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Smart Airports: Analysing Digital Transformation and Technological Advancements in Aviation.

The Cases of Ponta Delgada and Beijing Capital International Airports

(Versão final após defesa)

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Resumo

Esta dissertação explora o desenvolvimento de inovações em aeroportos através da aplicação de tecnologias recentes em procedimentos de segurança, diversas operações e a melhoria da experiência do passageiro. O foco está em dois casos de estudo contrastantes: o Aeroporto Internacional de Pequim Capital na China, um dos maiores e mais avançados aeroportos do mundo, e o Aeroporto de Ponta Delgada, nos Açores, Portugal, um aeroporto regional menor que visa utilizar a tecnologia para modernização.

A dissertação começa com uma revisão integrada da literatura sobre a emergência de aeroportos e aeroportos inteligentes com a sua transformação digital e progresso tecnológico que moldam a indústria da aviação. Este estudo investiga as tecnologias presentes nos aeroportos inteligentes como etiquetas RFID, *self-tagging*, *check-in* inteligente e sistemas automatizados de bagagem para ilustrar o potencial de eficiência operacional impulsionada pela automação, satisfação do passageiro e segurança.

Os estudos de caso do Aeroporto Internacional de Pequim Capital e do Aeroporto de Ponta Delgada são exemplos de aplicações de tecnologias de aeroportos inteligentes e dos seus efeitos em ambientes distintos. A transformação digital de ambos os aeroportos é analisada, em particular as diferenças e a situação atual de cada aeroporto, atualizações futuras ou em andamento, e razões para negá-las.

Os resultados sugerem que ambos os aeroportos progrediram na incorporação de tecnologias inteligentes, mas enfrentam alguns desafios e oportunidades que tendem a variar. O Aeroporto Internacional de Pequim Capital está na vanguarda da transformação digital e o Aeroporto de Ponta Delgada está mais focado na abordagem local para a modernização. A dissertação fornece uma comparação dos efeitos positivos e negativos do avanço tecnológico entre ambos os aeroportos, examinando o seu impacto na experiência do passageiro e na dinâmica da força de trabalho.

Por fim, este estudo oferece uma análise detalhada do processo de um aeroporto inteligente, destacando que o planeamento inteligente, o investimento e a inovação contínua são a chave para operações aeroportuárias sustentáveis, eficientes e centradas no passageiro. A dissertação conclui com perspetivas de pesquisa futura na área de aeroportos inteligentes, sublinhando o potencial para a evolução e desenvolvimento futuro.

Palavras-chave

Aeroporto Inteligente; Inovação; Tecnologia; IA; IoT; Eficiência; Melhoria; Satisfação dos Passageiros;

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Resumo Alargado

A indústria da aviação global tem testemunhado um crescimento significativo nos últimos anos, impulsionada pela crescente preferência pelo transporte aéreo. Este aumento da procura resultou na expansão das aeronaves e dos serviços associados, amplificando o crescimento deste setor. Apesar dos contratempos devido à pandemia sem precedentes, a indústria mostrou sinais de recuperação em 2022, atingindo os níveis pré-pandemia. As projeções indicam uma continuação da expansão, impulsionando a necessidade de avanços tecnológicos nos aeroportos. O crescimento exponencial do setor da aviação criou uma demanda urgente por tecnologias avançadas para melhorar a eficiência dos aeroportos e lidar com o aumento do volume de viagens aéreas. Os aeroportos inteligentes apresentam uma solução convincente para este desafio, otimizando as operações aeroportuárias e elevando a experiência dos passageiros através da integração de tecnologias de ponta e da análise de dados.

Um aeroporto inteligente utiliza as mais recentes tecnologias para simplificar processos e melhorar a experiência geral de viagem. Este estudo visa analisar a implementação de sistemas de aeroportos inteligentes e tecnologias inovadoras nos aeroportos atuais, oferecendo informações sobre o futuro das viagens aéreas. A investigação sobre as tecnologias da *Internet of Things* (IoT) aplicadas às operações aeroportuárias proporciona uma oportunidade para explorar os benefícios e desafios destas intervenções tecnológicas. Desde o reconhecimento biométrico até à gestão automatizada de bagagens, o potencial destas tecnologias para transformar o ambiente aeroportuário é vasto, abordando questões de eficiência, segurança e experiência dos passageiros. Além disso, a análise da digitalização dos aeroportos oferece *insights* sobre a relação entre tecnologia, sustentabilidade e rentabilidade. Ao compreender como os aeroportos inteligentes mitigam a sua pegada ecológica enquanto melhoram a viabilidade financeira, o estudo fornece lições aplicáveis a outros setores. Além disso, examinar o impacto da tecnologia na força de trabalho aeroportuária revela as competências necessárias para o futuro das viagens aéreas, garantindo que os funcionários estejam adequadamente preparados para os avanços tecnológicos.

Esta dissertação começa com uma descrição dos objetivos e metodologia do projeto para proporcionar uma compreensão clara do seu âmbito e abordagem. Analisa o crescimento, os desafios e as possibilidades dos aeroportos, enfatizando o papel da tecnologia na criação de aeroportos inteligentes. O estudo examina os projetos de aeroportos inteligentes existentes em todo o mundo e apresenta uma descrição detalhada das tecnologias da Indústria 4.0 e as suas aplicações em contextos aeroportuários reais.

A pesquisa foca-se em dois aeroportos específicos: Aeroporto Internacional de Pequim-Capital (BCIA) na China e Aeroporto João Paulo II (PDL) em Portugal. O objetivo principal é investigar a importância do investimento e implementação de tecnologia nos aeroportos e comparar como aeroportos de diferentes tamanhos utilizam estrategicamente os avanços tecnológicos para melhorar a eficiência operacional, a experiência dos passageiros e a segurança. Os objetivos específicos incluem analisar o crescimento dos aeroportos, melhorias tecnológicas e o impacto do crescimento da aviação global; examinar as tecnologias existentes nos aeroportos e as suas diferenças com base no orçamento e tamanho; e investigar a viabilidade da implementação dessas tecnologias de acordo com o orçamento e tamanho de cada aeroporto. O estudo também visa entender o impacto dessas decisões nos passageiros e funcionários.

A metodologia envolve uma extensa revisão de literatura sobre tecnologia aeroportuária, sistemas de segurança e processos de identificação biométrica. Esta revisão inclui uma vasta gama de recursos para construir uma base de conhecimento abrangente. O estudo foca-se então no Aeroporto João Paulo II e no Aeroporto Internacional de Pequim-Capital, proporcionando detalhes sobre as tecnologias atuais, desafios e áreas de melhoria. A metodologia é detalhada num fluxograma, com cada seção correspondendo a um capítulo da dissertação.

A dissertação está estruturada em cinco capítulos: Introdução, Estado da Arte, Caso de Estudo, Análise de Resultados e Conclusão. O primeiro capítulo delineia a motivação para a pesquisa, os objetivos e a metodologia. O segundo capítulo apresenta uma revisão de literatura, examinando teorias pertinentes, conceitos e pesquisas anteriores. Esta revisão proporciona uma compreensão abrangente do estado atual dos aeroportos inteligentes, das tecnologias utilizadas e das soluções potenciais para melhorias futuras. O terceiro capítulo introduz os casos de estudo, descrevendo as tecnologias implementadas em cada aeroporto e o desenvolvimento tecnológico de cada país. O quarto capítulo analisa os resultados, comparando as vantagens e desvantagens das tecnologias e o seu impacto nos passageiros e na força de trabalho. O quinto e último capítulo resume os achados, oferece reflexões finais e fornece recomendações para pesquisas futuras.

Em conclusão, a dissertação sintetiza os achados da análise histórica, exame tecnológico de cada aeroporto e estudos de caso comparativos. Apesar das limitações, como a incapacidade de estudar mais aeroportos e obter certos dados, a dissertação fornece uma análise abrangente de dois grandes aeroportos. Pesquisas futuras poderiam envolver uma gama mais ampla de aeroportos para comparação, incorporando dados

quantitativos sobre vários KPIs, métricas financeiras e índices de satisfação dos passageiros. Uma maior cooperação com autoridades aeroportuárias e principais atores da indústria poderia facilitar o acesso a informações proprietárias, melhorando a compreensão da adoção de tecnologias e atualizações de infraestrutura. Estudos longitudinais poderiam monitorizar o desenvolvimento de tecnologias de aeroportos inteligentes ao longo do tempo, fornecendo *insights* valiosos sobre as suas implicações a longo prazo. Além disso, pesquisas interdisciplinares poderiam abordar os aspetos sociotécnicos dos sistemas de aeroportos inteligentes, enquanto a análise de quadros políticos e mecanismos regulatórios poderia enriquecer a compreensão ambiente no qual esses desenvolvimentos ocorrem.

O campo dos aeroportos inteligentes está preparado para crescer à medida que novas tecnologias e soluções surgem, oferecendo o potencial de transformar as operações aeroportuárias. Estudos futuros poderiam explorar os avanços na IA, IoT e tecnologia *blockchain* para avaliar sua viabilidade na melhoria da eficiência, segurança e sustentabilidade nos aeroportos. Esta abordagem holística permitirá aos pesquisadores abordar desafios complexos relacionados ao design de infraestrutura, experiência do passageiro e sustentabilidade, contribuindo, em última análise, para a criação de aeroportos mais inteligentes e eficientes.

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Abstract

This dissertation explores the development of airport innovations through the application of recent technologies in safety procedures, diverse operations and the improvement of passenger's experience. The focus is on two contrasting case studies: Beijing Capital International Airport of China, one of the largest and most advanced airports in the world, and Ponta Delgada Airport of the Azores, Portugal, a smaller, regionally based airport which aims to use technology for modernisation.

The dissertation begins with an integrated literature review of the emergence of airports and smart airports with their digital transformation and technological progress which shapes the aviation industry. This study delves on smart airport technologies such as RFID tags, self-tagging, smart check-in, and automated baggage systems to illustrate the potential for automation-driven operational efficiency, passenger satisfaction, and security.

Beijing Capital International Airport and Ponta Delgada Airport case studies are examples of smart airport technology applications and their effects on various environments. The digital transformation of both these airports is analysed, in particular, the differences and present situation at each airport, upcoming or ongoing upgrades, and reasons for denying them.

The results imply that both airports have basically progressed in incorporating smart technologies, but they are confronted with some challenges and opportunities that tend to vary. Beijing Capital International Airport is first in the digital transformation and Ponta Delgada Airport is more focused on the local approach to modernisation. The dissertation provides a comparison of positive and negative effects of technological advancement among both airports examining their impact on passenger experience and labour force dynamics.

Finally, this study gives a detailed analysis of the process of a smart airport, underlining the fact that smart planning, investment and continuous innovation are the key to sustainable, efficient and passenger-centric airport operations. The dissertation concludes with future research prospects in the area of smart airports, highlighting the potential for further evolution and development in the domain.

Keywords

Smart airport; Innovation; Technology; AI; IoT; Efficiency; Improvement; Passenger Satisfaction;

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List of Abbreviations

ACI	Airport Council International
A-CDM	Airport Collaborative Decision Making
AI	Artificial Intelligence
ANA	Aeroportos e Navegação Aérea
ANSP	Air Navigation Service Providers
AR	Augmented Reality
ASQ	Airport Service Quality
ASQR	Airport Service Quality Regime
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
AWS	Amazon Web Services
B2B	Business-to-Business
B2C	Business-to-Costumer
BCIA	Beijing Capital International Aiport
BFE	Basic Formal Education
BIM	Building Information Modelling
BMS	Building Management System
BSACE	Beijing Sino-Aero Construction Engineering
CIP	Confederação Empresarial de Portugal
CPS	Cyber Physical Systems
CT	Computer Tomography
CUPPS	Common Use Passenger Processing Systems
CUTE	Common Use Terminal Equipment
CUSS	Common Use Self-Service

DESI	Digital Economy and Society Index
DPIAs	Data Protection Impact Assessment
DPO	Data Protection Officer
DX	Digital Transformation
EMPD	Estrutura de Misso Portugal Digital
ENISA	European Union Agency for Cybersecurity
ESG	Economic, Social and Governance
EU	European Union
FTTH	Fiber to the Home
FOD	Foreign Object Detection
GDPR	General Data Protection Regulation
GII	Global Innovation Index
GRP	Gabinete de Relações Públicas
GSE	Groud Support Equipment
HVAC	Heat Ventilation Air Conditioning
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICT	Information Communication Technology
IoT	Internet of Things
KPI	Key Performance Indicator
LEDs	Liquid Explosive Detection System
ML	Machine Learning
NFC	Near Field Communication
NGA	Next Generation Access
NRI	Network Readiness Index

O2O	Online to Offline
PCO	Personal Competence
PDL	Ponta Delgada
PRM	Passengers with Reduced Mobility
RFID	Radio Frequency Identification
RPA	Robotic Process Automation
SMEs	Small and Medium-sized Enterprises
SMS	Safety Management System
SSTs	Self-Service Technologies
UBI	Universidade da Beira Interior
UV	Ultraviolet
VE	Virtual Environment
VHCN	Very High-Capacity Network
VR	Virtual reality
WIPO	World Intellectual Property Organization
WMA	Warm Mix Asphalt

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Chapter 1 - Introduction

1.1 Motivation

The global aviation industry has witnessed a rise in recent years, as an increasing number of individuals are preferring to travel by air. This has resulted in an escalated demand for aircraft and associated services, thereby, amplifying the growth of the aviation industry. Despite a severe setback that the industry experienced due to the unprecedented pandemic, it is believed to have recovered in 2022, thereby gradually regaining its pre-pandemic levels. According to the thrilling industry projections, the aviation sector is likely to continue its expansion in the forthcoming years, as seen in the map (Figure 1) below, which has consequently induced a growth of technological advancements [1].

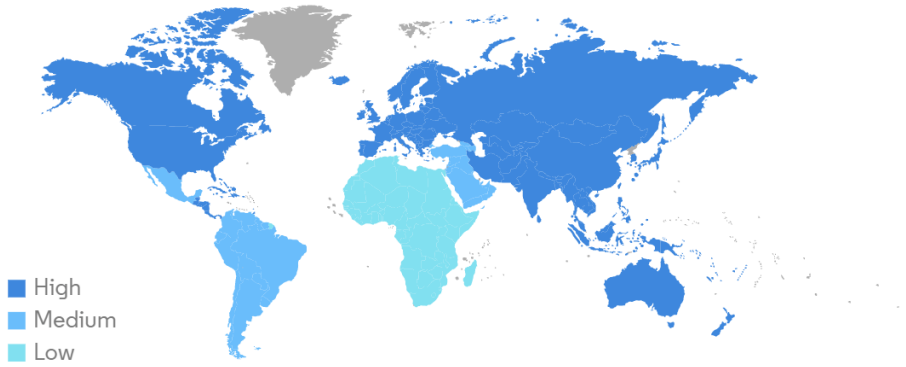

Figure 1 - Aviation market - Growth Rate by Region (2022-2027) [1].

The exponential growth in the aviation sector has led to a pressing demand for highly advanced technologies in airports. With growing need for airports to be increasingly efficient and equipped to cope with the skyrocketing demand for air travel, a smart airport presents a compelling solution to this challenge by optimizing airport operations and elevating the passenger experience to new heights.

A smart airport is a modern and innovative concept that is transforming the way we travel. It leverages the latest technology and data analysis to streamline processes and enhance overall travel experience. In today's fast-paced world, where time is a valuable commodity, smart airports are playing a critical role in making air travel easier, more efficient, and more enjoyable. As of so it becomes important to analyse the implementation of a smart airport and innovative systems in current airports.

The study of Internet of Things (IoT) technologies applied to airport business operations offers an alluring opportunity to get insightful knowledge about the various advantages

and difficulties that technology may bring to the airport environment. The potential of such research is astounding, ranging from the game-changing effects of cutting-edge technology like biometric recognition and automated luggage handling to the challenging issues of efficiency, security, and passenger experience. It is possible to uncover a large variety of opportunities that can completely modify how we fly and experience airports by properly examining the vast effects of these technology interventions.

Investigating the digitization of airports presents an alluring opportunity to explore the relationship between technology, sustainability, and cost-effectiveness. By comprehending the intricate ways in which intelligent airports are mitigating their ecological footprint while simultaneously enhancing their financial viability, it is possible to learn important lessons about how this advanced technological innovation can be transposed to other sectors, creating a more sustainable and equitable tomorrow.

The prospect of scrutinizing the effect of technology on the labour force is an intriguing opportunity. The way the airport's staff operate has been fundamentally changed by the integration of innovative technologies. Hence it becomes conceivable to attain a thorough understanding of the skills that would be required in the forthcoming era of air travel, thereby guaranteeing that the employees are adequately equipped and primed for the upcoming technological revolution.

This way it becomes important to study this new form of operating airports as it provides valuable insights into the future of air travel. This study consists of an important step in shaping the future of aviation industry and ensuring its continued success.

1.2 Object and Objectives

The object of study of this dissertation will be the airport Beijing Capital International Airport (BCIA) located in Beijing, China and João Paulo II airport (PDL) located in Ponta Delgada, Portugal.

The main objective of this work is to investigate the importance of investing and implementing technology in airports and compare how different sized airports strategically leverage technological advancements to enhance operational efficiency, passenger experience, and overall safety. This main goal can be divided into specific objectives:

- Analyse how airports have grown, how improvements have been made overtime and the background behind the innovative technologies.

- Analyse and study the existing technologies in the airports and how they differ according to their budget and size.
- Exposing the impact of the global air industry's growth and analyse the advantages and disadvantages of implementing such technologies.
- Investigate and understand at what extent the implementation of these technologies is viable according to each airport's budget and size.
- Analyse the results and verify the impact this decision would have in passengers and employees.

1.3 Methodology

This study aims to examine document and bibliographic research on airport technology, security systems, and biometric identification processes. The methodology used in this dissertation starts with an extensive and meticulous literature review aimed at acquiring a more profound and nuanced comprehension of the present-day cutting-edge innovations in airport technology, security systems, and biometric identification. This review will include a vast diversity of resources, including but not limited to, academic journals, books, and online resources, to cast a wider net and amass a comprehensive knowledge base that will serve as a foundation for the rest of the study.

Following this a study is conducted on the João Paulo II airport and Beijing Capital International airport, providing valuable insights about the current technologies used in the airport, challenges faced by it, the current level of satisfaction with the technology and security systems and areas for improvement.
In Figure 2 it is possible to see the methodology used in this dissertation which is furtherly and minutely explained in the next section.

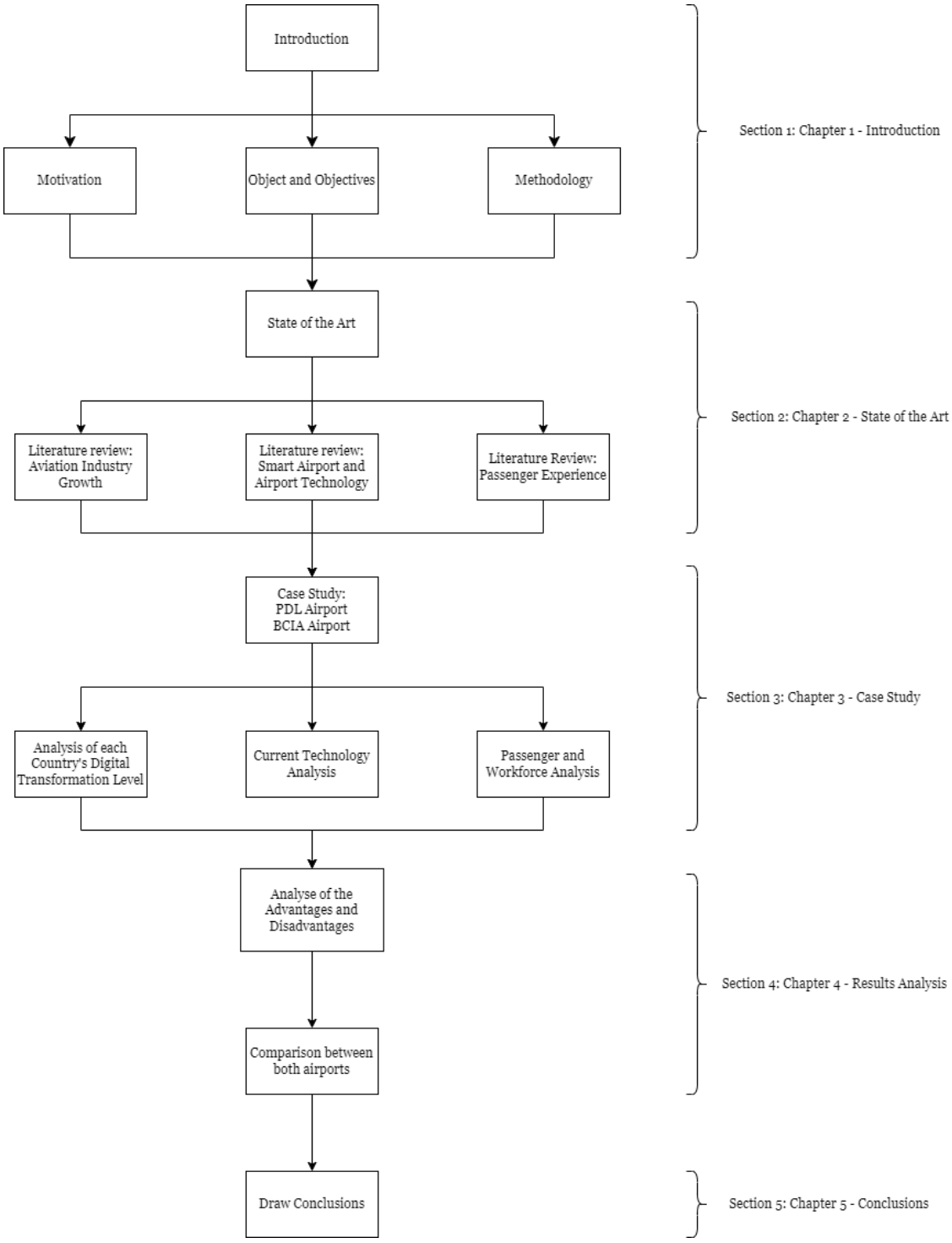

Figure 2 - Flowchart of the methodology utilized.

The flowchart above is divided in sections each one corresponding to a different chapter that will be explained in detail in the following segment.

1.4 Structure of the Dissertation

This dissertation is organized to provide a clear and comprehensive understanding of the research topic. It is composed of five chapters: Introduction, State of the Art, Case Study, Results Analysis, and Conclusion.

The first chapter begins with the motivation that has led to the choosing of the research topic, showcasing the object and objectives of the study as well as the methodology to be followed throughout the dissertation. In this chapter it is also displayed the work's structure.

The second chapter of this dissertation comprises an enthralling literature review, which accentuates pertinent theories, concepts, and antecedent research regarding the subject matter. This segment includes a meticulous examination of the existing knowledge, techniques, and practices, including an evaluation of their efficacy, limitations, and constraints. This chapter's main objective is to provide a comprehensive review of the current status of the discipline, explain the most recent innovations, and identify promising areas for more study and improvement. This segment delves into the intricacies of the notion of a "smart airport," the cutting-edge technologies utilized in current airports and their evolutionary trajectory over the years and makes suggestions for putting potential answers into action.

The third chapter introduces the different case studies and which technologies are currently implemented and a comprehensive description of the various airports is made. An analyse of the technological development of each country is also made.

In the fourth chapter, the results and data obtained from the previous segments were subjected to a rigorous review and dissection. Through a careful analysis of the advantages and disadvantages, a comprehensive evaluation was carried out and it was made possible to compare the different airports and see how size and different budgets affects the upgrades towards innovation and sustainability and how this has affected passengers and the overall community that utilizes these infrastructures. A comparison between the airports is also made analysing what airport seems to be at a more developed stance and what improvements could be implemented.

The fifth and final chapter summarizes the progress made thus far and offers final thoughts on the matter. A retrospection is carried out on the important aspects that have been covered and considerations are made for future work that would allow for a more thorough examination. Additionally, the chapter provides suggestions for areas that could be explored in greater depth in order to continue advancing the field. Furthermore,

recommendations are provided for future research projects that would build upon the work done in this study.

Chapter 2 - State of the Art

2.1 Introduction

This chapter delves into the evolution of airports, highlighting their transformation over the years and focusing on their future prospects. To better understand the current state of airports, it is essential to delve into the history of the aviation industry, including its impact on airport development. Understanding this history will provide an insight into the challenges and opportunities faced by airports today.

This chapter will focus on what makes a smart airport, including the digital transformation, industry 4.0 and its technologies. This analysis looks at how these technologies have been incorporated into airports to design a smooth flow of activities and provide a customized travel experience for passengers. It starts by explaining what and how transformation and evolution happen, what is industry 4.0 and digital transformation while also giving a detailed explanation on the idea of smart airports including the different technological issues like biometrics, robotics, data intelligence among others.

Ultimately, this section describes current initiatives related to a smart airport that are taking place in many airports. It presents current examples of technological improvements happening around the world.

2.2 Airport Evolution Through the Years

The aviation industry is one of the fastest growing industries in the world, having drastically changed and evolved since the first attempts at flying emerged during the late 19th century and the first successful flight occurred in 1903. The third technological revolution and both World Wars contributed to this rapid progress [2], [3].

Through the years, there have been numerous improvements relating to aircraft technologies and security developments. The aircraft invention in the early 20th century triggered the need to create an area where aircraft flight operations would occur whether they included air freight, passengers, or neither, and whether they were for public or private usage. This way airports were created as the field of aviation began to take off.

Originally, the main uses of aircraft were for military operations or as a sort of luxury amusement for the affluent. However, as commercial aviation developed, with the first commercial flight taking place in 1914, the need for airports to accommodate passenger flights on a larger scale rose. The first records of airports show that these were relatively

small and simple, and many were no more than grassy fields where aircraft could take off and land. One example is the College Park Airport located in Maryland, United States which is today considered the first airport in the US. Here was where Wilbur Wright first landed in 1909 to train two military officers for the US army. At the time a few hangars and a dirt runway were all that the airfield had [4].

Today, less than 200 years after its beginning, the aviation industry has become one of the main means of transportation for the average passenger moving away from the early occurrence when only the wealthy were able to fly. Nowadays flying is no longer seen as an extreme luxury, especially with the rise of low-cost airlines, flying can be as cheap as taking public transportation, which has led to a burst of traffic in airports. Airports are considered crucial infrastructures in the aviation industry serving as connection points between destinations all over the world and vital parts of global commerce. They are considered gateways to the global economy easing the movement of people, goods and services around the globe.

As aircraft evolve so do airports and the overall industry as a response to the growing demand for air travel. This prompted the development of new and improved technology, including more fuel-efficient engines and superior avionics, allowing airlines to fly longer, quicker, and more effectively than ever before. Airports have had to adapt to accommodate larger and more sophisticated airplanes, as well as the growing amount of passenger and freight traffic.

2.2.1 Brief History of the Aviation Industry and Airports

The first airports were very rudimental being compromised of simple grass runways where planes could take off and land. Airports were few and far away from each other in the early days of aviation, and a lot of flights were conducted from fields or other open areas. This changed with the outbreak of World War I when nations started to invest in the construction of airports after realising the strategic value of aviation. Airports improved in organisation and were given basic amenities like hangars and fuelling stations during this period. This allowed the military to conduct more efficient and effective air operations.

The 1920s and 1930s were categorized as a period of accelerated progress in the aviation industry. Flying technology evolved quickly, military and commercial aviation expanded greatly, and record-breaking and racing attracted media attention and popular interest [5]. It was not until the 1930s that the modern air transport business as we know it began to take root. The first commercial airports were established during this period to meet

the rising demand for air travel. These airports had modern infrastructures, including passenger terminals, control towers, and asphalt runways. After WWI aircraft construction transitioned from wood to metal to enable longer routes and travel along longitudinal lines where climates change from arctic to temperate to tropical to arid [6]. During these years systems like the Instrument Landing System, the first lighting and approach lights were developed [7]. This was considered the golden age of flight and the start of the golden years of air travel, although it was not the most pleasant experience but rather noisy and cold [8].

WWII and the invention of the jet engine led to another spurt of innovation in the aviation industry. During the second World War airports played a critical role in military operations and many were built or expanded to accommodate the need of the armed forces. After the war, the demand for air travel continued to grow and airports became an essential component of the global transportation infrastructure. Although having been conceptualised in 1939, mass-produced jet-powered flying was not made feasible until 1944 when the war was coming to an end [9]. As a result of this, paved runways were introduced to allow larger and heavier aircraft to land and take off. This type of runways made airports safer and more reliable which was a critical aspect of the growth of commercial flights. During this time airport lounges were created to provide a more comfortable and relaxing environment for passengers. Restaurants and shops also emerged in airports during this time. However, despite these improvements, the infrastructure still faced some challenges such as the lack of standardization in airport design and construction.

After the 1940s came to an end, the 1950s and 1960s were the first years of commercial aviation. This period was known as the Golden Age of Air Travel and Jet Set [8]. Air travel was still costly and only available to the wealthy and famous despite its enormous rise.

During the 60s and 70s airports had become more advanced. With jet aircraft becoming more popular runways were extended and new technologies emerged including computerized reservations systems, baggage handling systems, and advanced radar systems [7]. These developments made air travel more efficient and reliable, and airports became more important than ever. The Golden Age of Air Travel led on into the late 1970s up until the act of deregulation was installed in 1978 in the US. This also happened later in Europe which led to changes in the overall aviation industry including airports [10]. This process removed government control over air transport and promoted competition and efficiency in the European aviation market. These efficiency improvements

democratised air travel and increased accessibility for all people [11]. The deregulation led to greater competition decreased prices and increased innovation in the industry.

The last two decades of the 20th century were marked by the rise of airlines such as Virgin Atlantic and Ryanair that made flying available for ordinary people. During this time security was still very rudimental even though metal detectors had been previously introduced a decade earlier they were very simple compared to what they look like today. Restaurants and shops were not very common in airports and the experience of flying was comparable to riding the bus as arriving early at the airport was not something mandatory as there weren't prolonged security and boarding procedures [12]. In this period airport privatization happened and alliances between airlines started to rise.

The 21st century saw the emergence of low-cost carriers and technological improvements. The attacks that occurred in 2001 led to a big development in airport security. The airports become more efficient through introduction of advanced baggage handle technology, computerized checking in and other modernized techniques. Shopping and entertainment options were built specifically with visitors in mind, resulting in numerous airports becoming attractions today.

As a significant factor affecting change in the industry, sustainability has contributed greatly towards recent modern innovations in airport design. Airports are major sources of CO2 emissions and some of them have developed initiatives for environment-neutral impact. This implies creating energy efficient structures utilizing green materials and sourcing of clean energy through solar or wind power. In addition, the integration of technology for improved passenger experience has become another major trend in airport architecture. Such solutions include use of biometric technology for a speedy check-in process, smart airport systems enabling travellers to see their baggage on mobile phones and lead them about airport and so forth.

2.3 Airport Digital Transformation

Airports have been at the forefront of the tremendous digital change that has recently taken place in the aviation sector and have made significant investments in innovative systems and solutions to improve their operations and increase passenger happiness. As a result of the emergence of digital technology and the rising need for seamless travel experiences, airports are utilising a variety of cutting-edge technology to improve how they operate and serve their clients, from mobile check-in and baggage monitoring to self-service kiosks and biometric identification.

In this context, the concept of airport transformation has become increasingly important, and it involves introducing cutting-edge technology and modernising processes to improve airport operations and make them more user-friendly. In order to guarantee that existing business models and operational procedures meet the requirements and expectations of contemporary passengers, this process not only entails the adoption of new technologies but also requires them to be rethought.

2.3.1 Key Factors in Airport Transformation and Evolution

The above sections have examined some of the reasons which explain why there is a necessity to redesign and renovate airports. The main factors are the increased competition, shift in passengers' experience, and global economic trends.

Low-cost airlines and increased airport networks have intensified competition within the aviation industry causing the need for efficiency and cutting of expenditure within airports. Alongside that, currently, passengers demand a travel experience more personalised and with fewer interruptions which has resulted in the creation of new services and amenities in airports such as premium lounges and several restaurants and stores.

With the current state of the world, sustainability problem has also impacted airports and measurements have been implemented to reduce energy consumption and use renewable energy options. Besides that, five specific forces have been considered to be driving the airport transformation these being the externalization of airport profiles, internal focus on airport operations, increasing constraints due to regulatory and law enforcement requirements, changes in strategic and financial drivers, and technology [13].

The process of making information about airports accessible to external stakeholders or users is referred to as the externalisation of airport profiles. Airport operators can improve collaboration, transparency, and the overall travel experience for travellers and airlines by externalising this information. According to Wilson-Smythe [13], airports have become the focal point of entry of a region by visitors and the passenger experience does not solely resume to the time spent at the airport expanding itself beyond the boundaries of the facility. Efficacy and efficiency in the operations of a particular airport can be enhanced by managing and controlling the daily tasks and resource utilisation on the airport. Internal focus on airport operations involves a variety of departments and stakeholders working together, including airport operations, maintenance, security, and customer service. Travellers, along with the airport's workforce, spend a considerable

amount of time at the airport, as connections have been prioritized for their affordability The airports are also compelled to create a civic environment in response to the social and economic needs of their respective workers and passengers.

Regulatory and law enforcement requirements are becoming more restrictive, hindering the capability to run flexible airport operations. All of these aspects, including restrictions on security and baggage screening, runway safety, noise reduction, and the environmental effect of airport operations, have played a significant role in defining the landscape of modern airports. These have impacts on passengers both positively and negatively which itself produces both positive and negative consequences in the airport. As a result, airports must balance the benefits of meeting regulatory requirements with the need to provide a positive experience for their passengers [13].

Wilson-Smythe, [13], believes that economic challenges have been the consequence of changes in the configuration of airports whether it be in the business model or structure itself. Managing costs and generating revenue has been an issue in the current days as airports expand and become more modern their costs of maintaining and operating have increased. As a way, non-aeronautical revenue such as restaurants and shops have become important. These improve customer experience while creating revenues for the airports. New technology and state-of-the-art amenities have been invested in to compete favourably against other means of transportation which has attracted more travellers. However, these investments often require significant capital expenditures, which can be difficult to finance and sustain over time. Another economic challenge that is often related to this issue involves balancing against different stakeholders. Resolving the tension arising from the need to meet airlines, passengers and local community demands proves to be challenging.

Essential changes have been made as a consequence of the four forces described earlier however challenges among them occur and a solution to these is to integrate a fifth force, technology [13]. Technology has proven to be efficient and enjoyable and not only is it a way of entertainment, but it also decreases costs in airport operations. Over the years, airports have experienced digitisation that has led to improved efficiency, safety and customer experience.

The first aim of these five forces is improving the passenger experience, the airport operation, as well as non-aeronautical revenues' growth. These three drivers are considered as the critical transformational factors for an airport.

2.3.2 Industry 4.0 and the Digital Transformation

Technology has always been a key factor in society and its shape, and it has been the backbone of all the industrial revolutions the world has suffered throughout the years. The first industrial revolution came up in the 18th century and introduced the concept of mechanized power supplied by water vapour. Advances in sciences such as replacing steam power with electric energy, the emergence of mass production systems etc. were an important part of the second industrial revolution of the 19th century. The utilisation of nuclear energy, as well as the broad adoption of automation and computerization, brought in the third industrial revolution, occasionally known as the "digital age" [14], [15].

This ongoing fourth industry revolution was brought about by the rise of Industry 4.0. Instead of prolonging the third revolution, the arrival of a fourth is a consequence of three reasons: velocity, scope and systems impact which has led to an exponential evolution rather than a linear one as it had happened with previous breakthroughs [14]. It is an age that entails developments from the Digital Revolution and uses intelligent system to monitor, map, and respond to the operations in real time based on the digital world. With the progress made during the third Industrial Revolution, it has become feasible to establish network connectivity in systems that already utilize computer technology [16].

Industry 4.0 has the potential to deliver major advances in factory environments by utilizing technologies associated with automation and data exchange such as the internet of things, big data analytics, cloud computing, virtual modelling and simulation, cognitive computing, additive manufacturing, blockchain, cybersecurity, augmented reality, artificial intelligence and systems integration [17]. It has allowed the digitalization of manufacturing, and it is constantly associated with digital transformation as Industry 4.0 serves a subset of the broader digital transformation process.

The Industry 4.0 idea has proven to be one of the most important concepts in developing the global industry and the world economy as it presents itself as a logical continuation of the previous three industrial revolutions. Introduced in 2011 by Germany it led to the emergence of Cyber-Physical-Systems (CPS) as a way to establish automation in the industry, paving the way for smart factories in which production systems, components, and personnel can communicate with each other via a network, leading to nearly autonomous production [15]. The CPS integrates computing techniques, data transmission and processing, and modern mechanical systems, resulting in smart

factories that represent a new era of manufacturing by interconnecting systems, components, and human operators in a network, resulting in highly automated production processes [15], [16].

As stated by Drljača, Štimac, Bračic & Petar [15], this fourth-generation industry, products and processes are intelligently networked across the supply chain by using cutting-edge information and communication technology. This attempts to improve the production of goods and services and optimise organisational processes, eventually giving customers cutting-edge goods and services that satisfy their demands. The main goal of this concept is to improve production and efficiency while maintaining a great quality service with better maintenance and cost reduction.

Digital Transformation (DX) has been a reoccurring concept over the past two decades. As the world evolves and new technologies emerge the need to implement them in current business models, corporations and infrastructures also rises [18].

Digital transformation refers to a process where an organization applies digital technologies in different areas of a business or organization [19]. Its main objective is to integrate the technologies linked with Industry 4.0 across all segments of the business. It is considered a change in mentality that corporations are using to solve problems such as drops in development, productivity, effectiveness, and efficiency. Organizations undergo structural change as a result of this transformation, which leads to cultural and operational changes that better meet consumer needs and keep them competitive in a rapidly evolving technology environment [19].

According to Accenture [20], the process is often associated with digitization and digitalization. The first concept corresponds to the conversion of analogue data and information into digital forms, such as when a photo or document is scanned and saved on a computer. This stage is the most rudimentary, yet it is the most crucial for digital transformation. On the other hand, digitalization is the application of digital technology to alter corporate operations and initiatives, such as training staff members to use new software platforms intended to hasten product launches. While initiatives for digitalization may be included, digital transformation affects the entire business and goes beyond projects.

Digital transformation comes down to four key factors these being: technology, data, process people, and organizational change capability [21]. Employing technology in systems and processes acts as a driving force for digital transformation, and it is the primary factor behind the changes that are presently occurring. Businesses can reduce

their costs, use less time to implement work processes, and make unprecedented achievements through integration of technology [21].

In the past, data was generated primarily within a company and mainly utilized for making decisions and predictions. Nowadays data is generated in an unprecedented amount whether it be through conversation, interaction, and process, both within and outside of an organization. However, this data is often unstructured, which presents a significant challenge in terms of comprehending its significance. As stated by Davenport and Redman [21], the current state of data does not meet the basic requirements, and the demands of the transformation process require a substantial improvement in data quality and analytics. This requires organisations to take on roles as data customers and creators to improve their work processes.

To succeed in this digital transformation, it is necessary to rethink the ways to attend to the customer's needs and maintain work activities constantly connected. However, a significant number of individuals have encountered difficulties in reconciling process management, which involves a horizontal approach across silos and a customer-centric focus, with the traditional hierarchical thinking prevalent in many organizations [21]. The organizational change capability domain includes topics such as leadership, teamwork, courage, and emotional intelligence and its purpose is to reinvent the whole organization or internal culture to shift the focus to the customers [19], [21].

The introduction of technology is not a monolithic process, and the digital transformation process can be divided into four types these being: business process, business model, domain, and cultural/organizational (Figure 3) [22].

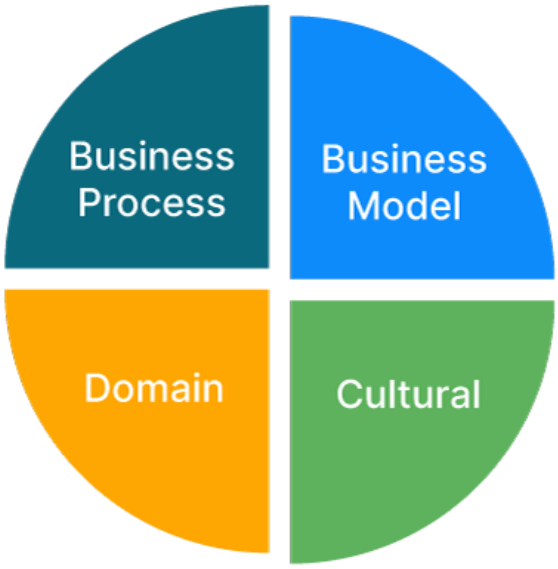

Figure 3 - Four Types of Digital Transformation [23].

The business process analyses innovative ways to improve internal and external workflows. Most times new technologies change and improve processes radically in order to achieve a greater level of effectiveness and efficiency [24]. This type of transformation entails a comprehensive evaluation of the current processes and systems, intending to identify opportunities for enhancement and implement modifications to more effectively attain the organization's goals [24]. Using technology as a way to change the business process can be done by implementing workflow automation software or adopting cloud-based systems to digitize paper-based processes.
According to Vaughan [24], digital technologies are being used as a way to transform the traditional business model. The main aim is to provide essential business services in new ways or through different channels in order to increase revenue growth and expand the customer base. These kinds of innovations can be currently seen in numerous day-to-day applications such as Netflix, Apple and Uber. These three majorly known companies reinvented how video is distributed, and music is delivered (iTunes) and altered the taxi industry.

The existing market for domain transformation presents one of the most substantial prospects for company expansion. The successful transition of a company into a different industry is commonly referred to as a domain transformation and implementing technology has made this expansion easier and more profitable. A great example of this is the domain transformation that happened with Amazon. The online retailer expanded into two completely new domains: Amazon Web Services (AWS) and the Amazon Prime streaming which have resulted in excellent revenue growth and market dominance in their respective services [23].

The cultural or organizational transformation aims to completely alter all internal cultures and organizations to be more agile, innovative, and digital-first while focusing on providing the highest value to customers. It is the best way to anticipate and stay ahead of the competition and attain business goals quicker. To accomplish a thorough and long-term digital transformation, the organization's mindset, procedures, skills, and capacities must be redefined to fit with the digital world [19]. This may require building cross-functional teams, employing digital expertise, or introducing new digital training programmes for staff.

According to Mai [23], even though digital transformation is not an easy process it is imperative for companies striving to remain competitive. It entails a comprehensive overhaul of the company's operations from the ground up, evaluating and improving every part of the organisation in order to stay up with the rapidly expanding digital

environment. Incorporating digital transformation allows corporations to grow their business since the benefits that come with this outweigh the costs. Benefits such as improving productivity and customer experience and lowering operational costs.

2.3.3 Airport Digitization

As the concept of Industry 4.0 rises the need to incorporate it into different industries also emerges. Incorporating digital transformation into airports is no different than what was described before. Digital technology allows airports to implement an array of opportunities and ways to differentiate from competitors. It has had a significant impact on airports, revolutionizing the way passengers and airport personnel interact with technology and becoming a key factor in airport operations. The concept of a smart airport has emerged as a result of implementing digital technology to connect various airport processes and systems to create a seamless, integrated experience for everyone in the facility.

As stated by Mann [25], compared to other industries airports have been slower when adopting digital technologies. This was mostly attributed to the fact that airports depended heavily on aeronautical revenues which nowadays does not happen. In recent times, non-aeronautical revenue has gained momentum, and passengers have become an increasingly important customer segment. This shift has propelled airport digital transformation to become more sophisticated.

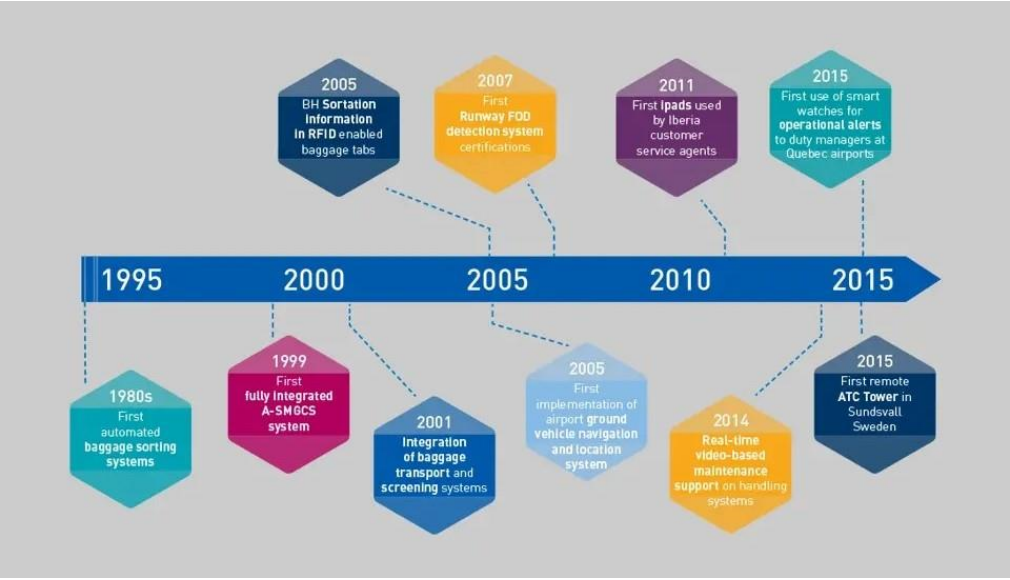

Figure 4 - Evolution of the Digital Transformation at Airports: Internal Airport Processes [25].

During the 1990s, some first digitization efforts include introduction of the first e-ticket by United Airlines in 1994 and opening of kiosks by Continental for self-check-in in 1995

(Figure 4 and Figure 5). Alaska Airlines first introduced the precursor to online check-in in 1999. Electronic tickets were introduced into the aviation industry in 2008 marking a major breakthrough leading up to the introduction of mobile boarding passes by Continental the same year. In 2011 various enhancements were done including holographic announcements at Luton airport, self-boarding at the Vienna airport, self-check-in for checked bags at the Amsterdam airport, and the introduction of electronic tags by Qantas. In 2014, the Helsinki airport implemented a passenger flow management system. These developments demonstrate the importance of innovation management and information technology on the global economy, particularly in the pandemic and post pandemic periods [26].

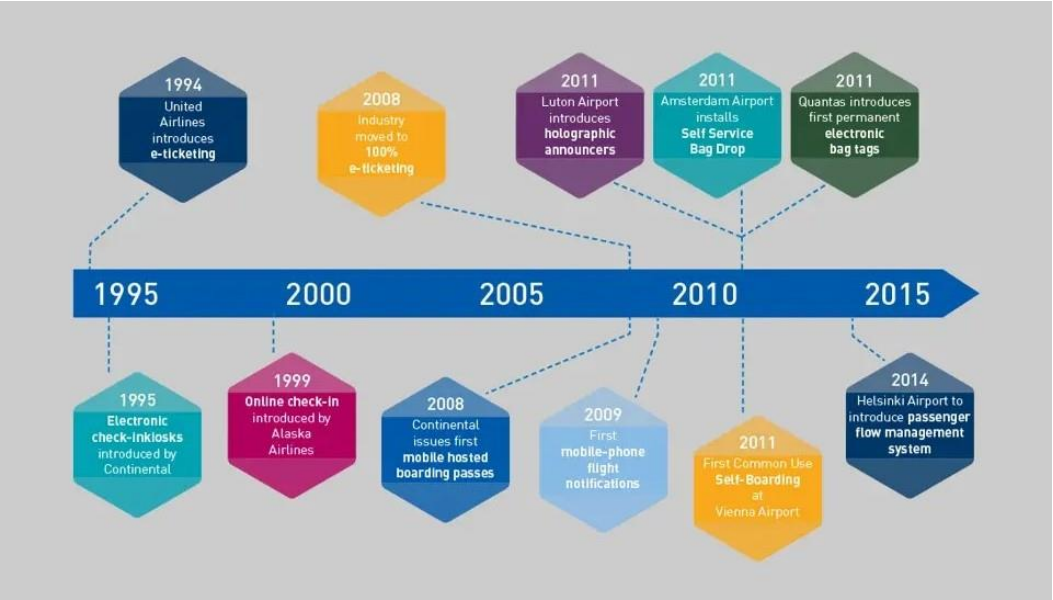

Figure 5 - Evolution of the Digital Transformation at Airports: Passenger Processes [25].

As described by Mann [25] , the introduction of digital marketing and the creation of airport websites and e-commerce platforms began the airport digitization journey. Subsequently, mobile applications were developed, some of which were interactive and featured on social media channels which has helped to communicate and manage customer relations. Today, digital content is sourced from airport partners or retrieved from a centralised database. Alternatively, marketing teams create content that is disseminated through online and mobile media to third parties.

In today's airports the main areas that are leading the digital transformation are those in Table 1.

Table 1 - Key areas at the forefront of digital transformation in leading airports [27].

Digitization Area	Transformational Objective	Digital Transformation Benefits
Passenger Journey	• Maximize the time spent in shops and lounges vs. waiting in a queue for dropping luggage or getting a boarding pass.	• Push real-time travel information to passengers to help them anticipate changes to their journey. • Guide the passenger throughout his or her travel journey via a smartphone. Increase level of self-service to save time and avoid queues
Operational Efficiency	• Streamline processes to achieve better efficiency in ground activities, i.e., security, ground handling, runway and maintenance operations. • Reduce operational risks causing potential delays or incidents.	• Automate ground activities, including luggage management and security checks with potential for automated runway activities over the longer-term. • Automate proactive measures for irregular operations (caused by weather, political events, technology outages by carriers, etc.) with right use of AI platforms. • Monitor operations in real time to quickly deal with issues and anticipate incidents. • Optimize preventative maintenance leading to cost savings.
Retail, ancillary revenue	• Maximize revenues generated through travel retail. • Optimize the use of valuable space at the airports.	• Proactively push commercial information to customers, e.g., special deals or tailored offers. • Optimize retail space to increase revenues, e.g., using digital walls to order duty-free products. • Introduce new retail possibilities, e.g., online order and pick-up at the airport

According to Nau and Benoit [28], airport digitization is not something brand new having occurred in waves since the advent of the Internet under the pulse of airlines. In the 80's, airlines and ground handlers wanted to share IT resources at the airport as a way to cut down on the costs associated with the launch of new routes, especially for seasonal or charter flights. Airports were also having trouble locating additional space for check-in agents since it was getting more and more expensive for operators. The idea of CUTE (Common Use Terminal Equipment) was introduced and it allowed for a large decrease in the space needed to build check-in booths. Additionally, it made it possible for the airport and all the airlines utilising the desks to split the expense of the investments. This CUTE deployment led to the first wave of digitization beginning in the 1990s and 2000s which was then followed by the introduction of self-service check-in in 2003, emerging here the concept of CUSS (Common Use Self-Service). Just like CUTE,

CUSS had many advantages such as asset optimisation and greater flexibility, a reduction in process time and an increase in throughput, a free-flowing terminal, benefitting all airlines/airports by contributing to passenger satisfaction. This allowed operators to be more resilient as well as it created the opportunity for future growth.

The development of CUPPS (Common Use Passenger Processing System) was introduced by the International Air Transport Association during this second wave of digitization in 2009. This system aimed to enhance the efficiency and management of airport and airline operations, systems, and services by providing shared systems that can be used by both. CUPPS is a protocol for airline interface specifications as well as services and standards that allows different service facilities to link on common-use systems as well as equipment situated at airport terminals. Previously, airlines relied on their designated technological systems, such as check-in counters and luggage systems [29].

The third wave started in 2010 and involved the installation of self-service options across various stages of the airport's customer journey, including baggage drop-off, border control, and boarding. Unexpectedly, the fourth wave of digitalization began in 2012. The outstanding performance of tech giants like Google and Facebook, who brought the ideas of open data and big data to the technology sector, helped to fuel this wave. A small number of airports worldwide have adopted this most recent wave of digitalization, despite it still being in its early stages [28].

For digital transformation to succeed in the airports, all the stakeholders like airlines, government agencies and the passengers need to collaborate. These acts require collaborative measures between all players geared towards enhancing security, efficiency in operations, and customer services on part of other players. Digital transformation must be well planned for it to succeed. It should also include great leadership, as well as change and creation readiness [28], [30].

2.3.4 Digital Maturity of Airports – Airport 1.0 to 4.0

These four waves contributed to different airports adopting technologies at different rates which led to the creation of the concept of digital maturity. Digital maturity refers to the level of technology adopted by each airport and since there are four waves of

digitization it led to the emergence of 4 different types of airports these being Airport 1.0, Airport 2.0, Airport 3.0 and Airport 4.0, as seen in Figure 6.

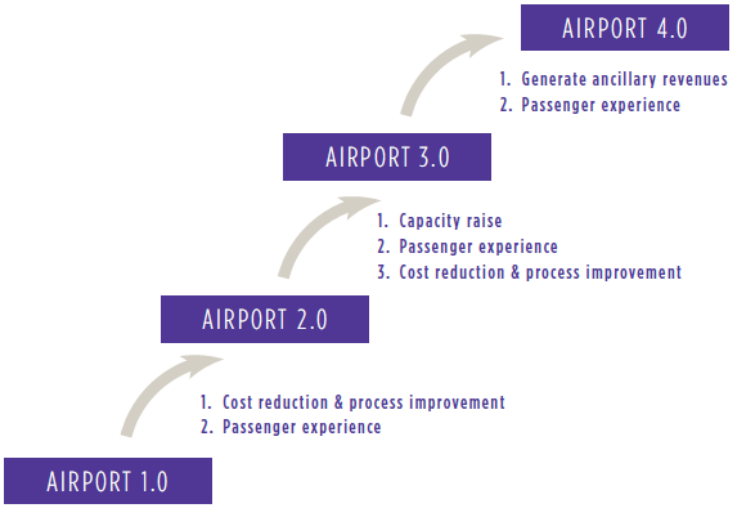

Figure 6 - Airport 1.0 to 4.0 [28].

Airport 1.0 is considered a traditional airport where mainly manual processes are employed. Basic IT solutions are applied such as CUTE or basic management resources. According to Nau and Benoit [28], attention to the passenger's needs is not the main priority as they operate as business-to-business (B2B) entities without promoting any services directly to the passenger. The main focus of these airports is to ensure the safe execution of aircraft operations such as take-offs, landings, and refuelling [31], [32]. As of so, these airports offer crucial services such as cargo transportation, passenger boarding, security measures, luggage handling, and more.

The next stage of digital maturity, Airport 2.0, is mainly characterized by the massive deployment of CUTE. Partial self-service is adopted however it is very limited to just the check-in process and Wi-Fi technology being implemented in these airports [28].

The third version of airports, known as Airport 3.0, places greater emphasis on self-service and utilizes mobile technology and cloud/web-based systems. During this stage, all aspects of passenger services at the airport are equipped to offer complete self-service by utilizing fully automated processes [33].

Big data and open data are used by the idea of Airport 4.0 to spur innovation and boost operational effectiveness. Airlines can use real-time data to measure passenger flow and characteristics of passengers at the various airports. This stage is characterized by the digital transformation process where many intelligent technologies mainly associated with the Industry 4.0 concept are deployed. The airports within this stage perceive a

change in their operations, as they are transitioning from a business-to-business focus to a business-to-consumer (B2C) approach making the consumer the main focal point of the operation [28].

The shift between the different levels of digital maturity, as seen in Figure 6, is mainly derived from challenges presented by the industry whether they be a reduction in costs, improving efficiency and processes and focusing on the passenger experience.

2.4 Defining the Smart Airport

According to Alabsi and Gill [34], a smart city is defined as a combination of six smart characteristics: economy, people, living, government, environment, and mobility.

The concept of a smart airport emerges as a subsystem of a smart city and its definitions are not commonly accepted. Both a smart city and a smart airport are the result of Industry 4.0 and the implementation of its technologies. The use of technology in smart cities strives to provide a comfortable and sustainable urban environment. This includes the integration of urban transportation management, air traffic control, and airlines to facilitate the exchange of information related to aircraft movements and urban life. The primary goals are to maximise individual procedures and airport operations while also assuring customer satisfaction [35].

Within the airport operations context, Industry 4.0, refers to the combination of contemporary Information Communication Technology (ICT) with traditional operations such as aircraft handling, baggage handling, passenger management, and cargo handling operational processes [15].

Figure 7 - Representation of a Smart Airport [36].

Defining an airport as a smart airport is a challenge, as this concept lacks a clear set of measurable criteria. However, it is commonly associated with airports that have adopted the most advanced technological solutions, as seen in Figure 7, a possible representation of what a smart airport is. It is important to note that even airports currently considered smart may not implement every technology associated with Industry 4.0 and may not fully align with the ideal concept of a smart airport. Nevertheless, given that the concept of a smart airport is still evolving, every step taken towards its realization is valuable.

An airport plays a significant role in globalization by facilitating the movement of people and goods, which in turn has a direct economic impact on regional development. As of so and due to the exponential growth in the number of passengers each year, airports have consistently been at the forefront of technological innovation, requiring modernizations in airport infrastructure to keep up with the demand.

Some important definitions of a smart airport include the one from European Union Agency for Cybersecurity (ENISA) which states that a smart airport leverages networked data-driven responses and automated services to enhance the passenger experience throughout their trip [37]. Another important definition is that a smart airport refers to an ecosystem that employs effective solutions for its components, including passengers, airlines, airport, and cargo [34], [38].

According to Qi and Pan [39], the concept of a smart airport is based on Humanism and Online-to-Offline (O2O) mode. In the civil aviation business, Humanism aims to please both customers and employees by offering a pleasurable travel experience and a productive workplace. The O2O mode, on the other hand, aims to establish a successful fusion of offline and online airports. In this configuration, the offline airport offers individualised assistance to travellers, while the online airport offers all relevant digital information and assistance services.

As stated by to Drljača et al. [15], a smart airport is considered a complex structure made of smart structural elements such as Mobility, Logistics, Infrastructure, Services, Equipment, and Grids:

- The term mobility refers to the sustainable movement of passengers, staff, and other guests through the airport. This involves utilizing various modes of transportation such as subways, railways, bicycles, and electric cars to ensure the quickest route possible. Additionally, adequate access roads and parking facilities must be available to accommodate demand.

- The concept of smart logistics is associated with the services and goods required for airport operations, and routes that connect airports with cities in the vicinity and the wider geographical area. All these elements are based on smart technologies.
- The infrastructure of a smart airport comprises sustainable management of several operating areas, including a passenger terminal, runway, apron, and other areas, using ICT. This sustainable management approach applies not only to the passenger infrastructure but also to the cargo infrastructure, including the warehouse, access roads, parking lot, exit to the parking lot, and other areas.
- Smart airport services automate the business processes of handling aircraft, passengers, cargo, and mail during all phases of the airport operation while minimizing the workload of the airport's operational staff.
- Smart airport equipment aims to reduce physical human labour, speed up airport operations, and minimize negative impacts on the environment.
- In order to merge and allow the structural elements enumerated before to function well together it is necessary to also create smart airport grids.

2.4.1 Smart Airport Enabling Technologies

Digitization has changed the airport sector in ways that go beyond just enhancing the traveller experience. There has also been a significant transformation in the way airport management operates behind the scenes. Airport management systems have been upgraded to ensure a seamless experience for passengers.

The technologies behind the concept of a smart airport are the main technologies associated with Industry 4.0. As stated by Pell and Blondel [30], these technologies can be divided into three groups according to their level of priority. The first group, also known as core enabling technologies, includes technologies such as big data, advanced analytics and cloud technology that were the main denominators in the transition from the second to the third stage of the airport's digital maturity. These technologies will continue to be the primary focus of airport digital strategy, highlighting the fact that big data and cloud technology applications are versatile and can add value to various aspects of airport business operations.

Airports now have a compelling need to increase operational effectiveness and efficiency. Process and automation, which includes four important technologies, is the second category of technology driving this necessity. These technologies include the Internet of

Things, technologies geared towards increasing the automation of core airport processes, the introduction of solutions based on integrated ecosystems and mobile value-add. These technologies will lead to the breakdown of organizational barriers and improve data exchange, both in human-to-human and human-to-machine interactions [30].

The third group, fringe technologies, includes augmented reality and autonomous transport systems and it is not considered a priority in technologies to adopt by airports. Based on a representative sample of airports, investment in alternative digital technologies is anticipated to take precedence in many instances. This is because chances for using particular technologies, like blockchain, in the early stages of exploration for airport-specific applications. While some established international hubs might prioritise certain technologies, many airports might not [30].

The main technologies that have been considered the backbone of the digital transformation and the most important in airports have been big data analytics and the IoT [28], [30]. However, it is imperative to explain these technologies and others before elucidating their potential integration into airports.

2.4.1.1 Internet of Things

The Internet of things refers to a web of interconnected objects which have the ability to communicate among themselves using the Internet, for example, starting from low-end sensors up to mobile phones and tablets. It is a contemporary wireless telecommunication paradigm that is currently gaining popularity [40].

The IoT is fast penetrating various fields, creating new opportunities, and becoming a powerful weapon in competition as, both internal and external, improvement is the priority in all sectors. The growth of the IoT is expected to progress as more items join this system and more applications develop [40].

A notable advantage is that the IoT links the web with real life, thus enabling users to see, talk, monitor and trace real issues. As a result, these capabilities have facilitated the development of innovations like smart energy management, intelligent transportation systems, and remote health monitoring [41]. This is a crucial aspect that makes it applicable to smart airports.

The benefits associated with application of IoT technology in smart airports are based on its ability to bridge the gap between the virtual and the real worlds by enabling tracking and interactivity with the real world objects. Nevertheless, among all smart airport application technologies listed, that of the IoT is presently the biggest one that will

remain relevant now and in the nearest time. It functions as many of the underpinning framework where on majority airport transformation infrastructure will develop.

2.4.1.2 Big Data

The term big data has become extremely prevalent however it still lacks a formal definition format. It mainly refers to extremely large datasets that are too complex to be processed by traditional data processing techniques. These datasets can come from a variety of sources such as social media, scientific experiments, financial transactions, and sensor networks [42].

Big data is a result of the digital transformation process most importantly the digitization phase of the process which has led to the mass digitization of countless paper format information into a digital, machine-readable format [42].

The concept of big ata is related to 3 factors these being velocity, volume and variety [42]. The sheer volume of data that has to be processed is referred to as volume. The term velocity describes the rate at which data is created and must be processed and variety describes the various sorts of data being produced, including text, photos, and videos [43].

According to Krishnan [44], effectively handling and processing big data is one of its main difficulties. New technologies and techniques are required for the provision of processing for big data as is not possible in the conventional case because of their volume and complex nature. Therefore, Hadoop and other big data systems were born out, allowing to process gigantic data sets across multiple computers.

Through its analysis, big data can be a source of worthwhile information in various disciplines including business, medical and research. Using big data, one is able to ascertain hidden patterns that may otherwise go undetected by conventional data collection tools.

2.4.1.3 Cloud Technology

Cloud computing technology refers to computer services that are transmitted on the internet or the cloud. In essence, it is a collection of networks [45]. This is a system designed to allow swift access for a user sharing pools of reconfigurable devices such as routers, switches, IP address, servers, networks, software and storage facilities. It provides simple and fast on demand network connections. Cloud computing also ensures quick services which do not entail many efforts by the user [46]. Customers can rely on these services anywhere as long as there is an internet connection and only pay for what

they use. This paradigm is commonly used in numerous fields as well as applications ranging from a simple use at home level up to commercial systems, providing benefits including scalability, flexibility, and relatively lower development costs.

According to Kim [47], the flexibility of cloud computing is one of its main advantages. Instead of investing in expensive equipment, users can just pay for what they use. This simplifies scaling depending on need and goes hand in hand with business that have changing demands. This will therefore enable the remote workers and the remote teams to access the required resources or information from any place thus enhancing productivity. Scalability is another advantage of cloud computing. Moreover, since cloud providers have an overflow of resources, they can increase a customer's processing power and storage on demand. By comparison, upgrading traditional on-premises systems could also be costly and consume a lot of time.

2.4.1.4 Artificial Intelligence

Artificial Intelligence (AI), one of the most popular technologies associated with the Fourth Industrial Revolution, refers to the use of computer systems to mimic human cognitive processes and its applications include expert systems, machine vision, speech recognition, and natural language processing [48].

The goal of artificial intelligence (AI), a branch of science and technology, is to create intelligent robots and computer programmes that can carry out jobs that traditionally demand for human intellect. To execute at a high level for their assigned responsibilities, these systems rely on external data, such as big data. AI essentially allows machines to learn from data and make judgements based on that information by mimicking a variety of tasks that people can accomplish [49].

Similar to the aforementioned technologies, AI lacks a precise definition. Some consider it to be the automation of cognition or that it is the social and cognitive phenomena that enables a machine to socially integrate society to perform competitive tasks requiring cognitive processes and communicate with other entities by exchanging messages with high information content and shorter representations [50].

In compliance with Learning Outcomes of Classroom research [49], Artificial Intelligence has become increasingly popular since its applications are very vast including areas like engineering, manufacturing, security, medicine and a variety of others in which prediction, control and decision-making applications are needed. It has facilitated the swift dissemination of knowledge with minimal associated errors, enabling timely decision-making.

It is considered to become one of the most disruptive technologies in the next decade as advances in computational power, big data, IoT, machine learning (ML) and deep neural networks happen [51].

2.4.1.5 Robotics and Automation Technology

Automation and robotics can be interrelatable however they are certainly not the same concept as robotics is one method for achieving automation, but many other kinds of automation do not necessarily involve robots.

Robotics is an emerging field that involves the programming of machines to perform tasks [52]. The branch of engineering develops and applies various technologies for creation of the programmable machines designed for automatic work performance and/or controlled activity based on user's action. These fields include mechanics, electronics, and computer science combining to form robots that perform complex activities [53] .

However, automation is the adoption of technology to carry out functions which are usually done manually. This can be achieved by means of automation that could range from simple devices like motors, to sophisticated systems, which are equipped with artificial intelligence and data manipulation [54].

2.4.1.6 Beacon Technology

According to Stein and Urbanski [55], beacon technology dates back to ancient times where beacons were used for long distance signalling via fire or lighthouses. Initially, beacons were based on Bluetooth technology that later evolved into BLE or Bluetooth Smart. These essentially comprise of wireless-small sized devices using BLE to send signals to close by smart gadgets. Beacons can detect the presence of other devices within their range and can send information to them, such as location-based notifications, advertising messages, or other relevant data.

At present there are two types of the software protocols – the App based iBeacon protocol and the Browser based one called Eddystone. To work with beacons both of these protocols require the recipient to have enabled Bluetooth [55].

Businesses often take advantage of this technology for proximity marketing by targeting consumers within a particular area with promotional messages via beacons. Beacon technology can also be employed in indoor positioning systems, and it helps the users in navigating through complicated indoor settings like an airport or a shopping mall. This encouraged increased investment on beacons and BLE, since GPS could not be relied at

home and offices [55]. Besides, beacons can also aid in tracking equipment or products' location and conditions through real-time monitoring.

2.4.1.7 Blockchain Technology

Blockchain technology originally emerged as the design underpinning the operation of the digital currency Bitcoin [56]. Blockchain allows reliable financial transactions and made it possible to build a globally functional currency relying on code. Today, the use of blockchain technology goes beyond digital currency as it is currently applied in simple authentication of digital identities to highly automated multilayered payment procedures through advanced smart contracts [57].

As stated by Al-Saqaf and Seidler [57], blockchain is a distributed digital ledger or accounting book. Here, the members' (nodes) transactions are recorded in a secure database through the use of strong cryptography mechanisms, which negates the necessity of relying on banks or attorneys for confirmation of value transfer or contract completion. Each full node has a copy of the database and the features of blockchain make it impossible for a node to tamper with or fake the content of the database. The design involves a mechanism for collective consensus and mining verification with a proof of work in order to ensure consistency across all copies of blocks as well as prevent contradictory versions from being formed.

Decentralization, transparency, equality and accountability on the internet can be enhanced by blockchain [57]. The strength of blockchain lies in the manner in which they store data such that no point can easily be hacked [58]. Even though it is still a fairly new technology projects have been developed to expand blockchain's application into three main fields these being: digital payment, contracts and electronic records and data keeping [56].

2.4.1.8 Biometric Technology

By its turn, biometrics refer to modern methodologies of human identification using their measurable physical characteristics like fingerprints, voice, and iris, physiological (such as heartbeat or brainwaves), or behavioural (such as voice, handwriting, or gait) [59].

As mentioned by Teodorović [59], seven variables determine the reliability and accuracy of any biological trait employed for forensic identification. In this regard, these parameters include universality which defines the trait as common among the members of a population; uniqueness which establishes the fact that the characteristic is not identical across all people; permanence which requires the characteristic to endure

beyond time span; measurability which implies the ability to collect, digitize, and process the trait; performance, which relates to the accuracy of recognition; acceptability, which depends on individuals being willing to present the trait for identification purposes; and circumvention, which considers the ease with which the trait can be forged or circumvented.

Biometric measures are mainly linked to security processes, but they have also been used in different sectors like health, banking, and even entertainment. This type of technology is being applied more often now for the purpose of improving effectiveness, convenience, and consumer satisfaction in many industries. As such, it now constitutes a recurring technological pattern in smart airports.

2.4.1.9 Augmented Reality

Augmented Reality (AR) can be defined as a technology that augments the user's view of the real world with information and virtual objects created by a computer. This is done mainly by using cameras enabled devices like headsets and smartphones that superpose virtual information on what the users get to see in his/her view of the real world. These virtual objects or information are interactive and responsive enabling the users involve themselves in real time. Some of these practical areas are games development, educational learning, advertisement, virtual hospitals or medicine [60].

It is considered a variation of a Virtual Environment (VE) or Virtual Reality (VR). However, VR technologies offer a fully immersive experience by transporting users to a synthetic environment where they cannot see the real world while AR uses digital or computer-generated information and overlays them in a real-time environment [60].

Despite being dated back to the 1950s AR is just now becoming a reality [60]. According to Kipper and Rampolla [61], AR's biggest potential is in democratizing access to information. Presenting interactive data in a geospatial framework can improve training and learning.

2.5 Implementation of Smart Technologies in Airport Operations

Although these technologies are in the early stages of development, the question that rises is what could be the process of incorporating them into airports to move them a step towards the idea of a smart airport.

Passengers' activities in the airport could be categorized into processing activities and discretionary activities. Processing activities refer to those actions which would be

directly in line with the legal and regulatory conditions for boarding a given flight. They include registering for the flight, finishing any required departure documentation, passing through several identity and security checks, and then boarding the aircraft at the gate. Any activities outside this category are considered discretionary [62].

Incorporating technologies into both types of passenger activities and airport management is a hard and long process however the benefits they bring, such as increased security and operational efficiency, the optimization of limited resources and passenger convenience are all that make the concept of a smart airport so desirable.

2.5.1 RFID Tags, Self-tagging, Automated Baggage Drop-Off and Lost Luggage Kiosks

A smart airport typically employs IoT technology which provides means for efficient management of flow of passengers and goods in or out of the airport during normal operation and operational disturbances [63]. Wide-ranging impacts that are associated with the IoT have a great promise for the aviation industry. This would help reduce the time spent during travel, improve security as well, passenger's safety to a great extent [64].

Enabling technology for IoT involves RFID tags, especially for baggage handling purposes. It uses several interfaces for remote monitoring [35]. With RFID communication technology embedded in information systems, information can be transmitted wirelessly for identification as well as tracking of objects without deploying physical devices. It is an automated process which uses centralized database for ease of management of information within the supply chain [64]. The tracking system operates by attaching a tag to the object that needs to be monitored. This tag contains crucial information about the identity and location of the object and the wireless reader then receives and records this information from the tag. RFID readers detect these objects by emitting electromagnetic waves that surround the movement of the objects [65].

When the RFID tag enters the zone of the RFID reader it sends out electromagnetic waves to power the tag. Subsequently, the tag delivers data and the information it stores to the reader. Next, the collected data by this RFID reader sends it to a centralized database for verification purposes. Precision and natural tracking of the physical world is attainable through RFID technology [64].

In airport scenario RFID tags are mostly used in the check-in processes, majorly applied when labelling a passenger's luggage for tracing its movements and also notifying the owner if their bags have been loaded or unloaded from the aircraft. According to Qazi,

Vivero and Elmirghani [66], they can also be attached on boarder passes and enable location of passengers for efficiency in airport operations.

The RFID tag would be used after checking in so as to record the passenger's information like the flight number and details of the origins and destinations among many others. Furthermore, it is used to track lost luggage and can follow passengers that haven't made it to their departure gate. For example, the RFID tag can be incorporated into a boarding pass or a luggage label [63].

RFID tags can integrate supplementary information, such as the manufacturer and type of product, and can even monitor environmental conditions like temperature and with them, airports can reduce the risk of mishandling baggage [35].

As technology is evolving, automated operations are gaining popularity in airlines including the use of self-service processes which has been integrated to improve on saving time and cut on costs as it also offers convenience for all passengers. Passengers tag their bags by printing tags at home or at designated kiosks at the airport [67]. By doing this, queues at check-in counters are eliminated, and passengers get to learn about the baggage status using their cell phones. Airlines or ground handling agents may have to change the flight or off load plans. As a result, they use the digital bar code and update it remotely to reflect this change [35].

Smart airports are installing automated baggage drop off systems and combining them with the tagging process. Passengers drop their bags into specially dedicated machines at departure terminals, hence checking in their luggage faster but without the help of airline's personnel. It takes less time thus reducing traffic around the airports and ensures that this luggage is secure for them.

The RFID technology can also be utilized to solve the lost luggage problem and is usually connected to WorldTracer, a global database for lost luggage maintained by SITA [67]. Furthermore, this arrangement allows for reduced staff and operating costs since it is considered a self-service procedure that runs for twenty-four hours [68]. To report a lost bag, the passenger scans their boarding pass, describes the missing item and what it included, and enters contact details for the delivery for when the luggage has been found [35], [67].

2.5.2 Advanced Analytics in Baggage Handling

Performance related contractual agreements between ground handlers and air carriers will be successful only when accurate, and consistent data is available about the speed and efficiency with which baggage gets handled. This includes measuring luggage

delivery times, processing times, and accuracy of baggage processing, such as the delivery of the first and last bags. Secondly, ground handlers keep track of operational baggage flow and use simulations and models to analyse past information and system processes [67].

Robotic arms that prioritise space efficiency and the handling of large loads can be used to load and unload luggage as another approach to introducing technology, particularly IoT technology, into the baggage handling process [32].

2.5.3 Smart Check-in and Self-Boarding

Check in procedures are fundamental for maintaining effective operations, as well as an exceptional passenger experience for airlines and airports. From the viewpoint of travellers, check-in processes are associated with lengthy wait times and complex procedures at airports [69].

Several other options besides desk check-ins at airports have evolved over time. Whether it be online using the web, mobile phones or self-service check-in methods at the airport by utilizing computer-based kiosks or as what happens in the Zurich airport where passengers can also check-in by phoning the airport and the boarding pass can be sent to a mobile phone, email or picked up at the airline service desk or another option is the railway station check-in where passengers check-in at a railway station and drop their bags there. This procedure can be done between 4 to 23 hours before departure [69].

The use of these options limits human interference thereby reduces cost and human errors aspect. Passengers who use any of these check-in options take less time in queues hence they may get discounted prices particularly on low costs airlines. Multiple airlines share check-in application at kiosks in airports so that the passengers can check into any of these placed terminals. Shared kiosks offer many advantages as it allows for savings in both capital and operational expenses [35], [67].

The concept of a smart airport places emphasis on efficiency and user-friendliness, relying on the connectivity of multiple digital networks aimed at maximizing passenger satisfaction. While the boarding experience is one of the most stressful elements of air travel, introducing boarding card scanning machines allows each passenger to scan his/her respective boarding pass thus eases the boarding experience. The use of RFID scanning in this streamlined process eliminates the need for staff and makes the entire operation cheaper. Therefore, there are shorter waiting periods for passengers which translate into improved customer satisfaction [35], [67].

Self-Service Technologies (SSTs) like retail or information kiosks for product search and navigation as well as common usage self-service kiosks for check-in are made possible by the use of cloud computing in airports. SSTs enhance the processing of passengers and potentially cut operating expenses by up to 95.6% per passenger. Survey research further demonstrates that SSTs boost passenger pleasure by giving them autonomy and control [70].

2.5.4 Security and Border Control Biometric Services

In a smart airport the ways to ensure passengers' safety and security as well as the staff and the infrastructure itself are predominantly associated with the use of biometric identification systems, advanced video surveillance and artificial intelligence to detect and prevent security threats.

To ensure safe air travel it is critical to verify the identity of an individual and the goal at a smart airport is to verify passenger's documents without personal assistance and then screen passenger's belongings [34]. At different regulating points, automated personal identification systems using biometric technology are being used. These systems operate in two modes: identification and verification. The aim of the verification mode, as its name indicates, is to confirm that the user is who they say they are rather than trying to identify them among a group of people and stop others from using the same identity. On the other hand, identification mode is used to identify a person by comparing their biometric data against a database of stored data. In identification mode, the system is attempting to identify a person among a group of individuals [59].

Robustness and uniqueness are the two key criterions that must be addressed when analysing a biometric identification. Robustness is defined as the ability of a certain biometric identification to always pass information into the biometric system correctly and automatically for measurement purposes. With respect to biometric distinctiveness: this refers to the measurable ability or capacity of the person's unique characteristics to set him/her apart in user population [71].

A biometric system is an automated process that serves 5 goals. The verification process involves acquisition of biometric identifiers through the use of an electronic device, extraction and comparisons of the obtained data, match between the identifier and a given template, and verification and validation of the identity. A biometric system will take some biometric data from this person and compare it with a template to identify it. For the biometric system to operate, each individual must submit external documentation providing biographical information, such as a passport, during the

enrolment procedure. A biometric identification, such as a fingerprint or eye scan, is captured during the initial interaction with the system, stored, and connected to the external document that is being shown [71].

The process in a smart airport would start by scanning passengers' documents and capturing their photos to confirm the match between their information in the e-passport and the taken photo with stored information in the government database. In the end, the security officer would proceed to the security screen after receiving the passenger's information [34].

Security screening mainly focuses on identifying prohibited items and is primarily conducted via metal detectors and x-ray machines at a rate of approximately 149/pax/hour [72]. According to Wetter [73], most European airports use dual-energy x-ray systems to screen cabin baggage while only some employ computer tomography (CT) systems. However, for future developments airports are set to include CT technology and multi-view screening for cabin baggage and not only for screening hold baggage. These technologies are set to be upgraded over the years to improve security with faster scanning times, higher resolution, and lower costs. The automated screening will be a crucial improvement as security officers, in order to streamline the security process, mainly rely on the warning given by the baggage screening system. Various technologies will be available for screening liquids, aerosols, and gels and the introduction of new technology will change job profiles and require different skills for operators.

Based on Kalakou, Psaraki-Kalouptsidi and Moura [72], another approach would be creating a new security checkpoint configuration to streamline the screening process. Biometric data will be used to create a database of well-known passengers, enabling officers to quickly identify them. International databases will be utilized instead of national ones, and officers will receive real-time risk updates. Automatic behaviour analysis and different track points will be used to screen passengers. The checkpoint will consist of a biometric verification area and three security halls, each assigned to a specific risk level: normal, known or frequent, and enhanced. Frequent flyers will be required to undergo background checks with governmental authorities, and their information will be included in the database. These passengers will have the chance to skip security checks which would allow for a reduction in queue times. Normal passengers are the majority of travellers while enhanced passengers are those whose information is scarce and will require scrupulous screening. It uses Near Field Communication (NFC) technology and is available in many recent mobile phones which can serve as digital wallets.

Smartphones can use NFC for payment services, storing airline tickets or transferring information with one another when there are two phones having such a capacity. The biometrics machines are also conveniently placed such that when passengers arrive, they merely scan their phones and proceed to a corridor depending on their itineraries.

These types of digital innovations can also be applied at border control. Border control plays a critical role in ensuring national security and managing immigration, however, due to the rise in passenger traffic and limited human resources at airports, processing times have increased, resulting in passengers spending significant amounts of time in queues. The existing border control procedure involves several manual biographic assessments such as verifying a persons' passport details and comparing them against a terrorism screening facility, wanted lists and no fly lists. The need for border officials to decide about a traveller's ability to cross the border in less than 12 seconds emphasises the significance of automated processing for accelerating passenger clearance while preserving strict security requirements [71].

Electronic gate, CCTV, thermal camera, motion sensor should be integrated into the physical security measures for internal monitoring using a restricted access mechanism with key cards, RFID, NFC technology, and electronic locks [32].

2.5.5 Smart Apps

According to Rajapaksha and Jayasuriya [35], the smart airport journey typically begins at least 48 hours prior to travel and an array of services exist via a smart application. Passengers may have their luggage collected from anywhere and receive ongoing alerts including regular notifications on their scheduled flights after they input necessary details and info relating to their travel to the airport.

Such applications allow for tracking the statuses of flights in real time; hence, one can receive notifications about any delay or change of a gate or cancellation of a flight. Therefore, the passengers could use this information to make contingency plans or to alter their travel schedule appropriately. These applications, however, are useful for way finding purposes, as they deploy different kinds of indoor localization techniques like beacons, Wi-Fi or Bluetooth signals, which guide the passengers through the airport. The app provides step-by-step directions to gates, restaurants, lounges, and other facilities within the airport and enables passengers to book services like car rentals, hotels, and airport transfers directly from their mobile devices. It is also possible to secure a parking space and go to an airport lounge using this application. This smart airport system uses a broad IoT network with numerous sensors (such as line queuing sensors, parking

sensors, etc.) to gather data, AI to analyse the data and make decisions based on it, cloud services to simplify data administration, and application processing [35], [70].

By using artificial intelligence and natural language processing they can provide personalized assistance to passengers by answering a common question and offering suggestions on nearby amenities.

Moreover, by using big data analytics and machine learning these applications help to determine waiting times in security points and immigration centres allowing them to reduce stress among travellers as they can make their travel arrangements accordingly. As NFC technology generates a great volume of data coming from different sources simultaneously it can be processed through big data analytics which facilitates the provision of context-aware personalized services. Thus, in real time, smartphone applications can deliver location-based recommendation and contextual personalised services to the user [72].

Smart apps play a crucial role in enhancing the passenger experience. They integrate various technologies discussed earlier in separate segments to demonstrate that while each technology can function independently when paired together, they can lead to even better and more efficient results.

2.5.6 Indoor Navigation, Smart Wheelchairs and Smart Wearables

Airport indoor navigation entails applying specialized devices and techniques meant to aid travellers on their journey around the airport terminal. Such directional indicators include digital maps, signage, and mobile applications which offer a user with details related to different locations within this terminal. The goal of indoor navigation is to improve the overall airport experience for travellers by reducing confusion and anxiety caused by navigating large and complex terminals [35]. Some of these airports, however, are adapting technology like Bluetooth beacons, Wi-Fi, and virtual reality to give passengers superior and exciting guidance.

This form of technology will not only be of assistance to passengers who are unfamiliar with the airport but also to elderly passengers who may experience confusion. Currently, ground handling agents provide specialized assistance services for elderly passengers, individuals with reduced mobility, and unaccompanied minors. However, the use of smart applications by passengers will likely lead to reduced reliance on ground handling staff to provide assistance and special assistance services that are not pre-booked. Additionally, it will lessen the need for signage within the airport terminal [35], [67].

The indoor navigation technology is supplemented using smart wheelchairs as a way to disrupt the market for airport assistance services even more. Modern assistive technology which is called smart wheelchair provides additional functionalities and increased independence and mobility for disabled persons. These wheelchairs are electrically powered and equipped with sensors, cameras, and other devices that can detect and avoid obstacles, provide navigation assistance, and improve safety [74]. Smart wheelchairs can be designed to integrate functions like voice recognition, home automation, and mobile phone connections helping people to control different parts of their surrounding and social life better. According to Kovynyov and Mikut [67], mobility-impaired people can get more independence by using smart wheelchairs at the airport terminal. These wheelchairs come as a way to substitute the existing wheelchairs or golf carts driven by the airport staff. The use of this type of wheelchair can lead to a reduction of ground staff which itself comes with a reduction in costs.

Smart wearable devices include but are not limited to, smart watches, fitness trackers, augmented reality goggles, Bluetooth hats and headphones, among others, which have embedded sensors. These accessories are increasingly being used by the general public and it is not considered a novelty however they can bring benefits when associated with airport operations. The use of these modern technologies and wearable hardware solutions will also help alert passengers on such updates as boarding gate changes, check-in counters, flight delays, among others [35].

Up to 45% of an airport's overall revenue might come from non-aeronautical sources including retail, food and beverage, and duty-free stores. Predictive analytic can also be applied in order to forecast retail sale for increasing revenues and enhance aircraft placement strategies. Using passenger data, airport concessionaries design targeted marketing campaigns. Virtual shopping and advanced sensory panels enhance passenger’s experience and increase revenues [70]. Smart wearables such as smart screening helmets and smartwatches have become valuable in measuring body temperature, heart rate, and blood pressure, which are now crucial health metrics in the wake of the pandemic [33].

As stated by Kovynyov & Mikut [67], these wearables have many capabilities and are frequently used for a variety of purposes, including helping the visually impaired navigate interior spaces, providing health-related reports to help in instances involving international contagion, and even transmitting alerts in emergency circumstances.

In response to the pandemic major smart cleaning devices emerged mainly utilizing ultraviolet (UV) cleaning technology. UV cleaning, predominantly UV-C, which has a

wavelength of 200-280 nanometres is effective at disinfecting surfaces and killing bacteria, viruses and other pathogens. Many airports including Changi International Airport, Vancouver International Airport and Houston International Airport implemented this type of technology in response to the COVID-19 crisis. From autonomous cleaning robots that are equipped with spray technology and UV-C LED technology to an ultraviolet cleaning lamp and contactless screen protector placed in kiosks these were some technological implementations that these airports made to combat the outbreak [33].

The use of sensors to track people are also used to determine how many people are using the facilities namely the restrooms and determine when they should be cleaned. The cleaning personnel are informed through IoT devices and sensors. These smart sensors enable automated flushing, contactless faucets, and hand dryers, as well as environmental control [32].

2.5.7 Runway Monitoring, Smart Lighting and Asset's Tracking

In order to monitor the structural integrity of the runway and identify blockages and defects, smart airports utilise automated technology like heat sensors and terrain-bound drones. Compared to manual, traditional visual examinations that are subject to human mistakes, these technologies are more trustworthy. Some of the network protocols used in these types of equipment include RFID chips, ZigBee, Bluetooth, LoRa as they link autonomous drones to command-and-control systems. Predictive maintenance and airside operations optimization can use real-time sensor data, lowering passenger wait time and improving environmental impact [32], [70].

Smart lightings in smart airports enable efficient controlling and monitoring of lighting along the entire airport area including runway illuminations indispensable for aircraft's landing. The devices can be managed via smartphone apps or web-based platforms; thus, if an error occurs, they alert airport employees promptly. Furthermore, IoT based devices are connected to the runway illumination and advise the control tower of any equipment failure [32].

The effective organisation and location of specialised assets like luggage trollies and ground support equipment are made possible by the use of IoT technology in airport asset tracking. These assets are equipped with sensors that use RFID, Zigbee, Bluetooth, and lightweight network protocols. Signals from these sensors are collected by a sensor bridge and sent to a server where administrative staff may use it to find the assets. This

reduces aircraft turnaround time, increases their usage, and upholds effective airport operations [32].

2.5.8 Robot Parking and Electric Vehicles

A new development in airports is robotic parking, which has been linked to the idea of a smart airport. Robots are used in robotic parking, an automated parking system, to place and retrieve automobiles in predetermined parking slots. Some airports are now adopting the use of this technology in their parking facilities so as to improve productivity and shorten time spent by travellers in search of a parking spot. In this system, users simply leave the vehicle at an assigned point before it is hauled by a robot platform to another assigned spot for parking. On arrival at the airport, travellers can either make use of a kiosk or a smartphone which connects them with various robots to call for their vehicles [75].

In addition to robotic parking, autonomous robotic vehicles have also been introduced to airports, marking a shift towards smart airports. These robotic vehicles have the potential to replace a variety of ground tasks including carrying people, handling freight, and hauling airplanes, thus reducing work force and increasing productivity. When compared to a single-robot operation, a multi-robot control system was evaluated and shown to dramatically cut operating time. These multi-robot control systems might involve a LadderBot, LuggageBot, PassengerBot and a TaxiBot [70].

According to Hájnik, Harantová and Kalašová [76], there is growing pressure on airports to handle more passengers while minimizing road congestion and pollutions hence they have opted for the use of electric and autonomous vehicles. With increasing emissions restrictions in Europe, it is important to use electric cars in airport property. Electric and autonomous cars are incorporated in airports to promote sustainability and efficiency through decreased emissions and better transport. As a result, airports that make investments in cutting-edge technology like electric and autonomous cars are expected to gain a competitive edge over time.

2.5.9 Environmental Conditions

Smart airports make significant strides towards improving the environment through different actions and programs. These airports invest highly in energy economy by applying technologies such as LED lighting, intelligent HVAC (Heat, Ventilation, and Air Conditioning) systems and energy management. These projects assist in reducing energy consumption and carbon emissions hence making the environment greener [77].

With IoT enabled sensors smart airports can measure the air quality, detect fire and smoke and measure the temperature. They can also be used in conjunction with air conditioners to improve passenger comfort. For control towers, these sensors can regularly report on the weather, which is crucial information. Several kinds of sensors that make use of various network protocols are coordinated via network bridges [32].

This type of airport relies on a sustainable infrastructure, which also employs green building principles, renewable energy sources, and eco-friendly building materials [78]. It is a strategy that reduces the adverse effects on the environment during the construction phase and the operational phase.

Sensors and monitoring systems track environmental characteristics such as air quality, noise levels, and water quality. Therefore, measures can be put in-place to minimize the effects and ensure safety of both employees and customers. Smart airports incorporate green spaces like gardens and green roofs in an effort to foster biodiversity and maintain the ecological balance. These areas have many advantages, including enhancing air quality, and establishing habitats for native wildlife [32].

Smart airports promote the usage of electric and autonomous vehicles by optimizing their efficient transportation systems. Autonomous vehicles increase traffic flow and reduce congestion that consequently reduces air pollution thus improving air quality. In addition, electric vehicles are a major contribution to lowering the emission of hazardous gases [76], [78].

Smart airports reduce waste output and help to create a cleaner environment by encouraging a circular economy approach. Effective water management techniques are used, such as rainwater collection, water recycling, and intelligent irrigation systems. These programs conserve water and lessen the airport's overall water footprint [79].

Smart airports work to reduce their environmental impact and support a more ecologically friendly and sustainable aviation business by integrating sustainable practices, utilizing cutting-edge technology, and promoting environmental awareness. They show their dedication to environmental stewardship by adopting these measures, which also improve the entire airport experience.

2.6 Management Process

Following Bouyakoub, Belkhir & Guebli [80], an IoT-based system can be utilized for airport management. This system takes each item in the airport as ‘a thing’ that communicates by itself with other elements. This is a smart system which incorporates

an operations room, check-in tables, departure lounges, planes, and crew members, and assigns each passenger an electronic access card and luggage an electronic sticker. It monitors its passenger and their baggage independently, informing them every time they are to get aboard.

This IoT system is made up of autonomous components that communicate with one another via input and output interfaces. It is made up of three layers: the abstract layer, which describes the system and how it interacts with the environment; the temporal layer, which depicts how things are synchronised and related in time; and the physical layer, which explains how things are made up physically and provide access to their interface for manipulation. The system consists of two types of things: active and passive. Passive things cannot engage in system transactions. They can be detected by active things, but they cannot detect any entity on their own within their vicinity [80].

In the abstract layer, the system's things are detailed, along with how they interact and communicate. The active things that make up the system are the operations room, check-in desk, departure lounge, plane, and crew members while the passive ones are the passengers and luggage. After check-in passengers and luggage, become objects with behaviour and limitations. The check-in counter, boarding area, and aircraft are all reprogrammable, communicating entities that engage with their surroundings. The system's numerous parts communicate with one another, this includes communication between passengers and crew members and between the boarding area and the check-in counter. At certain intervals, the operations room, which is solely a communicating object, triggers the check-in counter and the boarding area and receives data on passengers, luggage, and crew members [80].

The temporal layer focuses on the synchronization and temporal constraints of objects in a system. During their check in, luggage and passengers receive electronic access stickers and cards, respectively, transforming these inactive things into active communicative objects. A list of all enrolled passengers is delivered to the boarding area before take-off, and only those who are assigned to the appropriate hall are allowed to board. Before departure, every passenger is verified as present, and anyone late is not permitted to board the aircraft. Once all passengers are confirmed to be on board, the aircraft records the necessary information and prepares for take-off. Upon landing, the system updates the lists and prepares the plane for its next take-off [80].

The physical layer establishes a link between the system's things and the real world so that they may be controlled and supported in their interactions with the system. It is possible to define two profiles: the ordinary one where two types of attributes are

distinguished, the reprogrammable and the static attributes, and the collection profile. The system includes three collections: passengers, luggage, and crew. Each flight, passenger and luggage have a unique profile that includes information such as capacity, destination and flight number when it comes to the flight profile; identification, name and information about their luggage when it comes to the passenger profile; and the baggage profile includes an electronic tag so the system can recognise it. Electronic badges containing the crew member's identification and personal data are part of the crew collection [80].

Both travellers and airport administrators may benefit from this management approach. It automates processes for travellers and lowers the possibility of mistakes, saving time that may be put towards leisure pursuits. Enabling complete passenger tracking, streamlines administration, lowers the need for employees and improves security for airport administrators. After every flight, the system is optimised by removing outdated data and resetting object profiles while maintaining the most recent information about passengers [80].

Automation can be used in conjunction with humans in air traffic control and management to enhance safety and maximise air traffic. The development of nowcasting models for weather conditions, the prediction of departure capacity, taxi-out times, and arrival/departure delays, as well as the identification of environmental elements that contribute to taxiing delays, may all be accomplished using methods like neural networks, data mining, and machine learning. To prevent potential aircraft delays and passenger backlogs, ground traffic may be monitored and controlled in real-time using information from ground-traffic surveillance systems and ADS-B [70].

Another way airports can enhance their efficiency and reduce costs is by optimizing their back-office systems and processes, which often represent a significant portion of their IT expenditure. Robotic process automation (RPA) and other digital technologies have the potential to improve management decision-making consistency and lower costs by allowing employees to be decreased or reallocated to more value-adding tasks. RPA's versatility and scalability make it particularly well suited for implementation in airport back-office settings. RPA applications may eventually be integrated with big data and artificial intelligence systems to further boost productivity as they become more widely used [30].

2.6.1 HR and Training

As technology is introduced into airports and is paving the way to the smart airport concept, the workforce will require training and preparation in order to correctly deal with these innovations.

From the organization's perspective, employees are viewed as valuable assets whose worth grows through their development and contribution. In accordance with Drljača, Štimac, Bračić & Petar [15], their competence consists of four elements: basic formal education (BFE), specialist education, practical experience and psychosocial characteristics. Airport personnel are required to have a thorough grasp of the process approach, the roles and responsibilities of employees, and the significance of prioritizing passengers and other service users. Additionally, they should be conscious of the significance of safety for airport operations and the necessity for long-term sustainable business practices. Quality management principles must be implemented to ensure that the airport service is both safe and efficient. The ongoing process of Personnel Competence (PCO) demands a significant investment of time and financial resources to transform human potential into human capital, which, in turn, results in the development of capable individuals, teams, and processes. This process is fundamental to achieving successful outcomes and necessitates commitment from both employers and employees.

According to Kovynyov & Mikut [67], digital innovation is transforming HR and training procedures in airport ground operations. Digital employee profiles, which combine diverse employee-related data into a centralised overview, and web-based training programs, which take the place of traditional classroom training and enable better knowledge transfer and financial savings, are two instances of this. These online training courses include a variety of subjects, such as health and safety, code of conduct, and technical skill development for operational employees. The benefits of these modifications include decreased training expenses and increased HR process efficiency.

To quickly inform staff members of news and announcements, ground-handling agents utilise social media and smartphone apps. In order to effectively handle hiring, onboarding, performance evaluations, professional development, talent management, succession planning, and departures, they also utilise integrated employee lifecycle management. They utilise internal job marketplaces to post job opportunities and communicate with candidates on social networks to increase cost-effectiveness. They make sure job application submissions are simple to examine and immediately reply to applicants [67].

2.6.2 Staff Planning and Scheduling

Staff planning and scheduling is a vital component in airports' operation; in this case, people resources are assigned so as to ensure that every work is done well within time schedule. Smart airport technology is useful in improving staff planning and scheduling with effectiveness and efficiency. Smart airport technology enables airport managers to use different tools such as communication platforms, workforce management software, and time and attendance systems that make it possible for them to remotely monitor and manage their staff in real time. With this technology, resources are allocated properly, workers are scheduled effectively, and workflows are clearer.

A way to determine how many workers are needed is discussed in literature. As mentioned in the previous segment a smart airport journey starts a few hours before the actual departure. By tracking passengers and their position anonymously it is possible to determine at what time they will arrive at the airport as well as how many people will be at the terminal at every hour. This is a way of conducting how many workers are needed in each station [81].

By utilizing IoT it is possible to optimize the use of check-in counters and security checkpoints. As the arrival time of passengers is considered a random variable that varies according to several factors, coordinating how many workers are needed is a difficult task however as stated by Mrňa Badánik & Novák [63], in order to collect data on passenger occupancy it is possible to use traffic management systems, sensors at transport stops or data from passengers' smartphones. The collected data would be stored in the cloud for airport staff to access, enabling them to determine the number of staff needed for airport handling processes. Airlines are also expected to share their passenger data to help optimize staff usage for initial passenger processing at the airport.

Due to labour expenses making up 60–80% of overall expenditures, automation of personnel planning and scheduling is a significant goal in airport ground operations. The most typical method discussed in the literature and associated with the concept of a smart airport is automated centralised planning, which begins six months in advance utilising predictions of the upcoming season's airline schedules. The precise flight schedule projection is converted into a shift plan two months in advance, which is subsequently converted into a rostering plan that designates personnel to specific shifts. The task schedule, which allocates specific tasks to the shifts using a specialised real-time application with the broadcasting capability to the employees' hand-held, is integrated with the rostering plan using a time and attendance system [67].

De-peaking is a technique for spreading out air traffic throughout the day. Additional de-peaking techniques are used by ground-handling agents in their planning processes. Employee happiness is increased through shift trading, which enables employees to swap work shifts and lessens scheduling issues. A satellite website or private social media groups can be used by workers to organise shift trading, or it can be integrated into the time and attendance tracking system [67].

Improved communication between employees and management is another benefit of careful staff planning and scheduling. With real-time communication tools, staff can immediately contact their supervisors, receive assignment or schedule updates, as well as report issues. In this case, it may produce shorter response time with increased awareness of the environment [67].

Such smart airport technology could also contribute towards a higher rate of accomplishment regarding employment training and development programs. By monitoring the employee's performance and skills, airport operators can pinpoint the areas of growth that can develop to enhance personnel capacity and efficiency in order to offer specialized training programmes to suit individual needs.

2.6.3 GSE Management

Ground Support Equipment (GSE) is the term used for some of the vehicles used frequently on airport ramp areas such as the refueler, the loader, and the catering van. One of the most prominent outcomes of this digital revolution process is automated scheduling of GSE equipment which in turn reduces operational expenses and eliminates the requirement for many vehicles. Airport managers would be able to track the fleet in real-time through wireless communication technologies like GPS tracking, RFID tagging, and sensors. This system improves visibility for GSE activities; it also boosts maintenance planning and optimal resources allocation [67].

Implementing smart airport technology in GSE management can contribute greatly in reduced maintenance costs and downtimes. However, through active monitoring of the scheduled maintenance regimen specifically designed to prevent GSE malfunctions and subsequently expensive repairs, airport operators can ensure their GSE is kept in good condition.

Having the power to allocate resources more efficiently is another benefit of smart GSE management. This will enable the airport operators to identify areas where such equipment is being used either efficiently or excessively thereby making it possible for them to adjust the size of their fleet accordingly. It can lead to a higher degree of

environmental sustainability and efficient utilisation of resources as well as reduced fuel consumption.

2.6.4 Lounge Services

According to Kovynyov & Mikut [67], lounge services have been provided by ground-handling agents on behalf of airlines and digital innovation has affected these services, particularly in the areas of lounge access gates and new lounge-type tickets. The necessity for ground agents to be familiar with the policies of various airlines and lounge clubs, as well as the ability of lounge staff to swiftly implement these policies, is growing. This digital innovation has led to the implementation of additional lounge product categories, including family tickets and lounge access coupons provided by tour operators. These impose new demands on the ground handling agent's IT systems, adding new requirements for data analytics, invoicing systems, and integrating lounge access gates with family tickets and tour operator tickets.

2.7 Smart Airport Architecture

The technological advancements shown in previous segments come as a result of the growth in air traffic making airports extremely complex environments. The airport terminals should have strong computer systems to effectively handle the modern air transport. Such systems support intelligent automation, quality of passenger services, and precise safety and security rules. These systems must be ubiquitous and uninterrupted, ensuring that the airport can function without interruption. This has led to the need to develop an advanced telecommunication network with an infrastructure able to provide integration at the service, network and physical layers [66].

According to Qazi, Grado Vivero & Elmirghani [66], to accommodate such technological progress the airport's infrastructure as it is known today will have to change to handle a large number of wireless personal, passenger, and staff devices. This type of airport's network would have up to 10 million RFID tags, 1000 fixed and 500 mobile cameras, 500 displays, and 500 biometric devices.

An approach to the smart airport architecture, in accordance with Alghadeir & Al-Sakran [64], is an architecture for resource management in airport services, using smart technologies such as RFID, IoT, and Google Maps to create an intelligent application that provides personalized services and content for travellers. Smart airport architecture comprises of a mobile app, kiosks, and RFID readers for baggage distribution, customer payment verification, and tracking travellers' locations. This architecture is mainly focused on an IoT architecture which consists of three layers: the physical layer, the

network layer and the application layer. The physical layer uses various wired, wireless, and mobile platforms to build a connection for the internet. In the proposed architecture, that leverages RFID technology to transform airports into smart airports, the physical layer acts as a backbone that links the network and application layers. The smartphone-based mobile application functions by using the physical layer as a communication channel. The network layer is responsible for ensuring that data packets are transported from the source to the destination through one or more systems while maintaining quality-of-service features. The mobile application connects with various components, such as the database server, sensors, RFID reader, RFID tags, and passengers, through the network layer The application layer delivers smart airport services through its ability to deliver data which can be accessed on an app through the physical and network layers It also provides application-related services including software implementation, protocols, human interaction, among others. Not all client apps use the application layer in the same way, and the working system can also take advantage of benefits directly at the application layer. The proposed airport application, which uses RFID and IoT technologies, aims to improve efficiency and better cater to passenger needs. It has several requirements, such as providing airport services through mobile applications and ticket kiosks after the itinerary has been booked, directing users to use smart airport services through the mobile application, and displaying accurate terminal directions using Google Maps.

Another innovation associated with smart airport architecture is the Building Information Modelling (BIM) which offers a digital 3D depiction of airport infrastructure and enables collaboration and virtual design by all stakeholders as airports evolve to meet the evolving demands of travellers and become more complicated. BIM also incorporates data to enable programme and space design optimization, simulation of operations, and building models. Airport planning and design may also be done virtually using simulation technologies. While data from ground traffic surveillance systems may be utilised for airport master planning to determine airport capacity, gaming technology can be leveraged to create crowd simulation models to mimic a variety of applications at the airside and the terminal, simulation is used in airports [70].

Most infrastructural changes are based on IoT technology and are the result of the applications explained in the previous segment. Some of these changes have already been implemented over the years however others may require a bigger change in the current airport structure for it to be considered a smart airport.

These changes mainly include the implementation of [32]:

- smart kiosk to allow automated check-in;
- heat sensors and drones to monitor runways;
- IoT-based sensors to monitor people, air quality, fire, smoke and temperature;
- eGates for automated border control;
- CCTV, thermal cameras, and motion sensors for physical security purposes;
- IoT-based system for smart lightning;
- IT improvements and network bridges.

2.8 Smart Airport Projects

The airport IT&T sector has grown significantly in recent years as seen in Figure 8, and it is anticipated that this trend will continue. Since 2011, the sector has had yearly double-digit growth, with Airport Operation Systems accounting for more than 40% of worldwide IT&T investment. IT&T investments have grown over the years as it can be seen in the graph presented in Figure 8 and is expected to continue its growth. With roughly 25% of the world's IT&T deliveries under its control, SITA is the industry leader. IT integrators, airline IT editors, start-ups, and small businesses are competitors in the industry. To handle the growing complexity of airport administration, airports are now looking for real-time and predictive solutions [28].

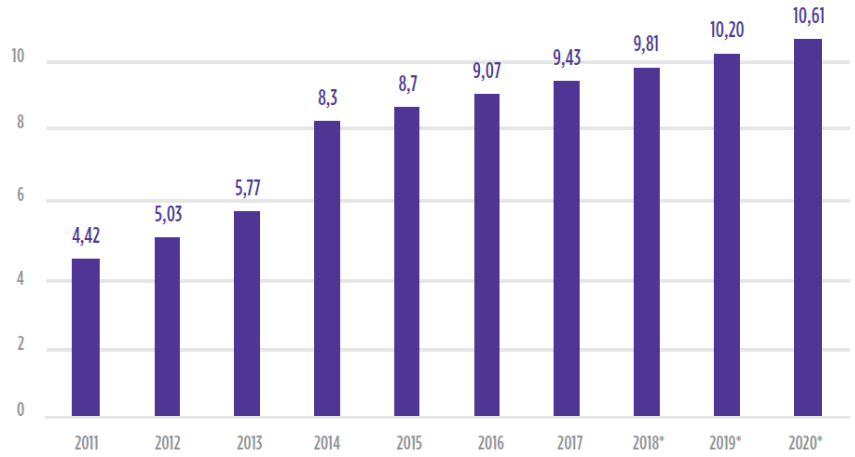

Figure 8 - Total airport IT&T build and run expenses (in $ billions) [28].

As the definition of a smart airport has not yet been fully established, determining which airports worldwide can be considered smart airports is difficult. The most common approach is to rank which airports have the most technology developments. On the other hand, investing in and adopting Industry 4.0 technologies is a difficult and time-

consuming process however many airports are working to become smart airports by experimenting with digital innovation. Some of the projects presented below are steps towards a smart airport, even though most of the airports where they are implemented fall short of the ideal concept of a smart airport.

2.8.1 Airport Collaborative Decision-Making Plan

The Airport Collaborative Decision Making (A-CDM), is an approach that had success in a number of European airports leading to improvement of operational effectiveness and resilience. A-CDM system entails collaborative work by airport operators, airline operators, the air navigation service providers (ANSP) and any other company providing ground handling services. Partnering through the A-CDM allows information to be shared in real time for optimal decision making [82]. A-CDM is a system that promotes cooperation and information sharing among airport partners such as airport and aircraft operators, ground handlers, and ATC (Air Traffic Control) in an effort to increase the efficiency and predictability of airport operations. It focuses on enhancing the pre-departure and aircraft turnaround procedures and enables more precise departure information to be transmitted with the European ATFCM (Air Traffic Flow and Capacity Management) network, boosting sectoral and en-route planning. 32 airports in Europe are using A-CDM, and it is already well-known worldwide [83].

2.8.2 BRUcloud

The cargo and logistics platform at Brussels Airport is called BRUcloud. The system acts like a neutral data exchange platform among airline, ground handler, freight forwarder, customs officer and even truck companies. One of the benefits of the platform is that it allows for slot booking for trucks [84], [85].

The users of BRUcloud can enjoy different features ranging from collaborative software, data exchange and real time tracking of cargo traffic. Stakeholders may collaborate more effectively and efficiently, cutting down on the time and expenses related to air cargo operations, by exchanging shipment data [84], [85].

Further, BRUcloud provides its customers with multiple added values such as temperature monitoring, quality assurance, and compliance check. It ensures that cargo is delivered securely, safely, and in compliance with all regulatory provisions and legislation [84], [85].

The platform is designed to encourage voluntary data sharing. As such, users of the platform can decide what data they want to share, to whom, and for which purpose. The

source controls and maintains the data, resulting in a single, publicly accessible version of the truth The platform aims at categorizing every collected piece of data within the same system for all the applications to be able to make sound decisions on the aggregated information of all the users [84], [85].

Such a platform is successfully employed in Dallas Fort Worth and London Heathrow.

2.8.3 Baggage Robots - LEO & KATE

SITA is a leading information technology and communications solution provider in the airport industry which recently developed two luggage robots called LEO and KATE intending to ease baggage handling for travellers. LEO is a fully self-contained autonomous luggage trolley which is capable of navigating through an airport and identify any obstacle in his path It has an intuitive touch screen interface which will enable passengers to weigh their baggage without involving any airport personnel. In contrast, KATE represents a compact mobile ticketing system that travellers can use to print boarding tickets, checking in baggage as well as pay for additional baggage fee. As part of SITA's initiatives to advance airport technology and enhance the passenger experience [86], [87].

The LEO robot has been deployed in various airports across the world including Amsterdam Schipol Airport, Boston Logan International Airport, Geneva International Airport, Miami International Airport, Munich Airport, JFK International Airport, Incheon International Airport and Changi Airport. LEO can check in, print bag tags and transport up to two suitcases with a maximum weight of 32 kg. It moves through crowded places, steers its way around obstructions and meets passengers where they are and lets them scan and tag their suitcases with SITA's Scan&Fly bag drop interface before placing them securely in a depository. LEO tags the bags, fastens them, announces the boarding gate and departure time, and then carries the suitcases immediately to baggage handling where they will be sorted and assigned to the appropriate aircraft. LEO is a good example of how robotics development can be applied in airports for improving the efficiency of the baggage delivery process. It is just one of several robots that have appeared at airports these past years as technology companies look into the potential of cybernetics in the aviation industry [88].

KATE is a collaborative project between the SITA laboratory and a company called BluBotics from Switzerland. KATE, a smart kiosk for airports, uses available data sources such as flight schedules and security screening queues, to identify those areas of the airport where additional kiosks may be needed to reduce passenger check-in lines. The

robotic kiosk, which combines geolocation and obstacle avoidance technologies to roam freely across the airport terminal, may be installed manually or automatically to help travellers. During times of interruption, the kiosks can potentially be moved to off-site sites like railway stations [89].

2.8.4 SITA Smart Path

Sita's Smart Path program is an enhanced identity verification system that utilizes face-recognition technologies to ease passengers' journey through check-in, immigration and even boarding, which has been adopted majorly by the majority of major airports across the globe. It offers customers a seamless, touchless experience at low prices for airports, airlines, and governments. Airports may increase retail sales, lower operating expenses, and encourage a low-touch atmosphere. This can help airlines offer customized services, enhance self-service provision, as well as avoid the need for second-party verification. In order to comply with legal and regulatory obligations, governments might verify passengers early in the process. SITA Smart Path makes it simple for customers to travel without fuss using their own mobile devices by integrating them with current airline and airport infrastructure. It increases security surveillance en route, boosts passenger's movement, and decreases a need labour force for watching passenger way [90].

The self-bag drop units, gates for self-boarding and access control, CUSS kiosks or mobile applications for quick and secure biometric enrolment, self-bag drop units, and a single platform for integrated common-use systems are the solution components of the biometric ID management system. The background identity management system also gathers passenger information and associates it with their biometric identification [90].

Recently, SITA has implemented a biometric authentication and identity control system in two global airports namely, the Hamad International Airport and Orlando Airport, for efficiency of traveller flows and impeccable travelling experiences. At Orlando airport, a biometric exit check at boarding process was carried out successfully, and passengers embraced the whole idea because they found it easy and safe. Both airports believe that biometric ID management would aid in the digital revolution of the aviation sector [90].

The second sub-solution related to the SITA Smart Path is the Drop and Fly which aims to improve the speed and efficiency of the security check process at airports. This sub-solution has been installed at Incheon International Airport and has been effectively boosting capacity and enhancing the traveller experience. With the self-bag drop technology known as SITA Smart Path Drop and Fly, airports may expand their terminal capacity while also reducing operating expenses and enhancing the traveller experience.

In less than a minute, passengers may conveniently and independently check in their bags. For streamlined bag drop procedures, the system also features common-use payment, ID scanning, and a mobile application for agents [91].

The Scan and Fly is another sub-solution from SITA's Smart Path that consists of a self-service baggage drop and with it, travellers may effectively and swiftly check in their bags without requiring agent assistance. It may be adapted to already-existing check-in counters and conveyor belts, which can improve terminal capacity, shorten lines, and save operational expenses. A common-use payment terminal, an ID scanner, portable or fixed scanners, a ScanArch, an agent mobile application, and many process choices are included in the system. SITA Smart Path Scan and Fly was successfully deployed at Geneva Airport to address capacity issues and enhance the traveller experience. The answer gives travellers more control over their route, and terminal capacity has undoubtedly increased. Recently it has also been deployed in Finland at the Helsinki Airport [92].

The most frequently employed SITA technology is the TS6 kiosk. It is a modular and sustainable self-service platform for airports that can be customised to strengthen corporate identification and is economical for airlines. The kiosks can feature biometrics, numerous printers, and payment modules and may also be customised to meet the specific requirements of any airline or airport, enabling touchless passenger processing and maintaining a consistent appearance and feel across the airport. More than 130 airports now use SITA's Smart Path Kiosks, which maximise floor space and uplift passenger processing throughput by up to 25% [93].

These kiosks can also be solely utilized for self-tagging baggage. By utilising SITA Self-Tagging kiosks airports may expand terminal capacity, enhance the passenger experience, and save operating expenses. The kiosks let users print their luggage tags independently, which helps shorten lines and ease congestion. They can be altered to meet the requirements of the airport and feature a user-friendly design and also include add-on capabilities like mobility and biometric technology, which makes them a flexible answer to changing demand. According to a case study, the installation of these kiosks at a major European airport has greatly decreased passenger wait times and enhanced customer experience [94].

2.8.5 Autonomous and Electric Vehicles

A completely automated parking system by Stanley Robotics allows for high-density automobile storage by using robots to park cars with extremely accurate navigation. The

system is dependent on centimetre-level localization, which is made possible by perceptive algorithms, clever management software, and dependable GNSS technology. The robot also makes a map of the parking lot using two LiDAR scanners and four cameras. After testing began in 2017, four robots are fully operational at Lyon Saint-Exupéry Airport, which can hold up to 500 vehicles. The first outdoor car park run by robots opened to the public in 2018 and has expanded to other airports such as Gatwick Airport in London [75], [95].

Passengers using the system may reserve a parking place online, leave their car in a designated compartment, and take a shuttle to the terminals. When they return from their trip, they may pick up their automobile from a cabin where the valet robot parked it in a secure area. The initiative contributes to Aéroports de Lyon's commitment to sustainability by minimising environmental impact and CO2 emissions. The technology is anticipated to gradually enhance parking density and provide 50% more places to the same amount of surface area. The initiative fits well with the innovation goal of VINCI Airports and Aéroports de Lyon to improve the quality of the passenger experience while influencing future mobility [96].

To move staff between various airport facilities, Gatwick Airport started testing autonomous electric cars in the airport region in 2018. Oxbotica, a company that creates software that enables vehicles to operate independently without relying on GPS or other off-vehicle technology, provided the vehicles [76].

Electric vehicles have also been implemented as a way to turn airports into a more sustainable environment. At Hamburg Airport, alternative energy sources currently supply 30% of the energy requirements and the Stuttgart Airport hopes to achieve carbon neutrality by 2050 after cutting CO2 emissions by more than 80% during the past ten years. By 2030, Munich Airport wants to be the first airport in Germany with no emissions [76].

Another robotic application can be made in taxiing aircraft and has been applied at Frankfurt Airport. Israel Aerospace Industries created Taxibot, a semi-autonomous, pilot-controlled towing tractor that Frankfurt Airport uses to tow aeroplanes from the gate to the runway. Taxibot can be controlled from the cockpit using the Pilot Control Mode. By taxying with their engines off, airplanes may save on fuel expenses, airport carbon emissions, and congestion at the gates. Long-haul flights at Frankfurt Airport might save up to 2,700t of fuel annually by using a Taxibot [78].

2.8.6 Bebot

In 2015, Akemi Tsunagawa established Bespoke as a chat bot venture to help tourists locate not-so-common places of interest other than those usually named in guides' volumes. Her creation, the AI chatbot, Bebot, guides visitors through airports, railway stations, and hotels so they may locate one-of-a-kind experiences they will not find anywhere else. The most commonly utilized multilingual chatbot in the hospitality industry currently known as Bebot is associated with renowned enterprises like Narita International Airport, Sofitel hotel, and JR Tokyo station [97].

The service can provide a lot of information requests across various languages. It has employed a natural language software that was designed specifically for disabled people. The service is simply accessible by scanning QR codes and the free Wi-Fi. Many companies, both domestically and abroad, including government agencies and transportation hubs, have adopted Bebot [98].

2.8.7 Aruba Happy Flow

The Aruba Airport has started a project with many stakeholders, including the governments of Aruba and the Netherlands, Schiphol Group, KLM, the Aruba Airport Authority, and lead contractor Vision-Box, to streamline the processes around the passenger into one secure seamless passenger flow and reduce repetitive identity checks [99].

The Aruba Happy Flow initiative replaces the requirement for repeated passport and boarding pass checks at various points of an airport trip by using face recognition technology to establish a single passenger token [100].

The Aruba Happy Flow system uses biometric identification to verify each passenger's identity, enhancing airport security. Therefore, there are more satisfied passengers, reduced stress of traveling through the airport, and reduced risks for the airlines. The required preconditions to use this system are using ePassport as a means of identification and verification and ensuring user's data privacy protection according to privacy-by-design principles. The system prioritises connection, scalability, and a strong multi-stakeholder collaboration agreement in order to be future proof [99].

2.8.8 Spencer Project

The SPENCER project was a research endeavour supported by the Horizon 2020 programme of the European Union with the goal of creating socially intelligent robots that could interact with people in public settings. A partnership of different universities,

research organisations, and business from all around Europe worked on the project from 2016 to 2019 [101].

The SPENCER robots are designed to navigate in publicly accessible environments, such as airports or shopping malls, interacting in a socially intelligible manner. Their aim is to help people, share information and answer questions. They had various sensors such as cameras, microphones among others, which made them aware of the environment and be able to respond to human requests [102].

It was mainly developed for utilizations in public areas such as airport. At airports, SPENCER robots assisted passengers to acquire information regarding flight schedules, gate locations, and similar airport services. The robots might also give directions, respond to basic inquiries, and assist travellers with their bags [101], [102].

The strength of the SPENCER robots was that they could move through heavily congested and complex places. This allowed the robots to manoeuvre past crowds of people in airports while dodging obstacles and adjusting to shifting circumstances. Additionally, the robots were made to be able to speak with travellers in a variety of languages, which was particularly helpful in airports with a global reach [103].

2.8.9 LuggageBot, LadderBot and PassengerBot

Autonomous robotic vehicles can replace manpower in ground works of airliners, including haul airplanes, handle cargo, passenger's transportation etc. These applications for autonomous robots can be expanded to include several robots. To allocate jobs to the available robots based on a set of criteria, an AJAVA simulation of a multi-robot control system incorporating a LadderBot (ladder for passenger boarding), LuggageBot (for luggage delivery to plane), and PassengerBot (to carry passengers from terminal to plane) was conducted. According to the simulation results, using many robots in concert can save operating time by more than 70% as compared to using only one robot. At Frankfurt Airport in Germany, automated aircraft taxiing from the apron to the runway was tested using taxiing robots (dubbed "TaxiBot"). In order to avoid crashes, these TaxiBots are equipped with sensors to identify potential hazards including automobiles, pedestrians, and airplanes [70].

2.8.10 Pepper Robot

A new 120 cm tall humanoid robot Josie Pepper created by SoftBank Robotics has been launched into service at Munich Airport's Terminal 2 to help passengers. The cloud based IoT AI technology from IBM Watson uses individualised learning for more accurate

results, which is used by Josie Pepper. The robot was initially stationed in the private part of Terminal 2 within a trial period as a means of gauging passenger acceptability. During a trial period to gauge passenger approval, the robot was situated in Terminal 2's private section. To analyse and understand speech and relate it to airport data, it uses a high-performance CPU with WLAN internet connectivity to connect to a cloud service. There are already similar robots in use at airports all around the world [104], [105].

2.8.11 Mobbeel Barcelona-El Prat

Face recognition technology is now being used across the whole travel process at Josep Tarradellas Barcelona-El Prat Airport, including check-in, self-bag drop, security screening, and boarding. The idea is to enable travellers go the full distance without having to present any identification. Passengers who choose to participate can enrol their biometrics using the Aena app, which incorporates Mobbeel's facial recognition and ID verification technology. Passengers may now take advantage of a more flexible, effective, and frictionless travel experience thanks to the trial programme, which was initiated by Vueling Airlines and Aena [106].

2.8.12 Paris Airports Smart Airport Program

In the main Parisian airports, both Charles de Gaulle and Orly, innovations have been implemented in order to transition to more intelligent facilities. From testing biometric security features, the concept of immersive reality, beacons, smart lighting on aircraft stands, and an automatic translator to implementing Wi-fi on shuttles, kiosks and mobile tools [107].

Groupe ADP has created a test area for new security procedures and equipment in collaboration with stakeholders. These new facilities evaluate a facial recognition solution using video surveillance cameras and a database of willing employees, while adhering to CNIL regulations and providing alternative routes for those who wish to bypass the cameras. It has also tested an immersive 360º experience to possibly implement in boarding lounges [107].

As a way to become more sustainable and reduce energy consumption, Groupe ADP has been testing smart lightning on aircraft stands. By substituting high-pressure sodium floodlights with LED technology, it is possible to modulate the lightning according to the different phases of the aircraft’s handling [107].

In order to reduce congestion at the airport, camera-based passenger counting and boarding pass scanning have been tested at the airports. Related to it, beacons have also

been tested to improve services for passengers with reduced mobility, which helped to pinpoint their location and resulted in more efficient staff assignment [107].

A 3D visualisation tool for operations has been helpful for anticipating situations and is used on a tablet in order to have a 3D augmented view of the facilities alongside all the important information such as passenger counts, waiting times, surveillance camera reports, availability of equipment and information about flights [107].

2.9 Conclusion

In conclusion, this chapter has provided an understanding of the concept, evolution, and digitization of airports along with significant components, prospects, and advancements of smart airports. From a brief history of the aviation industry to the emergence of Industry 4.0 and the digital maturity of airports, it is clearly observed that there has been a considerable enhancement in the areas of airport operation and services.

Through the application of smart technologies such as RFID tags and self-tagging, smart baggage handling and smart check-in, it is evident that airports have adopted the new trends and technologies that would assist in bringing efficiency, security and better customer experience.

It is the case of smart airport architecture, and all the projects presented in this chapter which show that airports all over the world are searching for new solutions to meet the new expectations of passengers and other users.

In this regard, the conclusion of this chapter reveals the benefits and prospects that arise from the utilization of smart technologies in contemporary airport management and operations.

Chapter 3 - Case Study

3.1 Introduction

In this chapter the technologies previously presented in the segments above are now analysed in two airports in order to determine how they are and how they could be deployed in the future and the results obtained are presented. Initially a small introduction of the country and the airport is conducted followed by a description of a methodology to determine the level of digital transformation of the country.

The technologies currently in use in the airport are studied as well as the upgrades that these could benefit from. Possible deployments of Industry 4.0 technologies are analysed as well as the current progresses that are being made or planned to be introduced in the future.

A comparison between João Paulo II Airport and Beijing Capital International Airport is also conducted.

3.2 Ponta Delgada - João Paulo II Airport

Named after the Pope John Paul II, the Ponta Delgada Airport (IATA: PDL, ICAO: LPPD) is located on São Miguel Island in Azores, the largest and the most populous island in the archipelago. It is the primary getaway of the archipelago Azores and plays a crucial role in connecting the archipelago to the mainland and other international destinations. The airport has a capacity of 1.5 to 2 million passengers a year.

The airport was inaugurated on the 24th of August 1969, six years after its construction was planned. Initially named Nordela Airport, it turned mainly geared towards inter-island connections and flights to mainland Portugal, using a national airline Boeing 727 from TAP [108].

The runway, which was initially 1800 meters long and topped up only recently with 2353 meters in length and 45 meters in width, began to host regularly occurring flights with Lisbon only in the year 1971, from which time forward it became possible to speak of consistent communication with the Portuguese mainland owing to TAP. In 1988, a new control tower was introduced, and the runway was extended to its current dimensions the following year [108].

It was on one such day, in 1995, this airport marked a significant day of its history when opened a new passenger terminal together with an expanded parking apron to accommodate nine aircraft at a time [108].

With the modern facilities and improved infrastructures, Ponta Delgada Airport still remains as the main aviation structure of the region of Azores where flights connect the archipelago of the world in order for the travellers to explore the wondrous uniqueness each island has.

3.3 Beijing Capital International Airport

The capital of China, Beijing, is served by two airports one of them being Beijing Capital International Airport (BCIA, IATA: PEK, ICAO: ZBAA) located 32 km northeast of the city's centre. It opened nearly 7 decades ago on the 2nd of March 1958 and consisted of one terminal that still stands today being used for charter flights and VIPs [109].

Being one of the largest airports in the world, BCIA has the capacity of 100 million passengers a year.

Already in 1980, with the construction of a parking lot and other ancillary, a new building for passenger service and asphalt was built to the old terminal. Starting from the mid-1990s, almost every year the number of passengers grew so much that the capacity of the Passenger Service Terminal was not enough. With the opening of T2, the terminal was closed for repair [110].

Further enlargement of the airport took place in 1999 in honour of the People's Republic of China's 50th anniversary. The third runway opened on October 29th, 2007, to ease traffic on the existing two runways [110].

Finally, on January 29th, 2005, the first non-stop direct flight from the Chinese mainland to Taiwan left Hong Kong and with China hosting Olympics by opening Terminal 3, Beijing Airport rose up to become the busiest airport in Asia [110].

Currently the airport is equipped with 3 terminals, Terminal 1 for domestic flights, Terminal 2 for domestic and international flights and the most recent terminal, Terminal 3, one of the largest terminals in the world that exclusively caters to international flights, was concluded in 2008.

3.4 Digital Transformation Analysis

3.4.1 The Level of Digital Transformation

Several indices serve to determine degree of digitization of countries. They often consider factors in relation to digital technology development, digital maturity, education and training abilities, innovative and entrepreneurial efforts, digital management, cyber

security issues as well as citizens' inclusiveness in the digital realm. Some of these indices include Network Readiness Index, Global Innovation Index and DESI.

3.4.1.1 Network Readiness Index (NRI)

Developed by World Economic Forum, the Network Readiness Index (NRI), measures a country's use of information and communication technology (ICTs) for fostering competition and development [111]. It seeks to better understand the impact of ICT on the competitiveness of nations, and it is composed of the environment for ICT offered by a given country or community, the readiness of the community's key stakeholders (individuals, businesses, and governments) to use ICT, and the usage of ICT among these stakeholders [112] .

This index is based on a composite score that includes items like level of accessibility of ICT, percentage of use ICTs among people, business entities and governments, and impacts of ICTs on social and economic development.

In turn, NRI helps the countries to identify where their ICT infrastructure and policy needs to be revised then compares it with the others. It is commonly used by governments, corporations, and nongovernmental organizations to guide ICT policies and interventions [113].

3.4.1.2 Global Innovation Index (GII)

WIPO (World Intellectual Property Organization) annually releases the GII, a worldwide index ranking countries on their levels of capacity for and outcomes of innovation [114]. The study investigates how research and development, technology transfer, human capital and research infrastructure, creative outputs, and business sophistication affect innovation [114].

The GII serves as a guide for governments, businesses, and other leaders to understand the innovation ecosystem and potential improvement avenues [115]. It is also a helpful tool for evaluating and tracking advancement over time [114].

These GII rankings make use of both quantitative and qualitative indicators drawn from various global organisations such as the World Bank and United Nations, as well as opinion polls involving corporate managers, academics, and other specialists. A higher score indicates a country's degree of innovation performance and the index rates nations from 0 to 100.

The index ranks world economies according to their innovation capabilities by using roughly 80 indicators grouped into innovation inputs and outputs [116].

3.4.1.3 Digital Economy and Society Index (DESI)

The Digital Economy and Society Index (DESI) compiles data on digital performance indicators for Europe and monitors member states' development.

Through the Digital Economy and Society Index (DESI) publications, the European Commission has been keeping track of the Member States' advancement in digital technology since 2014. Thematic chapters in DESI provide a European-level analysis across important digital domains, which is crucial for supporting policy choices. Country profiles in DESI assist Member States in identifying areas requiring urgent attention [117].

The European Union (EU) nations' digital performance is measured by the DESI, an annual composite index, in four major areas: connectivity, human capital, corporate adoption of digital technology, and digital public services. The European Commission originally introduced the index in 2014, and it has since been modified and expanded yearly [117].

The DESI gives decision-makers, stakeholders, and people a summary of the advancements made by each EU member state in the digital sphere and highlights areas in need of more development. The index is based on a variety of variables, including broadband availability and speed, internet usage rate, accessibility of e-government services, and quantity of digital technology-related patent applications [118].

This index is designed to serve the EU's larger objectives of fostering economic growth, generating employment, and enhancing people' well-being as well as to encourage the creation of a digital single market in the EU. The index also acts as a benchmarking tool for evaluating how well EU member states perform online relative to one another and to other nations outside the EU [119].

Although it would have been ideal to obtain similar data and index regarding China for a comparative analysis, it was not possible to obtain them, and therefore only the data related to Portugal are presented.

3.4.2 Portugal’s Digital Transformation Level

Portugal has made remarkable progress in its digital transformation process, embracing technology to foster innovation and economic growth as well as to raise the standard of living for its people.

The creation of a strong digital infrastructure is one of the foundational elements of Portugal's digital transformation. The nation has made large expenditures in broadband

infrastructure, ensuring that both urban and rural regions have extensive access to high-speed internet. As a result, residents may now benefit from the digital economy and take part in the larger digital ecosystem thanks to the foundation that has been established for digital inclusion.

3.4.2.1 Network Readiness Index

Through the advancements made in different areas, Portugal has been able to have high values in the indices presented above. In terms of NRI, in 2022, the country rated 29th out of 131 economies with an average score of 65.63 [120]. The country's main strengths are technology and impact as seen in Figure 9.

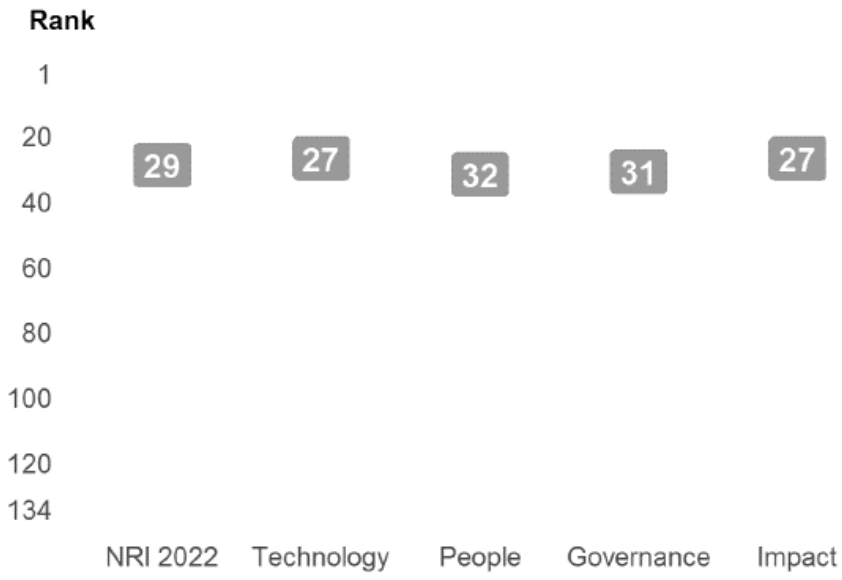

Figure 9 - Portugal global ranking, overall and by pillar [120].

Among high-income countries, Portugal ranks 28th. In terms of individual pillars, Portugal's ratings are slightly lower than the average for high-income countries, except for the impact pillar, where it surpasses both high-income countries and the average rating for the entire continent. Table 2 shows the rating comparison [120].

The ratings assigned to Portugal can be attributed to the fact that the country excels in four indicators, securing the top rank among its twelve strongest indicators. These notable indicators encompass internet access in schools, e-commerce legislation, privacy protection through legal content, and women's economic opportunity. However, Portugal's economy exhibits weaker performance in indicators such as mobile tariffs, concentration of AI talent, mobile broadband internet traffic within the country, and the gender gap in Internet usage [120].

Table 2 - Portugal's scores vs average of high-income countries and Europe [120].

Dimension	*Portugal*	*High-income countries*	*Europe*
NRI	65.63	66.21	63.72
Technology	59.34	60.28	56.43
People	56.79	58.83	56.35
Governance	76.14	76.89	74.79
Impact	70.26	68.86	67.3

Portugal demonstrates a high performance in three sub-pillar levels, SDG contribution, regulation and quality of life, having the country scored the lowest on inclusion, trust and individuals, as seen on Table 3.

As shown in Figure 10, given its income level, Portugal demonstrates a higher network readiness than expected, surpassing the trend line for the anticipated NRI score in the economy [120].

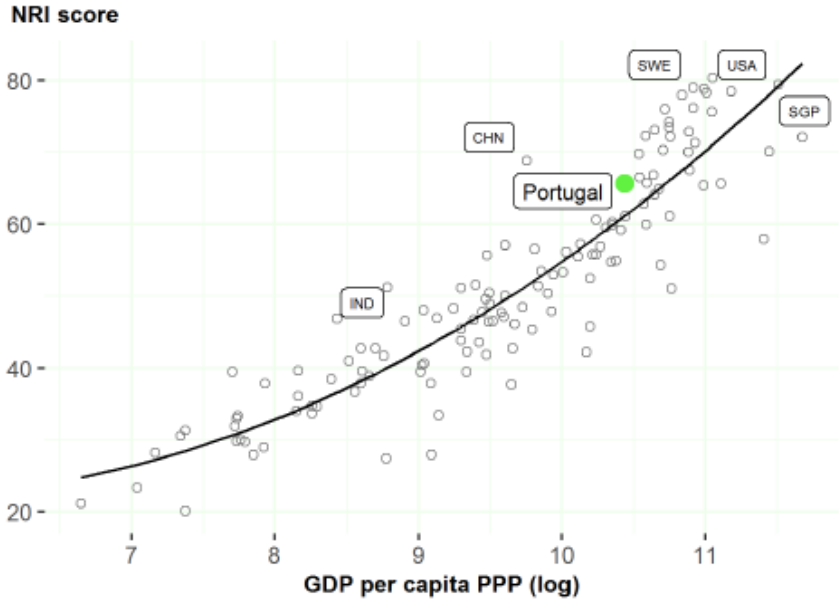

Figure 10 - NRI score and GDP per capita PPP graphic [120].

Table 3 - Portugal sub-pillar rankings [120].

Sub-Pillar	*Rank*
SDG Contribution	11
Regulation	14
Quality of Life	25
Future technologies	26
Content	27
Governments	28
Access	29
Businesses	34
Economy	37
Inclusion	38
Trust	43
Individual	52

3.4.2.2 Global Innovation Index

According to the GII 2022 rankings, Portugal stands at 32nd place among the 132 countries featured and 20th among the European countries. The overall GII ranking for Portugal in 2022 is lower than the two previous years where the country ranked 31st [116].

Based on WIPO [116], the seven GII 2022 pillars are human capital and research, creative outputs, global innovation index, business sophistication, knowledge and technology outputs, infrastructure, market sophistication and institutions. Portugal's weakest performance is in the institutions pillar, ranking 47th, followed by market sophistication at 42nd place and infrastructures at 39th place. The country achieved a rank of 35th in knowledge and technology outputs and 34th in business sophistication. On the positive side, Portugal excelled in human capital and research, securing a 22nd place, and creative outputs with a 25th place. Overall, Portugal attained a global innovation index rank of 32nd, showing better performance in innovation outputs (31st) compared to innovation inputs (32nd).

Upon analysing the indicators, three notable strengths emerged: domestic industry diversification, software spending (%GDP), and scientific and technical articles, ranking 1st, 6th, and 9th, respectively. However, the table below (Table 4) reveals three significant weaknesses: labour productivity growth (%), gross capital formation (%), and cost of redundancy dismissal, ranking 96th, 95th, and 69th, respectively.

Table 4 - Overview of Portugal's indicator strengths and weaknesses [116].

Strengths				*Weaknesses*			
Indicator name	Rank	Indicator name	Rank	Indicator Name	Rank	Indicator name	Rank
Domestic industry diversification	1	Government funding/pupil, secondary [%GDP/cap]	15	Intangible asset intensity [top 15, %]	47	Policies for doing business	64
Software spending [% GDP]	6	Researchers [FTE/mn pop.]	15	Market capitalization [% GDP]	48	Venture capital received [value % GDP]	64
Scientific and technical articles/bn PPP$ GDP	9	Industrial designs by origin/bn PPP$ GDP	15	Utility models by origin/bn PPP$ GDP	54	Cost of redundancy dismissal	69
Trademarks by origin/bn PPP$ GDP	14	School life expectancy [years]	19	Firms offering formal training [%]	58	Gross capital formation [% GDP]	95
Country-code TLDs/th pop. 15–69	14	GDP/unit of energy use	20	Entrepreneurship policies and culture	62	Labor productivity growth [%]	96

The table above (Table 4) highlights the most important indicators utilized in the ranking. These were extracted from the full list of indicators in Table 12 in the annex.

3.4.2.3 DESI

In the DESI 2022 ranking among European Union member states, Portugal secured the 15th position with a score of 50.8, slightly below the average EU score of 52.3 (Figure 11). This marks an improvement compared to the 16th position in 2021 and the 19th position in 2020 for Portugal. This improvement is due to the country's plan of action that was set up on the 21st of April 2020 with the main priorities being: digital inclusion, training of the public, digital transformation of businesses and the public administration [121].

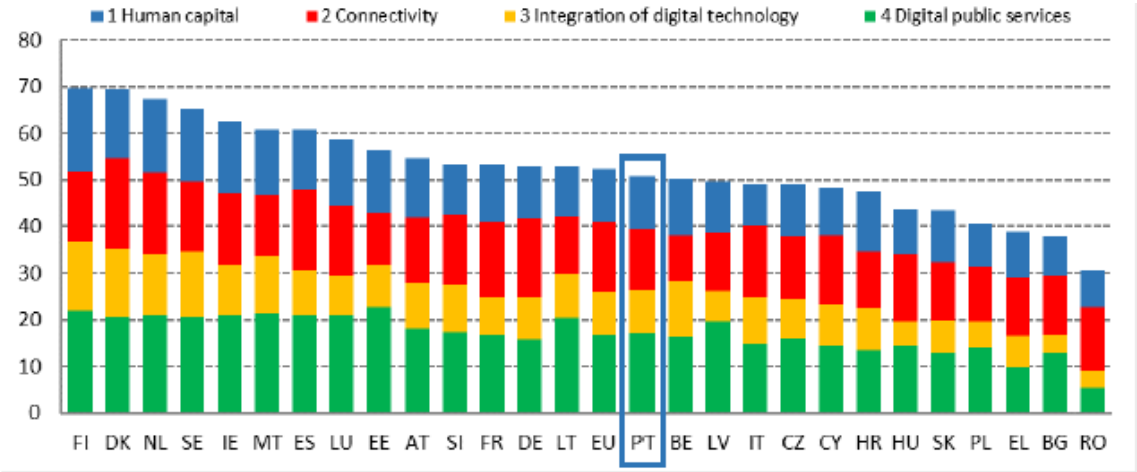

Figure 11 - DESI 2022 ranking [121].

Portugal's digital transformation strategy and action plan places a high priority on public education, industry and government digitization, and digital inclusion. These goals, which centre on digital skills and transition, are in line with the nation's recovery and resilience strategy. The strategy includes individuals, businesses, and public administration, and it expands on already successful programmes while adding new ones. In 2022, a national strategic roadmap for the digital decade is anticipated, which will link the action plan with the EU's 2030 policy agenda. The Estrutura de Missão Portugal Digital (EMPD) coordinates and keeps track of the action plan's execution. To gather and examine pertinent data, the government has strengthened its skills plan and established the Observatory for Digital Competencies. There are still differences in ICT use even though Portugal has taken steps to improve skills and technology adoption. However, the nation's proportion of ICT graduates is comparable to the EU average, which is encouraging for the future digital specialisation of its labour force [121].

Portugal is ranked 14th among EU nations in terms of Human capital with more than half of its population having at least basic digital abilities. To catch up with the best performers, though, there is still opportunity for development. Although the percentage of ICT graduates is below average, the proportion of ICT professionals in employment is comparable to the EU average. Portugal has a higher proportion of female ICT professionals than the rest of the EU. Furthermore, 23% of Portuguese businesses provide ICT training, above the EU average by 3% [121].

Portugal is ranked 18th in DESI 2022's Connectivity dimension. The nation excels in fixed Very High-Capacity Network (VHCN) coverage and fast broadband (NGA) because of the effective governmental and private investment and competition. Nearly 5.9 million households had access to high-speed networks in 2022, making up about 91% of all

households. Households with FTTH (Fiber-to-the-Home) networks were around 5.7 million making an 88% coverage. Millions more homes and companies should be able to get FTTH thanks to agreements between NOS, Vodafone, and Altice. Additionally, wholesale providers are expanding their networks in less populous regions [121].

Portugal has improved its use of digital technology in business operations, moving up five places to 12th place among EU nations this year. However, with a drop in e-commerce revenue from 16% to 13%, the proportion of Portuguese businesses utilising online commerce potential has fallen. The proportion of SMEs (Small and Medium-sized Enterprises) selling internationally and online is still below the EU average. Portuguese businesses use less big data and cloud services than what is typical across the EU. However, 52% of Portuguese businesses have at least a basic level of digital intensity, which is close to the EU average. Social media and electronic information exchange by businesses have grown significantly, outpacing EU average usage. Portugal stands out for its embrace of artificial intelligence and its above-average use of ICT for medium- to high-intensity environmental action in the EU [121].

Portugal aligns with the EU average in this area, ranking 14th in the EU for digital public services. Although the percentage of e-government users has risen marginally, it still falls short of the EU average of 65%. Portugal outperforms the EU average in digital public services for individuals and prefilled forms, scoring 79% and 76%, respectively. Portugal's performance in providing digital public services to companies is on par with the EU average at 82%. Portugal, however, is below the EU norm in the open data category with a score of 66% as opposed to the EU average of 81% [121].

3.4.3 China’s Digital Transformation Level

3.4.3.1 Network Readiness Index

In 2022 China ranked 23rd out of the 131 countries included in the study with its main’s strength being the People pillar where it ranked 8th with a score of 70.77 [120]. As seen on the graphic bellow, China’s greatest scope for improvement is Governance pillar where it ranked 35th, as seen in Figure 12. The country ranks 1st in the group of upper-middle-income countries, having a higher score than the income group average in each of the four pillars, as seen in Table 5. Within Asia and the Pacific, China ranks 6th scoring higher in every pillar than the overall average.

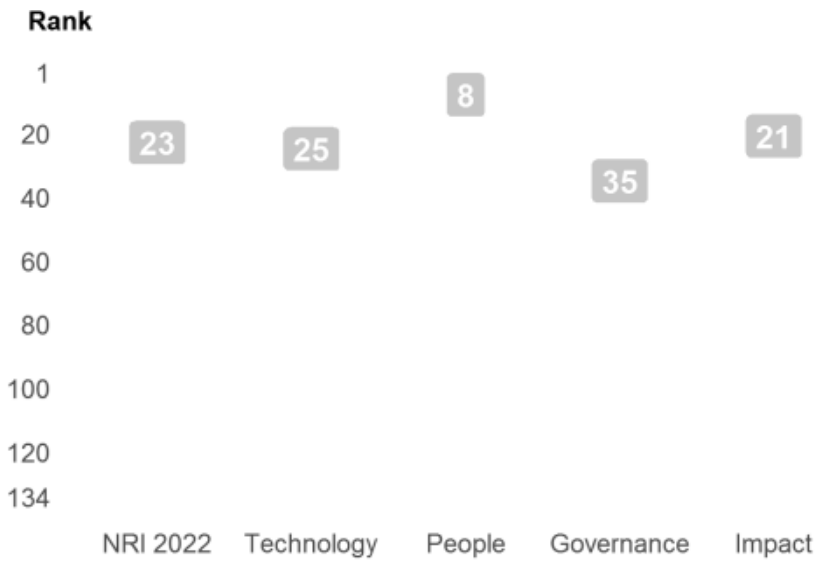

Figure 12 - China's overall ranking and by pillar [120].

Table 5 - China's scores vs average of high-income countries and Europe [120].

Dimension	*China*	*Upper-middle-income countries*	*Asia & Pacific*
NRI	68.83	49.66	55.18
Technology	59.69	43.11	51.78
People	70.77	44.94	50.21
Governance	72.52	57.05	59.66
Impact	72.32	53.5	59.07

Table 6 - China sub-pillar rankings [120].

Sub-Pillar	*Rank*	*Sub-Pillar*	*Rank*
Access	1	Trust	28
Economy	1	Future Technologies	29
Individuals	5	Content	39
Businesses	8	Quality of Life	50
Inclusion	17	SDG Contribution	54
Governments	19	Regulation	81

At a sub-pillar level, China rates higher in Access, Economy, Individuals and Businesses where it ranks 1st, 1st, 5th and 8th, respectively. However, the country could improve its performances in the Quality of Life, SDG Contribution and Regulation sub-pillars where it ranks 50th, 54th and 81st respectively, as seen on Table 6. At a sub-pillar, China

outperforms upper-middle-income countries in eleven of the twelve sub-pillars with the exception of Regulation.

These impressive scores are attributed to China's strong performance in 13 indicators, with its lowest rank among these being 3rd place. Notably, China secures the top position in several indicators, including FTTH/building Internet subscriptions, Mobile broadband internet traffic within the country, government promotion of investment in emerging technologies, e-commerce legislation, domestic market size, prevalence of gig economy, and quality education. On the other hand, the economy's weakest indicators include women's economic opportunity, affordable and clean energy, sustainable cities and communities, privacy protection by law content, and ICT regulatory environment where it rates 93rd, 109th, 117th, 122nd. and 124th respectively.

Figure 13 illustrates that China significantly surpasses the trend line, implying that its network readiness is higher than expected based on its income level.

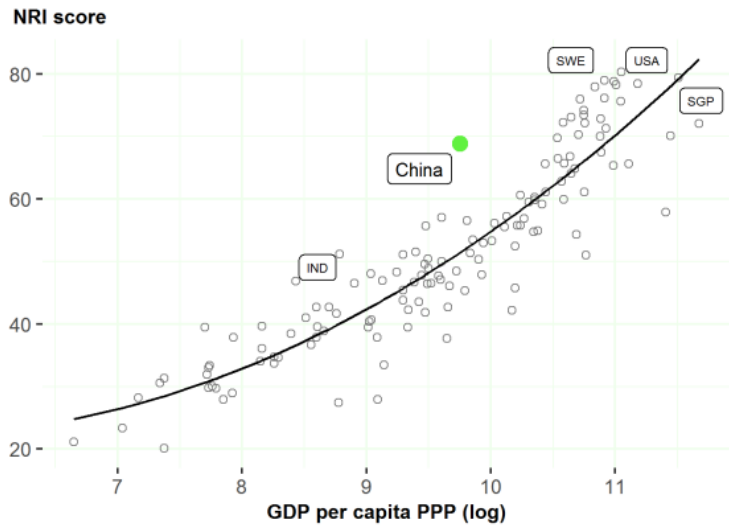

Figure 13 - NRI score and GDP per capita PPP (log) [120].

3.4.3.2 Global Innovation Index

In 2023, China ranked 11th among the 132 economies featured in the GII and 3rd among the 17 economies in Southeast Asia, East Asia and Oceania. The country stands in 1st place among the 36 upper-middle-income group economies [122].

When compared to previous years the country placed the same as in 2021 and higher than in 2020 where it ranked 11th and 14th respectively [122]. Overall, in 2022, the country ranks higher in innovation outputs, 8th, than in innovation inputs, 21st.

Among the seven pillars used in the rank, China ranks lowest in the Institutions pillar, 42nd, followed by Infrastructures, 25th and Human Capital and Research, 20th. The strongest areas are Knowledge and Technology Outputs where it ranks 6th, followed by Creative Outputs, 11th and Business sophistication and Market sophistication, where it ranks 12th in both pillars [122].

The results above are due to the fact that ranks 1st and 2nd in a lot of the indicators utilized to evaluate the countries. However, the country also presents some weaknesses as shown in the table below (Table 7). This table highlights the most important indicators, from the full list present in Table 13 in the annex, utilized in the ranking.

Table 7 - Overview of China's indicator strengths and weaknesses [122].

Strengths				*Weaknesses*			
Indicator name	Rank	Indicator Name	Rank	Indicator Name	Rank	Indicator Name	Rank
Domestic market scale, bn PPP$	1	Patents by origin/bn PPP$ GDP	1	National feature films/mn pop. 15-69	61	GDP/unit of energy use	104
Creative goods exports, % total trade	1	State of cluster development and depth	2	Printing and other media, % manufacturing	72	Cost of redundancy dismissal	111
Labor productivity growth, %	1	Domestic industry diversification	2	GERD financed by abroad, % GDP	77	Environmental performance	115
PISA scales in reading, maths and science	1	Global corporate R&D investors, top 3, mn US$	3	FDI net inflows, % GDP	86		
Trademarks by origin/bn PPP$ GDP	1	Gross capital formation, % GDP	3	GitHub commits/mn pop. 15-69	89		
77101041Utility models by origin/bn PPP$ GDP	1	GERD financed by business, %	3	Expenditure on education, % GDP	95		
Industrial designs by origin/bn PPP$ GDP	1	QS university ranking, top 3	3	Tertiary inbound mobility, %	100		

3.5 Technologies Present in the Airport

3.5.1 Ponta Delgada Airport

The Ponta Delgada airport is run by a private company ANA (Aeroportos e Navegação Aérea) Airports that in total manages 10 Portuguese airports located all over the country and the islands. In 2013, the company was acquired by VINCI whose airport division, Vinci Airports, is known as the global leader in airport concessions, managing over 70 airports in 13 different countries.

VINCI Airports has a service quality strategy that is based on three pillars these being digitalization, robotization and chatbots. Ponta Delgada airport has seen some of these improvements over the years.

3.5.1.1 ANA App

The ANA app is one of these improvements being available in all ANA airports and having been implemented in 2010. The app allows passengers, who download it, to gain access to a lot of services such as book an hotel, check-in, reserve a parking lot and request the ValetXpress service and also the Fast Track service, a priority channel that allows a faster security screening. The app also allows users to subscribe to flight updates, reserve the lounge area, explore the different shops and restaurants available and enhance their airport experience by facilitating business meetings and networking through BITA, Business in the Air. With Business in the Air, you can efficiently utilize your airport wait time by tapping into business opportunities [123]. The idea is simple: utilize your LinkedIn profile to forge new connections, suggest a business meeting at the airport, and verify whether the person you've connected with will be on the same flight. However, in Ponta Delgada the airport does not offer most of these services. The airport does not have a ValetXpress or FastTrack having only information about arrivals and departures, commercial spaces and services and contacts segment which is currently being updated.

3.5.1.2 Security

The airport makes use of HI-SCAN 6040-2is HR scanners produced by SMITHS DETECTION. These are dual-view X-ray instruments utilized in the automatic detection of solid and liquid explosives in personal belongings and cabin baggage [124].

Facilitating swift threat identification on the display, the ECAC EDS CB C1 approval signifies its suitability for screening checked cabin baggage. Additionally, it complies

with EU regulations for LEDS Standard 2 and 3 Type C, obtaining extended approval as a Liquid Explosive Detection System (LEDS) [124].

Employing established X-ray technology, this system produces dependable, top-tier dual-view images. Please note that it is exclusively available in standard resolution and is not sanctioned for screening aviation cabin baggage [124].

The airport has also implemented e-gates that allow for a faster processing of passengers due to their ability to read passports that store biometric data.

3.5.1.3 Passenger Inquiries

The passenger satisfaction assessment has been made possible since 2006 through the use of the Airport Council International's (ACI) program, Airport Service Quality, which is utilized in over 300 airports all over the world, 109 European and more than 50000 passengers surveyed each year, 9000 being at ANA airports. These inquiries were restored in the first semester of 2022 and were implemented in boarding gates [125].

3.5.1.4 Corruption Risk Assessment Program

In 2022, VINCI implemented the Program for Integrity, Transparency and Compliance with the General Framework for the Prevention of Corruption. The program entails 7 mechanisms these being: risk prevention plan, internal control system, charter of ethics & conduct and anti-corruption code of conduct, reporting channel, training program, procedure for assessment of corruption risk in third parties and assessment system [125].

As presented in the 2022 sustainability report [125], in 2021, the "Corruption Risk Mapping" project was originated with the goal of matching the corruption and influential peddling risk mapping, originally implemented by VINCI to cover airports' activities, to ANA's circumstances. The risk matrix and the methodology developed were eventually included in the Corruption Risk Prevention and Similar Infractions Prevention and Detection Plan. However, no circumstances of high or full risks were detected, and the plan denotes the "action plans" which are aimed at reinforcing some of preventive and corrective measures that have been implemented into the system. Its policies, procedures, and controls are aimed at making the organization prosper in achieving its targets.

The VINCI Code and the Charter, together with a special annex of Portuguese legislation, compose the ethical set. The alert unique device organizes and handles the complaints related to the Group's activities and the contractors of the service providers concerning

their activities. The information is highly secured through the Ethics and Conduct Charter.

A mandatory e-learning course for employees and managers, which is accompanied by instruction sessions and specific courses for managers and employees in responsible positions, is among the elements of the training process.

This process was set up in 2021 to audit the red flags of clients and external service providers/suppliers of goods for corruption and implement appropriate mitigation measures.

Internal audits are performed annually to check whether the controls defined in the Prevention Plan are being applied correctly as well as to ensure that the program is implemented according to the schedule, while external audits are conducted every third year.

3.5.2 Beijing Airport

As seen in the previous sections, China is at the forefront of technological innovation, and those improvements can also be seen in Chinese Airports such as Beijing Capital International Airport. By leveraging AI, biometrics, robotics, and other technologies the airport has been able to stay ahead of competition and maintain a competitive edge. Through partnerships with different companies the airport has been able to implement these technologies to improve its efficient, transform the passenger experience to make it seamless and enhance overall operational effectiveness, ensuring that the airport remains at the forefront of modern travel standards.

3.5.2.1 SITA AirportConnect Open

BCIA has partnered with SITA and implemented a variety of technologies. The four-year contract, implemented in 2014, with SITA, led to the incorporation of the company's common-use technology, the AirportConnect Open kiosks, that enabled 700 work stations, more than 1000 ticket or bag tag printers, nearly 300 scanners, more than 200 counters and 100 boarding gates in both Terminal 2 and 3 [126].

3.5.2.2 SITA Smart Path

In 2020, BCIA implemented SITA's most extensive biometric project enabling a fully automated experience from check-in to boarding supported by facial recognition. Passengers are able to enjoy a contactless experience by enrolling once through the registration of their facial token during check-in allowing subsequent touch points to be automated. This system is utilized for duty-free payments thus eliminating the need for

a boarding pass which highlights the main advantages associated with the smart path, these being shorter queuing times and reduced staff-traveller contact which was extremely valuable during Covid-19 [127].

The airport implemented 600 biometric checkpoints including 250 lanes of automatic gates, 80 kiosks and 30 self-bag drop stations. A test executed at the airport demonstrated that the system was able to process and board 400 passengers on an A380 aircraft in less than 20 minutes [128].

3.5.2.3 Smart Inquiry Equipment

In 2022, in its pursuit to establish itself as a global aviation powerhouse, BCIA is integrating intelligent technology across diverse sectors, ranging from pandemic prevention and control to enhancing passenger services and improving airport operational efficiency [129]. As of so the airport has installed 20 units of smart inquiry equipment which offer boarding gate information, guide passengers to transfer flight or public transport, and offer personalized shopping services. This equipment incorporates facial and speech recognition technologies as well as positioning and navigation tech [129]. BCIA has also implemented contactless body temperature checks, infrared buttons for elevators, intelligent restroom fixtures, and additional smart devices to alleviate travel-related stress for passengers [129].

3.5.2.4 RFID Technology

By the end of 2021 all major airports in China were to implement RFID technology into its operations and BCIA was not an exception. In order to help baggage control and diminish the number of lost baggage, with RFID tags, passengers are able to utilize a mobile app to check and trace their luggage through the airport.

3.5.2.5 5G Network

In collaboration with Beijing Mobile and China Tower, BCIA has deployed a 5G network in the end of 2020. This network covers all Terminals as well as parking buildings and is the result of a 10-month project that involved 101 indoor and outdoor wireless base stations starting in December 2019 [130].

This project has allowed 240000 people to have access to a high-speed network at the same time. Testing across multiple locations indicates that the average download speed for 5G at the airport exceeds 1000Mbps, ensuring excellent network quality and user experience [131].

3.5.2.6 Runaway Modifications

Being one of the busiest airports in the world has its consequences as the airport faces significant stress on its runway surfaces, with up to 70 flights per hour during peak times. In 2017 the airport conducted a runway renovation which included pavement milling, paving, and light installing. To address aging issues such as block cracking and fatigue cracking, the airport opted for Evotherm warm mix asphalt (WMA) technology. Chinese contractor Beijing Sino-Aero Construction Engineering (BSACE) collaborated with Evotherm to choose the right technology, focusing on maximizing compaction and mix consistency for the stiff runway mixture types [132].

3.5.2.7 Radar Technology and Communications

In partnership with Israeli company Xsight Systems, BCIA has implemented in 2019 a foreign object detection (FOD) technology. This system is based on sensors and airport intelligence algorithms and was set to be installed on the east runaway where it alerts to debris, birds and other hazardous objects [133].

Prior to 2008, the airport was utilizing analog radios with 15 channels and the ineffective utilization of frequency resources led to obstructions. Switching from old analog communications to a modern TETRA digital radio network from Airbus, BCIA was able to provide high quality command and dispatch services for over 10000 customers. The coverage extends from the exterior of the airport to the interior of all the terminals [134].

This equipment was also installed on Beijing's new airport Beijing Daxing International airport and was able to allow both airports to communication seamlessly by enabling authorities, airlines, ground service companies and other operators to arrange for the smooth transition of airport operations between them [134].

3.5.2.8 Sustainability

With the construction of Terminal 3 in 2008, the airport led a more sustainable approach to its infrastructure. With a soaring aerodynamic roof that utilizes skylight to make the most of the sun's heat and light, then terminal is one of the largest passenger terminals in the world and one of the most sustainable [135].

With an energy-efficient point of view, the gracefully curved roof, catches light effectively harnessing thermal energy, contributing to winter morning heating and consequently mitigating overall energy consumption. Additionally, their modest size plays a role in diminishing the building's cooling needs during the hotter summer seasons [135].

Other passive environmental technologies were included such as separate water systems for drinking and non-portable use were implemented. By using integrated environmental control systems thus reducing energy consumption, carbon emissions were diminished [135].

3.6 Upgrades Being Conducted at the Present Time or Planned for the Future

3.6.1 Ponta Delgada Airport

In the last few years, the João Paulo II airport's technological advancements were in a perspective of a technological upgrading in a way to correctly process passengers even with an increase in traffic. As of so the following measurements are or will be put in place to improve the airport's infrastructure.

3.6.1.1 Building Management System

The airport envisions the incorporation of a Building Management System (BMS) to enhance its energy efficiency. In simpler words, a Building Management System, or BMS, is a computer-controlled program. This program manages and observes a building's electrical elements, such as lighting, air systems, power, fire safety, and security. A BMS is made up of software and hardware parts. These parts are important in managing a building's energy needs efficiently. A BMS can help cut down energy bills and keep a comfortable environment for all people in the building. Plus, it makes managing a building's HVAC system from a distance possible. Therefore, maintenance crews no longer need to go to each building or room for tasks like starting, shutting down, or changing the temperature of air systems [136].

3.6.1.2 Biometric Experience

As part of the VINCI Airports mission to make the ANA airports more modernized, five of the biggest Portuguese airports, including Ponta Delgada's airport, are currently implementing a biometric programme called "The Biometrics Experience" which has already been launched in Lisbon and Porto and will be available in Faro, Funchal and Ponta Delgada during the second half of 2024 [137].

This solution will enable biometric boarding which is now being tested in selected TAP flights within the Schengen area. Advantages for passengers include the use of facial biometric data to ensure a smoother airport journey with no stops or queues as well as keyless boarding. The technology guarantees privacy and security since the data is deleted after each flight [138].

Participation in this identification process is not mandatory. Initially meant for flights within Europe, passengers who qualify can register using their mobile devices through the use of the Self Enrolment Mobile app or at specifically set up airport kiosks through 'Biometric Experience by VINCI Airports'. This procedure requires scanning of boarding cards, e-passports, or Portuguese national ID cards, taking a selfie and accepting the terms and conditions, as seen on Figure 14 [138].

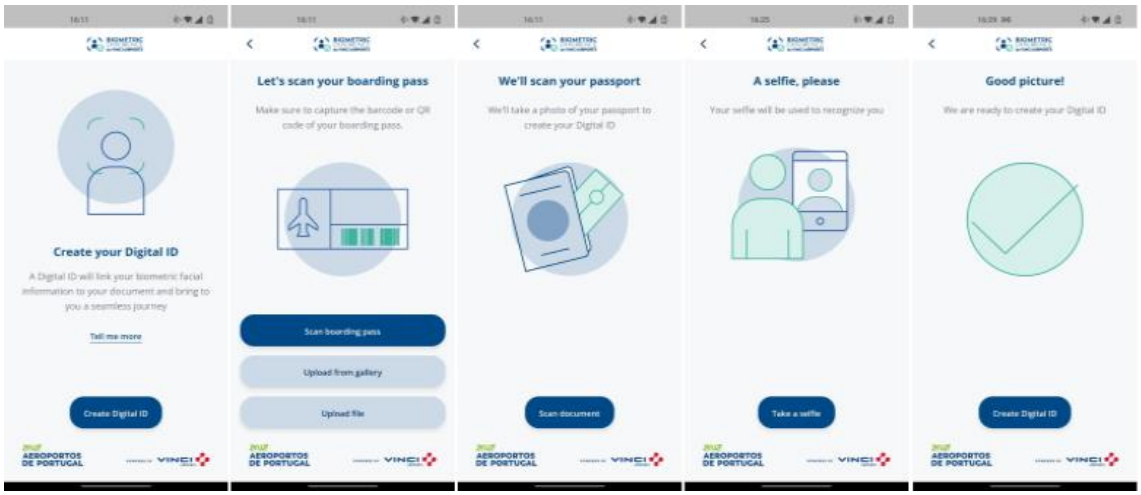

Figure 14 - Process of registration on the app [138].

This smart system verifies whether or not the passenger is who he claims to be throughout his/her journey through the use of sophisticated algorithms thereby eliminating multiple physical/digital identity verification points during boarding [138].

3.6.1.3 Passenger Accessibility

The assistance of passengers with special needs, from their entry into the airport until they are on board of the aircraft, is the responsibility of the airport. For this purpose, the airport utilizes a system to manage these assistances, supported by information from tablets, used by the PRM (Passengers with Reduced Mobility) service, and from the operational management systems. This allows staff to track in near real-time the passage of these passengers through all mandatory control points, as well as ensure reporting to the regulator.

3.6.1.4 Sustainability Solutions

Since 1998, ANA has consistently prioritized sustainability in the management of its airports. From the initial iteration of the Environment Policy, the company is committed to establishing and upholding an Environmental Management System that is both effective and suitable, actively contributing to the sustainable development [125]. The materiality matrix depicted in Figure 15 and Table 8 highlights energy, CO_2 emissions,

air quality, professional development, and recognition as the key focal points with significant relevance to both business and society.

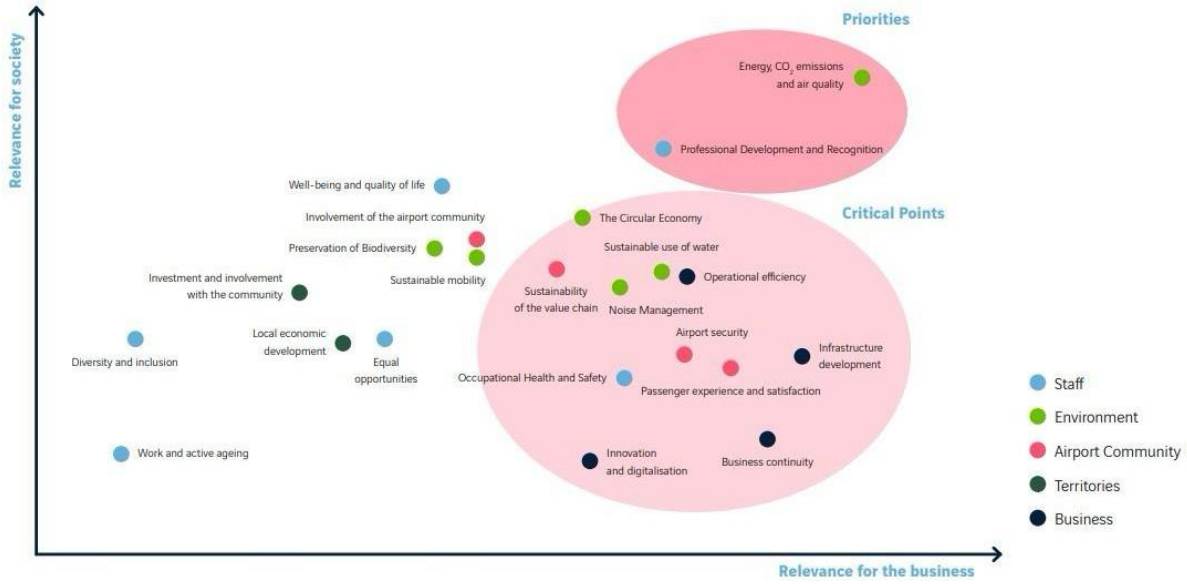

Figure 15 - ANA's Materiality Matrix from [125].

Table 8 - ESG issues rank adapted from [125].

Importance	*ESG Materiality Issues*	
High Importance / Priorities	1	Energy, CO_2 emissions and air quality
	2	Professional Development and Recognition
Medium Importance	3	The Circular Economy
	4	Sustainable Use of Water
	5	Sustainability of the Value Chain
	6	Noise Management
	7	Operational Efficiency
	8	Occupational Health and Safety
	9	Airport Security
	10	Passenger Experience and Satisfaction
	11	Infrastructure Development
	12	Innovation and Digitalisation
	13	Business Continuity

In 2022 an electrification plan that will extend until 2030 was initiated and it is set to substitute 11 light passenger vehicles in Lisbon, Porto, Faro, Madeira, and Azores for electric versions and for emergency vehicles, alternative fuels will be tested [125].

To control the air quality, the João Paulo II airport conducts a monitoring campaign every 3 years, having the last been conducted in 2022. The airport also conducts strategies to reduce waste. The initiatives include expanding strategies to reduce consumption and optimize material use in airports. There is also a focus on enhancing the involvement of all parties to ensure proper waste separation at Collection Points/Zones. Regular assessments of storage containers are proposed to optimize the cost of waste collection and dispatch based on quantities and collection frequency. Additionally, there is an emphasis on credibly determining the quantities of solid waste equivalent to municipal waste. In a general way, all ANA airports aim to maximize the prevention of production, reutilize and recover, to harmonize processes, and to reinforce third-party awareness, monitoring and control [125]. The airport has also implemented a wastewater treatment station.

In the Azores there has occurred the installation of heat pumps with support from solar panels to produce hot domestic water [125]. In the future, the airport is set to implement a solution with photovoltaic panels as a part of the Comprehensive Implementation Plan for Solar Plants. Currently, all the airport lighting is managed by an automatic system that turns the lights on and off based on the movement of aircraft and passengers in the terminal, ensuring that only the strictly necessary lighting is in use at any given moment.

3.6.1.5 Security and Cybersecurity

ANA has a Data Protection Officer (DPO) and groundbreaking corporate policy. Its data protection policy sets out several crucial goals including informing and disseminating information to new and existing personnel on matters relating to the processes and procedures for compliance with the GDPR (General Data Protection Regulation); ensuring its implementation; monitoring developments in GDPR; assessing its compliance; adhering to the GDPR; supervising the documentation of all DPIAs (Data Protection Impact Assessment); assessing potential exposure to risk; developing and ensuring continuity of the corrective process; documenting all activities covering data protection processing or operations; and providing training for all personnel on the best practices for data protection and control authority.

ANA disposes of an array of tools associated to the processes, people and technologies that manage and assure the safety of information. At the present time, ANA is implementing an information safety system based on ISO/IEC25001 as a means of formalizing the processes already in use. Considering the nature of the business, ANA has always had the need to ensure that its information systems are resilient and guarantee the operation of infrastructures. For example, the airport has always had and

continues to have critical systems in closed networks (air gap) with very restricted access and constant security updates.

With this security system the airport is able to assure the interoperability with its stakeholders to send and receive information in a way that together the infrastructure is able to smoothly run without conflicting and disturbing the passengers.

3.6.1.6 Airport Community App

The Airport Community App developed by Airport Labs, has been applied to over 2500 companies and gained over 120 million monthly interactions. According to Airport Labs, [139], this app allows for real time collaboration, where it collects data in real time for efficient time decision making and real time coordination, emergency messages are sent in real time for the entire community such as airport employees, authorities, airlines and ground handlers, etc. The app is to be implemented during March 2024.

3.6.2 Beijing Capital International Airport

In 2022 the airport took a proactive role that focused on safety first and increasing the quality and efficiency. Additionally the airport aims to initiate a new phase in the development of a high quality era for BCIA to achieve its key tasks. These include continuous improvement in operational safety capabilities, fostering consensus to propel aviation hub development, establishing a benchmark service standard aligned with the Chinese standards, and innovating business operations to enhance overall corporate effectiveness [140].

To proficiently oversee the carbon quota at Beijing Capital Airport, a "Green Gateway Airport," was established and contributes to the development of an environmentally conscious airport featuring attributes like "energy-saving, eco-friendly, hi-tech, and user-friendly," the airport diligently adheres to relevant national and local environmental protection laws and regulations. Additionally, it conscientiously fulfils its environmental obligations and actively responds to national initiatives focused on energy conservation and emission reduction [140].

In the last Economic, Social and Governance (ESG) report related to the year 2022, 20 ESG material issues were identified which were ranked according to its importance level (Table 9 & Figure 16).

The constant communication with the diverse stakeholders has allowed for the company to improve its overall efficiency and activities through different communication channels (Table 10).

Table 9 - ESG issues rank adapted from [140].

Importance	*ESG Materiality Issues*	
High Importance	1	Safe Operation
	2	Occupational Health and safety
	3	Passenger service
	4	Employee interests and benefits
	5	Customer privacy
	6	Risk management
	7	Business ethics
	8	Anti-corruption
Medium Importance	9	Corporate Governance
	10	Noise pollution
	11	Resource utilization
	12	Employee development and training
	13	Discharge management
	14	Public health
	15	Technology innovation
	16	Intellectual property protection
	17	Industry exchange
	18	Climate change
	19	Supply chain management
	20	Community investment and public welfare

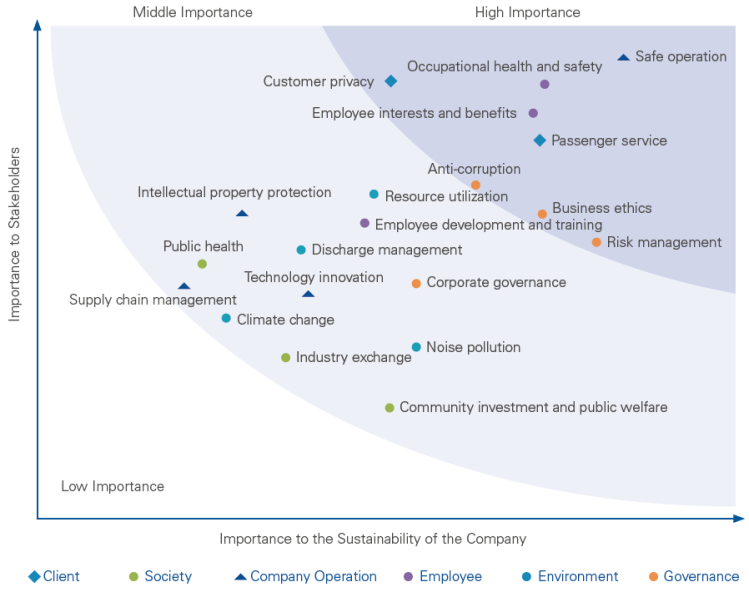

Figure 16 - BCIA's Materiality Matrix from [140].

Table 10 - Stakeholders engagement [140].

Stakeholders	*Expectation and appeal*	*Communication method*	*Stakeholders*	*Expectation and appeal*	*Communication method*
Government and regulatory authorities	• Safety support • Passenger service •Environmental responsibility • Staff's rights and interests • Public welfare	• Special report • Research and visit • Project cooperation • Work conference • Statistical statement	Employees	• Staff's rights and interests • Career development •Compensation and welfare	• Democratic communication • Workers representatives conference • Trade Union and Staff Service Center • Suggestions, mailboxes and WeChat
Passengers	• Safety support • Service quality	• Passenger service • Satisfaction survey • Online service	Suppliers	• Company reputation • Financial performance • Sunshine purchase	• Support of major events • Charity activities • Volunteer activities
Investors	• Information disclosure • Corporate governance • Financial performance • Investors' rights and interests guarantee	• Internal control system improvement • Regular announcements and reports • General meetings of stockholders and conferences of the Board and the Board of Supervisors • Investor visits, conference calls, and investment banking strategy sessions	Airlines and airport-based organizations	• Safety support • Passenger service • Common development	• Communication mechanisms including Beijing Capital International Airport Passenger Service Promotion Committee • Conference and communications • Activities to check and solve service problems
Community	• Volunteering • Public welfare • Community development	• Support of major events • Charity activities • Volunteer activities	Counterparts	• Exchange and cooperation • Industrial development	• Forum and conference • Exchange and learning • Alliance

3.6.2.1 Climatic Changes

The airport's upgrades that will be taking place in order to combat climate change are set on 4 pillars these being the optimization of the energy mix, the improvement of energy efficiency, the promotion of low-carbon transportation, and implementing green facilities.

As a result of the climate change, the airport has evaluated the physical and transition hazards related to climate change and has taken deliberate action to mitigate these risks. As a result, it has developed plans and solutions, modifying resource allocation and company growth to increase its resilience to climate change. Understanding how weather disasters might affect airport operations, the company has put in place extensive emergency response plans and security measures. The ongoing improvement of emergency response protocols guarantees timely and efficient reduction of the effects of climate change on its operations [140].

In order to encourage sustainable practices, BCIA has established objectives for carbon peaking and neutrality, recognising the prospects in low-carbon development and transition. It incorporates pollution reduction and energy conservation into regular activities. Targets for climate change assessments are shared by several departments, which improves management and responsiveness. In accordance with the 14th Five-Year Special Plan for Green Development in Civil Aviation, it intends to enhance its environmental performance goals. It will also make contributions to the national "dual carbon" targets and provide regular updates on its progress [140].

3.6.2.2 Safety Management System

The airport significantly advanced IT-based development in 2022 to improve operational safety monitoring was both accurate and effective. By adding the "Emergency Management" module and creating 48 new functions, such as personnel points management, safety responsibility puzzle management, and safety bottom-line index management, the "1-2-1" smart safety management system was improved. The inspection management system's performance and user interface were enhanced, leading to an 80% rise in reaction speed and fluency and a major gain in operational efficiency. Following the implementation of the "Safety Hand-shoot" feature, 4608 reported cases were received; 2347 of the issues were confirmed, and 2329 were fixed [140].

In order to smoothly combine the yearly Safety Management System (SMS) audit with daily inspections, the airport designed a safety management model that incorporates online safety systems with on-site operations [140].

The National Civil Aviation Safety and Security Programme, Training Programme, and Quality Control Plan are only a few of the aviation security rules and regulations that the airport carefully complies with. In an attempt to improve aviation security, three hazardous products management employees, ten security testers, and seventeen security quality control officers have been added to the team. Enhancements to training include arranging training on security duties and awareness, streamlining the quality control training needs, and optimising the management mechanism. New regulations for access control are reinforced, and liquid products undergo a thorough inspection based on the Material Safety Data Sheet. The airport carried out 3 security drills, 146 security tests, and 3,611 security inspections in 2022. Eight dangers were found during risk and hazard inspections, and the appropriate management measures were put in place. By December 2022, five new aviation security risks at the department level had been identified and handled, while a total of thirty-one company-level aviation security hazards had been introduced and fixed [140].

3.6.2.3 Best Safety Site Project

The airport launched the "Best Safety Site" trial initiative in 2022, emphasising the location, features, and standards. Standardisation, professionalism, proactiveness, dependability, intelligence, and safety were the objectives of the project. In order to raise the bar for site safety management, strengthen long-term on-site safety systems, and guarantee efficient and well-managed safety management, 14 pilot projects were launched. The airport laid the groundwork for the establishment of the "Version 3.0" safety culture by working with pertinent parties to strengthen the proactive safety culture and create a community of shared safety [140].

3.6.2.4 Cybersecurity

As a critical component of information security, the company gave cyber and data security management top priority in 2022. Strictly abiding by the People's Republic of China's Data Security Law, the airport consistently improved cybersecurity laws, particularly those pertaining to data sharing and management and cyber and information security. In an effort to fortify its strategy, the company established a Data Security Leading Group in order to develop a regional cybersecurity coordination mechanism. This involved outlining the duties and structure of the leading group for network security and information technology. In 2023, plans call for creating a

functional system for data security based on the Data Security Leading Group. The airport plans to improve its emergency response system, early warning system, and data security monitoring. Furthermore, by establishing data risk levels, it will arrange all departments to categorise and grade data in accordance with requirements, aiding in the standardisation of information security operations [140].

The organisation has created a Personal Information Protection Policy that outlines the goals and parameters to gather and use personal information in compliance with regulatory obligations. The policy covers a number of information categories, including contacts, luggage, location, travel information, and personal identity. Based on passenger demands, the airport provides 17 services, such as luggage services, amenities, care delivery, and convenient travel, to which the information gathered is used. Customers have the right to request that their personal information be deleted and to withdraw their consent for the airport to handle their data in the event that there are privacy concerns or information leaks that violate legal requirements. The main goal is to prioritise customer privacy and rights while facilitating the legitimate and orderly flow of information.

3.7 Upgrades that were denied

3.7.1 Ponta Delgada Airport

All solutions related to passenger flow optimization through video technology face significant obstacles to their introduction, both due to legal impediments associated with their exclusive installation in people and property security contexts, and issues related to GDPR. The delays and obstacles encountered in the implementation of these projects result in a deficient time-to-market.

3.7.2 Beijing Capital International Airport

Information about all the upgrades that were not conducted in the BCIA airport despite the efforts were not disclosed by the airport's representative.

3.8 Conclusion

This chapter provided an understanding of João Paulo II Airport and Beijing Capital International Airport, focusing the value of its digital development and technological context.

The analysis which started with the digital transformation initiatives in place in those countries went further in highlighting the technologies that had been brought in in those

airports. Regarding this, it can be mentioned that both Portuguese and Chinese economies are ready and actively participating in the process of digitalization, even though at different intensity and scope levels.

Furthermore, the chapter investigated ongoing and future upgrades, as well as instances where upgrade proposals were denied. For both airports, several changes and expansions are being envisioned. Ponta Delgada Airport aims at increasing the construction of new facilities in the airport context, with projects regarding passengers' well-being and airport efficiency. Similarly to the previous case, Beijing Capital International Airport has plans for future development with attention being paid to the security issues and construction changes. This comprehensive review sets the stage for a deeper understanding of the aviation landscape in these regions, offering valuable insights into the evolving nature of airport operations, technological advancements, and the strategic decisions that shape their trajectories.

However, there are problems since some of the proposed improvement schemes have had challenges. Nevertheless, there is no resting place for the two airports as they strive to come up with better innovations and services for the industry.

Chapter 4 - Results Analysis

4.1 Introduction

This chapter aims at comparing the technological advancement of João Paulo II Airport and Beijing Capital International Airport. Therefore, it looks at the advantages and disadvantages of these enhancements mainly in terms of effectiveness, convenience, costs and safety while also showing the manner in which some features of the technological advancements are incorporated depending on the size and the budget of the infrastructure. In addition, it evaluates the effects of such innovations on passengers and employees, training and passenger care programs. In conclusion, this chapter provides a summary of developmental changes in airport technology and their implications to airports and their counter parts.

4.2 Analysis of the Advantages and Disadvantages of the Improvements

4.2.1 Benefits of the Enhancements

On both airports it is possible to see an improve in efficiency and wait times as it was expected. In João Paulo II airport, the utilization of automatic systems such as e-gates has helped border control which leads to an increase in efficiency and a reduction in wait times. These results can be seen in the service quality inquiries' results present in the next and Annex section that show the improvements over 2021 and 2022. Passenger convenience is one the most important aspects of airport's operations and one of the backbones of technological improvements. Every airport is able to provide travellers a more efficient and customised travel experience through airport mobile applications, as is the case at Ponta Delgada's airport, and queries, which take place at BCIA. The incorporation of airport applications has completely changed how travellers engage with Ponta Delgada Airport. These applications usually come with several features, such as digital boarding cards, self-check-in choices, real-time flight information, and help finding your way around the airport. From the comfort of their smartphones, travellers can easily navigate the airport, get pertinent updates, and finish a variety of pre-flight procedures. The introduction of the Chatbot will also allow for the creation of a more direct and automated channel to provide operational and commercial information to passengers. Similarly, the introduction of the Airport Community App will enable the implementation of a dedicated app for staff, allowing greater sharing and access to

restricted operational information and specific aspects dedicated to staff, such as exclusive discounts in commercial spaces.

However, at Beijing Capital International Airport, the focus on passengers makes a substantial contribution to the improvement in general. When inquiry services are implemented, whether via digital platforms, information kiosks, or dedicated counters, travellers may quickly address problems, request assistance, and learn more about services. An airport that is more responsive and focused on the needs of its customers benefits from this individualised response to queries from travellers.

One benefit of integrating technology into airports is that it may streamline the passenger experience. Airports are empowering travellers by introducing self-drop luggage, self-checking kiosks, RFID, and biometric technologies, among other measures that put them in charge of their travel experience. Modern airport procedures have been completely transformed by the advent of technology like self-drop luggage and self-checking kiosks, which make it easier and more efficient for passengers to pass through numerous checkpoints. These developments guarantee travellers a smooth and convenient experience by cutting down on wait times and processing delays.

Combining RFID, biometric technologies and e-gates improves security protocols and streamlines the identity procedure, which further improves the traveller experience. Travellers can feel more at ease knowing that their luggage is being tracked precisely and in real time thanks to RFID-enabled equipment. Biometric technologies, such as fingerprint scanning and face recognition, streamline identity verification processes by decreasing the need for paper documentation and improving security protocols.

In this technologically advanced setting, passengers may experience an airport that is more seamless and customised. The use of these technologies guarantees a more seamless travel experience from the time passengers arrive until they board their planes, freeing them up to concentrate more on the thrill of their destination than the intricate procedures at the airport. The ultimate goal is to provide an airport environment that is more focused on the needs of passengers, where technology collaborates to optimise operations and raise travellers' level of satisfaction before they take off.

The optimisation of limited resources is also another benefit that smart technologies have allowed airports to take advantage off. In Beijing Capital International Airport, CUPPS and CUSS solutions have been put in place. In Ponta Delgada, the utilization, based on forecasted passenger numbers per flight, in operational management systems also ensures optimal efficiency in space utilization and anticipation of needs (e.g., if a flight with a 200-seat plane only has 80 passengers, it allows for the use of smaller

boarding areas and a reduction in the required assistance staff, who can then be allocated to another flight with greater needs).

Technology as a tool is an enhancer that increases traffic without reducing the quality of service. Thus, technology-induced economic benefits also flow from technological investment. Consequently, these technologies have been able to reduce processing times and thus improve turnaround times for flights and make better use of airport resources.

Both airports show their sustainable approaches due to the consistent efforts towards the adoption of innovative solutions that emphasize on environmental conservation as well as resource efficiency.

This can be illustrated in Beijing with the Terminal 3 which was built to be a sustainable infrastructure. In this respect, innovative technologies to preserve energy and water resources were introduced. The building, for example, deploys smart climate control systems which optimize HVAC based on real-time occupancy as well as weather conditions. Additionally, lightening that saves energy and renewable energy sources like solar panels contribute to lowering overall carbon footprints of the terminal.

The fact that these initiatives have succeeded shows the ability of technology to act as a spark for change in airport infrastructure when properly utilized. In order to keep leading in green buildings, airports must always be at the forefront of innovation.

Both airports were able to achieve real time update and communicate seamlessly beyond geographical boundaries through the use of these innovative technologies which made it possible for global connectivity to be fostered. This is essential since it allows for instant exchange of vital details between various airport sections, airlines, and relevant authorities due to the integration of cutting-edge communication systems. By incorporating real-time updates into their systems, airports become capable of efficiently monitoring and managing different aspects of their operations. For example, flight schedules can be dynamically adjusted based on up-to-the-minute information about baggage handlers, security protocols, or passenger flows. Consequently, this enhances overall efficiency in terms of operations while at the same time ensuring that travel experience is more organized as well as customer oriented. Furthermore, this extends the global linkages facilitated by the technologies even outside the airport precincts. Airports can be linked with one another in real time, airline partners and international organizations thereby creating a network that will enhance coordination of air traffic as well as improve safety protocols on a global scale.

Another role is played by having real-time data availability when it comes to anticipating and responding to unforeseen events like weather disruptions or security incidents. Instant access to accurate information allows airports to make quick and informed decisions, thus minimizing any interruptions and facilitating service continuity.

In essence, not only do these innovative technologies increase operational capabilities of individual airports but they also contribute towards a globally connected seamless air transport system. The existence of real-time communications via these advances is the basis upon which modern day efficient safe interconnected air travel rests.

4.2.2 Disadvantages of the Upgrades

These technological investments also have down sides for instance they can be extremely high on both airports. Implementing and maintaining these advanced technologies can be associated with a financial burden. Specialized equipment and software, along with personnel training, have a substantial upfront investment. Also, ongoing maintenance adds to the financial consideration. Systems require regular updates, chronic troubleshooting and keeping up with industry standards can incur substantial expenses. Moreover, skilled personnel must be hired and maintained to manage and support these technologies. While the appealing advantages of increased operational efficiency, heightened security, and an improved passenger experience are noteworthy, individuals involved must undertake financial considerations and calculations. Successful long-term deployment and sustainability of these advanced tech solutions in the aviation sector will depend greatly on finding the right balance between the immense potential benefits and added costs.

Associated with these technologies comes a higher threat risk as a vast range of personal information is stored online and at a risk of cyberthreats. Both airports are at risk of cyberattacks through different forms such as malware, DDoS or ransomware. Such cyber threats have the potential to trigger serious implications, ranging from disruptive aircraft delays to the violation of passengers' sensitive data, and substantial financial losses for both airport authorities and airlines.

Hence, the airport’s digital infrastructure can be compromised by malicious actors using sophisticated means to try and disrupt critical systems and normal operations. The effects of such an attack are far reaching in nature as they have a great impact on the affected parties. This is because flight delays affect all passengers traveling not only those directly on that flight, thus disrupting air travel efficiency in totality. When passenger data is compromised, concerns arise over privacy breaches which may undermine trust

in the airline industry. On top of these there are financial implications; costs related to restoring systems, compensating passengers involved, and impacts on aviation economy.

So as to effectively address these risks it is necessary for airports to put into place strong measures that will protect them from cyber threats by regularly updating their defence mechanisms against emerging threats as well as embedding proactive strategies against potential cyber-attacks. Airports, airlines, cybersecurity experts and relevant authorities working together is vital for establishing a resilient defence against cyber threats that continue morphing thereby ensuring the continued safety, efficiency, and dependability in air travel.

Another concern that rises from these technologies is the quick adaptation of technologies that passengers and employees are subjected to that can lead to setbacks. The progress of automation as well as self-service has the advantage of shortening the process duration but at the same time can undermine personal assistance and leave travellers disconnected. Incorporating recent technology may help improve customer convenience, yet for some people, particularly those who are older or less comfortable with it. The reason behind its low acceptance is also related to privacy and data security whereby they extensively gather passenger data that could be used against them which in turn leads to rampant mistrust toward smart airports.

4.3 Comparison between the Technological Improvements in the Different Airports

The preceding sections highlight the distinctiveness between the two airports. Their dissimilarities extend beyond geographical locations, encompassing varying technological advancements, support systems, and budgetary allocations.

In the previous chapter, a comparison between the digital transformation of each country was presented. While there were only 2 indicators out of the three most commonly used to rank countries, China outranked Portugal in both of them. Notably, this occurred despite China being situated in a lower classified group, specifically the upper-middle income group. This is also evident in how the airports have implemented technology over the years, showcasing China's commitment to leveraging digital solutions for enhanced efficiency and service delivery.

Both airports are not provided with the same kind of technology as described in the previous sections. Notably, Beijing Capital International Airport has adopted various technologies over the years, some of which have either not been implemented in Ponta Delgada or have been introduced several years later in comparison to their initial

deployment in China. An example is the biometric technology that has been present in China since 2020.

Budgetary allocations are obviously a constraint for both airports but more evident in Ponta Delgada. As a smaller airport, with less traffic it is obvious that its budget for technological upgrades is significantly lower when compared to BCIA. Besides being in the top 5 airports ran by ANA, the airport serves a much smaller city than Beijing which also leads to the discrepancy in its technology investments.

Despite differing economic perspectives, both BCIA and Ponta Delgada's airport prioritize security improvements by allocating a section of their financial budget towards this endeavour. Additionally, both airports share a common concern for passenger satisfaction, regularly conducting inquiries to identify areas for improvement. Furthermore, they actively seek feedback from travellers to promptly and effectively address any issues that may arise, demonstrating their commitment to providing a seamless and satisfactory travel experience.

Sustainability is a common problem for the airports. With the growing concern of air pollution and aviation industry as a contributing factor, both airports are turning to more sustainable practices to meet regulatory requirements. This is not limited to the modification of the existing physical infrastructure and the use of technology which portray a bright future for the earth. This commitment manifests itself in BCIA's new construction projects as well as in the plan of one day relying on renewable energy and water reuse techniques, just as it happens in Ponta Delgada. Collaborative projects including tree planting campaigns, waste reduction programs, and educational outreach would not only help alleviate negative environmental impacts but also citizens' social responsibility and involvement.

Some of the improvements seen on Beijing Capital International Airport could be implemented in Ponta Delgada's airport in the near future. For example, the use of RFID tags could be an improvement to implement as a way to increase efficiency by reducing lost bags and locating passengers and their baggage. An initial budget allocation would be required but in the end a decrease in lost baggage, a better tracking system for passengers and their luggage would certainly prove to be beneficial.

4.4 Passenger and Workforce Analysis

The introduction of the different technologies has led to improvements in passenger's and the workforce's reaction. Both airports have conducted programs and training

sessions in order to boost productivity but also familiarize employees to new technologies and to different work environments.

4.4.1 Ponta Delgada

From ANA's point of view, it becomes essential to invest in the professional growth and in the acknowledgement of the employees to ensure that the company is prepared to face the constant evolution. This way ANA promotes developing opportunities such as continuous training and education programmes.

To analyse and determine developmental progress, as stated in its 2022 sustainability report [125], ANA has implemented a model for all its employees that maintained the People Review methodology, an instrument utilized by VINCI to identify and manage potential, that can be applied to all parties of the management team. To evaluate, ANA hopes to assess the value each employee adds to the company in two main areas: skills and responsibilities and activities. The model, that is based on four main stages (self-assessment, assessment, feedback meeting, and official results) hopes to aid in the professional development of each employee in the short and long term.

ANA has invested in new training activities in order for employees to develop new skills while also focusing on upskilling and reskilling. These include a program created by the VINCI Group, the Business Game, that is based on an airport management simulator where the participants are given an initial budget in order to manage their airports. 72 trainees benefited from the 3 initiatives of this program that happened in 2022.

The Airport Management Advanced Professional Qualification Program is a recognizable international airport management program whereby participants acquire high level professional managerial skills and achieve the highest global airport management standards. In the past 13 years, 35 employees participated in the program.

The R-challenge, that took place in 2022 and was conclude in early 2023, is a training programme which was initiated with the main goal of retaining talents in ANA. In this simulation, participants played in an external setting where the familiarity of their comfort zone would be broken into and a more rounded business thinking could be stimulated using a circular business simulator. In 2022, 297 hours of the initiative were conducted, and 33 employees benefit from it.

The Leader of the Future is the international training program initiated by CEGOC, the certified training entity, covering the 40 practical hours of comprehensive, agile and collaborative leadership mindset development.

The multipliers module took place in 2022 and was the final program of the COVEY Leadership Training Program which began in 2020. This module allowed participants to learn the fact that they are leaders in team management on top of them being amplifiers or reducers of their team's potential. The program addressed all levels of management, including the Executive Committee of ANA.

The *Promova* program is a CIP's (Portuguese Business Confederation) program aimed at raising gender equality awareness in Portuguese companies through training, diagnosis, support for equality policy implementation, and sharing best practices. It seeks to achieve a more gender-balanced and fair workplace through the promotion of women's rights and equal opportunities.

The company has established goals and objectives for the next years until 2025 in areas such as training, appeal, awareness-raising and training on the subject of sustainability, health and safety, and gender opportunities.

The company aims to sharpen the average hours on training programs as per the specific goal of 36 days by 2023 and an annual rise by 1 hour until 2025. In addition to this, the company targets at upping the number of staff taking part in a minimum of twenty-five hours of training or finishing at least one course every year. This percentage is set to rise to 65% in 2023, 67% in 2024, and 70% in 2025.

In the appeal and sustainability area, ANA strives to increase its presence in trade fairs and open days for students, increase the percentage of training courses on sustainability for employees and the number of internal campaigns related to sustainable practices.

Issues like health and safety at ANA are addressed by setting a zero-accident goal, which includes a reduction in the lost-time injury rate to 3.13% within three years, as well as a severity rate of 0.43%.

As a way to promote equal opportunities for women ANA strives to increase the percentage of women in leadership roles by 1%.

In terms of customer satisfaction, ANA deploys the ACI Airport Service Quality (ASQ) survey program where indicators in two major areas are analysed these being indicator of the availability of airport infrastructure and of the level of passenger satisfaction.

In 2022 a non-compliance with Airport Service Quality Regime (ASQR) minimum service levels happened in Ponta Delgada indicating to people movers, more specifically, escalators during the second quarter.

The results from other areas of the inquiries regarding the year 2022 can be found in the table below (Table 11). Compared to the previous year, whose results are present in the Annex section, the airport has shown consistent improvement.

Table 11 - Passenger satisfaction inquiries results [141].

	Punctuality		*Security (<10 min)*	*Baggage (<20 min)*		*Passenger Satisfaction (out of 5)*
	% delays at arrivals	% delays at departure	Passenger Processing	First	Last	Overall
January	9.64%	10.29%				4.19
February	6.68%	7.29%				4.23
March	12.56%	12.65%				4.25
April	23.09%	21.46%				4.39
May	22.61%	20.33%				4.17
June	31.29%	32.83 %	98.19%	96.58%	91.94%	4.21
July	33.75%	38.67%				4.37
August	23.70%	26.96%				4.35
September	21.63%	21.63%				4.34
October	22.68%	23.74%				4.13
November	32.87%	30.35%				4.13
December	38.66%	37.27%				4.13

4.4.2 Beijing Capital International Airport

Beijing Capital International Airport also makes use of the ACI's airport service quality survey in which in 2022 was able to collect data from processes such as arrival, check-in, security, passport, shopping, and dining [140]. In the 1879 samples collected, a number that was affected by the pandemic during the fourth quarter of 2022, the results show that the overall passenger satisfaction score was 5.00 and the average sub-sector score was 4.99.

The airport tries to overcome passengers' complaints and claims by gathering them through different platforms. It also conducts the "1+N" passenger demand survey project whose aim is to appreciate the needs and expectations of travellers through the examination of their preferences, the progress of transport and facilities, and service optimization. External third-party reports are also used to enhance research reliability and optimize service quality.

In 2022, the Company upgraded its passenger opinion management system and emphasized standardized handling and closed-loop management of opinions. Service management scores were also elevated by cross-organizational monitoring which resulted in a decrease in complaints compared to previous years. A special emphasis was placed on the service for passengers with specific needs and the elderly. Initiatives such as the care lounge and the “Elderly Service Line” manual that covers various service aspects. All of these innovations are implemented with the aim to enhance overall airport experience and establish a high-quality standard for all passengers.

The airport prioritizes talent development and maintains a robust training system, offering comprehensive training for employees through both online and offline platforms. In 2022, they provided 94573 training hours with full coverage. Communication with employees is valued, utilizing platforms like the Employee Congress to understand their needs and encourage their involvement in decision-making processes. Special emphasis is placed on employee welfare, including regular care initiatives and support for those facing difficulties. Activities such as providing cooling fans for frontline staff demonstrate the airport's commitment to employee well-being and comfort.

4.5 Conclusion

In this chapter it was possible to discuss the advantages and disadvantages of the technologies employed by each airport as well as make a comparison between both airports. The chapter concluded with an analysis of the passengers and workforce and how each airport addresses their respective needs and concerns, ensuring a seamless and efficient travel experience for passengers while also fostering a productive and supportive work environment for employees. This analysis included results from passengers’ inquiries, an explanation about the training programs implemented by each infrastructure designed to adapt employees to the new environment.

The research and the contacts made with each airport’s representative during the development of this dissertation support the assertions made in this section. However, the absence of bibliographical references and data prevents the proper validation and consistency of the statements previously made.

Chapter 5 - Conclusions

5.1 Summary of the Dissertation

In this dissertation, firstly, a brief description of the project's objectives and goals as well as the work methodology was provided to give the reader a clear understanding of the scope and approach of the study.

The goals defined at the beginning of the study were to analyse the growth of airports and the improvements made over time, exploring the background behind the adoption of innovative technologies. The study aimed to examine existing airport technologies and understand how they vary according to budget and size. Additionally, it sought to expose the impact of the global air industry's growth, highlighting the advantages and disadvantages of implementing these technologies. Another key goal was to investigate the viability of these technological implementations based on each airport's budget and size. The study also aimed to analyse the results to verify the impact of these decisions on passengers and employees. However, due to constraints that will be further explained in the following sections, some of these goals were only partially attained while others couldn't even be reached.

Next an analysis into airport growth, challenges, and possibilities exhibiting the ever-changing character of airports was conducted. By scrutinizing the history of the development of the aviation industry and its influence on airport development, the fundamental elements that led to the idea of smart airports interpretation were exposed. Technology has played a pivotal role in providing a seamless experience during the creation of smart airports and their integration into activities. Along with this, it identified running smart airports projects worldwide. A thorough description of most common Industry 4.0 technologies and its applications in airports was presented as well as examples of its applications in real airport context.

A brief description and explanation of each airport's history was made. In order to be able to thoroughly compare João Paulo II's airport and Beijing Capital International Airport an analysis of both countries digital transformation level was conducted. Three of the most common indices were described and each country's results in 2022 were presented. A description of what technologies each airport has employed was done as well as upgrades planned for the future and upgrades that were rejected.

An analysis of the advantages and disadvantages of the smart technologies was conducted leading up to a comparison of both airports. The digital transformation

analysis allowed for an understanding of why both airports have different investment approaches alongside other reasons. An analysis of how the workforce and passengers were affected is also presented including results from passenger inquiries and explanations of every training program the passengers were subjected to.

5.2 Final Considerations and Limitations

The work that resulted from this dissertation had a different outcome than what was anticipated which was a more detailed, quantitative, and comparative work however due to some restraints associated with possible collaborations with different airports and time restraints it was only possible to study two airports. Therefore, the conclusion drawn from this dissertation differs somewhat from the original intention. The comparison reveals that BCIA outperforms PCL airport. BCIA demonstrates greater improvements and innovations, positioning itself as an Airport 4.0. In contrast, PCL appears to be more aligned with an Airport 2.0, exhibiting some characteristics of an Airport 3.0.

As explained previously, some of the goals sought to achieve were not met which required budgetary, KPI's and growth data from each airport. The study was also intended to explore different upgrades whose implementation was not successful however this information was never shared.

The initial plan was to study the Francisco Sá Carneiro airport however after 5 months of no response different approaches had to be made in order to comply with time restraints which led to a more descriptive qualitative approach.

After talking with over 8 airports[1], it was only possible to establish a continuous conversation with two of them and some of the information such as KPI information, workforce and passenger analysis, budget allocation was not possible to obtain from both airports.

Some information requested to BCIA such as a more detailed explanation of the technologies implemented, upgrades denied and in progress were not disclosed since the airport tends to collaborate with local universities. The data presented is due to internet research which is not as detailed as intended.

[1] Francisco Sá Carneiro Airport, Terceira's Airport, Ponta Delgada Airport, Beijing Capital International Airport, São Paulo/Guarulhos International Airport, Amsterdam Airport Schiphol, Fortaleza–Pinto Martins International Airport and Porto Alegre–Salgado Filho International Airport.

These limitations led to some of the initial objectives not being met, due to the limited information provided by each airport's representative and the information found online, which caused the dissertation to take a different direction than originally anticipated.

5.3 Perspectives for Future Investigations

Although this dissertation provided a comprehensive analysis of two major airports there is room for further research that can involve more airports for comparison. Such examination could be done through comparative analysis of airports of different sizes, locations and technological integrations to have a holistic view of factors contributing to smart airport development.

Nevertheless, future studies could be an opportunity to include more numbers in the analyses to complement the qualitative data. This may be done by collecting data on various KPIs, financial metrics, and passenger satisfaction scores to help in making comparisons about the smart airport initiatives.

There can be greater cooperation with airport authorities and key players to attain data that can give an outlook into the reasons behind technology adoptions and infrastructural upgrades. Collaboration with industry partners and academic institutions can facilitate the achievement of proprietary information and thus improve the comprehension of obstacles and possibilities of smart airport implementation.

A greater sense of communication and responsibility from part of the different airport representatives should be placed as some would show enthusiasm in the study but not disclose and disregard further contact.

Carrying out longitudinal studies to monitor the development of smart airport technologies and progress over time can provide useful information on the long-term implications and outcomes of these innovations. By analysing patterns of technology usage, passenger behaviour and operational efficiency, researchers identify new and existing best practices that help improve smart airport management.

Since smart airports are multidisciplinary, future studies could be made more complete by including information from other disciplines such as planning, transport engineering, and human-computer interaction. In consideration of a holistic approach that encompasses socio-technical aspects of smart airport systems, researchers will be able to handle complicated challenges related to infrastructure design, user experience, and sustainability.

Examining how policy frameworks and regulatory mechanisms contribute to the implementation of smart airport initiatives will enrich the background knowledge needed to understand the broader ecosystem in which such developments take place. Examining topics like data privacy, data security rules and regulations, and international standards could pinpoint obstacles to implementation and develop strategies for overcoming regulatory hurdles.

The area of smart airports will grow as the future of smart airports is created and new technologies and solutions that may have the ability to transform airport operations come up. As an example, one can examine the advancement of AI, IoT, and blockchain technology and assess their practicality to improve efficiency, safety, and sustainability within airports.

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Annex

Table 12 – Portugal's GII full indicators table [116].

		Score/ Value	Rank
Institutions		**62.5**	**47**
1.1	**Political environment**	77.7	25
1.1.1	Political and operational stability*	83.6	16
1.1.2	Government effectiveness*	71.7	31
1.2	**Regulatory environment**	76.7	34
1.2.1	Regulatory quality*	65.7	38
1.2.2	Rule of law*	76.8	23
1.2.3	Cost of redundancy dismissal	17.0	69 ○
1.3	**Business environment**	33.0	102 ○ ◇
1.3.1	Policies for doing business†	49.5	64 ○
1.3.2	Entrepreneurship policies and culture* ⊘	16.5	62 ○ ◇
Human capital and research		**49.4**	**22**
2.1	**Education**	63.7	18 ●
2.1.1	Expenditure on education, % GDP ⊘	4.7	53
2.1.2	Government funding/pupil, secondary, % GDP/cap	27.4	15 ● ◆
2.1.3	School life expectancy, years	16.9	19 ●
2.1.4	PISA scales in reading, maths and science	492.0	26
2.1.5	Pupil-teacher ratio, secondary	9.2	21
2.2	**Tertiary education**	44.0	27
2.2.1	Tertiary enrolment, % gross	67.9	39
2.2.2	Graduates in science and engineering, %	27.8	28
2.2.3	Tertiary inbound mobility, %	9.7	27
2.3	**Research and development (R&D)**	40.3	27
2.3.1	Researchers, FTE/mn pop.	5,214.8	15 ●
2.3.2	Gross expenditure on R&D, % GDP	1.6	24
2.3.3	Global corporate R&D investors, top 3, mn USD	45.4	34
2.3.4	QS university ranking, top 3*	30.9	40
Infrastructure		**53.4**	**39**
3.1	**Information and communication technologies (ICTs)**	82.4	36
3.1.1	ICT access*	90.7	40
3.1.2	ICT use*	73.2	47 ◇
3.1.3	Government's online service*	83.5	35
3.1.4	E-participation*	82.1	41
3.2	**General infrastructure**	41.1	37
3.2.1	Electricity output, GWh/mn pop.	5,070.9	42
3.2.2	Logistics performance*	74.0	23
3.2.3	Gross capital formation, % GDP	19.6	95 ○
3.3	**Ecological sustainability**	36.8	38
3.3.1	GDP/unit of energy use	15.7	20 ●
3.3.2	Environmental performance*	50.4	41
3.3.3	ISO 14001 environmental certificates/bn PPP$ GDP	2.5	34
Market sophistication		**38.8**	**42**
4.1	**Credit**	40.1	29
4.1.1	Finance for startups and scaleups* ⊘	42.4	34
4.1.2	Domestic credit to private sector, % GDP	101.2	26
4.1.3	Loans from microfinance institutions, % GDP	n/a	n/a
4.2	**Investment**	10.1	57 ○
4.2.1	Market capitalization, % GDP ⊘	29.1	48 ○
4.2.2	Venture capital investors, deals/bn PPP$ GDP	0.1	33
4.2.3	Venture capital recipients, deals/bn PPP$ GDP	0.0	38
4.2.4	Venture capital received, value, % GDP	0.0	64 ○
4.3	**Trade, diversification, and market scale**	66.2	27
4.3.1	Applied tariff rate, weighted avg., %	1.5	20
4.3.2	Domestic industry diversification	100.0	1 ●
4.3.3	Domestic market scale, bn PPP$	376.1	51

		Score/ Value	Rank
Business sophistication		**38.6**	**34**
5.1	**Knowledge workers**	50.1	30
5.1.1	Knowledge-intensive employment, %	42.7	26
5.1.2	Firms offering formal training, %	29.0	58 ○
5.1.3	GERD performed by business, % GDP	0.9	24
5.1.4	GERD financed by business, %	52.2	26
5.1.5	Females employed w/advanced degrees, %	21.1	28
5.2	**Innovation linkages**	30.6	38
5.2.1	University-industry R&D collaboration†	55.5	30
5.2.2	State of cluster development and depth†	53.1	41
5.2.3	GERD financed by abroad, % GDP	0.1	34
5.2.4	Joint venture/strategic alliance deals/bn PPP$ GDP	0.0	57
5.2.5	Patent families/bn PPP$ GDP	0.6	30
5.3	**Knowledge absorption**	35.2	49
5.3.1	Intellectual property payments, % total trade	0.9	46
5.3.2	High-tech imports, % total trade	9.4	48
5.3.3	ICT services imports, % total trade	1.5	65
5.3.4	FDI net inflows, % GDP	3.2	40
5.3.5	Research talent, % in businesses	41.3	33
Knowledge and technology outputs		**33.3**	**35**
6.1	**Knowledge creation**	29.4	31
6.1.1	Patents by origin/bn PPP$ GDP	2.7	27
6.1.2	PCT patents by origin/bn PPP$ GDP	0.7	30
6.1.3	Utility models by origin/bn PPP$ GDP	0.2	54 ○
6.1.4	Scientific and technical articles/bn PPP$ GDP	53.4	9 ● ◆
6.1.5	Citable documents H-index	33.1	30
6.2	**Knowledge impact**	39.5	27
6.2.1	Labor productivity growth, %	−0.3	96 ○
6.2.2	New businesses/th pop. 15–64	5.5	27
6.2.3	Software spending, % GDP	0.6	6 ● ◆
6.2.4	ISO 9001 quality certificates/bn PPP$ GDP	13.6	22
6.2.5	High-tech manufacturing, %	30.5	42
6.3	**Knowledge diffusion**	30.9	49
6.3.1	Intellectual property receipts, % total trade	0.1	49
6.3.2	Production and export complexity	56.5	38
6.3.3	High-tech exports, % total trade	3.9	44
6.3.4	ICT services exports, % total trade	3.0	46
Creative outputs		**38.1**	**25**
7.1	**Intangible assets**	51.2	19 ●
7.1.1	Intangible asset intensity, top 15, %	55.2	47 ○
7.1.2	Trademarks by origin/bn PPP$ GDP	97.7	14 ● ◆
7.1.3	Global brand value, top 5,000, % GDP	44.7	37
7.1.4	Industrial designs by origin/bn PPP$ GDP	7.1	15 ●
7.2	**Creative goods and services**	23.6	51
7.2.1	Cultural and creative services exports, % total trade	0.7	41
7.2.2	National feature films/mn pop. 15–69	5.1	22
7.2.3	Entertainment and media market/th pop. 15–69	32.4	22
7.2.4	Printing and other media, % manufacturing	1.1	41
7.2.5	Creative goods exports, % total trade	1.6	35
7.3	**Online creativity**	26.5	28
7.3.1	Generic top-level domains (TLDs)/th pop. 15–69	19.6	29
7.3.2	Country-code TLDs/th pop. 15–69	59.6	14 ●
7.3.3	GitHub commit pushes received/mn pop. 15–69	19.2	34
7.3.4	Mobile app creation/bn PPP$ GDP	7.4	50

Table 13 – China's GII full indicators table [122].

		Score/ Value	Rank	
Institutions		64.8	42	◆
1.1	**Political environment**	67.3	44	◆
1.1.1	Political and operational stability*	70.9	53	
1.1.2	Government effectiveness*	63.7	41	◆
1.2	**Regulatory environment**	52.7	101 ○	
1.2.1	Regulatory quality*	42.9	77	
1.2.2	Rule of law*	44.5	63	
1.2.3	Cost of redundancy dismissal	27.4	111 ○ ◇	
1.3	**Business environment**	74.6	13	◆
1.3.1	Policies for doing business†	71.9	16	◆
1.3.2	Entrepreneurship policies and culture* ⊘	77.3	9	◆
Human capital and research		53.1	20	◆
2.1	**Education**	69.3	[7]	
2.1.1	Expenditure on education, % GDP	3.6	95 ○	
2.1.2	Government funding/pupil, secondary, % GDP/cap	n/a	n/a	
2.1.3	School life expectancy, years	n/a	n/a	
2.1.4	PISA scales in reading, maths and science	579.0	1 ● ◆	
2.1.5	Pupil-teacher ratio, secondary	13.4	61	
2.2	**Tertiary education**	19.4	92 ○	
2.2.1	Tertiary enrolment, % gross	58.4	52	
2.2.2	Graduates in science and engineering, %	n/a	n/a	
2.2.3	Tertiary inbound mobility, %	0.4	100 ○ ◇	
2.3	**Research and development (R&D)**	70.5	8	◆
2.3.1	Researchers, FTE/mn pop.	1,584.9	48	
2.3.2	Gross expenditure on R&D, % GDP	2.4	13	◆
2.3.3	Global corporate R&D investors, top 3, mn USD	93.8	3 ● ◆	
2.3.4	QS university ranking, top 3*	86.8	3 ● ◆	
Infrastructure		57.5	25	◆
3.1	**Information and communication technologies (ICTs)**	87.6	20	◆
3.1.1	ICT access*	88.1	61	
3.1.2	ICT use*	75.3	39	◆
3.1.3	Government's online service*	90.6	12	◆
3.1.4	E-participation*	96.4	9	◆
3.2	**General infrastructure**	56.0	13	◆
3.2.1	Electricity output, GWh/mn pop.	5,537.7	35	◆
3.2.2	Logistics performance*	72.6	25	◆
3.2.3	Gross capital formation, % GDP	42.9	3 ● ◆	
3.3	**Ecological sustainability**	29.0	54	
3.3.1	GDP/unit of energy use	6.8	104 ○ ◇	
3.3.2	Environmental performance*	28.4	115 ○ ◇	
3.3.3	ISO 14001 environmental certificates/bn PPP$ GDP	7.0	15	
Market sophistication		56.0	12	◆
4.1	**Credit**	44.7	25	◆
4.1.1	Finance for startups and scaleups* ⊘	51.5	9	◆
4.1.2	Domestic credit to private sector, % GDP	182.4	4	◆
4.1.3	Loans from microfinance institutions, % GDP	0.9	29	
4.2	**Investment**	28.7	26	◆
4.2.1	Market capitalization, % GDP	62.7	29	
4.2.2	Venture capital investors, deals/bn PPP$ GDP	0.1	31	
4.2.3	Venture capital recipients, deals/bn PPP$ GDP	0.1	19	◆
4.2.4	Venture capital received, value, % GDP	0.0	16	◆
4.3	**Trade, diversification, and market scale**	94.6	3 ● ◆	
4.3.1	Applied tariff rate, weighted avg., %	2.5	67	
4.3.2	Domestic industry diversification ⊘	99.9	2 ●	
4.3.3	Domestic market scale, bn PPP$	27,072.0	1 ● ◆	

		Score/ Value	Rank	
Business sophistication		55.9	12	◆
5.1	**Knowledge workers**	77.8	[1]	
5.1.1	Knowledge-intensive employment, %	n/a	n/a	
5.1.2	Firms offering formal training, % ⊘	79.2	1 ● ◆	
5.1.3	GERD performed by business, % GDP	1.8	12	◆
5.1.4	GERD financed by business, %	77.5	3 ● ◆	
5.1.5	Females employed w/advanced degrees, %	n/a	n/a	
5.2	**Innovation linkages**	36.8	30	◆
5.2.1	University-industry R&D collaboration†	70.1	5	◆
5.2.2	State of cluster development and depth†	72.6	2 ● ◆	
5.2.3	GERD financed by abroad, % GDP	0.0	77 ○	
5.2.4	Joint venture/strategic alliance deals/bn PPP$ GDP	0.0	67	
5.2.5	Patent families/bn PPP$ GDP	1.5	23	◆
5.3	**Knowledge absorption**	53.0	8	◆
5.3.1	Intellectual property payments, % total trade	1.4	25	
5.3.2	High-tech imports, % total trade	26.9	5	◆
5.3.3	ICT services imports, % total trade	1.4	68	
5.3.4	FDI net inflows, % GDP	1.5	86 ○	
5.3.5	Research talent, % in businesses	58.5	15	◆
Knowledge and technology outputs		56.8	6	◆
6.1	**Knowledge creation**	69.5	4	◆
6.1.1	Patents by origin/bn PPP$ GDP	55.6	1 ● ◆	
6.1.2	PCT patents by origin/bn PPP$ GDP	2.6	14	◆
6.1.3	Utility models by origin/bn PPP$ GDP	120.7	1 ● ◆	
6.1.4	Scientific and technical articles/bn PPP$ GDP	23.1	39	◆
6.1.5	Citable documents H-index	64.1	11	◆
6.2	**Knowledge impact**	52.8	4	◆
6.2.1	Labor productivity growth, %	6.4	1 ● ◆	
6.2.2	New businesses/th pop. 15–64	8.6	17	◆
6.2.3	Software spending, % GDP	0.3	32	◆
6.2.4	ISO 9001 quality certificates/bn PPP$ GDP	13.4	23	
6.2.5	High-tech manufacturing, % ⊘	48.5	14	◆
6.3	**Knowledge diffusion**	48.2	19	◆
6.3.1	Intellectual property receipts, % total trade	0.3	35	◆
6.3.2	Production and export complexity	73.2	16	◆
6.3.3	High-tech exports, % total trade	32.4	4	◆
6.3.4	ICT services exports, % total trade	2.5	53	
Creative outputs		49.3	11	◆
7.1	**Intangible assets**	82.9	2 ● ◆	
7.1.1	Intangible asset intensity, top 15, %	78.4	11	◆
7.1.2	Trademarks by origin/bn PPP$ GDP	376.9	1 ● ◆	
7.1.3	Global brand value, top 5,000, % GDP	111.4	18	◆
7.1.4	Industrial designs by origin/bn PPP$ GDP	31.1	1 ● ◆	
7.2	**Creative goods and services**	28.8	33	◆
7.2.1	Cultural and creative services exports, % total trade	0.6	47	
7.2.2	National feature films/mn pop. 15–69	1.0	61 ○	
7.2.3	Entertainment and media market/th pop. 15–69	10.5	34	◆
7.2.4	Printing and other media, % manufacturing ⊘	0.7	72 ○	
7.2.5	Creative goods exports, % total trade	13.1	1 ● ◆	
7.3	**Online creativity**	2.8	77	
7.3.1	Generic top-level domains (TLDs)/th pop. 15–69	2.5	72	
7.3.2	Country-code TLDs/th pop. 15–69	4.0	58	
7.3.3	GitHub commit pushes received/mn pop. 15–69	1.7	89 ○	
7.3.4	Mobile app creation/bn PPP$ GDP	n/a	n/a	

	LIS	OPO	FAO	PDL	FNC
Indicadores sujeitos a penalização financeira					
nível mínimo de serviço 2,50					
Disponibilidade de carrinhos de bagagem	3,97	4,33	4,14	4,05	4,30
Facilidade em identificar o seu percurso no aeroporto	4,07	4,60	4,21	4,29	4,28
Ecrãs de informação de voo	4,14	4,66	4,24	4,15	4,31
Cortesia e ajuda do pessoal do aeroporto	4,17	4,48	4,27	4,27	4,32
Disponibilidade de instalações sanitárias	3,95	4,53	4,08	4,04	4,19
Limpeza das instalações sanitárias	3,87	4,45	4,05	4,07	4,25
Conforto das áreas de espera/portas de embarque	3,65	4,29	3,78	3,89	3,85
Limpeza do terminal do aeroporto	4,11	4,75	4,23	4,20	4,40
Indicadores sujeitos a planos de ação corretiva					
nível mínimo de serviço 3,00					
Satisfação geral com o aeroporto	4,02	4,49	4,19	4,04	4,31
Disponibilidade de estacionamento	3,78	4,20	4,24	3,77	3,64
Tempo de espera na fila de check-in	3,83	4,18	4,03	4,21	4,12
Tempo de espera no controlo de passaportes	4,02	4,39	4,33	4,15	nd
Tempo de espera no controlo de segurança	4,03	4,66	4,36	4,20	4,26
Facilidade em efetuar ligações com outros voos	4,06	4,37	na	4,04	na
Controlo de passaportes à chegada	4,03	4,26	4,12	4,04	4,25
Rapidez na entrega de bagagem	3,76	4,09	4,09	4,03	4,02
Controlo alfandegário	3,91	4,65	4,13	3,95	4,18

Figure 17 - Passenger satisfaction inquiries' results from the 1st trimester of 2021 - ANA Airports [141].

	LIS	OPO	FAO	PDL	FNC
Indicadores sujeitos a penalização financeira					
nível mínimo de serviço 2,50					
Disponibilidade de carrinhos de bagagem	3,97	4,35	4,01	4,18	4,25
Facilidade em identificar o seu percurso no aeroporto	3,99	4,51	4,12	4,47	4,33
Ecrãs de informação de voo	4,05	4,57	4,18	4,29	4,37
Cortesia e ajuda do pessoal do aeroporto	4,14	4,45	4,18	4,40	4,38
Disponibilidade de instalações sanitárias	3,90	4,36	4,08	4,14	4,21
Limpeza das instalações sanitárias	3,75	4,35	3,96	4,12	4,23
Conforto das áreas de espera/portas de embarque	3,64	4,16	3,71	3,86	3,78
Limpeza do terminal do aeroporto	4,04	4,64	4,19	4,41	4,36
Indicadores sujeitos a planos de ação corretiva					
nível mínimo de serviço 3,00					
Satisfação geral com o aeroporto	4,03	4,49	4,11	4,30	4,28
Disponibilidade de estacionamento	3,61	4,21	4,00	3,83	3,74
Tempo de espera na fila de check-in	3,89	4,24	4,00	4,38	4,14
Tempo de espera no controlo de passaportes	4,03	4,22	4,22	4,37	4,53
Tempo de espera no controlo de segurança	3,97	4,50	4,25	4,42	4,34
Facilidade em efetuar ligações com outros voos	4,16	4,27	na	4,32	na
Controlo de passaportes à chegada	3,99	4,06	3,97	4,37	4,27
Rapidez na entrega de bagagem	3,79	3,97	4,00	4,18	4,08
Controlo alfandegário	3,89	4,43	4,03	4,35	4,16

Figure 18 - Passenger satisfaction inquiries' results from the 2nd trimester of 2021 - ANA Airports [141].

	LIS	OPO	FAO	PDL	FNC
Indicadores sujeitos a penalização financeira					
nível mínimo de serviço 2,50					
Disponibilidade de carrinhos de bagagem	3,80	4,34	4,11	4,24	4,29
Facilidade em identificar o seu percurso no aeroporto	3,90	4,48	4,17	4,46	4,30
Ecrãs de informação de voo	3,92	4,51	4,13	4,37	4,34
Cortesia e ajuda do pessoal do aeroporto	4,05	4,44	4,22	4,42	4,32
Disponibilidade de instalações sanitárias	3,83	4,28	4,04	4,14	4,23
Limpeza das instalações sanitárias	3,64	4,12	3,68	4,05	4,11
Conforto das áreas de espera/portas de embarque	3,42	4,05	3,53	3,91	3,68
Limpeza do terminal do aeroporto	3,90	4,49	4,06	4,36	4,30
Indicadores sujeitos a planos de ação corretiva					
nível mínimo de serviço 3,00					
Satisfação geral com o aeroporto	3,83	4,41	4,09	4,30	4,20
Disponibilidade de estacionamento	3,78	4,11	4,05	4,04	3,78
Tempo de espera na fila de check-in	3,62	3,89	3,99	4,27	3,76
Tempo de espera no controlo de passaportes	3,82	4,37	4,29	4,26	4,58
Tempo de espera no controlo de segurança	3,83	4,31	4,13	4,32	4,29
Facilidade em efetuar ligações com outros voos	3,80	4,39	na	4,44	na
Controlo de passaportes à chegada	3,87	4,23	4,14	4,40	4,23
Rapidez na entrega de bagagem	3,64	3,85	4,08	4,12	3,96
Controlo alfandegário	3,76	4,36	4,13	4,31	4,20

Figure 19 - Passenger satisfaction inquiries' results from the 3rd trimester of 2021 - ANA Airports [141].

	LIS	OPO	FAO	PDL	FNC
Indicadores sujeitos a penalização financeira					
nível mínimo de serviço 2,50					
Disponibilidade de carrinhos de bagagem	3,73	4,29	4,09	4,11	4,26
Facilidade em identificar o seu percurso no aeroporto	3,82	4,47	4,16	4,36	4,25
Ecrãs de informação de voo	3,95	4,49	4,13	4,24	4,33
Cortesia e ajuda do pessoal do aeroporto	3,97	4,40	4,19	4,31	4,38
Disponibilidade de instalações sanitárias	3,78	4,23	3,99	4,01	4,16
Limpeza das instalações sanitárias	3,64	4,10	3,59	3,90	4,01
Conforto das áreas de espera/portas de embarque	3,50	4,00	3,52	3,66	3,64
Limpeza do terminal do aeroporto	3,92	4,45	3,97	4,25	4,32
Indicadores sujeitos a planos de ação corretiva					
nível mínimo de serviço 3,00					
Satisfação geral com o aeroporto	3,85	4,37	4,00	4,17	4,20
Disponibilidade de estacionamento	3,28	4,11	4,14	3,66	3,72
Tempo de espera na fila de check-in	3,69	3,95	3,81	4,08	3,97
Tempo de espera no controlo de passaportes	3,92	4,16	4,11	4,24	4,46
Tempo de espera no controlo de segurança	3,77	4,29	3,90	4,16	4,31
Facilidade em efetuar ligações com outros voos	3,94	4,16	na	4,39	na
Controlo de passaportes à chegada	3,82	4,08	4,04	4,24	4,27
Rapidez na entrega de bagagem	3,57	3,78	3,88	4,04	4,01
Controlo alfandegário	3,78	4,34	3,98	4,22	4,22

Figure 20 - Passenger satisfaction inquiries' results from the 4th trimester of 2021 - ANA Airports [141].

Appendix - Articles Submitted to Scientific Journals and Conferences with Double-Blind Review

A - Article Submitted to Journal of Airline and Airport Management (JAIRM)

Unveiling the Future: Smart Airports - Applications, Advantages, Strategies and Technological Challenges

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Abstract

Purpose: This paper aims to provide an insight onto the smart airport concept, its advantages and disadvantages as the world is constantly in a state of change. Concepts related to such revolution as well as its characteristics are increasingly being considered into various daily operations. As of so the concept of a Smart City has risen and with it the concept of a Smart Airport. These airports use these technologies to ease travelling processes and ensure safe and secure airports as well. Some of these are computerized check-ins and baggage tracks, smart screening, live tracking of passengers, and parking. Such changes in the aviation industry brought about by the fourth industrial revolution, guarantee that a number of airports will continue to grow.

Design/methodology/approach: Through a thorough study of the literature available it was possible to meticulously describe the concept of a smart airport. Therefore, the approach was to synthesize multiple perspectives, theoretical

perspectives to empirical evidence, which leads to the development of a solid and elaborate paper which aims at exploring the complexity of this emerging construct.

Findings: Findings indicate that airports tend to follow innovations as they occur around the world. Financial budgets, security concerns, passenger and workforce perception and acceptance are also factors on how airports tend to implement new technologies which leads to why airports around the world are so different technologically from each other.

Originality/value: This study is directly defined as a matter of explication and a qualitative investigation into airports of the future. This article which takes up a qualitative approach not only reports the existing trends, but also reflects the scheme of the theory and conclusion for the future. Furthermore, this paper adds to the conversation about smart cities and the aviation industry's effect at a broader scale.

Keywords: smart airport, IoT, AI, security, efficiency

B – Article Submitted to IX RIDITA, ISEC Lisboa, Portugal

Exploring the Impact of Innovative Technologies at Ponta Delgada Airport

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Abstract

The advent of the fourth industrial revolution is responsible for considerable transformation of different aspects of life leading to the development of smart cities and therefore smart airports. AI, IOT, and big data analytics have been used by these airports for the purpose of improving efficiency and effectiveness in operations, customer satisfaction and optimal utilization of resources. Coupled with the growth in aviation facilities that are fitted with automated baggage handling systems.

This study aims at examining how customer satisfaction, airport performance and general airport management are influenced when traditional methods are abandoned in favour of modern approaches. Through an extensive literature review, the research focuses on these advancements at Ponta Delgada Airport specifically as it looks for ways through which technological advancements have led to ongoing improvements and optimization of airport services. The findings are expected to provide directions for other airports that wish to become smart through changing technology scope and also to determine by comparison with other airports whether or not the airport would benefit from other upgrades.

C – Article Submitted to 27TH ATRS World Conference, ISEC Lisboa, Portugal

The Future of Airports: A Deep Dive into the Integration of Industry 4.0 Technologies at Ponta Delgada Airport

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Abstract

A concise description of the purpose of the research: Over the years technological advancements have spread through every industry and aviation has not been an exception. This article explores what is a smart airport and the integration of Industry 4.0 technologies at Ponta Delgada Airport in Portugal examining the advancements aimed at enhancing operational efficiency, passenger experience, and overall airport management.

A brief introduction of your research design, methodology or approach: The research aims to thoroughly examine Ponta Delgada Airport's technology-driven innovation strategy in areas like digital traveller services, automation and data-driven decision making. This involved a detailed examination of implemented technologies, interviews with airport operators and a comparative analysis of smart airports' trends.

A description of your (expected) research findings: A substantial change in the way the airport operates with technology integration that simplifies processes and enables enhanced passenger services and overall efficiency are some of the expected findings of this research.

A short summary of the originality/contribution of your research paper: The paper contributes to the body of knowledge on smart airports by presenting developments at

Ponta Delgada Airport and discussing how other airports can use technology to improve productivity and satisfy passengers more than before.