 2023).

Technology bridges this complexity by functioning in two interconnected roles: (1) As an operant resource, technology actively shapes network interactions and value co-creation processes through its intangible capabilities, such as artificial intelligence, data analytics, and digital innovation (Vargo & Lusch, 2017). These tools enhance firms' ability to analyze market trends, optimize resource allocation, and facilitate adaptive strategies in coopetition. (2) As an operand resource, technology provides the tangible infrastructure for coopetition, including digital platforms, cloud systems, and communication tools (Greer et al., 2016). These elements create the foundation for real-time collaboration, knowledge-sharing, and competitive differentiation within digital ecosystems.

By integrating these dual roles, technology reshapes value creation mechanisms, fostering interconnectedness, Adaptability, and resilience in coopetition networks. It facilitates resource integration, supports collaborative innovation, and enhances real-time decision-making, transforming coopetition networks into dynamic, self-adjusting ecosystems capable of responding to complex and rapidly changing market environments.

4.6. The Role of Institutional Work in Value Networks

The concept of institutional work, originating in organization studies, examines how individuals and organizations actively shape institutions through creation, maintenance, and disruption (Lawrence & Suddaby, 2006). This perspective offers a critical framework for understanding how actors influence institutional structures to foster value co-creation within ecosystems (Lawrence et al., 2009).

Institutions operate within three key pillars that structure ecosystems: (1) the Cognitive Pillar—represents shared understandings and belief systems that guide decision-making (Kleinaltenkamp et al., 2018); (2) the Normative Pillar encompasses social norms and values that shape expected behaviours (Vargo & Lusch, 2016); and (3) the Regulative Pillar consists of formal legal obligations and governance structures that establish rules and compliance mechanisms (Scott, 2014).

These institutional structures and processes provide the foundation for collective action and coordination, enabling actors to navigate complex ecosystems while facilitating stability and Adaptability in value co-creation networks (Sajtos et al., 2018). By engaging in institutional work, firms can reshape coopetition networks, ensuring that institutional arrangements align with evolving technological, competitive, and collaborative dynamics.

4.7. Ensuring Sustainability and Effectiveness in Real-World Coopetition Networks

The "paradox of embedded agency" is a key challenge in institutional work. While institutions shape actors' behaviours and decisions (Lawrence & Suddaby, 2006), those same actors actively work to modify, reinforce, or disrupt the institutional frameworks governing their actions (Greenwood & Meyer, 2008). This recursive dynamic underscores how coopetition ecosystems evolve through deliberate efforts to influence and adapt institutional structures to facilitate value co-creation (Vargo et al., 2020).

Institutional work manifests in three interconnected forms: (1) Creating Institutions—actors establish new frameworks, norms, and belief systems to support emerging practices and shared goals. Coopetition networks may involve developing collaborative governance structures or redefining resource-sharing norms (Vargo & Lusch, 2016). (2) Disrupting

Institutions—existing norms and systems are challenged to enable new approaches and innovations. This is often necessary to resolve conflicts, inefficiencies, or rigid institutional constraints (Hartmann et al., 2018). (3) Maintaining Institutions—actors engage in ongoing efforts to sustain stability and compliance, ensuring that institutional frameworks remain functional in response to organizational and environmental changes (Lawrence et al., 2009) (Lawrence et al., 2009). This involves subtle, iterative adaptations rather than overt transformations (Siltaloppi & Vargo, 2017).

These forms of institutional work do not occur sequentially but rather interact dynamically, with creation and disruption often leading to the maintenance and stabilization of other institutional elements.

Institutional work is critical for sustaining and reshaping coopetition networks to enable mutual value co-creation. However, this process is inherently complex, involving tensions, conflicts, and competing interests among multiple actors. Two key mechanisms emerge in this context: (1) Addressing Conflicts—overlapping institutional arrangements often generate tensions, requiring actors to negotiate, adapt, and align their practices to maintain ecosystem stability (Pedeliento et al., 2023) and (2) Fostering Adaptability—institutional work enhances the Adaptability of coopetition networks, allowing actors to respond dynamically to market shifts, technological advancements, and evolving collaborative relationships (Lawrence & Suddaby, 2006).

The institutionalization of value co-creation logic in coopetition networks occurs through continuous adjustments and negotiations as actors work toward establishing shared frameworks for balancing collaboration and competition (Chandler et al., 2019). This process is iterative, requiring ongoing refinements until a standardized model of institutionalized practices is widely accepted (Koskela-Huotari et al., 2020).

This perspective offers valuable insights into the mechanisms underpinning value co-creation in dynamic business ecosystems by examining how actors actively shape institutional arrangements (Lawrence et al., 2009). For cooperation networks, institutional work is both a conflict-resolution tool and a mechanism for building resilient, adaptable systems that sustain long-term value co-creation.

5. Advancing Coopetition Research: Bridging Value Co-Creation and Technological Integration Through S-D Logic

As highlighted in the literature review, despite extensive research on coopetition networks, two critical gaps remain: (1) the mechanisms through which value is co-created within these networks and (2) the role of technology in enabling and sustaining coopetition. Traditional theoretical frameworks often depict value creation as a static or linear process, failing to capture the dynamic, iterative, and multi-actor interactions that define contemporary coopetition ecosystems. Similarly, studies on technology's influence on coopetition tend to examine it in isolation, overlooking its interplay with institutional structures and service-based exchanges.

To address these gaps, this section explores (1) the evolution of value creation in coopetition networks, emphasizing resource integration, service exchange, and institutional alignment as key drivers of sustainable collaboration, and (2) technology's dual role as an enabler and structuring force in coopetition, shaping interactions, governance mechanisms, and the long-term sustainability of networks.

This section applies an S-D Logic perspective to offer a holistic and relational understanding of value co-creation in coopetition networks. It presents an integrated approach that links institutional work, technological advancements, and service ecosystems, contributing to a more comprehensive framework for sustainable coopetition strategies.

5.1. Addressing Value Creation Mechanisms in Coopetition Networks

S-D Logic conceptualizes value creation as a dynamic and interactive process (Jaakkola et al., 2024), emerging through reciprocal and iterative exchanges among network participants rather than being an intrinsic attribute of products or services (Vargo & Lusch, 2004). This perspective challenges traditional value paradigms, asserting that value is co-created through mutual engagement among firms, customers, and stakeholders (Vargo & Lusch, 2011).

This paradigm's core is operant resources—intangible assets such as knowledge, skills, and information (Lusch & Nambisan, 2015)—which are primary drivers of innovation, Adaptability, and collaboration in coopetition networks. These resources enable firms to generate unique forms of value that cannot be achieved in isolation, fostering new market opportunities and enhanced competitive positioning (M. Akaka et al., 2013). Moreover, S-D Logic asserts that competitive advantage in interconnected markets arises from possessing unique resources and the ability to dynamically integrate and recombine resources across organizational boundaries (Vargo, 2011). This Adaptability enables firms to navigate complex competitive and cooperative relationships, continuously aligning with shifting stakeholder needs (Chandler et al., 2019).

This evolving view of value creation emphasizes the need for coopetition networks to foster open dialogue, encourage shared learning, and support collaborative innovation (Vargo et al., 2024).

By adopting this resource-integration perspective, coopetition networks can redefine value creation, transforming their interactions into mechanisms for sustained innovation, strategic flexibility, and market leadership.

5.2. Addressing the Role of Technology in Coopetition Networks

S-D Logic provides a transformative perspective on how value is created and sustained within service ecosystems, positioning them as environments where value emerges through the collective interactions of all actors (Lusch & Vargo, 2014), coordinated by institutional and technological mechanisms (Barile et al., 2016). This perspective shifts away from traditional competitive models, reframing markets not as battlegrounds for competitive advantage but as collaborative spaces where competition and cooperation coexist within an intricate web of relationships (Uribe et al., 2020). Moreover, S-D Logic highlights service ecosystems' systemic and emergent nature, where value is not a fixed output but an ongoing process arising from interactions among network actors (Vargo et al., 2023b). Within these ecosystems, technology serves as both a facilitator and an amplifier of co-creative processes (Wieland et al., 2017).

From an S-D Logic perspective, coopetition within service ecosystems involves navigating the complex interplay of competition and collaboration to achieve (1) fostering innovation, (2) accessing new markets, and (3) enhancing customer experiences. As digital networks increasingly mediate economic and social interactions, technology's role in enabling, shaping, and scaling value co-creation becomes critical. Technology enhances coopetition networks by (1) enabling dynamic interactions and support to real-time, resource integration, and coordination among ecosystem participants; (2) joining problem-solving and innovation, providing shared infrastructures, capabilities, and data-driven decision-making insights; and (3) scaling value creation since technology allows coopetition networks to expand their operations and interactions, extending the reach of collaborative initiatives and enabling entry into new markets.

S-D Logic views technology as both a tool and a driver of ecosystem evolution, shaping how coopetition networks develop, function, and sustain themselves. Technology influences (1) institutional arrangements by redefining governance structures and resource

distribution models; (2) actor behaviours by enabling new forms of collaboration, trust-building, and strategic differentiation; and (3) resource integration by facilitating real-time knowledge exchange and seamless interoperability within networks.

As technology mediates increasing interactions, its impact on value co-creation and potential value co-destruction becomes more pronounced, requiring firms to manage their role within their ecosystems proactively.

Viewing coopetition through the lens of S-D Logic provides key insights for sustaining long-term network stability and value creation, including (1) institutional adaptability; (2) balancing collaboration and competition; (3) and network resilience.

Through this D-D Logic lens, coopetition is not just a firm-level strategy but a foundational principle shaping the evolution of service ecosystems. By understanding how technology fosters co-creative processes, firms can more effectively manage and sustain their coopetition networks, ensuring long-term value creation, Adaptability, and ecosystem stability.

6. Building Systemic and Institutional Foundations for Coopetition Technology-Driven Networks

Building on the theoretical foundations of S-D Logic, institutional work, and coopetition, this section directly engages with the research questions that shape this study. Examining these questions through an S-D Logic perspective establishes the foundation for the conceptual framework.

6.1. How Can Technology Facilitate Coopetition Within Networks?

From an S-D Logic perspective, technology and institutional work in coopetition networks are central in aligning diverse actors, including individuals and organizations, to enable sustainable and equitable value co-creation (Elo et al., 2024). This alignment is facilitated by creating, disrupting, and maintaining institutional frameworks (Beunen & Patterson, 2019; Vargo & Lusch, 2016), establishing the rules, norms, and shared understandings governing ecosystem interactions.

Under this view, coopetition networks rely on three key institutional elements: (1) Regulative Elements—laws, industry regulations, and contractual agreements define acceptable behaviours, ensuring structured governance (Friend et al., 2020). At the meso-level, joint agreements and operational rules help establish trust and consistency (M. Akaka et al., 2013); (2) Normative Elements—shared values, ethical codes, and cultural norms foster a collaborative yet competitive environment, extending beyond formal agreements to promote transparency and cooperation (Foschi, 1972); and (3) Cognitive Elements—shared goals, narratives, and strategic frameworks align actors by minimizing conflict and fostering mutual understanding (Hartmann et al., 2018). Moreover, technology is a critical enabler that reinforces these institutional dimensions through enhanced communication, real-time data sharing, and digital coordination tools (Vargo et al., 2024). Technology as an Enabler of Institutional Alignment: Technology facilitates coopetition networks by (1) enhancing collaboration, (2) ensuring Adaptability, and improving transparency and governance.

However, effective coopetition networks require periodic disruption of institutional structures to realign them with evolving market dynamics and collective ecosystem goals (Edvardsson et al., 2014). This incremental and iterative process allows flexibility without destabilizing the network (Lawrence & Suddaby, 2006).

Figure 1 illustrates the interaction between institutional elements, technology, and actor interactions within a coopetition network. It highlights how technological enablers integrate with regulative, normative, and cognitive structures to sustain value co-creation while balancing competition and collaboration.

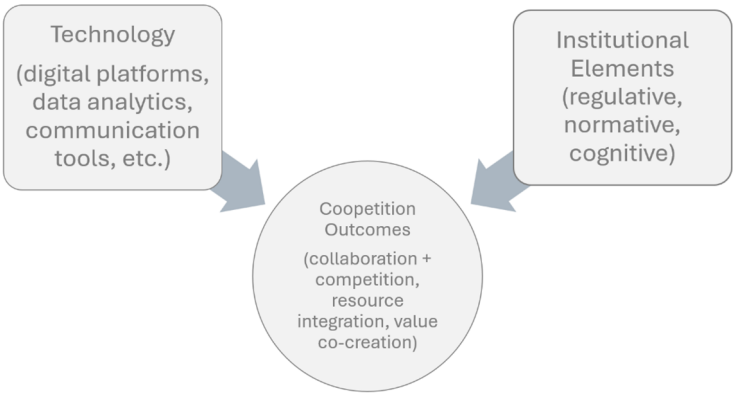


Figure 1. Key elements and technologies as enablers for value co-creation in coopetition networks.

In conclusion, creating and maintaining effective coopetition networks require institutional stability and technological Adaptability. By addressing regulative, normative, and cognitive dimensions, actors can co-create a balanced and resilient ecosystem where competition and collaboration coexist. Technology complements this process by providing the necessary platforms, data-driven insights, and communication tools that enhance collective value creation and ecosystem sustainability.

6.2. What Institutional and Technological Configurations Optimize Value Co-Creation in Coopetition Networks?

S-D Logic conceptualizes value creation as a dynamic, interactive process that emerges through reciprocal exchanges within service ecosystems (Jaakkola et al., 2024). Unlike traditional goods-centric approaches, S-D Logic highlights operant resources—knowledge, skills, and expertise—as the primary drivers of value co-creation (Lusch & Nambisan, 2015). Coopetition networks, by integrating resources and pooling competencies, unlock new opportunities for innovation, Adaptability, and growth that individual firms would struggle to achieve alone (Rouyre et al., 2024). The dynamic recombination of resources fosters shared learning and continuous innovation (Chandler et al., 2019), allowing firms to respond to market demands and maintain competitive differentiation simultaneously (Meena et al., 2023).

Within these networks, S-D Logic reframes value creation as a process shaped by institutional structures and technological enablers (Vargo et al., 2023a). Institutions provide the rules, norms, and cognitive frameworks that guide interactions. At the same time, technology serves as both a facilitator and an initiator of value co-creation: (1) as an operant resource, technology drives innovation and decision-making through artificial intelligence, data analytics, and machine learning, enhancing Adaptability (M. A. Akaka & Vargo, 2014); (2) as an operand resource, it provides the infrastructure for seamless collaboration, including cloud computing, blockchain, and IoT, enabling firms to efficiently coordinate, communicate, and integrate resources (Greer et al., 2016).

By fulfilling these roles, the technology scales resource integration, optimizes interactions, and ensures that coopetition networks remain agile and responsive to market shifts.

To maximize value co-creation, coopetition networks must align institutional and technological elements in the following ways: (1) Regulative Structures—clear legal frameworks, standardization policies, and contractual agreements that establish trust and mitigate risks in coopetitive relationships; (2) Normative Structures—shared industry standards and best practices that encourage collaboration while preserving competitive incentives; and (3) Cognitive Structures—a shared understanding of value co-creation principles, fostering a culture of mutual learning and innovation.

Figure 2 illustrates the key institutional and technological drivers that optimize value co-creation in coopetition networks. It highlights (1) the interplay between institutional structures and service ecosystems, showing how regulative, normative, and cognitive frameworks shape cooperative interactions among firms; (2) the dual role of technology as an operant resource (driving innovation through AI, analytics, and automation) and an operand resource (providing digital infrastructure such as IoT, blockchain, and cloud platforms to enable collaboration); and (3) the continuous feedback loop between institutional governance and technological advancements, demonstrating how aligned configurations reinforce Adaptability, innovation, and sustainable value co-creation.

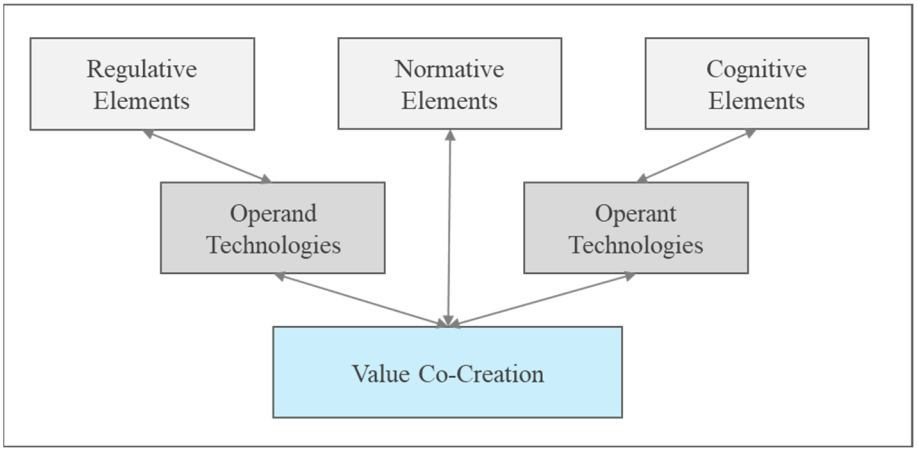


Figure 2. Institutional and technological drivers of value co-creation in coopetition networks.

By effectively integrating these institutional and technological configurations, coopetition networks balance competition and collaboration, fostering continuous innovation, operational efficiency, and long-term market resilience.

6.3. Responding to the Question: How Can Coopetition Networks Be Designed to Ensure Sustainable and Equitable Value Distribution?

The sustainability and equitable value distribution within coopetition networks hinge on their ability to adapt and evolve continuously. As market demands and environmental conditions shift, these ecosystems must engage in proactive governance, ensuring strategic alignment among diverse actors (Vargo et al., 2023b). Institutional maintenance becomes a pivotal mechanism for achieving this, encompassing the adaptation of regulative, normative, and cognitive elements to preserve alignment and cohesion within the network. Institutional maintenance mechanisms play a central role in fostering the longevity and equity of coopetition networks. These mechanisms include the following.

Regulative Elements: The rules, agreements, and standards that govern the network must remain flexible and responsive to changes in laws, market conditions, and industry norms. Regular adaptation ensures that institutional structures remain relevant and supportive of the network's objectives (Edvardsson et al., 2014). For example, revising collaborative agreements to reflect new regulatory landscapes or technological advancements can sustain trust and operational harmony among actors.

Normative Elements: Shared values, trust, and collaborative norms are essential for sustaining productive relationships within cooperation networks. Open dialogue, regular goal reassessment, and clear codes of conduct foster alignment and mutual understanding, mitigating conflicts and promoting cohesion (Koskela-Huotari et al., 2020). These practices ensure that competitive dynamics maintain the collaborative foundation of the ecosystem.

Cognitive Elements: Regular communication and shared narratives help actors align their perspectives and understand the network's evolving objectives. Narrative-building,

strategic storytelling, and sense-making practices ensure that participants remain united in their vision, even as external conditions change (Mustak & Plé, 2020). This cognitive alignment minimizes misunderstandings and enhances strategic coordination.

Coopetition networks are inherently dynamic, requiring continuous institutional maintenance and adaptation. Technologies such as blockchain for transparency, data analytics for monitoring value flows, and artificial intelligence for predictive insights can augment institutional mechanisms, ensuring equitable resource allocation and enhancing participant trust. Combined with institutional work that fosters alignment across regulative, normative, and cognitive dimensions, these technologies enable networks to balance collaboration and competition.

Figure 3 illustrates the key components and interactions required for ensuring sustainability and equitable value distribution in coopetition networks. It highlights the dynamic interplay of regulative, normative, and cognitive institutional maintenance mechanisms, supported by technology and strategic alignment, to foster Adaptability, trust, and shared understanding within a service ecosystem.

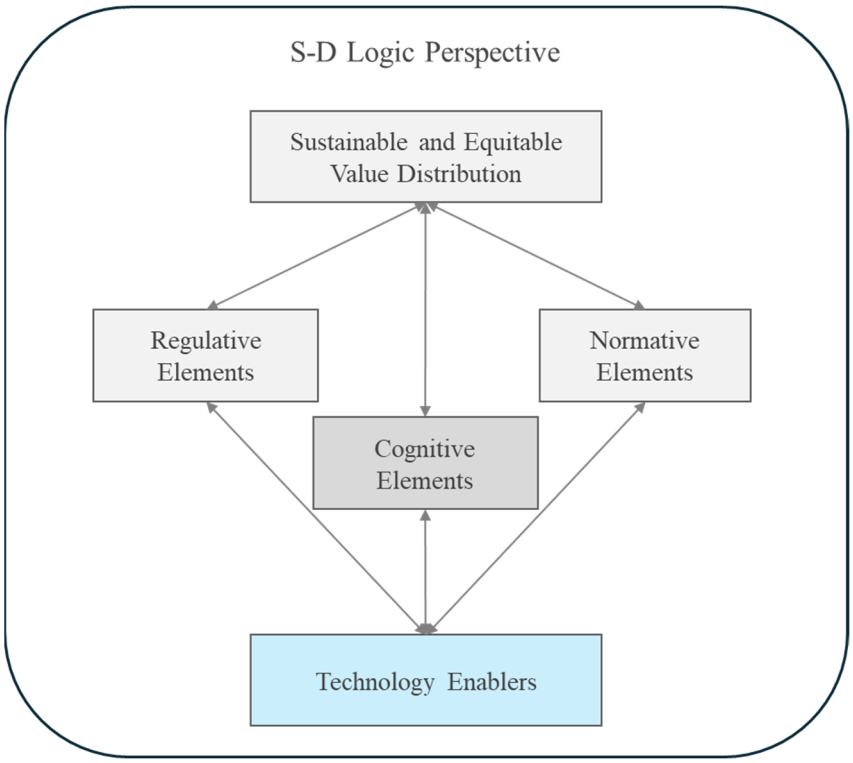


Figure 3. Sustainability mechanisms in coopetition networks, integrating institutional, and technological elements.

Adopting an S-D Logic perspective further enriches the understanding of sustainable and equitable value distribution in coopetition networks. S-D Logic emphasizes value creation's systemic and relational nature by viewing these ecosystems as service-oriented platforms where value emerges through iterative interactions and resource integration. This lens encourages stakeholders to prioritize the collective good, fostering an equitable distribution of benefits and ensuring the long-term viability of the ecosystem.

Through these integrative approaches, coopetition networks can become resilient ecosystems capable of addressing complex market challenges while ensuring equitable and sustainable value co-creation. This dynamic and adaptive framework equips networks to thrive in evolving market environments while balancing competition and collaboration.

7. A Strategic Framework for Technology-Enabled Coopetition Networks (TECNs)

Building on the service ecosystem perspective from S-D Logic (Vargo et al., 2015), this section introduces a structured and theoretically grounded framework for TECNs. The framework encapsulates the systemic interplay between institutional arrangements, technological enablers, and institutional work, offering a comprehensive model for fostering competition and collaboration within dynamic business ecosystems.

By integrating institutional structures with emerging technologies, this framework provides actionable insights into optimizing firm interactions, sustaining long-term partnerships, and driving continuous value co-creation. It delineates the key mechanisms that enable coopetition ecosystems to remain adaptive, resilient, and strategically aligned, leveraging technological advancements to enhance governance, resource integration, and network scalability.

This section elaborates on the framework's core constructs, illustrating how firms can design and implement technology-enabled cooperation networks that balance competitive tensions with cooperative synergies. By structuring interactions through technological infrastructure and institutional configurations, businesses can ensure sustainable and scalable value creation, effectively navigating the challenges of digital transformation and dynamic market conditions.

7.1. Core Constructs of the Framework

The proposed framework for coopetition networks is built upon three fundamental constructs: institutions and institutional arrangements, institutional technologies, and institutional work. These components shape interaction flows, governance structures, and the balance between collaboration and competition, ensuring the sustainability and Adaptability of coopetition networks.

7.1.1. Institutions and Institutional Arrangements

Institutions and institutional arrangements provide the foundation for coopetition networks, shaping behaviours, interactions, and collaborative efforts. These elements define the rules, norms, and shared understandings that regulate ecosystem operations, ensuring both cohesion and flexibility: (1) Regulative Elements—formal rules, contracts, agreements, and compliance mechanisms establish boundaries, ensuring consistency across the network; Normative Elements—shared values, ethical standards, and trust-based norms foster collaboration and guide behaviours toward collective goals; and (3) Cognitive Elements—a shared understanding of objectives and strategic alignment ensures coordination, minimizes conflicts and enhances adaptive decision-making.

By integrating these elements, coopetition networks achieve stability and strategic alignment while remaining adaptable to regulatory and market shifts.

7.1.2. Institutionalized Technologies

Technology plays a dual role in enabling coopetition networks, acting as both an operant and operand resource to drive innovation, interaction, and ecosystem scalability: (1) tangible innovation (operand) such as cloud computing, IoT, and blockchain, among others can provide the physical and digital infrastructure that supports resource integration and collaboration; and (2) intangible innovations (operant) such as AI, machine learning, and data analytics, among others, enhance strategic decision-making, enabling firms to identify new opportunities, optimize processes, and scale interactions.

These technologies enable seamless resource integration and service exchange by breaking down traditional barriers, allowing actors to co-create value in a digitally connected environment.

7.1.3. Institutional Work

Institutional work refers to the deliberate efforts by actors to create, maintain, and disrupt institutional frameworks, ensuring the network's long-term Adaptability and resilience. These efforts include (1) Creating New Institutions—establishing new rules, norms, and structures that align with the ecosystem's evolving needs; (2) Maintaining Existing Institutions—reinforcing and adapting current frameworks to sustain stability while remaining responsive to external shifts; (3) and Disrupting Institutions—challenging outdated structures and inefficiencies, enabling the network to realign with emerging opportunities and technological advancements.

This continuous cycle of institutional creation, maintenance, and disruption ensures that the coopetition network remains dynamic, fostering long-term innovation, collaboration, and competitive advantage.

Figure 4 illustrates the interplay between institutions, technologies, and institutional work in enabling coopetition networks. It highlights how new actors enter the network and interact with regulative, normative, and cognitive elements, shaping the institutional environment. Over time, actors engage in institutional work, either maintaining, disrupting, or creating new institutions, ensuring that the coopetition network remains adaptive, resilient, and strategically aligned.

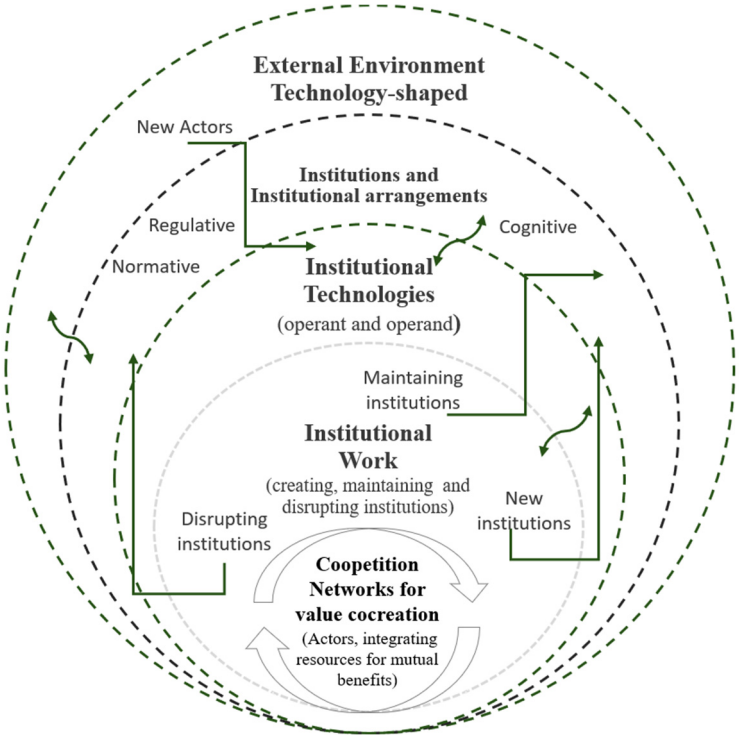


Figure 4. Key constructs of coopetition networks: institutions, technologies, and institutional work enabling collaboration, competition, and adaptability.

By integrating institutional arrangements, technological enablers, and institutional work, the framework provides a systematic approach to understanding how coopetition networks evolve, ensuring sustainable value co-creation and long-term competitive advantage.

7.2. Systemic Building Blocks for Technology-Driven Coopetition Networks

The framework identifies seven systemic building blocks that underpin technology-driven coopetition networks, ensuring sustainable value co-creation. These components interact dynamically, facilitating the balance between collaboration and competition while leveraging technology for innovation and network stability.

The key systemic building blocks are as follows:

1. Coopetition Actors—The core participants in the network, including firms, customers, and stakeholders, who navigate the inherent tensions between cooperation and competition. Their interactions drive innovation, market expansion, and collective value co-creation.
2. Resource Integration—The collaborative merging of diverse resources, capabilities, and competencies. This integration strengthens the network's collective value proposition, ensuring superior outcomes compared to individual contributions.
3. Service Exchange—The mechanism through which resources are shared and utilized. This process reinforces mutual benefits, demonstrating the interdependence of competitive and cooperative forces in value creation.
4. Institutions and Institutional Arrangements—Governance structures that provide rules, norms, and shared understandings. These frameworks guide interactions, ensuring stability while allowing for flexibility and innovation.
5. Nested Service Ecosystems—Coopetition networks operate within broader service ecosystems, interacting with external stakeholders, regulatory bodies, and industry standards. These nested layers reveal the complexity and richness of value co-creation processes.
6. Operand Technologies—Tangible digital tools such as IoT, blockchain, and cloud computing enable operational efficiency, facilitate coordination, and support seamless resource exchange.
7. Operant Technologies—Intangible, knowledge-based innovations like AI, machine learning, and predictive analytics catalyze decision-making, drive strategic realignments, and foster network scalability.

Figure 5 visualizes the interplay between these systemic building blocks, demonstrating how technological advancements (operant and operand technologies) integrate with institutional structures and coopetition actors to sustain adaptive and resilient ecosystems.

7.2.1. How the Building Blocks Enable Value Co-Creation

Coopetition networks can thrive in dynamic market environments by integrating these interdependent elements. The framework highlights three critical processes:

1. Coordinating Resource Integration—Ensuring pooled resources are strategically leveraged to maximize collective benefits.
2. Enabling Seamless Service Exchange—Facilitating efficient, reciprocal interactions among network actors.
3. Fostering Dynamic Value Co-Creation—Encouraging continuous innovation and Adaptability, maintaining the balance between competitive differentiation and cooperative synergies.

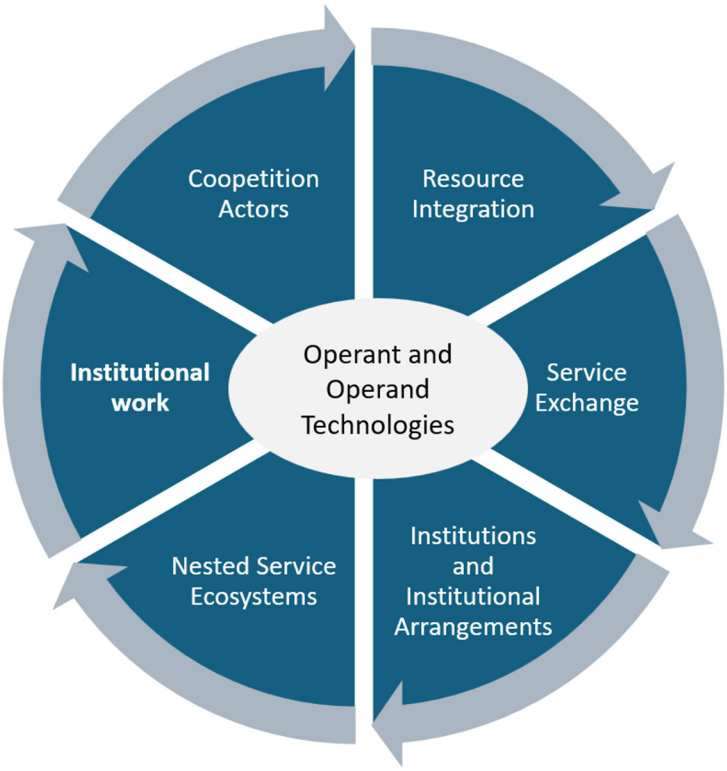


Figure 5. Building blocks for technology-driven coopetition networks.

7.2.2. Strategic Implications for Coopetition Networks

This systemic approach provides stakeholders with a structured foundation for managing the complexities of technology-driven coopetition. The key strategic takeaways are as follows:

1. Leveraging Technology—Harnessing digital tools and platforms to enhance collaboration, automation, and innovation.
2. Aligning Institutional Structures—Establishing shared governance mechanisms to balance competition and cooperation, ensuring long-term sustainability.
3. Promoting Dynamic Interactions—Encouraging continuous adaptation to address emerging challenges, driving sustained innovation and competitive advantage.

By aligning institutional frameworks with technological advancements, this framework transforms potential rivalries into synergistic opportunities, fostering long-term ecosystem resilience, growth, and value creation in an interconnected world.

8. Conclusions

This study uses S-D Logic as a guiding lens to explore the interplay of technology and institutional frameworks in fostering sustainable value co-creation within coopetition networks. This study offers theoretical insights and practical implications for organizations navigating the complexities of competition and collaboration in technology-driven ecosystems by addressing the fundamental questions surrounding technology's role, institutional configurations, and value distribution.

The findings reveal that technology serves as both an enabler and a driver of coopetition, functioning as an operant resource that fuels innovation, predictive analytics, and knowledge sharing and an operand resource that provides the infrastructure necessary for seamless coordination and secure interactions. Technologies such as AI, blockchain, and cloud computing, among others, enhance trust and transparency and facilitate resource

integration and adaptive decision-making, allowing firms to balance competitive tensions with collaborative synergies.

Beyond technology, this study underscores the critical role of institutional structures in ensuring effective coopetition. Regulative elements, such as contracts and industry standards, establish trust and operational consistency. Normative elements, including shared values and ethical norms, align organizational behaviours toward collective goals, and cognitive elements, such as common narratives and shared mental models, help actors coordinate strategies and minimize conflicts. These institutional dimensions create a resilient foundation for value co-creation when integrated with enabling technologies.

Sustaining coopetition networks requires a dynamic and iterative approach to value distribution. As actors continuously reconfigure and recombine their resources, institutional mechanisms must monitor and balance contributions and benefits, ensuring equitable participation and long-term stability. Technologies like blockchain can reinforce fairness and accountability, while data analytics offer real-time insights into value flows, promoting informed decision-making. Institutional work is at the heart of this dynamic process, enabling networks to adapt, evolve, and balance competitive differentiation and cooperative success.

Bringing these elements together, this study introduces a comprehensive framework built on seven systemic building blocks, including coopetition actors, resource integration, service exchange, institutional arrangements, nested service ecosystems, operand technologies, and operant technologies. This framework provides a structured approach to designing technology-enabled coopetition networks, offering a blueprint for firms to cultivate innovation, resilience, and sustainable value creation.

8.1. Limitations

While this study provides valuable conceptual insights into the role of technology in coopetition networks, it remains theoretical and requires empirical validation to assess its applicability in real-world settings. As a conceptual study, the findings are derived from a systematic synthesis of the existing literature and theoretical perspectives rather than direct empirical observations. While valuable for theory-building, this methodological approach presents several limitations that should be acknowledged.

One of this study's primary limitations is the lack of empirical validation. While the proposed framework integrates well-established theories—S-D Logic, Institutional Theory, and technology research—its practical applicability remains untested. Future research should seek to validate this model through case studies, industry surveys, or empirical network analyses, ensuring that the theoretical insights hold across diverse industries, business models, and market conditions.

Another limitation stems from potential selection bias in the literature review process. The conceptual framework was developed through a targeted academic literature review, prioritizing peer-reviewed journal articles and established theoretical contributions. However, there is always a risk that specific relevant perspectives, emerging theories, or industry-specific insights are unintentionally omitted. Future research could mitigate this by incorporating systematic literature reviews or meta-analyses, ensuring a more comprehensive and representative examination of coopetition dynamics.

This study adopts a generalized approach to coopetition, which may not fully account for sector-specific nuances. Coopetition strategies and technology adoption patterns can vary significantly across industries due to differences in regulatory environments, market structures, and competitive landscapes. For instance, coopetition in high-tech industries (e.g., platform-based digital ecosystems) may differ substantially from coopetition in traditional manufacturing or service sectors. Future studies should explore how

industry-specific characteristics influence the applicability of the proposed framework, thereby enhancing its Adaptability and relevance.

Another key limitation lies in categorizing technology as an operand or operant resource. While this classification helps clarify technology's role in coopetition, it may oversimplify how different technologies shape coopetition dynamics. For example, the impact of AI-driven decision-making, blockchain-enabled trust mechanisms, and IoT-facilitated resource sharing varies depending on the industry, firm size, and market maturity. Future research should conduct context-specific analyses to assess the differentiated impact of specific technologies in various coopetition scenarios.

Recognizing these limitations provides opportunities for further research and refinement. Empirical studies could apply mixed-method approaches, integrating qualitative case studies with quantitative modelling to test the robustness of the proposed framework. Moreover, cross-industry comparisons and longitudinal studies could provide deeper insights into how technology-driven coopetition evolves.

Despite these limitations, this study serves as a theoretical foundation for understanding the role of technology in coopetition ecosystems. By addressing these gaps, future research can enhance the proposed framework's empirical robustness, industry relevance, and practical applicability, contributing to academic discourse and strategic business practice.

8.2. Practical and Future Implications

This study offers practical guidance for businesses and policymakers on designing and managing technology-enabled coopetition networks. Firms must strategically leverage digital technologies to enhance collaboration while maintaining a competitive edge. For instance, predictive analytics can help identify areas of mutual benefit, while blockchain can ensure transparency in value-sharing agreements. Additionally, firms must actively engage in institutional work, aligning governance structures with evolving market demands to foster trust, Adaptability, and long-term sustainability.

A key takeaway is that coopetition should be viewed as a continuous process rather than a static strategy. Firms that continuously refine their collaborative efforts can unlock shared innovation opportunities, expand market reach, and enhance industry resilience. By recognizing competition and collaboration as complementary forces, businesses can navigate industry complexities more effectively and cultivate strategic partnerships that drive long-term value creation.

While this study lays a strong theoretical foundation, its real-world implications will only be fully realized through empirical validation. Future research should test and refine this framework through qualitative case studies, industry surveys, and empirical modelling, ensuring its relevance across diverse business contexts. As digital ecosystems continue to evolve, further exploration into the role of emerging technologies—such as AI-driven analytics, blockchain, and decentralized networks—will be essential to refining our understanding of how firms balance competition and collaboration in an increasingly interconnected world.

Ultimately, successfully navigating coopetition—leveraging technology as both a competitive tool and a collaborative enabler—will define the firms that thrive in the digital economy. Organizations that effectively integrate institutional stability, technological innovation, and cooperative strategies will be best positioned to lead in the evolving global landscape.

Author Contributions: A.A.d.S.—Conceptualization, Data curation, Writing—original draft, Writing—review and editing, Formal analysis, Project administration. A.J.M.C.—Conceptualization, Data

curation, Writing—review and editing, Formal analysis. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data supporting this study's findings are available from the corresponding author upon request.

Conflicts of Interest: The authors declare no conflict of interest to disclose.

References

Akaka, M. A., & Vargo, S. L. (2014). Technology as an operant resource in service (eco)systems. *Information Systems and E-Business Management*, *12*(3), 367–384. [CrossRef]

Akaka, M., Schau, H., & Vargo, S. L. (2023, January 3–6). *How practice diffusion drives IoT technology adoption and institutionalization of solutions in service ecosystems*. 56th Hawaii International Conference on System Sciences, HICSS 2023 (pp. 1427–1435), Maui, HI, USA. Available online: https://hdl.handle.net/10125/102808 (accessed on 23 November 2024).

Akaka, M., Vargo, S., & Lusch, R. (2013). The complexity of context: A service ecosystems approach for international marketing. *Journal of International Marketing*, *21*(4), 1–20. [CrossRef]

Akwei, A., Peppard, J., & Hughes, P. (2010). The process of creating dynamic capabilities. *British Journal of Management*, *44*, 1–45. Available online: https://dspace.lboro.ac.uk/2134/7869 (accessed on 25 November 2024).

Amit, R., & Zott, C. (2001). Value creation in E-business. *Strategic Management Journal*, *22*(6–7), 493–520. [CrossRef]

Arthur, W. B. (2009). *The nature of technology*. Penguin Books Ltd., Registered Offices. Available online: https://edisciplinas.usp.br/pluginfile.php/4210376/mod_resource/content/1/Brian%20Arthur-The%20nature%20of%20technology-2009.pdf (accessed on 25 November 2024).

Barile, S., Lusch, R., Reynoso, J., Marialuisa, S., & Spohrer, J. (2016). Systems, networks, and ecosystems in service research. *Journal of Service Management*, *34*(1), 652–674. [CrossRef]

Bettencourt, L. A., Lusch, R. F., & Vargo, S. L. (2014). A Service lens on value creation: Marketing's role in achieving strategic advantage. *California Management Review*, *57*(1), 44–66. [CrossRef]

Beunen, R., & Patterson, J. J. (2019). Analysing institutional change in environmental governance: Exploring the concept of 'institutional work'. *Journal of Environmental Planning and Management*, *62*(1), 12–29. [CrossRef]

Bicen, P., Hunt, S., & Madhavaram, S. (2021). Coopetitive innovation alliance performance: Alliance competence, alliance's market orientation, and relational governance. *Journal of Business Research*, *123*, 23–31. [CrossRef]

Bouncken, R. B., Gast, J., Kraus, S., & Bogers, M. (2015). Coopetition: A systematic review, synthesis, and future research directions. *Review of Managerial Science*, *9*(3), 577–601. [CrossRef]

Bouncken, R., Kumar, A., Connell, J., Bhattacharyya, A., & He, K. (2024). Coopetition for corporate responsibility and sustainability: Does it influence firm performance? *International Journal of Entrepreneurial Behavior & Research*, *30*(1), 128–154. [CrossRef]

Burga, R., & Rezania, D. (2017). Project accountability: An exploratory case study using actor–network theory. *International Journal of Project Management*, *35*(6), 1024–1036. [CrossRef]

Chandler, J. D., Danatzis, I., Wernicke, C., Akaka, M. A., & Reynolds, D. (2019). How does innovation emerge in a service ecosystem? *Journal of Service Research*, *22*(1), 75–89. [CrossRef]

Chen, M., Lv, C., Wang, X., Li, L., & Yang, P. (2023). A critical review of studies on coopetition in educational settings. *Sustainability*, *15*(10), 8370. [CrossRef]

Chesbrough, H., & Rosenbloom, R. (2002). The role of the business model in capturing value from innovation: Evidence from Xerox corporation's technology spin-off companies. *Industrial and Corporate Change*, *11*(3), 529–555. [CrossRef]

Clemens, V., Wilden, R., Akaka, M. A., Foege, J. N., & Nüesch, S. (2025). Multi-level value creation in the sharing economy: A configurational co-creation approach to business model development. *Industrial Marketing Management*, *125*, 272–289. [CrossRef]

Corbo, L., Kraus, S., Vlačić, B., Dabić, M., Caputo, A., & Pellegrini, M. M. (2023). Coopetition and innovation: A review and research agenda. *Technovation*, *122*, 102624. [CrossRef]

Crick, J. (2019). The dark side of coopetition: When collaborating with competitors is harmful for company performance. *Journal of Business & Industrial Marketing*, *35*(2), 318–337. [CrossRef]

Dome, T. (2003). David Ricardo on Public Debt. *History of Political Economy*, *35*(3), 570–571. [CrossRef]

da Silva, A., & Cardoso, A. J. M. (2024). Co-opetition and the industrial internet of things: A strategic framework for operational efficiency in the portuguese ornamental stone sector. *Administrative Sciences*, *14*(6), 125. [CrossRef]

Edvardsson, B., Kleinaltenkamp, M., Tronvoll, B., McHugh, P., & Windahl, C. (2014). Institutional logics matter when coordinating resource integration. *Marketing Theory*, *14*(3), 291–309. [CrossRef]

Elo, J., Lumivalo, J., Tuunanen, T., & Vargo, S. L. (2024, January 3–6). *Enabling value co-creation in partner collaboration ecosystems: An institutional work perspective*. 57th Hawaii International Conference on System Sciences, Waikiki, HI, USA. Available online: https://www.sdlogic.net/pdf/post2018/24_0031.pdf (accessed on 25 November 2024).

Foschi, M. (1972). On the concept of "Expectations". *Sage Journals—Acta Sociologica*, *15*, 124–131. [CrossRef]

Friend, S. B., Malshe, A., & Fisher, G. J. (2020). What drives customer re-engagement? The foundational role of the sales-service interplay in episodic value co-creation. *Industrial Marketing Management*, *84*, 271–286. [CrossRef]

Fullerton, R. R., Kennedy, F. A., & Widener, S. K. (2014). Lean manufacturing and firm performance: The incremental contribution of lean management accounting practices. *Journal of Operations Management*, *32*(7–8), 414–428. [CrossRef]

Garay-Rondero, C. L., Martinez-Flores, J. L., Smith, N. R., Caballero Morales, S. O., & Aldrette-Malacara, A. (2020). Digital supply chain model in Industry 4.0. *Journal of Manufacturing Technology Management*, *31*(5), 887–933. [CrossRef]

Gernsheimer, O., Kanbach, D. K., & Gast, J. (2021). Coopetition research—A systematic literature review on recent accomplishments and trajectories. *Industrial Marketing Management*, *96*, 113–134. [CrossRef]

Gnyawali, D. R., & Song, Y. (2016). Pursuit of rigor in research: Illustration from coopetition literature. *Industrial Marketing Management*, *57*, 12–22. [CrossRef]

Greenwood, R., & Meyer, R. E. (2008). Influencing ideas: A celebration of DiMaggio and Powell (1983). *Journal of Management Inquiry*, *17*(4), 258–264. [CrossRef]

Greer, C., Lusch, R., & Vargo, S. (2016). A service perspective. Key managerial insights from service-dominant (S-D) logic. *Organizational Dynamics*, *45*(1), 28–38. [CrossRef]

Hargadon, A. B., & Douglas, Y. (2001). When innovations meet institutions: Edison and the design of the electric light. *Administrative Science Quarterly*, *46*(3), 476–501. [CrossRef]

Hartmann, N. N., Wieland, H., & Vargo, S. L. (2018). Converging on a new theoretical foundation for selling. *Journal of Marketing*, *82*(2), 1–18. [CrossRef]

Hunt, S. D. (2000). *A general theory of competition: Resources, competences, productivity, economic growth* (Vol. 16, pp. 385–393). Sage Publications.

Jaakkola, E. (2020). Designing conceptual articles: Four approaches. *AMS Review*, *10*(1–2), 18–26. [CrossRef]

Jaakkola, E., & Vargo, S. L. (2021). Assessing and enhancing the impact potential of marketing articles. *AMS Review*, *11*(3–4), 407–415. [CrossRef]

Jaakkola, E., Kaartemo, V., Siltaloppi, J., & Vargo, S. L. (2024). Advancing service-dominant logic with systems thinking. *Journal of Business Research*, *177*, 114592. [CrossRef]

Joiner, K., & Lusch, R. (2016). Evolving to a new service-dominant logic for health care. *Innovation and Entrepreneurship in Health*, *3*, 25–33. [CrossRef]

Kaartemo, V., Akaka, M., & Vargo, S. (2017). A service-ecosystem perspective on value creation: Implications for international business. In *Value creation in international business* (pp. 131–149). Palgrave Macmillan. [CrossRef]

Kleinaltenkamp, M., Corsaro, D., & Sebastiani, R. (2018). The role of proto-institutions within the change of service ecosystems. *Journal of Service Theory and Practice*, *28*(5), 609–635. [CrossRef]

Klein, H. K., & Kleinman, D. L. (2002). The social construction of technology: Structural considerations. *Science, Technology, & Human Values*, *27*(1), 28–52. [CrossRef]

Klimas, P., Ahmadian, A. A., Soltani, M., Shahbazi, M., & Hamidizadeh, A. (2023). Coopetition, where do you come from? identification, categorization, and configuration of theoretical roots of coopetition. *SAGE Open*, *13*(1), 215824402210850. [CrossRef]

Koskela-Huotari, K., Vink, J., & Edvardsson, B. (2020). The institutional turn in service research: Taking stock and moving ahead. *Journal of Services Marketing*, *34*(3), 373–387. [CrossRef]

Lawrence, T. B., & Suddaby, R. (2006). Institutions and institutional work. In *The SAGE handbook of organization studies: Chapter 6*. Sage. [CrossRef]

Lawrence, T. B., Suddaby, R., & Leca, B. (2009). Introduction: Theorizing and studying institutional work. In *Institutional work* (pp. 1–28). Cambridge University Press. [CrossRef]

Lusch, R. F., Vargo, S. L., & Tanniru, M. (2010). Service, value networks and learning. *Journal of the Academy of Marketing Science*, *38*(1), 19–31. [CrossRef]

Lusch, R., & Nambisan, S. (2015). Service innovation: A service-dominant logic perspective. *MIS Quarterly*, *39*(1), 155–175. [CrossRef]

Lusch, R., & Vargo, S. (2014). Service ecosystems. In *Service-dominant logic* (pp. 158–176). Cambridge University Press. [CrossRef]

Manzhynski, S., & Biedenbach, G. (2023). The knotted paradox of coopetition for sustainability: Investigating the interplay between core paradox properties. *Industrial Marketing Management*, *110*, 31–45. [CrossRef]

Meena, A., Dhir, S., & Sushil, S. (2023). A review of coopetition and future research agenda. *Journal of Business and Industrial Marketing*, *38*(1), 118–136. [CrossRef]

Moore, J. F. (1993). A new ecology of competition harvardbusinessreview. *Harvard Business Review*, *71*(3), 75–86. Available online: https://hbr.org/1993/05/predators-and-prey-a-new-ecology-of-competition (accessed on 3 December 2024). [PubMed]

Mokyr, J. (2004). Accounting for the Industrial Revolution. In *The Cambridge Economic History of Modern Britain* (pp. 1–27). Cambridge University Press. [CrossRef]

Munir, K. A., & Phillips, N. (2005). The birth of the "Kodak Moment": Institutional entrepreneurship and the adoption of new technologies. *Organization Studies*, *26*(11), 1665–1687. [CrossRef]

Mustak, M., & Plé, L. (2020). A critical analysis of service ecosystems research: Rethinking its premises to move forward. *Journal of Services Marketing*, *34*(3), 399–413. [CrossRef]

Nalebuff, B. J., & Brandenburger, A. M. (1997). Co-opetition: Competitive and cooperative business strategies for the digital economy. *Strategy & Leadership*, *25*(6), 28–33. [CrossRef]

Normann, R., & Ramirez, R. (1993). From value chain to value constellation: Designing interactive strategy. In *Harvard business review* (Vol. 71, pp. 65–77). Available online: http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=9309166477&site=eds-live (accessed on 2 December 2024).

Parayitam, S., & Guru-Gharana, K. (2010). Economics Of Resource Based And Dynamic Capabilities View: A Contemporary Framework. *Academy of Strategic Management Journal*, *9*(1), 83–94.

Pedeliento, G., Mangiò, F., Murtas, G., & Andreini, D. (2023). Market system dynamics (MSD): A process-oriented review of the literature. *AMS Review*, *13*(3–4), 173–195. [CrossRef]

Peteraf, M. A. (1993). The cornerstones of competitive advantage: A resource-based view. *Strategic Management Journal*, *14*(3), 179–191. [CrossRef]

Pinch, T. J., & Bijker, W. E. (1984). The social construction of facts and artefacts: Or how the sociology of science and the sociology of technology might benefit each other. *Social Studies of Science*, *14*(3), 399–441. [CrossRef]

Reeves, M., Lotan, H., Legrand, J., & Jacobides, M. G. (2022). Chapter 3 how business ecosystems rise (and often fall). In *Business ecosystems* (pp. 27–34). De Gruyter. [CrossRef]

Rouyre, A., Fernandez, A.-S., & Bruyaka, O. (2024). Big problems require large collective actions: Managing multilateral coopetition in strategic innovation networks. *Technovation*, *132*, 102968. [CrossRef]

Sajtos, L., Kleinaltenkamp, M., & Harrison, J. (2018). Boundary objects for institutional work across service ecosystems. *Journal of Service Management*, *29*(4), 615–640. [CrossRef]

Scott, W. (2014). *Institutions and organizations* (4th ed.). SAGE Publications.

Siltaloppi, J., & Vargo, S. L. (2017). Triads: A review and analytical framework. *Marketing Theory*, *17*(4), 395–414. [CrossRef]

Spiller, P. T. (2010). A tribute to Oliver Williamson: Regulation: A transaction cost perspective. *California Management Review*, *52*(2), 147–158. [CrossRef]

Uribe, J., Sytch, M., & Kim, Y. H. (2020). When friends become foes: Collaboration as a catalyst for conflict. *Administrative Science Quarterly*, *65*(3), 751–794. [CrossRef]

Vargo, S. L. (2011). Market systems, stakeholders and value propositions: Toward a service-dominant logic-based theory of the market. *European Journal of Marketing*, *45*(1), 217–222. [CrossRef]

Vargo, S. L., Akaka, M. A., & Wieland, H. (2020). Rethinking the process of diffusion in innovation: A service-ecosystems and institutional perspective. *Journal of Business Research*, *116*, 526–534. [CrossRef]

Vargo, S. L., Fehrer, J. A., Wieland, H., & Nariswari, A. (2024). The nature and fundamental elements of digital service innovation. *Journal of Service Management*, *35*(2), 227–252. [CrossRef]

Vargo, S. L., & Koskela-Huotari, K. (2020). Advancing conceptual-only articles in marketing. *AMS Review*, *10*(1–2), 1–5. [CrossRef]

Vargo, S. L., & Lusch, R. F. (2004). Evolving to a new dominant logic for marketing. *Journal of Marketing*, *68*(1), 1–17. [CrossRef]

Vargo, S. L., & Lusch, R. F. (2008). From goods to service(s): Divergences and convergences of logics. *Industrial Marketing Management*, *37*(1), 254–259. [CrossRef]

Vargo, S. L., & Lusch, R. F. (2010). *Handbook of service science* (P. P. Maglio, C. A. Kieliszewski, & J. C. Spohrer, Eds.). Springer US. [CrossRef]

Vargo, S. L., & Lusch, R. F. (2011). It's all B2B…and beyond: Toward a systems perspective of the market. *Industrial Marketing Management*, *40*(2), 181–187. [CrossRef]

Vargo, S. L., & Lusch, R. F. (2014). Inversions of service-dominant logic. *Marketing Theory*, *14*(3), 239–248. [CrossRef]

Vargo, S. L., & Lusch, R. F. (2016). Institutions and axioms: An extension and update of service-dominant logic. *Journal of the Academy of Marketing Science*, *44*(1), 5–23. [CrossRef]

Vargo, S. L., & Lusch, R. F. (2017). Service-dominant logic 2025. *International Journal of Research in Marketing*, *34*(1), 46–67. [CrossRef]

Vargo, S. L., Peters, L., Kjellberg, H., Koskela-Huotari, K., Nenonen, S., Polese, F., Sarno, D., & Vaughan, C. (2023a). Emergence in marketing: An institutional and ecosystem framework. *Journal of the Academy of Marketing Science*, *51*(1), 2–22. [CrossRef]

Vargo, S. L., Wieland, H., & Akaka, M. (2015). Innovation through institutionalization: A service ecosystems perspective. *Industrial Marketing Management*, *44*, 63–72. [CrossRef]

Vargo, S. L., Wieland, H., & O'Brien, M. (2023b). Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline. *Journal of Business Research*, *164*, 113965. [CrossRef]

Wieland, H., Hartmann, N., & Vargo, S. (2017). Business models as service strategy. *Journal of the Academy of Marketing Science*, *45*(6), 925–943. [CrossRef]

Xie, Q., Gao, Y., Xia, N., Zhang, S., & Tao, G. (2023). Coopetition and organizational performance outcomes: A meta-analysis of the main and moderator effects. *Journal of Business Research*, *154*, 113363. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

systems

MDPI

Article

Systemic Approaches to Coopetition: Technology and Service Integration in Dynamic Ecosystems Among SMEs

Agostinho da Silva [1,2,*] and Antonio J. Marques Cardoso [1]

[1] CISE—Electromechatronic Systems Research Centre, University of Beira Interior, 6201-001 Covilhã, Portugal; ajmcardoso@ieee.org
[2] CIGEST—Centre for Research in Management, Lisbon Business School, 1000-002 Lisboa, Portugal
* Correspondence: a.silva@zipor.com

Abstract: In the globalized, technologically advanced landscape, coopetition—simultaneously cooperating and competing—has become a key strategy for innovation and enhanced value creation. This research focuses on the impact of technology-driven coopetition networks in the Portuguese ornamental stone sector, using a framework based on Service-Dominant Logic (S-D Logic). It emphasizes the importance of resource integration, service exchange, and institutional arrangements in successful coopetition. Employing a two-phase experimental approach with selected small and medium enterprises (SMEs), this study assesses customer perceptions of product quality under traditional best practices versus those enabled by technology-driven coopetition networks. The results indicate a notable improvement in the customer-perceived quality and outcome consistency. The statistical analysis shows that these networks allow firms to better align with customer expectations, optimize resource allocation, and improve operational coordination. The findings highlight the strategic potential of coopetition networks, particularly when augmented by advanced technologies like IoT-based systems. These networks facilitate sustainable value co-creation and operational resilience by enabling firms to share expertise, distribute tasks, and synchronize efforts. This research contributes to the coopetition and S-D Logic literature by offering a practical framework for firms aiming to boost competitiveness and sustain growth in dynamic service ecosystems.

Keywords: coopetition; IoT; business transformation; service-dominant logic; value co-creation; innovation

check for updates

Academic Editor: Alberto Paucar-Caceres

Received: 5 January 2025
Revised: 29 January 2025
Accepted: 3 February 2025
Published: 5 February 2025

Citation: da Silva, A.; Cardoso, A.J.M. Systemic Approaches to Coopetition: Technology and Service Integration in Dynamic Ecosystems Among SMEs. *Systems* **2025**, *13*, 97. https://doi.org/10.3390/systems13020097

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

In an era characterized by market globalization and resource asymmetry, the business network landscape has undergone profound transformations, giving rise to diverse and complex network structures [1]. One such structure, coopetition—defined as the simultaneous collaboration and competition between firms—has emerged as a crucial strategy for reshaping organizational dynamics and network ecosystems [2]. Coopetition enables firms to leverage competitive advantages [3] while mitigating external risks and uncertainties [4]. Despite increasing academic attention to this phenomenon [5], significant gaps remain in understanding how coopetition networks facilitate or obstruct value creation and capture [6]. These gaps are particularly pressing given the transient nature of coopetition networks, which often dissolve prematurely before achieving their intended objectives [7].

The existing research primarily examines coopetition through two dominant lenses. First, the competitive dynamics perspective explores firm behavior and market structuring as critical drivers [8,9]. Second, the resource-based view positions coopetition as a strategic

pathway to accessing unattainable resources, enabling firms to exploit unique capabilities for a competitive advantage [2]. While these perspectives provide valuable insights, they primarily focus on dyadic relationships, neglecting the broader complexities of multi-party interactions in networked environments [10].

A critical shortcoming in the literature lies in the limited exploration of value creation mechanisms and the crucial role of technology within coopetition networks [11]. Although theoretical frameworks such as game theory, the resource-based view, paradox theory, transaction cost theory, and network theory have been widely applied [5], there remains a lack of clarity regarding how value is created, distributed, and sustained among diverse stakeholders [2]. This is particularly concerning as unmet expectations often drive the premature collapse of coopetition networks [7]. Furthermore, research in the financial technology sector demonstrates that coopetition arises when firms clearly understand their core competencies and strategic focus, enabling them to collaborate with external partners who complement their strengths [12,13]. These studies suggest that coopetition is not an equilibrium state but evolves as firms develop new capabilities and adapt to dynamic market conditions. Recognizing the increasing significance of technology in modern business ecosystems, this study addresses the following research question: What framework is best suited for coopetition networks to meet customer expectations?

To answer this question, the research adopts Service-Dominant Logic (S-D Logic) as its theoretical foundation [14]. S-D Logic emphasizes that value is co-created through resource integration and reciprocal service exchange processes among actors in service ecosystems [15], positioning customers as essential participants in the value creation process [16]. This perspective highlights the importance of partner collaboration ecosystems in coopetition networks to align firms' collective efforts to meet customer expectations [17]. By leveraging advanced technologies, such as IoT-based systems, firms can optimize their resource-sharing capabilities and operational coordination [18], enabling them to deliver outcomes that resonate more effectively with customer needs [19,20].

This research tests the hypothesis that transitioning to technology-driven coopetition networks enhances value co-creation by enabling firms to align their offerings with customer expectations better. By fostering collaborative processes and integrating shared resources, coopetition networks can improve the perceived product quality and operational consistency, critical in meeting customer requirements and driving sustainable value co-creation.

To empirically test this hypothesis, this study examines the Portuguese ornamental stone sector, an industry of national significance with a global presence. Comprising predominantly SMEs, this sector has demonstrated exceptional economic performance, with exports exceeding imports and a considerable market reach beyond Europe.

The Portuguese ornamental stone sector holds significant historical, cultural, and economic importance. Since the 15th century, this sector has contributed to iconic monuments worldwide, showcasing Portugal's deep-rooted expertise in stone craftsmanship [21]. According to the Portuguese Stone Federation, this sector ranks ninth globally in the International Stone Trade and second in international trade per capita, exporting to 116 countries [22].

Coopetition, in the context of this study, refers to a strategic interplay where companies collaborate and compete simultaneously to achieve mutual benefits that would be unattainable independently. This article is structured as follows: The literature review explores the role of technology in enabling resource integration and value co-creation within coopetition networks. The research design outlines the methodological approach to address the research question and test the proposed hypothesis. The study develops and validates a framework for enhancing customer expectations through technology-driven

coopetition networks by investigating the interplay between coopetition, technology, and value co-creation.

2. Literature Review

Coopetition has gained increasing recognition in recent business literature as a key strategy for enhancing competitive advantage and fostering innovation within networks [23]. Coopetition serves dual strategic purposes: a deliberate move to strengthen market power [24] or a dynamic response to external opportunities and threats [25]. A firm's knowledge structure often influences the decision to engage in coopetition, which shapes its strategic choices to cooperate, compete, or adopt a combination of both [26]. At the core of coopetition's strategic value lies its orientation toward innovation, enabling firms to bridge knowledge gaps and effectively address market challenges [9].

Coopetition networks arise at the intersection of cooperative and competitive interests, where firms recognize the mutual benefits of collaboration despite direct competition in certain areas [23]. These interactions often extend beyond dyadic relationships, evolving into multi-firm networks where participants collaborate equally to achieve common goals [27].

Scholarly perspectives on coopetition are diverse. Some researchers conceptualize these relationships as hybrid networks characterized by paradoxical interactions between cooperation and competition [2]. Analytical frameworks generally fall into two primary lenses: (1) competitive dynamics, which emphasize the structural and behavioral aspects of relationships [27], and (2) the resource-advantage perspective, which views coopetition as a strategic mechanism to access otherwise unattainable resources, enhancing firms' competitive capabilities [28].

Despite the varying viewpoints, the prevailing consensus highlights the firm-centric nature of coopetition, where individual competitiveness often takes precedence over collective value creation within networks [2].

Empirical research underscores the advantages of coopetition, including access to new markets, external knowledge sharing, risk and cost distribution, and enhanced scalability through asset complementarity [29]. Coopetition has been linked to increased innovation, particularly in supply chain security and knowledge creation processes [9]. Table 1 provides an overview of key definitions and perspectives on coopetition.

Table 1. Coopetition: definitions and perspectives.

Coopetition: Definition and Perspectives	Source
Coopetition represents a hybrid activity combining cooperation and competition within firms.	[30]
Coopetition describes a triadic relationship where collaboration among firms influences competition with others.	[31]
Coopetition involves simultaneous competition and collaboration within the same relationship.	[25]
Coopetition is a hybrid behavior where firms engage in both competition and cooperation.	[24]
In a coopetition relationship, firms typically cooperate in upstream activities and compete in downstream activities.	[30,32]
Coopetition is a dyadic and paradoxical relationship that emerges when two firms cooperate in some activities.	[33]
Coopetition involves simultaneous cooperative and competitive interactions across multiple levels of analysis.	[34]
Coopetition is the balance between cooperation and competition in a competitive environment.	[35]

While coopetition delivers notable advantages, several critical research gaps persist:

- RG1: The predominant focus on individual competitive benefits overshadows processes for collective value creation. How can value creation in coopetition networks be effectively addressed?
- RG2: Variability in firms' motivations leads to unresolved dysfunctions within coopetition networks. How can dysfunctions in coopetition networks be managed?
- RG3: Despite coopetition's recognized complexity, discussions on coordination mechanisms for balancing collaboration and competition still need to be improved. How can coordination among actors in coopetition networks be facilitated?

Moreover, coopetition networks are prone to significant challenges, including uncertainty, competitive pressures, and risks like knowledge leakage. These challenges sometimes outweigh the benefits, leading to the premature dissolution of coopetition relationships [36].

2.1. Value Creation Through the Lens of Service-Dominant Logic

The conceptualization of "service" as a cornerstone of economic exchange can be traced back to the mid-19th century with early thinkers like Frederick Bastiat (1848). However, in the early 21st century, Lusch and Vargo (2004) revolutionized this discourse by introducing S-D Logic [16]. This paradigm shift placed operant resources—intangible assets such as knowledge, skills, and capabilities—at the forefront of value creation [37], challenging the traditional operand resource view that prioritized tangible goods. In the S-D Logic perspective [38], goods are not the primary creators of value but serve as vehicles for service delivery, embodying the application of specialized competencies to benefit others [39].

At its core, S-D Logic redefines value creation as a co-creation process, emphasizing that value emerges through interactions among various actors within a networked ecosystem [25]. This perspective aligns with foundational theories such as the resource-based view [40], competency core theory [41], and corporate core competencies theory [42], underscoring its broad applicability to contemporary discussions on value generation (Table 2).

Table 2. Value creation for service-dominant logic.

	Core Concept	Source
Phenomenological Nature	Value is experiential and perceived differently by various service ecosystem actors across diverse contexts.	[43]
Resource Integration and Exchange	Value is co-created through the integration and exchange of resources among multiple actors, including firms, customers, suppliers, and government agencies.	[44]
Well-Being Enhancement Through Resources	Value co-creation occurs as actors enhance their well-being by relying on operant resources (knowledge and skills) and operand resources (tangible tools).	[45]
Multidimensional Nature	Value comprises individual, social, technological, and cultural components and is derived through interactions among actors within intersecting institutional frameworks.	[46–48]
Emergent Property	Value is emergent and cannot be predetermined; it arises through the ongoing relationships between actors and the system, shaping the service ecosystem's identity.	[19,44]
Resource-Enacting Phenomenal Practices	Beneficiaries participate in value co-creation through phenomenal practices, where their experiences enact and exchange services to generate value.	[38]

Historically, classical economists like Adam Smith (1776) and David Ricardo (1817) approached value through the lens of labor theory, focusing on tangible production. However,

modern economic discourse has evolved to embrace value co-creation, which highlights the collaborative roles of suppliers, partners, and customers in generating value [49]. This evolution—from coproduction to co-creation and ultimately to value co-creation within service ecosystems—reflects an enhanced understanding of value as multifaceted and dynamic [50].

Under S-D Logic, service ecosystems are viewed as complex adaptive systems where value is derived and continuously re-evaluated through actor interactions. Instead of viewing value as a predefined delivery, S-D Logic emphasizes the role of value propositions as facilitators of co-creative interactions [14]. This perspective further distinguishes between value-in-exchange (traditional market transactions) and value-in-use (value derived through application and interaction), emphasizing the process-oriented and relational nature of value creation and realization [14].

2.2. Value Networks and Technology as Catalysts for Collaborative Value Creation

Granovetter (1985) emphasizes that economic behaviors are embedded within network relationships, advocating for a more nuanced understanding of how cooperation and competition operate at multiple levels [51]. Other historical perspectives on networks, rooted in sociology and organizational theory, highlight their structural implications for value creation [52]. However, recent literature has called for re-examining network concepts to align theoretical insights with the practical realities of contemporary industries and management practices [5].

Building on this foundation, Mariotti (2002) introduces the concept of a value network, describing it as an interconnected ecosystem where information, technology, and human interactions converge to generate value across nodes. Mariotti highlights the role of technology in facilitating exchanges that transcend spatial and temporal boundaries, enabling dynamic collaboration and interaction among network participants [53].

The concept of "network" plays a dual role in modern economic and social ecosystems, encompassing both networking and the structural configuration of interconnected systems. This duality highlights networks as platforms where diverse actors—individuals to organizations—interact and collaborate to achieve economic, social, and environmental objectives [5]. Within the framework of S-D Logic, networks are reconceptualized as interconnected systems of actors who contribute specialized competencies and engage in reciprocal value propositions [54]. This perspective shifts the focus from transactional exchanges of goods and services to collaborative interactions and relationships as the primary drivers of value creation [55].

Under this view, technology plays a transformative role in shaping and redefining value networks [56]. Traditionally viewed as a societal tool for addressing needs [57], technology is now recognized within S-D Logic for its dual nature as both an operand resource (an enabling tool) and an operant resource (a source of knowledge and innovation) [58]. This nuanced understanding positions technology as a critical enabler of value co-creation by fostering new resource integration, collaboration, and innovation [37].

The convergence of digital transformation and technological innovation further amplifies technology's role within value networks. Wieland et al. (2017) explore this interplay, emphasizing how technological advancements drive service innovation, enabling network actors to integrate resources more efficiently and create enhanced value [15]. In modern ecosystems, technology connects actors and facilitates adaptive and dynamic relationships, supporting the emergence of new value propositions and resource exchanges.

Drawing on this critical evaluation of value creation mechanisms and the role of technology in coopetition networks, a theoretical framework can be formulated to test the hypothesis that transitioning to technology-driven coopetition networks enhances

customer-perceived quality, thereby fostering value co-creation. This framework aims to uncover how technological advancements catalyze collaboration, drive innovation, and contribute to the sustainable success of coopetition networks.

3. Methodology

This research design is grounded in critical decisions regarding its theoretical foundation, which provides a framework for investigating complex phenomena across diverse fields such as medicine, computer science, engineering, management, and economics [59]. Integrative approaches, known for their ability to analyze both individual components and the system as a whole, are particularly suited for exploring the multifaceted nature of coopetition networks [60].

This study employs an integrative methodology to comprehensively understand service-centric networks [61]. It shifts the focus from firm-centric views to a service-oriented lens emphasizing institutional change and collaborative value creation [14]. By facilitating processes such as logistics, learning, and knowledge transfer, coopetition within ecosystems drives innovation and enables firms to achieve collective and individual benefits [62].

Coopetition ecosystems incorporate multiple innovation processes [63] facilitated by sharing resources and fostering an environment that enhances the network's collective capacity for innovation [64]. Scholars further argue that innovation in these networks is not merely an outcome but also a driver of dynamic reconfigurations within institutional spaces [8]. These reconfigurations are shaped by ongoing interaction and co-creation, underscoring the importance of continuous adaptation within service ecosystems [17].

3.1. Integrative Framework and Hypothesis Development

Building on S-D Logic, this study proposes an integrative framework to address existing gaps in the coopetition literature [65]. The framework encompasses three interconnected components: (1) Framing Networks and Service Ecosystems—understanding the foundational role of networks and their transformation into service ecosystems as platforms for value co-creation; (2) Framing Coopetition and Value Creation—articulating how coopetition facilitates innovation and dynamic value creation processes within service ecosystems; and (3) Bridging Theoretical Gaps—leveraging this integrative perspective to address gaps in the coopetition literature, particularly in service ecosystems and institutional networks.

Building on these systemic constructs, this study implements a Technology-Driven Coopetition Network to test the hypothesis that transitioning to technology-driven coopetition networks enhances customer-perceived quality, thereby fostering value co-creation.

3.2. Evaluation Metrics for Assessing Value Co-Creation in the Ornamental Stone Industry

From the perspective of S-D Logic, value emerges as the result of a co-creative process in which the customer is a fundamental actor [16]. Higher alignment with customer expectations leads to higher co-created value. Among the various indicators suggested in the marketing literature, the perceived product quality is considered one of the most reliable and widely adopted Key Performance Indicators (KPIs) [66].

In stone SMEs supplying ornamental stone products, customer orders often involve multiple items, such as kitchen countertops, facades, flooring, staircases, thresholds, and baseboards [22]. However, as stone is a natural product, its raw material is inherently heterogeneous, even within the same material type (e.g., granite, limestone, marble, or slate).

When a company secures an order, it must produce multiple product types using various raw materials, often lacking the full production capabilities or technical know-how to handle all aspects efficiently. Companies can distribute portions of their orders to other network members with the necessary expertise and production capacity by participating

in a technology-driven coopetition network. This collaboration occurs while ensuring customer identity confidentiality and preserving market integrity.

As a result, companies operating within a coopetition framework are better positioned to meet or exceed customer expectations, thereby improving perceived product quality.

3.3. Measuring Value Co-Creation Through Perceived Product Quality

In value co-creation, the Perceived Quality of Products (QpP) is defined as the degree to which the delivered product meets or surpasses the customer's initial expectations. For this study, the Key Performance Indicator for Perceived Product Quality (KPIQpP) is quantified using a five-point Likert scale, where a score of 1 indicates that the product quality falls significantly below expectations, and a score of 5 indicates that it far exceeds expectations.

To evaluate the value co-creation gain (VCG) of transitioning from traditional best practices (BP) to a technology-driven coopetition network (CP), the gain in value co-creation can be calculated as a percentage improvement using Equation (1), where (1) KPIQpP(BP) represents the average customer rating for the perceived product quality under best practices (conventional methods), and (2) KPIQpP(CP) represents the average customer rating for the perceived product quality within the coopetition network.

$$\text{VCG } (\%) = \frac{\text{KPIQpP(CP)} - \text{KPIQpP(BP)}}{\text{KPIQpP(BP)}} \times 100\% \quad (1)$$

This systematic metric quantitatively assesses how technology-enabled coopetition networks influence customer perceptions of quality. Applied to the Portuguese ornamental stone sector, it offers valuable insights into how cooperative efforts enhanced by technology can drive improvements in the perceived product quality and foster greater value co-creation.

This integrative framework offers theoretical insights and practical pathways for rethinking coopetition, aligning the methodological approach with advancements in S-D Logic. It underscores the importance of continuous innovation and value co-creation processes within institutional networks, positioning coopetition as a transformative strategy for fostering sustainable growth and collaboration in dynamic service ecosystems.

4. An Integrative Framework for Institutional Coopetition Networks

4.1. The Evolution from Value Networks to Service Ecosystems

The transition from value networks to service ecosystems represented more than a shift in terminology—it reflected an evolution in theoretical focus. From traditional perspectives, enterprises within value networks collaborate to enhance the value of tangible and intangible products, with the primary goal of capturing market share through added value [67]. However, this perspective underwent a transformative shift with the contributions of Vargo and Lusch (2011), who redefined value creation within the S-D Logic framework. They advocated moving from static value networks to dynamic service ecosystems, where resource integration is the central mechanism for connecting people, technology, and institutions, facilitating value co-creation through service exchange [68].

A critical advancement in this evolution was the recognition of the role played by institutions and institutional arrangements in enabling value co-creation within service ecosystems. Lusch and Vargo (2014) conceptualized service ecosystems as self-regulating systems composed of resource-integrating actors whose interactions are governed by shared institutional logic and mutual value creation objectives [69]. Based on Scott's (2001) definition, institutions within these ecosystems are seen as structured sets of rules, norms, and beliefs that enable and constrain actors' behaviors, rendering social interactions predictable and meaningful [70].

The role of institutional logic within service ecosystems, as explored by Koskela-Huotari and Vargo (2016), extends beyond organizational boundaries. Institutional logics operate at a supra-organizational level, coordinating actions and governance through material–symbolic languages that align actor behaviors within the ecosystem [71,72]. This perspective underscores the network-centric nature of modern ecosystems, where value is co-created through the integration of resources, collaboration, and adherence to shared institutional logic [72].

By focusing on the systemic and adaptive nature of service ecosystems, S-D Logic provides a comprehensive framework for analyzing the complex interplay among actors, resources, and institutions. This dynamic interplay enables the ongoing process of value co-creation, positioning service ecosystems as both drivers of innovation and platforms for fostering collaborative value creation [56].

4.2. Navigating Dual Dynamics: Framing Coopetition and Value Creation

In business literature, coopetition has been conceptualized as embodying two distinct yet interconnected dimensions. Bengtsson and Kock (2014) describe these dimensions as "parallel lanes," where firms collaborate with rivals in specific markets or activities while maintaining competitive postures in others [73]. This duality creates strategic opportunities and operational challenges, requiring firms to balance these opposing forces to achieve sustainable outcomes carefully [2].

Contrasting this "dual-lane" perspective, other scholars introduce the concept of syncretic rent-seeking behavior [74]. From this viewpoint, coopetition is not a simple balance of distinct strategies but rather an integrated approach operating along a single continuum where cooperation and competition coexist in dynamic tension [75]. This perspective emphasizes that firms must navigate the complexities and trade-offs inherent in these dual dynamics, developing strategies to harmonize collaborative and competitive intents effectively.

The inherent tensions within coopetition networks necessitate mechanisms for managing these dynamics. Scholars highlight the importance of establishing cooperative norms, rules, and institutions to guide actor interactions and mitigate conflicts [26]. This institutionalized approach aligns closely with the S-D Logic framework, which positions service ecosystems as systems of shared institutional logic that facilitate value co-creation [58]. Drawing on Scott's (2001) institutional theory, institutions within service ecosystems act as higher-order structures, providing the symbols, rules, and organizing principles needed to address tensions and paradoxes inherent in coopetition networks [56].

Within this institutional framework, value cooperation in coopetition networks emerges through dynamic service exchanges among various actors, including firms, competitors, customers, and regulatory authorities [76]. This process is inherently experiential and iterative, as actors continuously learn and adapt. By observing and assessing what creates value—and what does not—actors adjust their behaviors and interactions to align with evolving expectations [77].

As with any ecosystem, this dynamic learning environment fosters an ongoing cycle of adaptation and innovation, ensuring the survival and growth of coopetition networks. Firms that embrace this adaptive capacity can better navigate the dual dynamics of cooperation and competition, unlocking opportunities for sustainable value creation and enhancing their collective resilience within the network [77].

4.3. Addressing Coopetition Challenges Through the Lens of Service Ecosystems

Coopetition networks provide platforms for firms to acquire and integrate resources and capabilities, enhancing their competitive advantage and innovation capacity [78]. This

aligns with the S-D Logic perspective, which positions all actors as resource integrators and views value as co-created through dynamic service exchanges. Institutions—understood as shared rules, norms, and meanings—are crucial in enabling and constraining actions, ensuring coordinated value co-creation within complex service ecosystems [79]. To address critical challenges within coopetition networks, this section explores how the service ecosystem perspective provides solutions to the identified research gaps (RG1, RG2, and RG3).

Bridging RG1—Overcoming the Focus on Individual Competitive Benefits to Enable Collective Value Creation: Focusing on individual firm competitiveness often overshadows collective value creation processes. Through the lens of S-D Logic, value creation is conceptualized as a shared process where firms collaborate to integrate resources and generate mutual benefits. In coopetition networks, actors must recognize that value emerges not from isolated outcomes but from reciprocal exchanges and service integration across the ecosystem. Institutions play a critical role in facilitating this transition. By establishing shared norms, expectations, and collaborative frameworks, institutions encourage firms to shift from a firm-centric mindset to a network-centric approach. Resource integration within coopetition networks ensures that firms collectively enhance operational efficiency and deliver value propositions that align with customer expectations. This process addresses RG1 by repositioning value creation as a collective endeavor that benefits all network participants [62].

Bridging RG2—Managing Variability in Motivations to Overcome Dysfunctional Coopetition: Variability in firms' motivations can lead to unresolved dysfunctions, including trust issues, competitive misalignment, and resource misuse. Addressing these challenges requires the implementation of institutional arrangements that establish organic governance mechanisms and align actor behaviors. Through shared norms, social rules, and evaluative frameworks, institutions serve as stabilizing forces that guide interactions within the network. By adopting a service ecosystem perspective, firms can effectively navigate tensions between collaboration and competition. Shared institutional logic provides actors with common goals and a structured approach to resolving conflicts. For example, confidentiality agreements, operational norms, and incentive mechanisms can reduce opportunism and align motivations, enabling firms to balance their competitive and cooperative intents. This structured governance ensures that coopetition relationships remain productive, addressing RG2 by reducing dysfunctions and fostering trust-driven coordination [26,80].

Bridging RG3—Facilitating Coordination Mechanisms to Balance Collaboration and Competition: Coopetition's inherent complexity necessitates effective coordination mechanisms to balance collaboration and competition. Institutions within service ecosystems play a dual role in facilitating coordination: they act as mechanisms for collaboration and evaluative frameworks for assessing performance. From an S-D Logic perspective, coordination emerges through actor-generated institutions, such as shared social norms, rules, and expectations, streamlining interactions and resource exchanges. Technologies, such as IoT systems and digital platforms, also function as critical enablers of coordination, allowing actors to share resources, track progress, and align operational activities dynamically. Technological solutions provide structural support for balancing the dual dynamics of coopetition by enabling firms to connect their processes and exchange services seamlessly. This systemic approach to coordination addresses RG3 by providing firms with actionable tools and institutional frameworks to facilitate collaboration without compromising competitive interests. Effective coordination ensures the sustainability of coopetition networks, enabling firms to achieve mutual gains and co-create value over time

By addressing these research gaps, the service ecosystem perspective provides a comprehensive understanding of coopetition networks. Institutions and institutional

arrangements serve as foundational elements for (1) facilitating collective value creation through resource integration and shared norms; (2) managing variability in motivations by establishing governance mechanisms that align actor behaviors and reduce dysfunctions; and (3) enhancing coordination through shared frameworks, technological enablers, and evaluative mechanisms that balance collaboration and competition.

The dynamic interplay between actors, institutions, and technology underscores the importance of adaptive governance and resource alignment within coopetition networks. This perspective ensures that value is co-created sustainably while mitigating the risks of conflict, fragmentation, or co-destruction. By adopting this framework, firms can navigate the challenges of coopetition, leveraging collective capabilities to foster innovation, operational efficiency, and customer-aligned value creation.

Through the lens of S-D Logic and service ecosystems, this study demonstrates how coopetition networks can address key challenges and bridge existing gaps in value creation, actor alignment, and coordination mechanisms. By leveraging institutions and technological solutions, firms can build resilient networks that enhance value co-creation and drive sustainable growth.

5. Institutional Constructs and Systemic Building Blocks for Coopetition Networks

Understanding institutions involves recognizing their regulative, normative, and cultural–cognitive dimensions in coopetition networks. These institutional elements become critical when organized actors—often called institutional entrepreneurs—identify opportunities to pursue shared, highly valued interests within a network [81]. Within this institutionalized environment, cognitive institutional arrangements act as enablers for transforming coopetition networks into fertile ground for value co-creation [70]. This transformation aligns with the S-D Logic perspective, which envisions value co-creation as actors engaging in meaningful experiences within nested and overlapping service ecosystems. These ecosystems operate under governance and evaluation mechanisms provided by institutional arrangements [79].

Highlighting the critical role of dynamic interactions in networks, S-D Logic conceptualizes networks as fluid configurations of institutions [71]. These configurations, built upon reciprocal connections among actors, drive technological and market innovations that ensure the resilience and endurance of coopetition networks [15].

Building on this service ecosystems perspective, the following set of systemic constructs can be proposed for understanding and developing coopetition networks:

Coopetition Network Institutionalization (Systemic Construct 1): (1) emphasizing the bidirectional relationship between institutions and actor behaviors within networks, (2) institutions emerge organically through bottom-up processes, evolving from micro-level practices (actor-specific behaviors) to mezzo-level arrangements (network norms), and (3) coopetition practices at the micro level catalyze the development of actor-generated institutions, setting the stage for future value creation interactions within the network.

Coopetition Network Coordination (Systemic Construct 2): (1) at the micro-level, firms (competitors and partners) engage in resource exchange within networks to co-create value; (2) coordination mechanisms—such as shared motivations, norms, and expectations—facilitate seamless resource integration; and (3) the outcomes of value co-creation are governed and evaluated by actor-generated institutions and broader institutional arrangements.

Coopetition Enabled by Technology in the Network (Systemic Construct 3): Technology plays a simultaneous dual role within coopetition networks, acting as both an enabler (operand resource) and an initiator (operant resource). As an institutional enabler, technol-

ogy reshapes resource integration patterns, enhances innovative capacity, and effectively empowers actors to co-create value.

These systemic constructs give rise to specific Systemic Building Blocks essential for constructing effective coopetition networks.

Building Block 1—coopetition actors are the primary agents of value co-creation, including firms, customers, and other stakeholders. These actors navigate the dual roles of collaboration and competition within the ecosystem. Building Block 2—the collaborative effort among actors to combine diverse resources, capabilities, and competencies to enhance the network's collective value proposition. Building Block 3—the mechanism through which integrated resources are offered and utilized, enabling mutual benefits and value co-creation among network participants. Systemic Building Block 4—coopetition institutions and institutional arrangements are the rules, norms, and cultural–cognitive elements that guide coopetition actions and governance, ensuring alignment across the network. Systemic Building Block 5—the broader context within which resource integration and service exchange occur. Multiple, interlinked layers of coopetition and collaboration characterize these ecosystems.

The role of technology as both an enabler and initiator of coopetition is captured in two additional building blocks. Building Block 6—technology that acts as enablers of coopetition actions by providing tools and platforms for resource integration and service exchange. Building Block 7—technology that acts as initiators of coopetition actions, driving innovation and enabling strategic reconfigurations through advanced capabilities and insights.

Figure 1 illustrates the systemic structure of coopetition networks, emphasizing the role of technology-enabled collaboration in service ecosystems. It is divided into two interrelated levels: Coordination Level (mezzo-level): (1) coopetitors establish nested and interlocking service ecosystems to enhance collaboration; and (2) ecosystems are shaped by institutional arrangements, such as governance structures, shared norms, and mutual expectations. Operational Level (micro-level): (1) actors integrate resources for mutual benefit, optimizing efficiency and value creation, and (2) technology plays a pivotal role in facilitating service exchange and strengthening interactions within the ecosystem.

At their core, coopetition networks leverage technology within service ecosystems to drive value co-creation, balancing cooperation.

This framework provides a comprehensive approach to understanding and developing coopetition networks within service ecosystems by identifying and integrating the Systemic Building Blocks. It underscores the crucial role of institutions in shaping actor interactions, facilitating resource integration, and governing service exchanges. Additionally, it highlights technology as both an enabler and catalyst for coopetition, reinforcing the dynamic and interconnected nature of modern service ecosystems.

This approach offers theoretical and practical insights into the structural and operational dynamics of coopetition networks, positioning them as key drivers of value co-creation, innovation, and sustainable growth within complex business ecosystems.

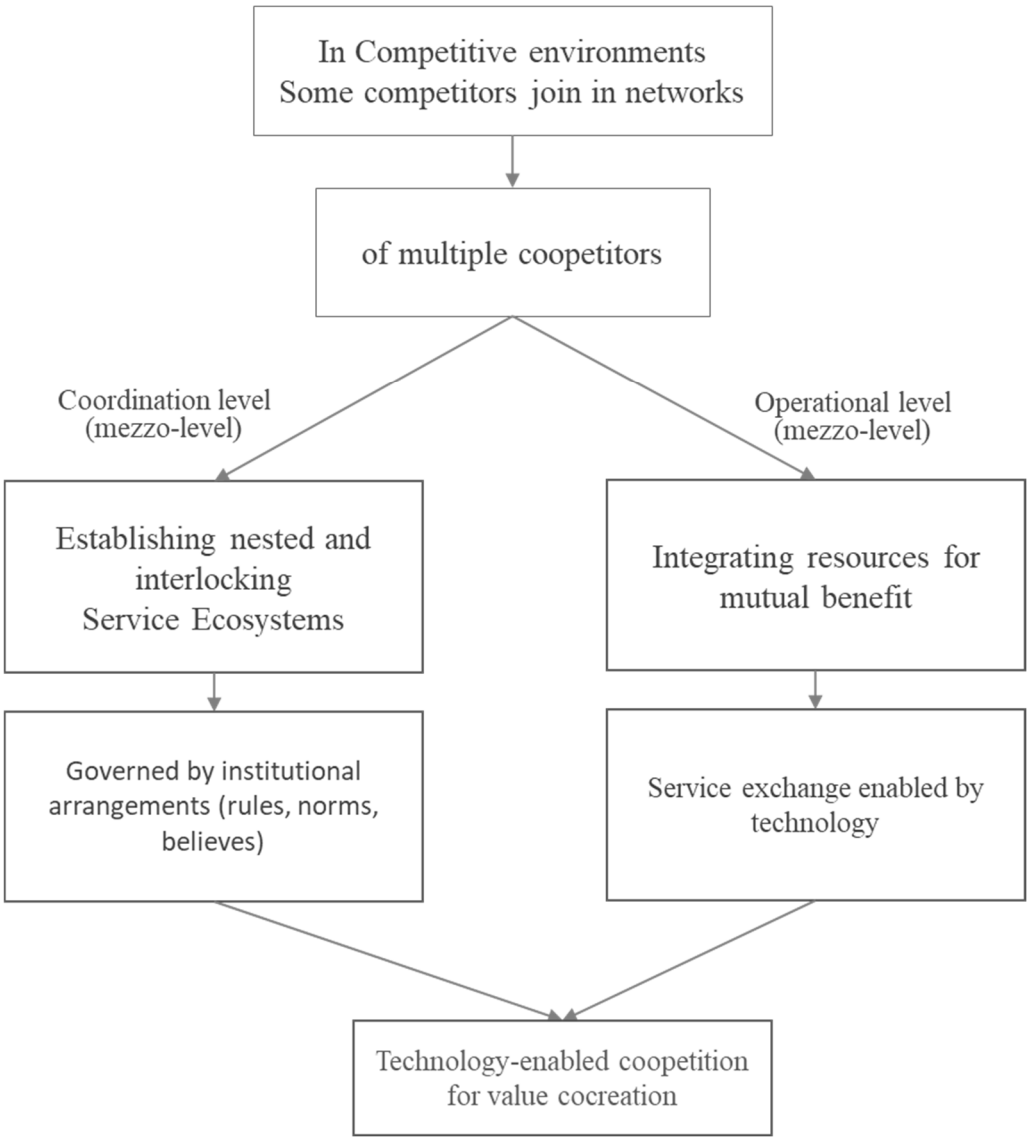


Figure 1. Systemic framework for technology-driven coopetition networks.

6. Implementing an Experimental, Technology-Driven Coopetition Network

This section details the application of the proposed framework to establish an experimental, technology-driven coopetition network within the Portuguese ornamental stone sector. The network integrates a select group of technologically advanced SMEs identified as key actors within the industry.

Institutional arrangements such as confidentiality agreements and standardized operational norms are implemented to facilitate effective collaboration. These governance mechanisms play a vital role in fostering trust, ensuring alignment of objectives, and maintaining consistency across participants. By establishing a foundation of mutual accountability, these measures support the integrity of the network while enabling efficient and seamless coordination among its members.

6.1. Experimental Design: Population and Sample

The Portuguese ornamental stone sector holds significant historical, cultural, and economic importance. Since the 15th century, Portuguese stone craftsmanship has contributed to iconic monuments worldwide [82]. Today, according to the Portuguese Stone Federation,

the sector ranks ninth globally in the International Stone Trade and second in per capita international trade, exporting to 116 countries. Predominantly composed of SMEs, the sector has demonstrated strong economic performance, with exports surpassing imports by 660%. In 2021 alone, the sector generated a turnover of EUR 1.23 billion, supporting over 16,600 direct jobs, particularly in inland regions [22].

To identify companies eligible for this study, specific criteria were established to ensure participation by technological leaders representing best practices in the sector. Companies had to meet the following requirements: (1) export finished products to at least two continents, (2) digitally integrate production shop-floor machinery with their ERP systems and Building Information Modeling (BIM) systems used by architects, and (3) employ more than 20 workers.

A total of 23 companies were identified as meeting these criteria, and invitations to participate were extended to all of them. However, only six companies agreed to participate in the experimental coopetition network due to concerns about costs and potential operational disruptions.

Although developing a new IoT system was outside the scope of this research, Cockpit4.0—a state-of-the-art platform for the ornamental stone sector [83]—was evaluated as a tool to transform operational technology and facilitate the experimental, technology-driven coopetition network. Some enhancements were made to the platform to maximize its potential for fostering collaboration. These enhancements included new functionalities to enable secure connections between competitor firms. The resulting advanced IoT-based system was specifically designed to connect rival ornamental stone companies, enhancing technological capabilities and fostering a collaborative industrial environment conducive to a coopetition network.

Figure 2 below illustrates the implementation of the experimental, technology-driven coopetition network.

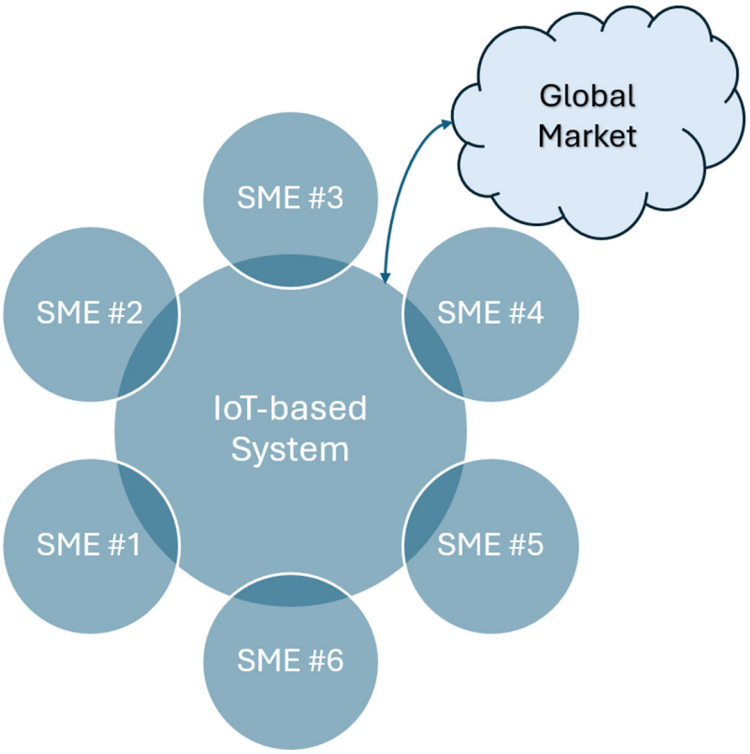


Figure 2. Implementation of the experimental technology-driven coopetition network.

The six SMEs were successfully integrated into the experimental coopetition network, facilitated by the IoT-based system. These firms demonstrated advanced technological capabilities, mainly by integrating their production machinery with BIM systems that architects use. This strategic integration enabled seamless information and resource sharing, allowing the firms to evaluate how technology-driven coopetition could enhance value co-creation collaboratively.

To address concerns about proprietary information, a comprehensive confidentiality agreement was established. This agreement safeguarded sensitive operational data, including customer details, employee information, resources, and competitive positioning. By ensuring the confidentiality of proprietary knowledge, all participating firms could collaborate effectively within the coopetition framework without compromising their competitive advantages.

6.2. Data Collection and Analysis

The data collection process was conducted over two consecutive 60-day periods to evaluate the impact of transitioning from conventional best practices (BP) to technology-driven coopetition network practices (CP). This structured approach enabled a comparative analysis of customer-perceived product quality (KPIQpP) under both operational models.

Phase 1: The first 60-day period, from April to June 2024, established a baseline customer feedback measurement under current best practices (BP) at the participating companies. During this phase, customers provided ratings based on their perceived product quality using a 1-5 Likert scale. This phase served as a reference point for assessing the subsequent effects of competition.

Phase 2: The second 60-day period was conducted from September to November 2024. During this phase, the six participating firms were integrated into the experimental technology-driven coopetition network, enabling real-time collaboration while maintaining competitive autonomy. Firms could exchange key operational data through the IoT-based system, enhancing efficiency, flexibility, and responsiveness in production and logistics. The IoT system provided real-time visibility into network-wide resource availability, allowing firms to optimize workflow and mitigate bottlenecks:

Shared Activities (Cooperation): (1) Raw Material Optimization—firms could access and share excess raw materials available in the network, reducing procurement delays and minimizing waste; (2) Production Capacity Coordination—companies could share machine availability, allowing them to outsource specific tasks within the network to meet deadlines and balance workloads; (3) Warehouse and Logistics Support—firms could utilize available warehouse space in partner facilities, improving inventory management and reducing storage inefficiencies.

Retained Competitive Activities: (1) Customer Ownership and Market Positioning—each company maintained exclusive relationships with its customers, ensuring brand differentiation and protecting market share; (2) Pricing and Sales Strategies—while firms collaborated operationally, pricing structures, sales tactics, and contract negotiations remained independent; and (3) Product Design and Customization—each firm retained complete control over the design, finishing, and customization of its products, maintaining its unique value proposition.

By leveraging this hybrid model of collaboration and competition, the coopetition network enabled firms to enhance operational efficiency while preserving strategic independence.

The customers provided feedback on the perceived product quality using the same Likert scale as in the baseline phase, allowing for a comparative analysis between the BP and CP models. The feedback was collected from customers interacting with the companies during the analyzed period. While some customers participated in both phases,

others did not. Additionally, all responses were anonymous, preventing the direct pairing of individual customer assessments over time. Table 3 summarizes the everyday data collected, on average, from the customers during the Phase 1 and Phase 2 periods.

Table 3. Customer-perceived product quality (KPIQpP) under best practices (BP) and coopetition practices (CP).

Day	KPIQpP (BP)	KPIQpP (CP)	Day	KPIQpP (BP)	KPIQpP (CP)	Day	KPIQpP (BP)	KPIQpP (CP)	Day	KPIQpP (BP)	KPIQpP (CP)
1	2.0	3.3	16	2.5	3.2	31	3.2	3.6	46	3.5	2.5
2	2.5	3.5	17	3.3	3.3	32	2.5	3.9	47	3.5	3.5
3	3.0	2.7	18	4.3	3.8	33	3.6	3.3	48	3.0	2.8
4	3.4	3.1	19	3.0	4.0	34	3.0	3.2	49	2.3	3.0
5	2.3	3.3	20	3.3	3.3	35	3.1	3.5	50	3.3	3.5
6	2.5	3.5	21	4.0	3.5	36	3.3	3.3	51	3.5	3.8
7	3.8	3.5	22	2.5	3.8	37	4.0	3.5	52	3.0	3.5
8	3.5	2.8	23	2.8	3.9	38	2.0	3.5	53	3.2	3.0
9	1.8	3.2	24	2.5	2.5	39	3.0	3.6	54	2.7	3.5
10	2.5	3.3	25	3.0	2.3	40	3.2	4.0	55	2.4	4.0
11	3.5	3.6	26	3.3	3.3	41	3.5	3.5	56	2.5	3.8
12	3.3	3.0	27	2.3	4.3	42	3.3	3.5	57	3.2	3.5
13	2.5	2.5	28	3.0	3.0	43	3.0	3.6	58	2.9	3.8
14	1.8	3.5	29	3.8	3.3	44	3.3	3.4	59	2.8	3.5
15	3.3	3.7	30	3.0	4.0	45	4.5	4.5	60	2.6	3.8

Strict data privacy and confidentiality agreements were enforced throughout the study to safeguard sensitive business information. Customer feedback and company-specific data were anonymized and referred to by company labels. This ensured a secure, ethical, and transparent approach to data management, maintaining integrity in the analysis. Table 4 summarizes the customer feedback ratings, including the average KPIQpP values, standard deviation, and value co-creation gain (VCG) during both periods.

Table 4. Summary of customer feedback ratings and value co-creation gain (VCG) assessment.

Feedback Ratings	KPIQpP (Average)	Standard Deviation	Feedbacks Received
Best Practices KPIQpP(BP)	3.01	0.57	351
Coopetition Practices KPIQpP(CP)	3.41	0.43	393
Value Co-creation Gain (VCG)	13.4%	24.3%	-

Increase in Average Product Quality—the average KPIQpP improved from 3.01 (BP) to 3.41 (CP), representing a 13.4% increase in the perceived product quality.

Enhanced Consistency in Quality Ratings—the standard deviation decreased from 0.57 to 0.43, indicating a 24.3% reduction in variability, reflecting greater product quality consistency.

Higher Customer Engagement—the number of feedback responses increased from 351 (BP) to 393 (CP), suggesting increased customer engagement during the coopetition phase.

The comparative analysis between BP and CP demonstrates that integrating a technology-driven coopetition network enhances the perceived product quality and reduces variability. The 13.4% improvement in KPIQpP, coupled with a 24.3% gain in consistency, highlights the effectiveness of coopetition networks in value co-creation within the Portuguese ornamental stone sector.

These findings support the hypothesis that transitioning to a technology-driven coopetition network significantly improves the customer-perceived quality, consistency, and overall value co-creation outcomes.

6.3. Results and Discussion

The feedback collected during both phases came from customers interacting with the companies in the respective periods. While some customers may have participated in both phases, others may not have, and all the responses were anonymous, preventing the direct pairing of customer assessments over time. This introduces a potential limitation in comparing individual perceptions but does not diminish the results' overall observed trends and statistical significance.

The experiment's results support the hypothesis that transitioning to a technology-driven coopetition network enhances the customer-perceived product quality, facilitating value co-creation. Figure 3 illustrates the daily average customer feedback trend recorded during the CP phase.

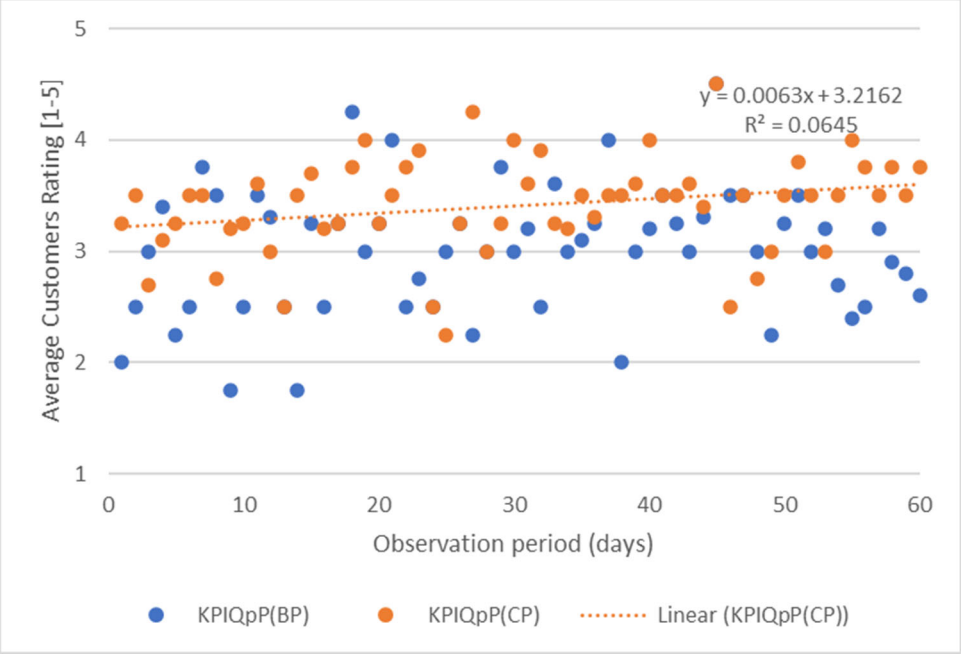


Figure 3. Daily average customer feedback evolution.

The positive slope of the trend line (0.0063) indicates a consistent upward trajectory in the perceived product quality under coopetition practices. While the immediate numerical increase in ratings may seem marginal, the sustained improvement trend suggests long-term operational and quality gains driven by technology-enabled coopetition.

An econometric analysis of the trend line further reveals an R^2 value of 0.0645, suggesting that while time contributes to KPIQpP improvements, other factors—such as resource sharing, technological integration, and enhanced operational coordination—also play a crucial role in driving performance gains.

The increase in customer responses during the CP phase suggests that the participating companies handled higher order volumes, likely indicating expanded production capacity. Importantly, this increase in production did not lead to a proportional rise in defects, underscoring the collective benefits of coopetition, such as optimized resource utilization, shared expertise, and improved operational efficiency.

A paired t-test was conducted to compare the mean KPIQpP ratings between BP and CP to validate the hypothesis statistically. The paired t-test results were as follows: (1) the

mean KPIQpP increased from 3.0067 (BP) to 3.4092 (CP), reflecting a 13.4% improvement in the perceived product quality; (2) the calculated t-statistic (-4.5099) exceeded the critical value (2.0010) for a two-tailed test at a 95% confidence level, confirming statistical significance; and (3) the p-value (3.14×10^{-5}) was significantly lower than the 0.05 threshold, providing strong evidence to reject the null hypothesis of no difference in perceived quality.

These results provide robust statistical confirmation that the technology-driven coopetition model significantly improves the perceived product quality.

The findings highlight several important takeaways: (1) Improved Perceived Product Quality—the 13.4% increase in KPIQpP validates the hypothesis that coopetition enhances customer satisfaction through better resource allocation and process optimization; (2) Greater Consistency in Quality Outcomes—the variance reduction (from 0.3309 to 0.1894) suggests improved coordination and more predictable quality levels, enhancing customer trust and reliability; and (3) Sustained Quality Gains Over Time—the positive trend line slope reinforces the idea that coopetition networks support continuous improvements, rather than just short-term gains.

These results underscore the value of technology-driven coopetition as a strategic tool for fostering operational synergies, leveraging shared resources, and enhancing collective capabilities. By allowing firms to distribute tasks based on expertise and capacity, coopetition networks enable companies to meet or exceed customer expectations more effectively, resulting in higher perceived product quality and sustained value co-creation.

7. Conclusions, Limitations, and Future Research Directions

The findings affirm that coopetition networks, facilitated by technological integration, significantly improve the customer-perceived quality. Notably, KPIQpP increased by 13.4%, rising from an average score of 3.01 under BP to 3.41 under CP. This improvement was accompanied by a reduction in variability, with the standard deviation decreasing from 0.57 to 0.43, reflecting greater consistency in quality delivery.

These results underscore the potential of coopetition frameworks to enable firms to leverage shared resources, distribute tasks more effectively, and consistently meet customer expectations. Furthermore, the positive trend observed over the experimental period suggests the potential for long-term quality improvements when companies adopt IoT-enabled coopetition frameworks.

This study highlights that the proposed framework—rooted in the S-D Logic perspective—offers a robust foundation for value co-creation. By fostering seamless resource integration and enhancing operational efficiency, technology-driven collaboration networks empower firms to deliver higher-quality products and promote sustainable value co-creation processes.

However, the study also reveals several risks and limitations that must be addressed. A key challenge is that many firms declined to participate in the experiment due to concerns over confidentiality breaches and the potential misuse of proprietary information. These concerns highlight the need for robust institutional safeguards, such as binding confidentiality agreements, to build trust and enable secure collaboration within coopetition frameworks. Another limitation is collecting customer feedback, which, although collected anonymously to ensure ethical data practices, made it impossible to track specific changes in individual customer perceptions over time. Consequently, the study could not provide insights into how individual customer experiences evolved across the experimental phases.

The small sample size also constrained the scope of the experiment, as only six firms from the Portuguese ornamental stone sector participated. This limited sample restricts the generalizability of the findings to other industries and contexts. Additionally, data collection was conducted over two 60-day intervals, offering insights into the short-term

effects of coopetition networks but leaving such frameworks' long-term dynamics and sustainability unexamined. Lastly, the study's focus on a single industry introduces another limitation, as the framework's applicability to sectors with varying technological capacities or operational challenges remains unexplored.

Building on the findings of this study, future research should address these limitations and further explore the potential of technology-driven coopetition networks. Expanding the scope and scale of the framework by testing it across multiple industries and regions with larger and more diverse sample sizes would help validate its generalizability and adaptability. Longitudinal studies would be particularly valuable in understanding the sustainability of coopetition networks and their long-term contributions to value co-creation. To address confidentiality concerns, future research could explore the development of more sophisticated data-sharing protocols and institutional safeguards, which would enhance trust and encourage broader participation. Integrating emerging technologies such as artificial intelligence (AI) and blockchain could improve resource transparency, operational integration, and customer-perceived quality.

Another important avenue for future research is to examine the influence of external factors, such as market conditions and resource variability, on the effectiveness of coopetition networks. This would provide a deeper understanding of how these frameworks adapt to dynamic environments. Future studies can refine and expand the proposed framework by addressing these areas, making it more robust and widely applicable. Ultimately, these efforts will unlock the full potential of technology-driven coopetition networks as a powerful mechanism for fostering value co-creation across diverse industries and market contexts.

Author Contributions: Conceptualization, A.d.S. and A.J.M.C.; methodology, A.d.S.; software, A.d.S.; validation, A.d.S. and A.J.M.C.; formal analysis, A.d.S.; investigation, A.d.S.; resources, A.d.S.; data curation, A.d.S.; writing—original draft preparation, A.d.S.; writing—review and editing, A.d.S.; visualization, A.d.S.; supervision, A.J.M.C.; project administration, A.d.S.; funding acquisition, A.d.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Hartmann, N.N.; Wieland, H.; Vargo, S.L. Converging on a New Theoretical Foundation for Selling. *J. Mark.* **2018**, *82*, 1–18. [CrossRef]
2. Meena, A.; Dhir, S.; Sushil, S. A review of coopetition and future research agenda. *J. Bus. Ind. Mark.* **2023**, *38*, 118–136. [CrossRef]
3. Da Silva, A.; Cardoso, A.J.M. Coopetition Networks for SMEs: A Lifecycle Model Grounded in Service-Dominant Logic. *Systems* **2024**, *12*, 461. [CrossRef]
4. Garay-Rondero, C.L.; Martinez-Flores, J.L.; Smith, N.R.; Morales, S.O.C.; Aldrette-Malacara, A. Digital supply chain model in Industry 4.0. *J. Manuf. Technol. Manag.* **2020**, *31*, 887–933. [CrossRef]
5. Corbo, L.; Kraus, S.; Vlačić, B.; Dabić, M.; Caputo, A.; Pellegrini, M.M. Coopetition and innovation: A review and research agenda. *Technovation* **2023**, *122*, 102624. [CrossRef]
6. Manzhynski, S.; Biedenbach, G. The knotted paradox of coopetition for sustainability: Investigating the interplay between core paradox properties. *Ind. Mark. Manag.* **2023**, *110*, 31–45. [CrossRef]
7. Reeves, M.; Lotan, H.; Legrand, J.; Jacobides, M.G. Chapter 3 How Business Ecosystems Rise (and Often Fall). In *Business Ecosystems*; De Gruyter: Berlin, Germany, 2022; pp. 27–34.

8. Gnyawali, D.R.; Ryan Charleton, T. Nuances in the Interplay of Competition and Cooperation: Towards a Theory of Coopetition. *J. Manag.* **2018**, *44*, 2511–2534. [CrossRef]
9. Bouncken, R.; Kumar, A.; Connell, J.; Bhattacharyya, A.; He, K. Coopetition for corporate responsibility and sustainability: Does it influence firm performance? *Int. J. Entrep. Behav. Res.* **2024**, *30*, 128–154. [CrossRef]
10. Xie, Q.; Gao, Y.; Xia, N.; Zhang, S.; Tao, G. Coopetition and organizational performance outcomes: A meta-analysis of the main and moderator effects. *J. Bus. Res.* **2023**, *154*, 113363. [CrossRef]
11. Chen, M.; Lv, C.; Wang, X.; Li, L.; Yang, P. A Critical Review of Studies on Coopetition in Educational Settings. *Sustainability* **2023**, *15*, 8370. [CrossRef]
12. Barge-Gil, A. Cooperation-based innovators and peripheral cooperators: An empirical analysis of their characteristics and behavior. *Technovation* **2010**, *30*, 195–206. [CrossRef]
13. de Mariz, F. *Finance with a Purpose*; WORLD SCIENTIFIC (EUROPE): London, UK, 2022; Volume 3.
14. Vargo, S.L.; Fehrer, J.A.; Wieland, H.; Nariswari, A. The nature and fundamental elements of digital service innovation. *J. Serv. Manag.* **2024**, *35*, 227–252. [CrossRef]
15. Wieland, H.; Hartmann, N.N.; Vargo, S.L. Business models as service strategy. *J. Acad. Mark. Sci.* **2017**, *45*, 925–943. [CrossRef]
16. Vargo, S.L.; Lusch, R.F. Evolving to a New Dominant Logic for Marketing. *J. Mark.* **2004**, *68*, 1–17. [CrossRef]
17. Elo, J.; Lumivalo, J.; Tuunanen, T.; Vargo, S.L. Enabling Value Co-Creation in Partner Collaboration Ecosystems: An Institutonal Work Perspective. In Proceedings of the 57th Annual Hawaii International Conference on System Sciences, Honolulu, HI, USA, 3–6 January 2024. Available online: https://www.sdlogic.net/pdf/post2018/24_0031.pdf (accessed on 2 October 2024).
18. Mustak, M.; Plé, L. A critical analysis of service ecosystems research: Rethinking its premises to move forward. *J. Serv. Mark.* **2020**, *34*, 399–413. [CrossRef]
19. Ho, M.H.-W.; Chung, H.F.; Kingshott, R.; Chiu, C.-C. Customer engagement, consumption and firm performance in a multi-actor service eco-system: The moderating role of resource integration. *J. Bus. Res.* **2020**, *121*, 557–566. [CrossRef]
20. Jaakkola, E.; Kaartemo, V.; Siltaloppi, J.; Vargo, S.L. Advancing service-dominant logic with systems thinking. *J. Bus. Res.* **2024**, *177*, 114592. [CrossRef]
21. Carvalho, J.M.F.; Lisboa, J.V. Ornamental stone potential areas for land use planning: A case study in a limestone massif from Portugal. *Environ. Earth Sci.* **2018**, *77*, 206. [CrossRef]
22. Silva, A.; Pata, A. Value Creation in Technology Service Ecosystems-Empirical Case Study. In *Innovations in Industrial Engeneering II*; Springer: Cham, Switzerland, 2022; pp. 26–36. [CrossRef]
23. Crick, J.M.; Crick, D. Coopetition and COVID-19: Collaborative business-to-business marketing strategies in a pandemic crisis. *Ind. Mark. Manag.* **2020**, *88*, 206–213. [CrossRef]
24. Dagnino, G.; Padula, G. Coopetition Strategy. Towards a New Kind of Interfirm Dynamics? In Proceedings of the EURAM—The European Academy of Management Second Annual Conference-"Innovative Research in Management", Stockholm, Sweden, 9–11 May 2002; pp. 9–11.
25. Bouncken, R.B.; Fredrich, V.; Ritala, P.; Kraus, S. Coopetition in New Product Development Alliances: Advantages and Tensions for Incremental and Radical Innovation. *Br. J. Manag.* **2018**, *29*, 391–410. [CrossRef]
26. Bicen, P.; Hunt, S.D.; Madhavaram, S. Coopetitive innovation alliance performance: Alliance competence, alliance's market orientation, and relational governance. *J. Bus. Res.* **2021**, *123*, 23–31. [CrossRef]
27. Bengtsson, M.; Kock, S.; Lundgren-Henriksson, E.-L.; Näsholm, M.H. Coopetition research in theory and practice: Growing new theoretical, empirical, and methodological domains. *Ind. Mark. Manag.* **2016**, *57*, 4–11. [CrossRef]
28. Mwesiumo, D.; Harun, M.; Hogset, H. Unravelling the black box between coopetition and firms' sustainability performance. *Ind. Mark. Manag.* **2023**, *114*, 110–124. [CrossRef]
29. Lascaux, A. Coopetition and trust: What we know, where to go next. *Ind. Mark. Manag.* **2020**, *84*, 2–18. [CrossRef]
30. Walley, K. Coopetition: An Introduction to the Subject and an Agenda for Research. *Int. Stud. Manag. Organ.* **2007**, *37*, 11–31. [CrossRef]
31. Rungtusanatham, M.; Salvador, F.; Forza, C.; Choi, T. Supply-chain linkages and operational performance. *Int. J. Oper. Prod. Manag.* **2003**, *23*, 1084–1099. [CrossRef]
32. Rusko, R. Exploring the concept of coopetition: A typology for the strategic moves of the Finnish forest industry. *Ind. Mark. Manag.* **2010**, *40*, 311–320. [CrossRef]
33. Bengtsson, M.; Kock, S. "Coopetition" in Business Networks—To Cooperate and Compete Simultaneously. *Ind. Mark. Manag.* **2000**, *29*, 411–426. [CrossRef]
34. Raza-Ullah, T.; Bengtsson, M.; Kock, S. The coopetition paradox and tension in coopetition at multiple levels. *Ind. Mark. Manag.* **2014**, *43*, 189–198. [CrossRef]
35. Eriksson, P.E. Achieving Suitable Coopetition in Buyer–Supplier Relationships: The Case of AstraZeneca. *J. Bus. Bus. Mark.* **2008**, *15*, 425–454. [CrossRef]

36. Crick, J.M. The dark side of coopetition: When collaborating with competitors is harmful for company performance. *J. Bus. Ind. Mark.* **2019**, *35*, 318–337. [CrossRef]
37. Lusch, R.F.; Nambisan, S. University of Wisconsin–Milwaukee Service Innovation: A Service-Dominant Logic Perspective. *MIS Q.* **2015**, *39*, 155–175. [CrossRef]
38. Kleinaltenkamp, M.J.; O Karpen, I. Resource entanglement and indeterminacy: Advancing the service-dominant logic through the philosophy of Karen Barad. *Mark. Theory* **2023**, *24*, 611–641. [CrossRef]
39. Matthies, B.D.; D'Amato, D.; Berghäll, S.; Ekholm, T.; Hoen, H.F.; Holopainen, J.; Korhonen, J.E.; Lähtinen, K.; Mattila, O.; Toppinen, A.; et al. An ecosystem service-dominant logic?—integrating the ecosystem service approach and the service-dominant logic. *J. Clean. Prod.* **2016**, *124*, 51–64. [CrossRef]
40. Klimas, P.; Ahmadian, A.A.; Soltani, M.; Shahbazi, M.; Hamidizadeh, A. Coopetition, Where Do You Come From? Identification, Categorization, and Configuration of Theoretical Roots of Coopetition. *SAGE Open* **2023**, *13*, 215824402210850. [CrossRef]
41. Autio, E.; Thomas, L.D.W. Innovation Ecosystems: Implications for Innovation Management. Oxford University Press: Oxford, UK, 2014.
42. Antai, I. A theory of the competing supply chain: Alternatives for development. *Int. Bus. Res.* **2010**, *4*, 74. [CrossRef]
43. Akaka, M.A.; Vargo, S.L.; Schau, H.J. The context of experience. *J. Serv. Manag.* **2015**, *26*, 206–223. [CrossRef]
44. Vargo, S.L.; Akaka, M.A.; Vaughan, C.M. Conceptualizing Value: A Service-ecosystem View. *J. Creat. Value* **2017**, *3*, 117–124. [CrossRef]
45. Vargo, S.L.; Lusch, R.F. The Four Service Marketing Myths: Remnants of a Goods-Based, Manufacturing Model. *J. Serv. Res.* **2004**, *6*, 324–335. [CrossRef]
46. Ganz, W.; Satzeger, G.; Schultz, C. *Methods in Service Innovation: Current Trends and Future Perspectives*; Fraunhofer: Magdeburg, Germany, 2012; Available online: https://www.ksri.kit.edu/downloads/Ganz_Satzger_Schultz_2012_Methods_in_Service_Innovation.pdf (accessed on 11 October 2024).
47. Lusch, R.F.; Vargo, S.L.; Gustafsson, A. Fostering a trans-disciplinary perspectives of service ecosystems. *J. Bus. Res.* **2016**, *69*, 2957–2963. [CrossRef]
48. Hoffman, D.L.; Novak, T.P. Consumer and Object Experience in the Internet of Things: An Assemblage Theory Approach. *J. Consum. Res.* **2017**, *44*, 1178–1204. [CrossRef]
49. Normann, R.; Ramírez, R. From value chain to value constellation: Designing interactive strategy. *Harv. Bus. Rev.* **1993**, *71*, 65–77. Available online: http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=9309166477&site=eds-live (accessed on 10 October 2024). [PubMed]
50. Vargo, S.L.; Lusch, R.F. Inversions of service-dominant logic. *Mark. Theory* **2014**, *14*, 239–248. [CrossRef]
51. Borgatti, S.P.; Mehra, A.; Brass, D.J.; Labianca, G.; Granovetter, M. The Myth of Social Network Analysis as a Special Metyhod on the Social Sciences. *Science* **1990**, *323*, 892–896. [CrossRef]
52. Amit, R.; Zott, C. Value creation in E-business. *Strat. Manag. J.* **2001**, *22*, 493–520. [CrossRef]
53. Mariotti, J.L. The Value Network. *Exec. Excell.* **2002**, *19*, 18. [CrossRef]
54. Breidbach, C.F.; Maglio, P.P. Technology-enabled value co-creation: An empirical analysis of actors, resources, and practices. *Ind. Mark. Manag.* **2016**, *56*, 73–85. [CrossRef]
55. Vargo, S.L.; Peters, L.; Kjellberg, H.; Koskela-Huotari, K.; Nenonen, S.; Polese, F.; Sarno, D.; Vaughan, C. Emergence in marketing: An institutional and ecosystem framework. *J. Acad. Mark. Sci.* **2023**, *51*, 2–22. [CrossRef]
56. Vargo, S.L.; Wieland, H.; O'Brien, M. Service-dominant logic as a unifying theoretical framework for the re-institutionalization of the marketing discipline. *J. Bus. Res.* **2023**, *164*, 113965. [CrossRef]
57. Arthur, W.B. *The Nature of Technology*; Penguin Books Ltd.; Registered Offices: London, UK, 2009.
58. Vargo, S.L.; Lusch, R.F. Service-dominant logic 2025. *Int. J. Res. Mark.* **2017**, *34*, 46–67. [CrossRef]
59. Jaakkola, E. Designing conceptual articles: Four approaches. *AMS Rev.* **2020**, *10*, 18–26. [CrossRef]
60. Jelinek, H.F.; Jones, C.L.; Warfel, M.D.; Lucas, C.; Depardieu, C.; Aurel, G. Understanding Fractal Analysis? The Case of Fractal Linguistics. *Complexus* **2006**, *3*, 66–73. [CrossRef]
61. Meissner, H.; Creswell, J.; Klassen, A.C.; Plano, V.; Smith, K.C. Best Practices for Mixed Methods Research in the Health Sciences. *Off. Behav. Soc. Sci. Res.* **2011**, *29*, 1–39. [CrossRef]
62. Bacon, E.; Williams, M.D.; Davies, G. Coopetition in innovation ecosystems: A comparative analysis of knowledge transfer configurations. *J. Bus. Res.* **2020**, *115*, 307–316. [CrossRef]
63. Koenig, G. Business ecosystems revisited. *Management* **2012**, *15*, 208–224.
64. Park, B.J.R.; Srivastava, M.K.; Gnyawali, D.R. Walking the tight rope of coopetition: Impact of competition and cooperation intensities and balance on firm innovation performance. *Ind. Mark. Manag.* **2014**, *43*, 210–221. [CrossRef]
65. Tsiotsou, R.H. A service ecosystem experience-based framework for sport marketing. *Serv. Ind. J.* **2016**, *36*, 478–509. [CrossRef]
66. Imschloss, M.; Schwemmle, M. Value creation in post-pandemic retailing: A conceptual framework and implications. *J. Bus. Econ.* **2023**, *94*, 851–889. [CrossRef]

67. Ruokolainen, T.; Ruohomaa, S.; Kutvonen, L. Solving Service Ecosystem Governance. In Proceedings of the 2011 15th IEEE International Enterprise Distributed Object Computing Conference Workshops (EDOCW), Helsinki, Finland, 29 August–2 September 2011; pp. 18–25.
68. Vargo, S.L.; Lusch, R.F. It's all B2B. . .and beyond: Toward a systems perspective of the market. *Ind. Mark. Manag.* **2011**, *40*, 181–187. [CrossRef]
69. Lusch, R.; Vargo, S. Service Ecosystems. In *Service-Dominant Logic*; Cambridge University Press: Cambridge, UK, 2014; pp. 158–176.
70. Scott, W. *Institutions and Organizations*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2001.
71. Koskela-Huotari, K.; Vargo, S.L. Institutions as resource context. *J. Serv. Theory Pract.* **2016**, *26*, 163–178. [CrossRef]
72. Siltaloppi, J.; Koskela-Huotari, K.; Vargo, S.L. Institutional Complexity as a Driver for Innovation in Service Ecosystems. *Serv. Sci.* **2016**, *8*, 333–343. [CrossRef]
73. Bengtsson, M.; Kock, S. Coopetition—Quo vadis? Past accomplishments and future challenges. *Ind. Mark. Manag.* **2014**, *43*, 180–188. [CrossRef]
74. Álvarez Gil, M.J.; Berrone, P.; Husillos, F.J.; Lado, N. The Explanatory Power of Trust and Commitment and Stakeholders' Salience: Their Influence on The Reverse Logistics Programs Performance. *Nº. Work. Paper. Bussiness Econ.* **2005**.
75. Luo, Y. A coopetition perspective of MNC–host government relations. *J. Int. Manag.* **2004**, *10*, 431–451. [CrossRef]
76. Akaka, M.A.; Vargo, S.L. Extending the context of service: From encounters to ecosystems. *J. Serv. Mark.* **2015**, *29*, 453–462. [CrossRef]
77. Barile, S.; Lusch, R.; Reynoso, J.; Saviano, M.; Spohrer, J. Systems, networks, and ecosystems in service research. *J. Serv. Manag.* **2016**, *27*, 652–674. [CrossRef]
78. Rindfleisch, A.; Moorman, C. Interfirm Cooperation and Customer Orientation. *J. Mark. Res.* **2003**, *40*, 421–436. [CrossRef]
79. Vargo, S.L.; Lusch, R.F. Institutions and axioms: An extension and update of service-dominant logic. *J. Acad. Mark. Sci.* **2016**, *44*, 5–23. [CrossRef]
80. Scott, W. *Institutions and Organizations-Ideas, Interests, and Identities*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2013.
81. Lawrence, T.; Suddaby, R. Institutions and Institutional Work. In *The SAGE Handbook of Organization Studies: Chapter 6*; SAGE Publications: Thousand Oaks, CA, USA, 2006.
82. Carvalho, J.; Lopes, C.; Mateus, A.; Martins, L.; Goulão, M. Planning the future exploitation of ornamental stones in Portugal using a weighed multi-dimensional approach. *Resour. Policy* **2018**, *59*, 298–317. [CrossRef]
83. da Silva, A.; Dionisio, A.; Almeida, I. Enabling Cyber-Physical Systems for Industry 4.0 operations: A Service Science Perspective. *Int. J. Innov. Technol. Explor. Eng.* **2020**, *9*, 838–846. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

Journal of
Theoretical and Applied Electronic Commerce Research

MDPI

Article

Enhancing Building Information Modeling Effectiveness Through Coopetition and the Industrial Internet of Things

Agostinho da Silva [1,2,*] and Antonio J. Marques Cardoso [1]

[1] CISE—Electromechatronic Systems Research Centre, University of Beira Interior, 6201-001 Covilhã, Portugal; ajmcardoso@ieee.org
[2] CIGEST—Centre for Research in Management, Lisbon Business School, 1000-002 Lisboa, Portugal
* Correspondence: a.silva@zipor.com

Abstract: The construction industry plays a crucial role in the global economy but faces significant challenges, including inefficiencies, high costs, and environmental impacts. Although Building Information Modeling (BIM) has been widely adopted as a solution to these issues, its practical impact remains limited. This study investigates how manufacturers can enhance their contributions to improve BIM's effectiveness, proposing that coopetition practices—combining competition and cooperation—can positively influence these contributions, thereby enhancing the benefits of BIM. To explore this hypothesis, an Experimental Coopetition Network was implemented in the Portuguese ornamental stone (POS) sector, utilizing Industrial IoT technology to facilitate collaboration among selected companies. The study assessed the impact of coopetition practices on key performance indicators related to BIM, including on-time delivery, labor productivity, and CO_2 emissions. The findings demonstrate significant improvements in scheduling, operational efficiency, and environmental sustainability, validating the hypothesis that coopetition practices can enhance manufacturers' contributions to BIM. These results suggest that coopetition practices contribute to better project outcomes, increased competitiveness, and sustainability within the construction industry. Despite the promising results, the study acknowledges limitations such as the scope of the sample size and observation periods, indicating areas for future research. This research contributes to the theoretical framework of coopetition, aligning with the United Nations Sustainable Development Goals (SDGs), and provides valuable insights for industry practitioners and policymakers seeking to implement more sustainable construction practices.

Keywords: coopetition; construction industry; BIM; sustainable development goals

check for updates

Citation: da Silva, A.; Marques Cardoso, A.J. Enhancing Building Information Modeling Effectiveness Through Coopetition and the Industrial Internet of Things. *J. Theor. Appl. Electron. Commer. Res.* **2024**, *19*, 3137–3153. https://doi.org/10.3390/jtaer19040152

Academic Editor: Zorica Bogdanović

Received: 1 October 2024
Revised: 8 November 2024
Accepted: 12 November 2024
Published: 15 November 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The construction industry is a cornerstone of the global economy, with growth projected to exceed USD 4.2 trillion over the next 15 years [1]. However, the United Nations Environment Programme (2023) identifies the sector as a significant contributor to global greenhouse gas emissions, accounting for 37% of the total amount. The substantial carbon footprint associated with producing and using materials such as cement, steel, and aluminum underscores the urgent need for innovative cooperation models in building and construction [2].

Despite its critical role, the industry continues to grapple with persistent challenges, including inefficiencies, high costs, extended project timelines, and considerable environmental impacts [3]. In response, governments and researchers have advocated for the adoption of Building Information Modeling (BIM) [4], a technology designed to enhance efficiency and sustainability in construction through comprehensive digital representations of physical and functional characteristics [5].

This situation explains the significant attention given over the past decade by governments and academics to the widespread adoption of BIM on a global scale [6]. BIM is

seen as the technology capable of transforming the current construction paradigm, which is not only unsustainable but also needs more transparency, generates substantial waste, and consequently remains inaccessible to many families [4].

However, despite the increased focus on BIM and its numerous advantages, its practical impact has remained limited [7]. Moreover, while BIM has been extensively promoted and adopted, a critical gap persists in understanding how manufacturers can fully capitalize on its benefits [8]. Each project component influences BIM's various dimensions differently, meaning the effectiveness of BIM depends on how well each component aligns with these dimensional requirements [9]. To unlock BIM's full potential, fabricators must effectively address these dimensions [10].

Given these challenges, a critical question arises: How can manufacturers enhance their contributions to improve BIM's effectiveness in the construction industry? A promising strategy to address this challenge lies in coopetition [11], which blends elements of competition and cooperation to achieve mutual benefits [12]. The hypothesis suggests that coopetition practices can positively influence manufacturers' contributions, enhancing BIM's benefits.

To test this hypothesis, this study explores the potential of coopetition practices to meet BIM requirements through a case study in the Portuguese ornamental stone (POS) sector. This investigation involves an Experimental Coopetition Network facilitated by Industrial Internet of Things (Industrial IoT) technology, encompassing selected companies within the POS sector. The study aims to assess the tangible benefits of coopetition practices across various indicators related to BIM dimensions that can enhance BIM's effectiveness. The findings are expected to offer valuable insights into the role of manufacturers in BIM-enhanced construction projects and the potential of coopetition to reduce costs, time, and carbon emissions.

To address these industry-wide challenges, BIM has been identified as a crucial tool in reshaping construction practices. BIM not only offers a pathway to enhanced efficiency and sustainability but also provides a framework for overcoming the sector's most persistent obstacles. By fostering transparency and streamlining processes, BIM holds the potential to redefine project management and collaboration across the industry. The following section explores BIM's role as a transformative catalyst in the construction industry, outlining its dimensions and applications that support a more efficient, cost-effective, and sustainable approach to construction.

2. BIM as a Catalyst for an Efficient Construction Industry

Traditional management practices in the construction industry have long been criticized for generating unnecessary waste [9], leading to high costs, extended project timelines, and considerable ecological impacts [13]. In response, governments and industry professionals have advocated for the gradual adoption of BIM to enhance transparency and efficiency [6].

BIM has emerged as a natural successor to Computer-Aided Design (CAD) in the construction sector [14]. Propelled by government mandates, the construction industry increasingly integrates BIM into its operations, driven by objectives to reduce costs, shorten project durations, and align with sustainability goals [15]. This integration marks a substantial shift towards more responsible and efficient design and construction practices [16].

BIM represents a fundamental shift in conceptualizing, executing, and managing construction projects in this context. At its core, BIM provides a digital twin of the physical construction [17], capturing every detail in a digital model that accurately reflects the physical reality [18]. However, this has led to some confusion within the industry regarding the distinction between BIM maturity levels and dimensions [16]. BIM maturity refers to the sophistication of information exchange within the supply chain, highlighting the collaborative capabilities of the involved parties [19]. In contrast, BIM dimensions refer to the various data types linked to a model, offering more profound insights into the project's lifecycle [20].

Incorporating data dimensions within a BIM allows for an unparalleled understanding of the construction process [21]. Designers and stakeholders can gain a comprehensive view of the project, which encompasses the initial design, work stages, and delivery methods for each component and both the budgeting and maintenance plans. These dimensions promote a more refined approach to project management [22].

While the first three dimensions (BIM.3D) pertain to the solid geometry of objects, the fourth dimension (BIM.4D) introduces the crucial element of time, marking a significant advancement in project management and coordination within the construction industry [4]. By integrating project timelines directly into digital models, BIM.4D offers a dynamic and interactive method for planning, enabling the real-time visualization of construction sequences [14].

The fifth dimension (BIM.5D) addresses cost management within construction projects by linking financial data with each component in the digital model [5]. This comprehensive approach transforms budgeting into a dynamic, detail-oriented process [23], allowing for immediate visibility and continuous updates on the financial implications of design decisions and manufacturing changes throughout the project [24].

The sixth dimension (BIM.6D) is centered on sustainability, incorporating environmental metrics directly into the building information model [25]. This dimension provides real-time insights into the ecological footprint of materials and processes throughout a project's lifecycle, empowering professionals to make decisions that support sustainability objectives [15].

Beyond these dimensions, BIM also encompasses maintenance and construction safety, offering a holistic perspective from project inception to demolition [10]. However, fabricators must effectively engage with and contribute to BIM dimensions to fully realize BIM's potential.

In parallel with the transformative role of BIM in enhancing construction efficiency and sustainability, the strategic concept of "coopetition" has gained prominence as a potential enabler of BIM's full benefits. By blending cooperation and competition, coopetition offers a unique approach to help industry stakeholders overcome competitive barriers while driving collective value creation. The following section provides a comprehensive review of the coopetition literature, exploring its evolution, definitions, and theoretical underpinnings, which form the basis for understanding how coopetition practices might be leveraged to enhance BIM's impact in the construction sector.

3. Literature Review

The concept of "coopetition" gained significant traction in business strategy through the seminal work of Nalebuff and Brandenburger (1997), marking a crucial shift in the understanding of competitive dynamics [26]. Over time, coopetition has attracted considerable attention in strategic management, evolving through various interpretations and applications [27].

Despite its widespread discussion, the definition of coopetition remains diverse, with interpretations varying across different goals, relationships, and organizational contexts [28]. It has been described as a strategy that simultaneously pursues cooperation and competition among firms [29], a hybrid activity within the same business entities [30], and a complex interplay that influences competitive dynamics among different market participants [12].

At the intersection of coopetition and networks, a strategic orientation focused on innovation emerges, which is crucial for firms aiming to close competitive gaps and effectively manage market challenges [31]. This orientation underscores the role of coopetition in navigating competitive landscapes and highlights its potential as a catalyst for transformative growth and resilience [32]. Various studies present a broad spectrum of findings, emphasizing the need for a more unified and thorough exploration of value co-creation processes within these complex networks [33].

A comprehensive review by Meena, Dhir, and Sushil (2023) reveals that coopetition has been analyzed through various theoretical lenses, including Game Theory, the Resource-Based View, Paradox Theory, Transaction Cost Theory, and Network Theory [31]. While each perspective offers valuable insights, they often address the concept within specific boundaries. Despite the diversity in definitions, the essence of coopetition converges on a hybrid relationship where competition and collaboration intertwine to benefit the participating companies [34]. This concept is particularly relevant in digital supply chains [32].

The hypothesis that coopetition practices can positively influence construction manufacturers' contributions in enhancing BIM benefits arose from viewing coopetition practices as strategic paradigms that leverage dual simultaneous forces to drive innovation, enhance competitive advantage, and achieve collective success. To test this hypothesis, the study explores the potential of coopetition practices to meet BIM's requirements through a case study in the POS industry involving an Experimental Coopetition Network facilitated by an Industrial IoT system encompassing selected enterprises within the POS sector.

Based on the literature review and theoretical foundations, this study aims to address the following research question:

- Research Question: How can coopetition practices enhance manufacturers' contributions to improve the effectiveness of Building Information Modeling (BIM) in the construction industry?

  To answer this question, the following hypotheses are proposed:

Hypothesis 1 (H1): *Coopetition practices positively influence manufacturers' on-time delivery performance, thereby improving the BIM 4D (time management) dimension in construction projects.*

Hypothesis 2 (H2): *Coopetition practices enhance labor productivity among manufacturers, contributing to cost savings and optimizing the BIM 5D (cost management) dimension.*

Hypothesis 3 (H3): *Coopetition practices reduce CO_2 emissions associated with manufacturing processes, supporting the BIM 6D (sustainability) dimension and promoting environmental sustainability in construction.*

These hypotheses will be tested using a case study in the Portuguese ornamental stone sector, employing an Experimental Coopetition Network facilitated by Industrial IoT technology to gather data on the impact of coopetition on key BIM dimensions.

The following section details the structured methodology used to implement an Experimental Coopetition Network, outlining the participant selection, technology integration, and data collection processes that provide insights into how coopetition practices might enhance manufacturers' contributions to BIM effectiveness.

4. Methodology

The case study approach was selected to explore the impact of coopetition practices on BIM effectiveness in the Portuguese ornamental stone sector. This method provides a structured framework for analyzing events, collecting data, and reporting results, allowing for an in-depth understanding of the phenomenon within its context (Hsu, 2016; [35,36].

To test the hypothesis that coopetition practices can enhance manufacturers' contributions to BIM, an Experimental Coopetition Network was implemented. The methodology involves the following structured steps, as illustrated in Table 1.

Table 1. Research procedure for implementing the Experimental Coopetition Network.

Step	Description
Step 1: Identification and Selection of Companies	Identify and select stone companies that meet participation criteria, including technological capability, willingness to collaborate, and relevance to the construction industry.
Step 2: Technology Integration	Establish the necessary technology to connect selected companies within the Experimental Coopetition Network. Set up and ensure real-time data collection and analysis capabilities.
Step 3: Definition of Metrics and KPIs	Define metrics and KPIs for evaluating coopetition practices, focusing on BIM dimensions: time efficiency (BIM 4D), cost-effectiveness (BIM 5D), and carbon reduction (BIM 6D).
Step 4: Data Collection and Analysis	Collect data on the defined KPIs through the Experimental Coopetition Network, monitoring the network's performance in real-time. Analyze the data to evaluate improvements.
Step 5: Hypothesis Testing	Assess whether the data support the hypothesis that coopetition practices enhance BIM benefits.

1. Identification and Selection of Companies: Stone companies were identified based on specific criteria essential for participation, including their technological readiness, openness to coopetition, and strategic relevance to the construction industry. This step was crucial in ensuring that selected companies could meaningfully contribute to and benefit from the Experimental Coopetition Network.
2. Technology Integration: The selected companies were integrated into the Experimental Coopetition Network, with technology set up to facilitate real-time data sharing and analysis. The network utilized Industrial IoT systems to connect participants, ensuring seamless communication and data flow necessary for BIM collaboration.
3. Definition of Metrics and KPIs: To evaluate the impact of coopetition practices on BIM, key performance indicators (KPIs) were defined across three BIM dimensions:
    - BIM 4D (Time Efficiency): Assessed through on-time delivery rates.
    - BIM 5D (Cost-Effectiveness): Measured through labor productivity indicators.
    - BIM 6D (Sustainability): Evaluated by calculating carbon emissions per unit produced.
4. Data Collection and Analysis: Data were collected on the defined KPIs, with real-time monitoring being used to capture the performance of each company under coopetition practices. The collected data were analyzed to gauge improvements in BIM dimensions and to generate insights into how coopetition practices influence project outcomes.
5. Hypothesis Testing: Based on the insights derived from the collected data, hypothesis testing was conducted to assess whether coopetition practices positively impact BIM benefits. This step involved a statistical analysis to determine the validity of the hypotheses proposed.

This structured methodology provides a systematic approach to assessing the role of coopetition practices in enhancing BIM effectiveness within the Portuguese ornamental stone sector. By clearly outlining the research procedure, this framework allows for replicability and offers a foundation for future studies to expand on these findings in other sectors.

4.1. Selecting Participants

The Portuguese ornamental stone sector, deeply rooted in the nation's cultural heritage, has been a cornerstone of architectural and construction achievements worldwide since the 15th century [37]. Renowned for its high-quality stone and engineering expertise, the sector embodies generations of accumulated knowledge and craftsmanship, making it an integral part of Portugal's identity [38]. As the global market continues to evolve, Portugal has firmly established itself as a leading producer of stone products [39], seamlessly integrating into the international construction industry. This success highlights the sector's competitive edge despite the country's modest geographic size [11].

With a diverse array of companies, the Portuguese ornamental stone sector offers a broad spectrum of operational environments. This diversity makes it an ideal population for testing the hypothesis that coopetition practices can positively influence manufacturers' contributions to improve BIM's effectiveness in the construction industry. The sector's established global presence—exporting to 116 countries and holding a significant position in the world stone trade—underscores its relevance to the study. According to the Portuguese Stone Federation (2022), the ornamental stone sector not only ranks as the ninth-most significant player in the World International Stone Trade, but it also secures the second position globally in terms of international trade per capita [40]. The industry's substantial turnover of EUR 1.230 million and its support of over 16,600 direct jobs further emphasize its economic importance [41].

The sector's mix of tradition and modernity and its readiness to engage in digital transformation make it an exemplary case for testing the hypothesis. The selection of participants for the Experimental Coopetition Network is based on criteria such as technological capability, openness to collaboration, and strategic importance within the industry. This approach ensures that the study captures a representative sample of the sector, providing valuable insights into the broader applicability of coopetition practices in enhancing BIM benefits.

Recognizing these characteristics in the Portuguese ornamental stone sector, the first step involved establishing direct and informal communication channels with the managing directors of potential participant companies, a process that uncovered three significant operational challenges:

Technological Capability: The first challenge was the limited number of companies with production systems capable of real-time connectivity to meet BIM procurement requirements. Given that BIM demands high levels of precision and interoperability, only a subset of 43 companies out of the 661 in the sector were found to have the necessary digital infrastructure. After in-person evaluations of these 43 companies, 23 were pre-selected based on their ability to integrate with an Industrial IoT platform.

Logistical Complexity and Costs: The second challenge involved the logistical complexities and costs of implementing the Experimental Coopetition Network and operationalizing data collection. The experimental nature of the project, combined with budget constraints, required careful planning to ensure its viability. Given the budget limitations, the number of participating companies had to be reduced to a minimum to manage costs effectively and create a controlled environment for testing the feasibility of BIM integration. The data collection period was also limited to two months to ensure the project remained within budget while providing meaningful insights.

Data Sharing Reluctance: The third and perhaps most critical challenge was the reluctance of companies to share sensitive data, a common issue in industries where proprietary knowledge is a critical competitive asset. In the context of BIM, where the success of a project relies on transparent and accurate data exchange, this reluctance posed a significant barrier. To overcome this, a comprehensive confidentiality agreement was developed to reassure participating companies that their competitive positions would not be compromised by their involvement in the network. This agreement covered all aspects of operations, including clientele, employee information, resources, and competitive strategies.

As a result of these strategic considerations, three ornamental stone companies formally committed to participating in the study, with confidentiality agreements signed to protect their interests. To maintain the integrity of the research and safeguard the identities of the companies involved, they are referred to anonymously as "POS.1", "POS.2", and "POS.3".

This Experimental Coopetition Network functioned as a laboratory for collecting data on independent variables to explore the benefits of coopetition practices, treated as dependent variables, in testing the hypothesis that coopetition practices can positively influence manufacturers' contributions and enhance the benefits of BIM. By fostering a

coopetition environment, these selected companies could improve their ability to meet BIM requirements more effectively.

With complete participant selection and confidentiality agreements in place, the study established the Experimental Coopetition Network. This network aimed to leverage advanced Industrial IoT technology, creating a collaborative environment where participating companies could integrate their operations seamlessly. The following section describes the implementation process of this network, focusing on the technological infrastructure, including Cockpit4.0+, and the steps taken to enable secure, real-time data exchange between firms to support BIM applications.

4.2. Implementation of the Experimental Coopetition Network

The advent of the IoT marks a transformative era, significantly impacting industries through advanced sensor technologies that enhance connectivity and data exchange [42]. Building on traditional IoT frameworks, the Industrial IoT introduces intelligence into industrial environments, enabling direct device-to-device communication and creating intelligent systems that dynamically adapt to user interactions, enhancing value co-creation [43]. Empirical studies highlight the transformative potential of Industrial IoT-based innovations, particularly in offering new services such as remote control and predictive maintenance [44]. These capabilities improve operational efficiency and open new avenues for value co-creation within coopetition frameworks, expanding service portfolios and enhancing enterprises' competitive and cooperative capacities [45].

In the Portuguese ornamental stone sector, for instance, an illustrative example of the Industrial IoT is the development of Cockpit4.0 [46], designed to connect stone companies with the digital marketplace [47]. This artifact refines product specifications and fosters collaborative interactions among machines, providers, and customers, ultimately enhancing customization and operational efficiency [48]. The current state of Cockpit4.0 exemplifies Industrial IoT's capacity to reshape market dynamics through direct engagement and cooperative efforts.

Although Industrial IoT development was not the primary focus of this research, Cockpit4.0, representing the state-of-the-art in the Ornamental Stone sector [48], was identified as a foundational platform for transforming operational technology within the Experimental Coopetition Network. To fully leverage its potential, Cockpit4.0 was enhanced with new functionalities, such as secure connections between competing firms, leading to an advanced version called Cockpit4.0+ for this research. This upgraded Industrial IoT system, specifically designed to connect ornamental stone companies, brought enhanced technological capabilities and fostered a collaborative industrial environment conducive to a real Experimental Coopetition Network.

A key component of Cockpit4.0+ is the integration of Open Platform Communications Unified Architecture (OPC-UA), a cross-platform, open-source standard (IEC62541) for data exchange from sensors to cloud applications, developed by the OPC Foundation [49]. OPC-UA enables secure and efficient data exchange, facilitating seamless connectivity between factory floor equipment and control systems, even across different communication protocols.

By embedding OPC-UA protocols, Cockpit4.0+ addresses gaps in connectivity, efficiency, and responsiveness, creating a network where companies can thrive through collective innovation and adaptive strategies. Integrating technological innovations, such as artificial intelligence, further promotes a collaborative industrial environment, ensuring sustainable operations and competitiveness among participating companies.

Once Cockpit4.0+ was finalized, even in its prototype form, the implementation of the Experimental Coopetition Network began. Three POSs companies were formally connected (Figure 1) into a real coopetition network. These companies could now operate in certain domains as if they were a single factory linked to BIM architects' stations, regardless of their geographical locations.

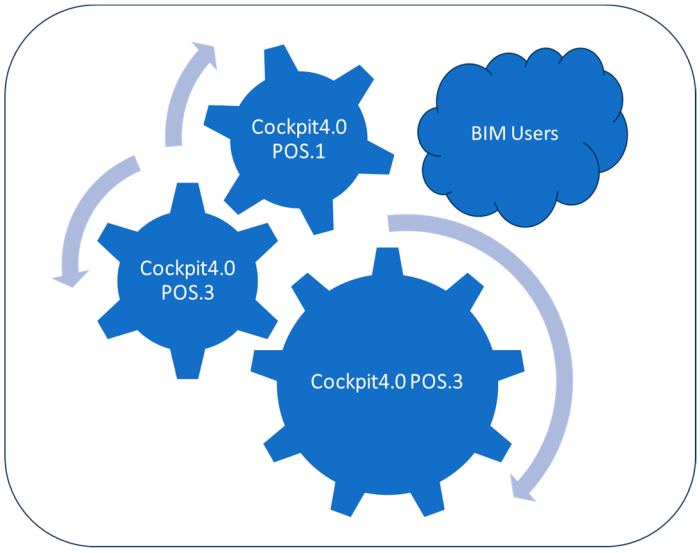


Figure 1. Experimental Coopetition Network for the Portuguese ornamental stone sector.

In each POS company involved in the case study, a Cockpit4.0+ system was installed, ensuring secure connectivity among companies and facilitating potential connections to BIM stations interested in prescribing customized stone globally.

With the Experimental Coopetition Network successfully established, the study defined specific metrics and KPIs necessary for assessing the impact of coopetition practices on BIM integration. The following section outlines the KPIs selected for this purpose, each aligned with the core dimensions of BIM (4D, 5D, and 6D). These metrics provide a structured approach to measuring improvements in time management, cost efficiency, and environmental sustainability—key areas where coopetition practices are expected to enhance BIM's effectiveness in the construction industry.

4.3. Defining Metrics and KPIs for BIM Integration

BIM's effectiveness in construction projects heavily depends on how well each component aligns with the requirements of the various BIM dimensions. The BIM.4D dimension integrates the element of time into the digital model, significantly enhancing time synchronization, accountability, and communication throughout the project lifecycle. BIM.4D enables the real-time visualization of construction sequences, which is essential for dynamic and timely project delivery.

To meet the stringent requirements of BIM.4D, manufacturers must optimize their scheduling, coordination, and productivity processes, emphasizing timely delivery [14]. The alignment of manufacturing timelines with project schedules is critical in ensuring that the overall project adheres to its planned timeline, thereby maintaining the integrity of the BIM model.

The on-time delivery (KPI_{OtD}) indicator is crucial for assessing a manufacturer's ability to consistently meet project deadlines [7]. This indicator measures the percentage of stone parts delivered within the agreed timeframe (PDoT) over the total parts produced (PD), reflecting the manufacturer's efficiency in adhering to the scheduled timeline (Equation (1)). KPI_{OtD} is not just a measure of logistical performance; it directly influences the effectiveness of BIM.4D by ensuring that all components arrive on time and in sequence, as required by the project schedule.

$$KPI_{OtD}(\%) = \sum_{1}^{n} \left(\frac{PDoT_{(daily)}}{PD_{(daily)}} \right) \quad (1)$$

Improvements in KPI_{OtD} are therefore critical for enhancing the overall effectiveness of BIM.4D. A higher KPI_{OtD} means that the manufacturer is more reliably delivering components as per the project's timeline, which supports the accurate and timely execution

of the construction plan. This alignment between delivery schedules and project timelines minimizes delays and disruptions, ensuring that the benefits of BIM.4D BIM—such as improved planning, better resource management, and enhanced project coordination—are fully realized.

The BIM.5D dimension integrates cost data with the 3D model, enabling comprehensive budget and financial management throughout the project lifecycle [24]. BIM.5D is critical for optimizing project costs by providing stakeholders with detailed financial insights directly linked to the construction model [22]. This integration allows for more accurate cost estimation, resource allocation, and ongoing cost monitoring, essential for keeping projects within budget while maintaining high-quality standards.

To fully leverage the benefits of BIM.5D, manufacturers must ensure that the components they produce meet required quality standards and do so at the lowest possible cost. Achieving this requires improvements in manufacturing efficiency, which can be accomplished by optimizing human and technological resources [16].

Drawing from lean management principles, industry efficiency is often measured through productivity indicators that relate output to labor input. For this case study, labor productivity (KPI_{LP}) has been selected as a critical metric to evaluate efficiency. KPI_{LP} measures the number of parts or tasks completed (PD) by a worker (LI) within a specified timeframe, providing a clear indication of labor efficiency (Equation (2)).

$$KPI_{LP}(\%) = \sum_{1}^{n} \left(\frac{PD_{(daily)}}{LI_{(daily)}} \right) \quad (2)$$

Enhancing KPI_{LP} is directly aligned with the requirements of BIM.5D. A higher KPI_{LP} indicates that a manufacturer is producing more with the same or fewer resources, effectively reducing costs without compromising quality. This increased efficiency supports the goals of BIM.5D by lowering overall construction costs while maintaining the project's financial health.

By improving labor productivity, stone companies can contribute to more efficient cost management throughout the project lifecycle. This alignment between labor productivity and cost efficiency is crucial for maximizing the benefits of BIM.5D, ensuring that projects are completed within budget and provide better value for stakeholders. The focus on optimizing labor inputs while maintaining output quality directly impacts the project's financial performance, making KPI_{LP} a vital metric for evaluating the success of BIM.5D in BIM-enabled construction projects.

The BIM.6D emphasizes sustainability by integrating environmental data into the BIM model, with the primary goal of reducing the ecological footprint of construction projects [15]. BIM.6D requires manufacturers to optimize the use of raw materials and processes to minimize the environmental impact of the building materials they produce [50]. This focus on sustainability is crucial in global efforts to combat climate change and promote environmentally responsible construction practices.

To evaluate how healthy fabricators are meeting the sustainability goals of BIM.6D, the CO_2 equivalent (CO_2-eq) factor is used as a critical metric [51]. This factor converts the energy consumed during production into equivalent carbon dioxide emissions, providing a standardized measure of the environmental impact associated with the manufacturing process.

Given the interconnected nature of power networks within the European Union, calculating the CO_2 equivalent for individual countries can be complex. For example, in Portugal, energy demands during critical periods often necessitate importing electricity from other European countries. These imports can significantly influence the carbon intensity of the energy used in production. Therefore, the average European CO_2 equivalent factor is applied for this case study to ensure a more accurate and standardized environmental impact assessment [52].

According to the European Electricity Review (2023), the carbon intensity of electricity across Europe varies significantly due to the diverse energy mixes of EU member states [53]. For instance, countries like Sweden and France have much lower carbon intensities (below 50 g CO_2/kWh) because of their heavy reliance on nuclear and renewable energy sources. In contrast, countries like Poland and Estonia have much higher carbon intensities (over 600 g CO_2/kWh) due to their dependence on coal and other fossil fuels. As of 2022, the EU's average carbon intensity of electricity generation was 276 g of CO_2 per kilowatt-hour (g CO_2/kWh) [53].

Equation (3) can be employed to calculate the CO_2 equivalent ($KPI_{CO_2\text{-}eq}$) for producing parts, reflecting the energy consumed (EC) per part delivered (PD). This metric allows for a precise evaluation of the environmental impact of manufacturing processes, enabling fabricators to assess their alignment with the sustainability objectives of BIM.6D.

By reducing the $KPI_{CO_2\text{-}eq}$, manufacturers can directly contribute to the environmental goals of BIM.6D, ensuring that their operations are efficient and environmentally responsible. This alignment with BIM.6D requirements is essential for promoting sustainable practices within the construction industry and achieving broader environmental targets, such as those outlined in the Sustainable Development Goals (SDGs).

$KPI_{CO_2\text{-}eq}$

$$KPI_{CO_2-eq}(\mathrm{KgCO_2/part}) = \sum_1^n \left(0.276 \times \frac{EC_{(daily)}}{PD_{(daily)}}\right) \quad (3)$$

Reductions in $KPI_{CO_2\text{-}eq}$ directly contribute to lowering the construction industry's CO_2 emissions and support SDG 11—Sustainable Cities and Communities—by promoting environmentally responsible practices and reducing urban carbon footprints.

With the KPIs established, the study progressed to an empirical assessment of the impact of coopetition practices on these metrics. The following section details the comparative analysis conducted over two distinct 54-day intervals, capturing baseline practices versus coopetition practices. This approach allows for an in-depth evaluation of how coopetition influences time efficiency, cost-effectiveness, and environmental impact, thereby providing valuable insights into the effectiveness of BIM dimensions within the Experimental Coopetition Network.

5. Data Collection and Analysis

A comprehensive data collection strategy was implemented over two fifty-four-day intervals to evaluate the impact of coopetition practices on the selected KPIs. This approach allowed for a comparison between the current or baseline practices (B.P), and a new set of practices termed coopetition practices (C.P). Under C.P, companies collaborated by sharing manufacturing resources and raw material stocks to better capitalize on market opportunities presented by BIM users.

The first 54-day period, conducted in the first half of 2023, focused on documenting the standard operations of the anonymized companies. This baseline phase provided essential reference data by capturing each company's reliance on internal resources for production and delivery.

The data collected during this period established a benchmark for subsequent comparisons (Table 2).

Table 2. Data collected during baseline practices (B.P).

Data ID	Independent Variables	Units	POS.1	POS.2	POS.3	Average (B.P)
Data 1	PD	Parts/day	362	185	469	339
Data 2	PDoT	Parts/day	258	116	364	240
Data 3	LI	hours/day	56	27	65	49
Data 4	EC	kWh/day	5023	2477	6577	4692

The second 54-day period, concluding in the second half of 2023, assessed the impact of integrating the same three companies into the Experimental Coopetition Network. During this period, the newly installed Cockpit4.0+ systems enabled real-time information sharing about manufacturing resources and raw material stocks among the companies (Table 3).

Table 3. Data collected during coopetition practices (C.P).

Data ID	Independent Variables	Units	POS.1	POS.2	POS.3	Average (B.P)
Data 5	PD	Parts/day	477	309	577	454
Data 6	PDoT	Parts/day	377	234	462	358
Data 7	LI	hours/day	56	27	65	49
Data 8	EC	kWh/day	4036	2472	5705	4071

Data management and privacy protocols were maintained throughout the study by confidentiality agreements. All data were anonymized, and companies were referred to only by their labels. Data collection, recording, and exportation followed established procedures, with results exported to Excel files as detailed in the methodology section. This approach ensured secure and consistent data handling, enabling detailed analysis while safeguarding the privacy and proprietary information of the participating companies. The assessment of KPIs as stone companies transitioned from B.P to C.P is presented in Table 4.

Table 4. Assessment of KPIs for B.P and C.P.

KPI	Dependent Variables	Units	B.P	C.P	Gain
KPI_{OtD}	On-time delivery	parts/parts	0.671	0.775	15.6%
KPI_{LP}	Labor productivity	parts/working_hours	6.84	8.72	27.38%
$KPI_{CO_2\text{-eq}}$	CO_2 emissions	$KgCO_2$/part	3.41	2.68	21.8%

Based on the data collected, the following section will interpret the results to assess whether coopetition practices can positively impact the ability of stone manufacturers to enhance the benefits of BIM [10]. This interpretation will provide insights into whether the hypothesis is validated or refuted, guiding conclusions about the efficacy of coopetition practices in this context.

Following the analysis of baseline and coopetition practices across key performance indicators, the study now focuses on testing the hypothesis. This section assesses how coopetition practices enhance BIM benefits by examining the data on time efficiency, labor productivity, and environmental impact. Each BIM dimension—4D, 5D, and 6D—will be evaluated, providing insights into whether the hypothesis is validated or refuted based on the improvements observed in the Experimental Coopetition Network.

6. Hypothesis Testing

6.1. Responding to BIM.4D: Enhancing On-Time Delivery Gains Through Coopetition Networks

The BIM.4D integrates the critical element of time, significantly advancing project management and coordination within the construction industry. Effective time management ensures that construction projects adhere to planned schedules, minimizing delays and enhancing overall project efficiency.

To evaluate how coopetition practices influence the ability of stone manufacturers to meet the requirements of BIM.4D, the KPI_{OtD} was assessed to determine the gains companies experienced when transitioning from baseline practices to coopetition practices. According to the data collected, under B.P, the average KPI_{OtD} was 67.1%, with 240 out of 339 parts delivered as scheduled. In contrast, under C.P, the KPI_{OtD} significantly increased to 77.5%, with 358 out of 454 parts delivered on time. This improvement underscores the effectiveness of C.P in ensuring more reliable customer deliveries and meeting project timelines.

The trend in on-time delivery during the observation periods provides further insights into the consistency and reliability of delivery services. Figure 2 illustrates the percentage

of deliveries made on time each day, showing how coopetition practices led to a gradual improvement in delivery performance.

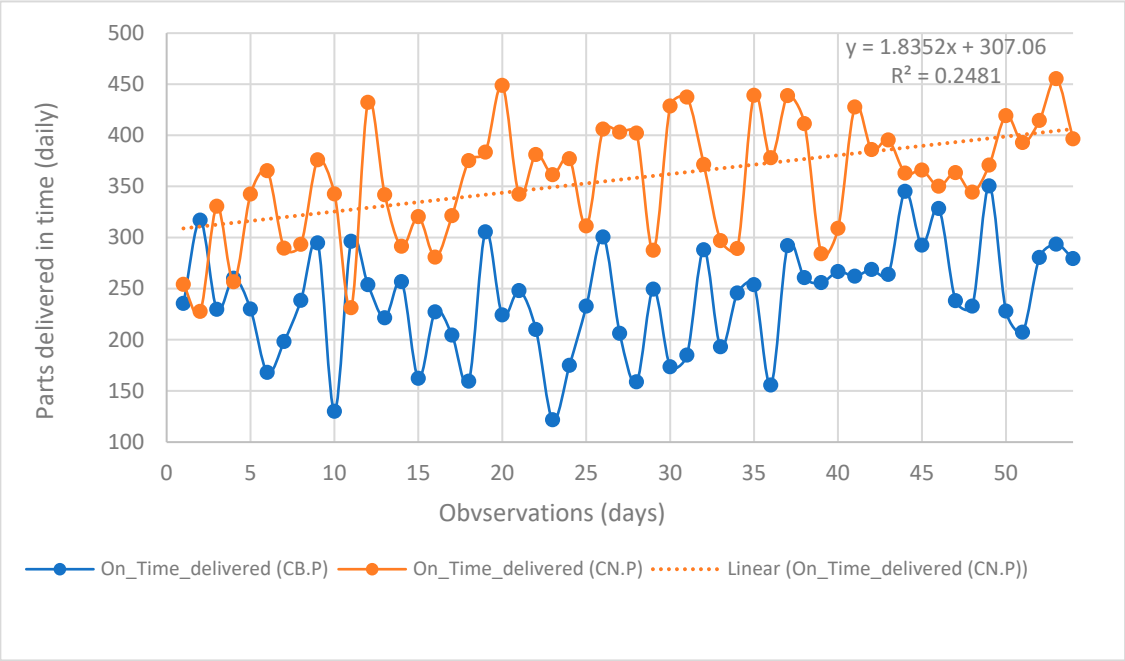


Figure 2. On-time delivery trend across 54 daily observations.

The positive slope of 1.8352 indicates a steady increase in the number of parts delivered daily on time. This upward trend demonstrates the boost given by coopetition practices in enhancing operational responsiveness, a critical component of the BIM.4D. However, the coefficient of determination (R^2 = 0.2481) suggests that this linear model explains approximately 24.81% of the variability in on-time delivery, indicating a moderate but not linear solid relationship between the days and the on-time delivery of parts.

The results indicate that companies involved in the Coopetition Network experienced substantial improvements in on-time delivery performance by transitioning to coopetition practices. The increase from 67.1% to 77.5% highlights the potential of coopetition to significantly enhance operational responsiveness, which is a crucial element in fulfilling the requirements of the BIM.4D. These findings suggest that coopetition practices can play a valuable role in improving project delivery timelines, thereby positively influencing stone manufacturers' contributions to enhance the benefits of BIM.4D.

6.2. Responding to BIM.5D: Enhancing Labor Productivity Through Coopetition

The BIM.5D dimension integrates cost data with the 3D model, enabling comprehensive budget and financial management throughout the project lifecycle.

Under B.P., employing an average workforce of 49.9, the intervenient companies managed a daily shipment of 338.5 parts, establishing an average labor productivity rate of 6.84 per worker. Implementing C.P. enhanced daily output to 415.8 parts on average while maintaining the same workforce size, boosting the KPI_{LP} to 8.72 per worker. This significant increase showcases the positive impact of cooperation on labor efficiency.

To further analyze the data, Figure 3 illustrates daily KPI_{LP} over 54 observations, highlighting in green the consistently higher productivity under C.P. This provides evidence of the potential contribution of coopetition practices in the stone manufacturing companies to improving the benefits of BIM.5D.

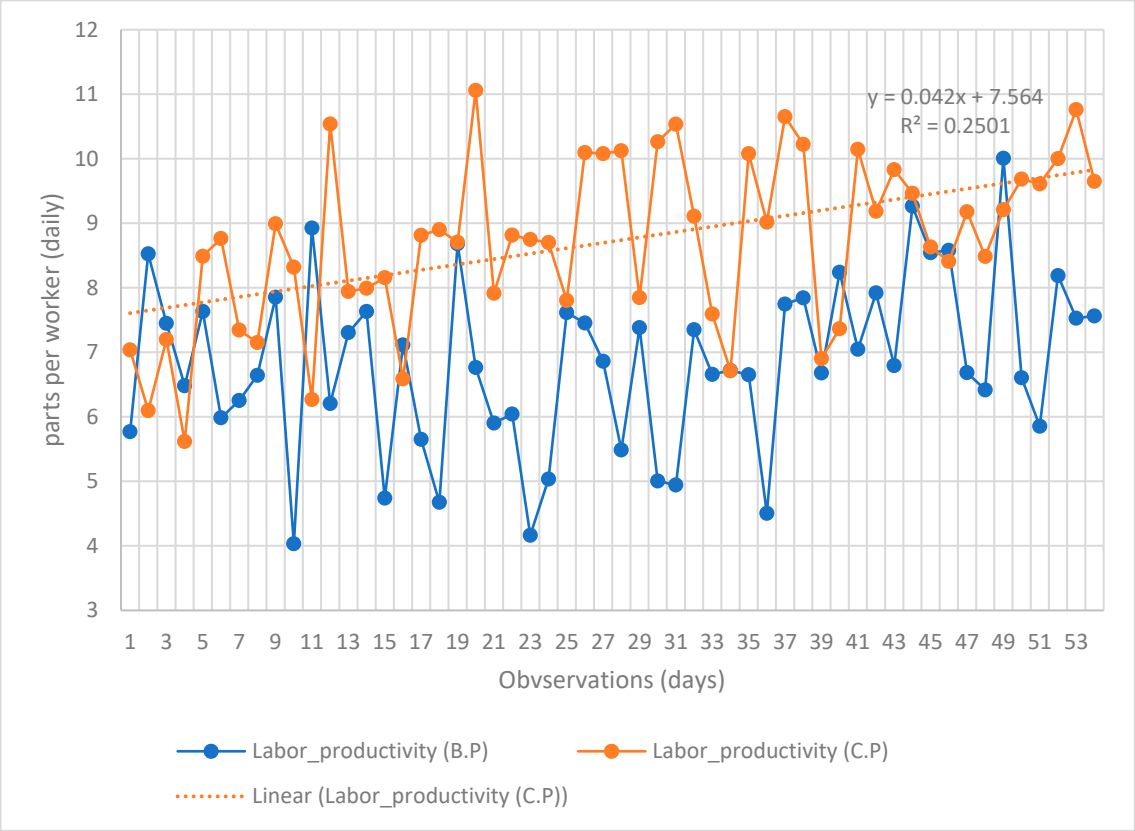


Figure 3. Labor productivity observed daily over 54 days.

The improvement in KPI_{LP} from 6.84 to 8.72 demonstrates how coopetition practices can enhance operational efficiency and cost management. Consequently, stone manufacturers are better equipped to meet the requirements of the BIM.5D, ensuring that projects are completed within budget and on time, leading to improved project outcomes and increased market competitiveness.

6.3. Responding to BIM.6D: CO_2 Emissions Reduction Through Coopetition

The BIM.6D dimension emphasizes sustainability by integrating environmental data into the BIM model to manage and reduce the ecological footprint of construction projects.

To evaluate how coopetition practices assist stone manufacturers in meeting the stringent sustainability requirements of BIM.6D, the $KPI_{CO_2\text{-eq}}$ was employed to measure the environmental impact of energy consumed during production, expressed as equivalent carbon dioxide emissions.

Under B.P, the stone companies recorded an average energy consumption of 4692 kWh per day, resulting in a $KPI_{CO_2\text{-eq}}$ of 3.41 kg CO_2 per part. However, with the implementation of C.P., energy consumption decreased to 4071 kWh per day on average, thereby reducing the $KPI_{CO_2\text{-eq}}$ to 2.68 kg CO_2 per part produced. This represents a 21.8% reduction in carbon emissions per part, underscoring the significant environmental benefits that coopetition practices can deliver.

Figure 4 illustrates the daily CO_2-eq emissions over 54 days, with an apparent reduction in emissions under C.P. highlighted in green.

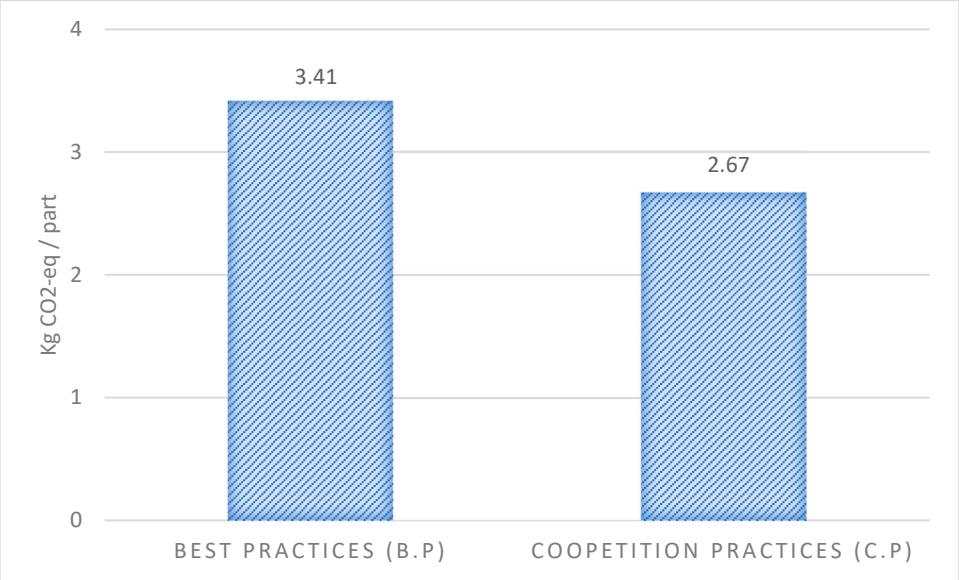


Figure 4. CO_2 emissions reduction achieved through coopetition practices in stone companies.

The improvements in $KPI_{CO_2\text{-eq}}$ demonstrate the potential of coopetition practices to significantly enhance the environmental performance of construction projects. By integrating sustainability considerations into their operations, fabricators can contribute to more sustainable and resilient built environments, aligning with global efforts to combat climate change and promote ecological responsibility.

A *t*-Test and ANOVA were conducted on the emissions data to assess the significance of these improvements. The F-statistic was 2.13, indicating a relatively low value; the *p*-value associated with the F-statistic was 0.1505, which was above the typical significance level of 0.05. This suggests that the regression model does not significantly explain the variation in the dependent variable based on the independent variable.

The analysis indicates that under B.P, the Significance F value (2.15×10^{-8}) indicates that the model is highly statistically significant, meaning the relationship between the CO_2 equivalent under baseline practices and $KPI_{CO_2\text{-eq}}$ is meaningful. In contrast, the F value (0.150532) under C.P suggests that the model is not statistically significant, indicating that the relationship between the CO_2 equivalent under coopetition practices and $KPI_{CO_2\text{-eq}}$ is not meaningful. This shift highlights that the transition from baseline to coopetition practices significantly reduces the impact of the CO_2 equivalent on $KPI_{CO_2\text{-eq}}$, indicating improved environmental sustainability.

However, the intercept is statistically significant, suggesting that the expected value of the dependent variable when the independent variable is zero is approximately 3.075. Despite this, the independent variable does not significantly contribute to changes in the dependent variable. These results suggest a statistically significant difference in environmental performance between B.P and C.P. The transition to coopetition practices has resulted in a significant improvement in sustainability, as evidenced by the reduction in carbon emissions per part.

7. Conclusions

This study addressed the following central question: How can manufacturers enhance their contributions to maximize BIM's effectiveness in the construction industry? By investigating the impact of coopetition practices, this research supports the hypothesis that coopetition can positively influence manufacturers' contributions, thereby enhancing the benefits of BIM in alignment with the United Nations Sustainable Development Goals (SDGs).

Through an Experimental Coopetition Network and a focused case study in the Portuguese ornamental stone sector, the study examined how coopetition affects critical

performance indicators such as on-time delivery, labor productivity, and CO_2 emissions. Key findings include the following:

1. On-Time Delivery: This improved from 67.1% under baseline practices (B.P.) to 77.5% under coopetition practices (C.P.) which was a 15.6% increase, reflecting enhanced scheduling and coordination.
2. Labor Productivity: This increased from 6.84 parts per worker under B.P. to 8.72 parts per worker under C.P., a 27.38% improvement, indicating the potential for cost savings and operational efficiency.
3. Environmental Impact: CO_2 emissions decreased from 3.41 kg CO_2-equivalent per part under B.P. to 2.68 kg CO_2-equivalent per part under C.P., a 21.8% reduction, demonstrating a positive environmental impact.

These findings validate the hypothesis within the context of the ornamental stone sector, suggesting that coopetition practices can enhance manufacturers' contributions and optimize BIM benefits. This supports the strategic role of competition in improving project outcomes, increasing competitiveness, and advancing sustainability in the construction industry, especially regarding SDG 11, which promotes sustainable cities and communities.

Practical Implications: The study provides actionable insights for industry professionals and policymakers. For industry practitioners, the observed improvements in scheduling, productivity, and environmental impact indicate that coopetition practices can enhance BIM outcomes and drive operational efficiencies. For policymakers, the findings underscore the potential of coopetition frameworks to foster collaboration and resource sharing within industry sectors, promoting sustainable construction practices and economic resilience.

Limitations and Future Research: While the findings are promising, they are based on a single-sector case study with a limited sample of companies. This scope limits the generalizability of the results across the broader construction industry. Expanding the sample size and including a diverse range of sectors within the construction industry that also utilize BIM would strengthen the representativeness of the findings and further validate the applicability of coopetition practices in varied contexts. Additionally, this study is limited by its cross-sectional design, which captures results at a single point in time. Future research could address these limitations through longitudinal studies that monitor companies over extended periods. Such research will help to determine whether the observed improvements in BIM effectiveness through coopetition are sustained over time or if specific short-term conditions influence them. Expanding the scope this way could also account for technological and contextual variations, providing a more comprehensive understanding of the impact of coopetition on BIM benefits in the construction sector.

Contribution to Theory and Practice: This study advances the theoretical understanding of coopetition by demonstrating its positive impact on BIM benefits and its alignment with SDGs, offering insights into sustainable construction practices. Additionally, the findings contribute a practical framework for implementing coopetition practices to enhance project performance, productivity, and environmental sustainability. These insights offer concrete guidance for industry practitioners and policymakers, supporting a shift towards a more collaborative and sustainable construction sector.

Author Contributions: Conceptualization, A.d.S. and A.J.M.C.; methodology, A.d.S.; software, A.d.S.; validation, A.d.S. and A.J.M.C.; formal analysis, A.d.S.; investigation, A.d.S.; resources, A.d.S.; data curation, A.d.S.; writing—original draft preparation, A.d.S.; writing—review and editing, A.d.S.; visualization, A.d.S.; supervision, A.d.S.; project administration, A.d.S.; funding acquisition, A.d.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by StonebyPortugal, Portaria n.º 43-A/2022 January 19th (Agenda C5—Aviso N.º 02/C05-i01/2022), founded by the Plano de Recuperação e Resiliência, Agendas para A Inovação Empresarial and The APC was funded by Ensinus Estudos Superiores, SA.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Fearnley, N.; Robinson, G.; Leonard, J. Global Construction Futures. 2023. Available online: https://www.oxfordeconomics.com/resource/global-construction-futures/ (accessed on 12 July 2024).
2. Dyson, A.; Keena, N.; Lokko, M.; Reck, B.; Ciardullo, C. *Building Materials and the Climate: Constructing A New Future*; United Nations Environment Programme Industry and Economy Division Energy and Climate Branch: Paris, France, 2023.
3. Kulinan, A.S.; Park, M.; Aung, P.P.W.; Cha, G.; Park, S. Advancing construction site workforce safety monitoring through BIM and computer vision integration. *Autom. Constr.* **2024**, *158*, 105227. [CrossRef]
4. Schery, C.A.D.; Caiado, R.G.G.; Vargas, S.A.; Vignon, Y.R. Paths to BIM-based digital transformation: A bibliometric and systematic review of critical factors. *Eng. Constr. Archit. Manag.* **2024**. *ahead of print*. [CrossRef]
5. Altaf, M.; Alalaoul, W.S.; Musarat, M.A.; Abdelaziz, A.A.; Thaheem, M.J. Optimisation of energy and life cycle costs via building envelope: A BIM approaches. *Environ. Dev. Sustain.* **2023**, *26*, 7105–7128. [CrossRef]
6. Wang, S.; Chong, H.-Y.; Zhang, W. The impact of BIM-based integration management on megaproject performance in China. *Alex. Eng. J.* **2024**, *94*, 34–43. [CrossRef]
7. Polat, F.; Demirkesen, S. Measuring the impact of lean implementation on BIM and project success: Case of construction firms. *Eng. Constr. Archit. Manag* **2024**. *ahead of print*. [CrossRef]
8. Nath, T.; Attarzadeh, M.; Tiong, R.L.K.; Chidambaram, C.; Yu, Z. Productivity improvement of precast shop drawings generation through BIM-based process re-engineering. *Autom. Constr.* **2015**, *54*, 54–68. [CrossRef]
9. Pan, Y.; Zhang, L. Integrating BIM and AI for Smart Construction Management: Current Status and Future Directions. *Arch. Comput. Methods Eng.* **2023**, *30*, 1081–1110. [CrossRef]
10. Chowdhury, M.; Hosseini, M.R.; Edwards, D.J.; Martek, I.; Shuchi, S. Comprehensive analysis of BIM adoption: From narrow focus to holistic understanding. *Autom. Constr.* **2024**, *160*, 105301. [CrossRef]
11. Da Silva, A.; Cardoso, A.J.M. Coopetition with the Industrial IoT: A Service-Dominant Logic Approach. *Appl. Syst. Innov.* **2024**, *7*, 47. [CrossRef]
12. Bouncken, R.; Kumar, A.; Connell, J.; Bhattacharyya, A.; He, K. Coopetition for corporate responsibility and sustainability: Does it influence firm performance? *Int. J. Entrep. Behav. Res.* **2024**, *30*, 128–154. [CrossRef]
13. Tam, V.W.; Zhou, Y.; Shen, L.; Le, K.N. Optimal BIM and LCA integration approach for embodied environmental impact assessment. *J. Clean. Prod.* **2023**, *385*, 135605. [CrossRef]
14. Abdumutalibovich, K.A.; Lutfillaevna, B.M. The Role of Bim Technologies in the Information System of Education. *Eur. J. Contemp. Bus. Law Technol. Cyber Law Blockchain Leg. Innov.* **2023**, *2*, 9–13. [CrossRef]
15. Wijeratne, P.U.; Gunarathna, C.; Yang, R.J.; Wu, P.; Hampson, K.; Shemery, A. BIM enabler for facilities management: A review of 33 cases. *Int. J. Constr. Manag.* **2024**, *24*, 251–260. [CrossRef]
16. Chen, Z.-S.; Wang, Z.-R.; Deveci, M.; Ding, W.; Pedrycz, W.; Skibniewski, M.J. Optimization-based probabilistic decision support for assessing building information modelling (BIM) maturity considering multiple objectives. *Inf. Fusion* **2024**, *102*, 102026. [CrossRef]
17. Vilas-Boas, J.; Mirnoori, V.; Razy, A.; Silva, A. Outlining a New Collaborative Business Model as a Result of the Green Building Information Modelling Impact in the AEC Supply Chain. In *Collaborative Networks and Digital Transformation*; Springer International Publishing: Cham, Switzerland, 2019; pp. 405–417.
18. Hadavi, A.; Alizadehsalehi, S. From BIM to metaverse for AEC industry. *Autom. Constr.* **2024**, *160*, 105248. [CrossRef]
19. Yilmaz, G.; Akcamete, A.; Demirors, O. BIM-CAREM: Assessing the BIM capabilities of design, construction and facilities management processes in the construction industry. *Comput. Ind.* **2023**, *147*, 103861. [CrossRef]
20. Yan, J.; Lu, Q.; Tang, J.; Chen, L.; Hong, J.; Broyd, T. Digital Tools for Revealing and Reducing Carbon Footprint in Infrastructure, Building, and City Scopes. *Buildings* **2022**, *12*, 1097. [CrossRef]
21. Raut, R.D.; Kumar, S.; Narwane, V.S.; Gardas, B.B.; Priyadarshinee, P.; Narkhede, B.E. Linking big data analytics and operational sustainability practices for sustainable business management. *J. Clean. Prod.* **2019**, *224*, 10–24. [CrossRef]
22. Alfarizi, M.R.; Rifai, A.I.; Indrastuti, I.; Prasetijo, J. Bibliometric Analysis of Cost and Time Management In Handling Avalanches on National Roads In Mountainous Areas Using BIM. *Asian J. Soc. Humanit.* **2024**, *2*, 1952–1966. [CrossRef]
23. Hakimi, O.; Liu, H.; Abudayyeh, O. Digital twin-enabled smart facility management: A bibliometric review. *Front. Eng. Manag.* **2024**, *11*, 32–49. [CrossRef]
24. Shao, S.; Cao, D. Contagion of BIM Implementation Practices in Interproject Networks: An Empirical Study in China. *J. Manag. Eng.* **2024**, *40*, 05023009. [CrossRef]
25. Waqar, A.; Qureshi, A.H.; Alaloul, W.S. Barriers to Building Information Modeling (BIM) Deployment in Small Construction Projects: Malaysian Construction Industry. *Sustainability* **2023**, *15*, 2477. [CrossRef]
26. Nalebuff, B.J.; Brandenburger, A.M. Co-opetition: Competitive and cooperative business strategies for the digital economy. *Strateg. Leadersh.* **1997**, *25*, 28–33. [CrossRef]
27. Corbo, L.; Kraus, S.; Vlačić, B.; Dabić, M.; Caputo, A.; Pellegrini, M.M. Coopetition and innovation: A review and research agenda. *Technovation* **2023**, *122*, 102624. [CrossRef]

28. Ramírez-López, C.; Till, K.; Boyd, A.; Bennet, M.; Piscione, J.; Bradley, S.; Giuliano, P.; Leduc, C.; Jones, B. Coopetition: Cooperation among competitors to enhance applied research and drive innovation in elite sport. *Br. J. Sports Med.* **2021**, *55*, 522–523. [CrossRef]
29. Chen, M.; Lv, C.; Wang, X.; Li, L.; Yang, P. A Critical Review of Studies on Coopetition in Educational Settings. *Sustainability* **2023**, *15*, 8370. [CrossRef]
30. Kämpf, D. Coopetition in the Context of the Sustainability Goals. *Reg. Bus. Stud.* **2022**, *14*, 47–61. [CrossRef]
31. Meena, A.; Dhir, S.; Sushil, S. A review of coopetition and future research agenda. *J. Bus. Ind. Mark.* **2023**, *38*, 118–136. [CrossRef]
32. Rouyre, A.; Fernandez, A.-S.; Bruyaka, O. Big problems require large collective actions: Managing multilateral coopetition in strategic innovation networks. *Technovation* **2024**, *132*, 102968. [CrossRef]
33. Gernsheimer, O.; Kanbach, D.K.; Gast, J. Coopetition research—A systematic literature review on recent accomplishments and trajectories. *Ind. Mark. Manag.* **2021**, *96*, 113–134. [CrossRef]
34. Estrada, I.; Dong, J. Learning from experience? Technological investments and the impact of coopetition experience on firm profitability. *Long Range Plann.* **2020**, *53*, 101866. [CrossRef]
35. Hollweck, T.; Robert, K.Y. Case Study Research Design and Methods (5th ed.). *Can. J. Progr. Eval.* **2015**, *30*, 108–110. [CrossRef]
36. Hsu, Y. Integrating Service Science and Information System Technology: A Case Study. *Int. J. Organ. Innov.* **2016**, *9*, 158–173. [CrossRef]
37. Carvalho, J.M.F.; Lisboa, J.V. Ornamental stone potential areas for land use planning: A case study in a limestone massif from Portugal. *Environ. Earth Sci.* **2018**, *77*, 206. [CrossRef]
38. Carvalho, J.; Lopes, C.; Mateus, A.; Martins, L.; Goulão, M. Planning the future exploitation of ornamental stones in Portugal using a weighed multi-dimensional approach. *Resour. Policy* **2018**, *59*, 298–317. [CrossRef]
39. Silva, A.; Pata, A. Value Creation in Technology Service Ecosystems—Empirical Case Study. In *Innovations in Industrial Engeneering II*; Springer International Publishing: Cham, Switzerland, 2022; pp. 26–36. [CrossRef]
40. Silva, A.; Cardoso, A.M. Technology Paths towards Coopetition Ecosystems—The Portuguese Stone Sector. In Proceedings of the 7th Globalstone Congress, Batalha, Portugal, 18–23 June 2023.
41. Silva, A.; Cardoso, A.M. BIM-based Supply Chain in AEC—Threats on the Portuguese Stone Sector. In Proceedings of the 7th Globalstone Congress, Batalha, Portugal, 18–23 June 2023.
42. Presciuttini, A.; Portioli-Staudacher, A. Applications of IoT and Advanced Analytics for manufacturing operations: A systematic literature review. *Procedia Comput. Sci.* **2024**, *232*, 327–336. [CrossRef]
43. Ng, I.; Wakenshaw, S. The Internet-of-Things: Review and research directions. *Int. J. Res. Mark.* **2017**, *34*, 3–21. [CrossRef]
44. Akaka, M.; Schau, H.; Vargo, S. How Practice Diffusion Drives IoT Technology Adoption and Institutionalization of Solutions in Service Ecosystems. In Proceedings of the 56th Hawaii International Conference on System Sciences, HICSS 2023, Maui, HI, USA, 3–6 January 2023; pp. 1427–1435. [CrossRef]
45. Latif, G.; Brahim, G.B.; Abdelhamid, S.E.; Alghazo, R.; Alhabib, G.; Alnujaidi, K. Learning at Your Fingertips: An Innovative IoT-Based AI-Powered Braille Learning System. *Appl. Syst. Innov.* **2023**, *6*, 91. [CrossRef]
46. Silva, A.; Rabadão, C.; Capela, C. Towards Industry 4.0: A case study of BIM deployment in ornamental stones sector. *Int. J. Innov. Technol. Explor. Eng.* **2020**, *67*, 24535.
47. Silva, A.; Gil, M. Industrial processes optimization in digital marketplace context: A case study in ornamental stone sector. *Results Eng.* **2020**, *7*, 100152. [CrossRef]
48. Silva, A.; Dionisio, A.; Almeida, I. Enabling Cyber-Physical Systems for Industry 4.0 operations: A Service Science Perspective. *Int. J. Innov. Technol. Explor. Eng.* **2020**, *9*, 838–846. [CrossRef]
49. Hoppe, S. OPC Unified Architecture-Interoperability for Industrie 4.0 and the Internet of Things. 2023. Available online: https://opcfoundation.org/wp-content/uploads/2023/05/OPC-UA-Interoperability-For-Industrie4-and-IoT-EN.pdf (accessed on 12 July 2024).
50. Li, M.; Lu, K.; Wang, H.; Wang, S. Integrating BIM with greenhouse-gas emissions in AEC: A scientometric review. *E3S Web Conf.* **2020**, *143*, 01008. [CrossRef]
51. Balsalobre-Lorente, D.; Parente, C.C.D.S.; Leitão, N.C.; Cantos-Cantos, J.M. The influence of economic complexity processes and renewable energy on CO_2 emissions of BRICS. What about industry 4.0? *Resour. Policy* **2023**, *82*, 103547. [CrossRef]
52. Cozzi, L. *CO_2 Emissions in 2022*; IEA Publications: Paris, France, 2023. [CrossRef]
53. Jones, D. European Electricity Review 2023. Available online: https://ember-energy.org/app/uploads/2023/01/Report-European-Electricity-Review-2023.pdf (accessed on 3 July 2024).

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.