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INTERNET OF THINGS APPLIED TO THE INTELLIGENT MANAGEMENT OF PARKING PARKS IN THE OLD AREA OF COVILHA

PAIVA, JOAO P. (1); BARATA, RUI (2); VELEZ, FERNANDO J. (3); FLANIGAN, KATHERINE A. (4); REIS, ANTONIO D. (5)

(1) Instituto de Telecomunicações & UBI, E-mail: joao.pedro.paiva@ubi.pt

(2) Universidade da Beira Interior, E-mail: rbarata@ubi.pt

(3) Instituto de Telecomunicações & UBI, E-mail: fjv@ubi.pt

(4) Carnegie Mellon University, E-mail: kflaniga@cmu.edu

(5) Universidade da Beira Interior, E-mail: adreis@ubi.pt

ABSTRACT

This paper presents a study on how the Internet of Things (IoT) can be applied to the intelligent management of parking lots in the historic area of Covilhã. The aim is to study the parking areas and car parks, the challenges faced when trying to find a parking space and, finally, to apply technologies, such as IoT, to mitigate and solve some of the existing problems. This study can be extrapolated to other mountain towns across Europe, as they have very similar characteristics to Covilhã, such as sloping terrain, narrow streets and old architecture. Ultimately, one of the main objectives of this study is to formulate how, through the use of technologies such as IoT, innovative solutions can be created to solve the current problems of cities, bringing them ever closer to a modern 'Smart City', a city capable of providing intelligent responses to its various users. A Smart City brings together various technologies which, when combined, facilitate the management of various functions such as mobility, energy, parking, transportation and other resources. The case study presented, as mentioned above, is Covilhã, Portugal. This city has an old and historic part, with dilapidated houses, narrow streets, difficult traffic circulation and a shortage of parking, and a new part, with modern buildings and wide streets. Consequently, in the historic part of the city, there are several car parking problems. To reduce this problem, parking silos have been built. However, these lack information on their location, operation and real-time information on how many parking spaces are available at any given time. Thus, combining the concepts of IoT and Smart City, some theoretical and practical proposals for modernization are explored in this article. The study focuses on the Mercado, Sporting Shopping and Pelourinho silos. There is also a proposal to prepare the spaces to prioritize the accommodation of electric cars, as well as making it possible to charge their batteries while they are parked inside the silos. As for the proposed vehicle counting mechanism, it consists of an electronic device equipped with ultrasonic sensors, placed on the roof of the parking lot, to count the free parking spaces. These sensors are then connected to an electronic prototyping platform, in this case an Arduino. This equipment is then able to count the number of vacant spaces and send the corresponding information to be displayed on digital screens, visible from outside the car park. This real-time information can also be sent via the IoT to screens in central areas of the city. In this way, drivers have access to privileged information to make the best decision when parking.

Keywords: *Internet of Things, Smart cities, Urban mobility, Embedded systems.*

RESUMO

Este trabalho apresenta um estudo sobre como a Internet das Coisas (IoT) pode ser aplicada à gestão inteligente de parques de estacionamento na zona histórica da Covilhã. O objetivo é estudar as áreas de estacionamento e os parques, os desafios enfrentados quando se tenta encontrar um lugar de estacionamento e, por último, aplicar tecnologias, como a IoT, para mitigar e resolver alguns dos problemas existentes. Este estudo pode ser extrapolado para outras cidades de montanha em toda a Europa, uma vez que têm características muito semelhantes às da Covilhã, como terrenos inclinados, ruas estreitas e uma arquitetura antiga. Em última análise, um dos principais objectivos deste estudo é formular como, através da utilização de tecnologias como a IoT, podem ser criadas soluções inovadoras para resolver os problemas actuais das cidades, aproximando-as cada vez mais de uma '*Smart City*' moderna, uma cidade capaz de dar respostas inteligentes aos seus vários utilizadores. Uma *Smart City* reúne várias tecnologias, que quando combinadas, facilitam a gestão de várias funções como a mobilidade, energia, estacionamento, transportes, entre outros recursos. O caso de estudo apresentado, como já foi referido anteriormente, é o da Covilhã, Portugal. Esta cidade tem uma parte antiga e histórica, com casas degradadas, ruas estreitas, difícil circulação de tráfego e escassez de estacionamento, e uma parte nova, com edifícios modernos e ruas largas. Consequentemente, na parte histórica da cidade, existem vários problemas de estacionamento automóvel. Para reduzir este problema, foram construídos silos auto. No entanto, estes carecem de informação sobre a sua localização, funcionamento e informação em tempo real sobre quantos lugares de estacionamento estão disponíveis num determinado momento. Assim, combinando os conceitos de IoT e *Smart City*, algumas propostas teóricas e práticas de modernização são exploradas neste artigo. O estudo é focado nos silos Mercado, Sporting *Shopping* e Pelourinho. Há também uma proposta no sentido de preparar os espaços para priorizar o alojamento de carros eléctricos, assim como possibilitar o carregamento das suas baterias enquanto estiverem estacionados dentro dos silos. Quanto ao mecanismo de contagem de veículos proposto, este consiste num dispositivo eletrónico equipado com sensores ultra-sónicos, colocado no teto do parque, para contar os lugares de estacionamento livres. Estes sensores são depois ligados a uma plataforma de prototipagem eletrónica, neste caso um Arduino. Este equipamento é então capaz de contabilizar o número de lugares vagos e enviar a informação correspondente para a apresentar nos ecrãs digitais, visíveis do exterior do parque. Esta informação em tempo real pode também ser enviada, através da IoT, para ecrãs em zonas centrais da cidade. Desta forma, os condutores têm acesso a informação privilegiada para tomarem a melhor decisão no momento de estacionar.

Palavras-chave: Internet das coisas, Cidade Inteligente, Mobilidade Urbana, Sistemas Embutidos

1 INTRODUCTION

The historic area of Covilhã, Portugal, presents a unique set of challenges when it comes to parking management. The narrow streets, steep terrain, and aged infrastructure of this mountainous city complicate traffic circulation and limit the availability of parking spaces. Historic areas worldwide face similar issues. Despite the construction of parking silos intended to alleviate these issues, a lack of real-time information and clear guidance for drivers has hindered their effectiveness. As a result, residents and visitors continue to experience significant difficulties in finding available parking, leading to increased frustration and inefficiency.

This study is motivated by the experiences of the authors as residents of Covilhã, combined with insights gathered from interviews with other residents who face these parking difficulties on a daily basis. These firsthand accounts underscore the need for a practical, cost-effective solution that can enhance the parking experience in the city's historic center. This work seeks to address these challenges by exploring the application of Smart City and Internet of Things (IoT) concepts to the intelligent management of parking facilities in Covilhã. The proposed solution involves the integration of an IoT architecture that enables real-time communication between sensors, centralized data storage, and wireless networking, all of which contribute to the efficient management of public utility services within the city.

A key aspect of this study is its focus on developing a low-cost, easily deployable, and non-invasive sensing system specifically tailored to the unique conditions of historic and mountainous urban environments. Traditional parking management systems can be prohibitively expensive, complex, and invasive, making them unsuitable for areas where preserving architectural integrity and minimizing disruption are priorities. The proposed solution offers a nimble and adaptable approach that not only addresses the immediate parking challenges but also supports broader urban planning efforts. The versatility of this system allows it to be used for short-term pilot studies, enabling urban planners to conduct feasibility assessments on how changes to transportation infrastructure might impact parking selection and usage. By providing real-time data, this system facilitates data-driven decision making, allowing planners to refine and optimize their strategies before committing to more permanent infrastructure investments. Furthermore, the non-invasive nature and affordability of the system make it suitable as a temporary solution while longer-term projects are being developed, ensuring continuous improvement in parking management even as broader Smart City initiatives are underway. Overall, and while park counting systems are not new, this research addresses a significant gap: the need for cost-effective, easily deployable solutions tailored to the unique challenges of historic and mountainous urban environments.

Methodologically, this study begins with a comprehensive literature review of the key concepts related to Smart Cities and IoT. Following this, relevant data and information specific to the case study of Covilhã have been collected and analyzed. The final component of this research involves the development and presentation of a prototype system, consisting of an Arduino microcontroller, ultrasonic sensors, and an LED display. This prototype is designed to count vacant parking spaces in real time, providing valuable data that can be used to inform drivers and optimize parking management in Covilhã.

2 LITERATURE REVIEW

2.1 PARKING AND ENERGY SUSTAINABILITY IN HISTORIC AREAS OF EUROPEAN CITIES

Historic areas of European cities are characterized by their narrow streets, aged infrastructure, and architectural heritage, which present unique challenges for modern urban planning, particularly within the scope of parking and energy sustainability. As urban populations continue to grow, with projections indicating that 70% of the world's population will live in cities by 2050 [1], the demand for vehicle access in these areas is expected to increase significantly. Forecasts suggest that by 2050 the number of vehicles in circulation will exceed 2.5 billion, according to the International Parking Institute (IPI) [1]. However, the physical space constraints inherent in historic districts such as limited road widths, irregular street patterns, and densely built environments, insufficient electrical infrastructure, and outdated technology for providing quick and clear information, severely limit the availability of parking spaces [2, 3]. Furthermore, the preservation of historical sites often restricts the extent to which modern parking infrastructure can be integrated without compromising the aesthetic and cultural value of these areas. Additionally, the high costs associated with repurposing vacant or old buildings for parking or redesigning infrastructure and traffic routes often make such projects unfeasible in many cities. In order to address these issues, it is above all necessary to first understand the underlying demand and associated limitations for parking spaces and related infrastructure [4]. This understanding can inform the development of targeted solutions that not only meet current needs but also anticipate future challenges as cities continue to evolve.

The primary challenges that historic areas of cities, particularly in Europe, face regarding parking and charging electric vehicles can be attributed to three main factors: physical space limitations, inadequate electrical infrastructure, and the need to preserve historical heritage [9]. While parking and charging in older parts of cities present complex challenges, they can be addressed through innovative solutions. By adapting underutilized spaces, fostering public-private partnerships, and employing advanced charging technologies, these obstacles can be overcome, facilitating the transition to more sustainable mobility [9].

2.2 SMART CITIES AND THE INTERNET OF THINGS (IoT)

The characterization and definition of a Smart City varies according to different authors, that is, depending on their area of expertise and their different points of view. For this reason, it is possible to find various definitions of the same concept in the literature. Even so, there are key aspects on which the authors largely agree [5]. In general terms, and combining some of the different opinions of authors in the literature, a Smart City is an urban area that uses Information and Communication

Technologies (ICT) to improve the quality of life of its inhabitants, optimize resource management and promote sustainable development [5]. In a Smart City, various systems and infrastructures are connected and integrated, allowing data to be collected, analysed and used in real time to make more efficient and convenient decisions for its users [5]. The 'Components' or 'Areas of Action' of Smart Cities are defined according to the areas of the city in which technological intervention may be required [8]. As with the topic discussed above, there are various interpretations and formulations of the components of a Smart City in order to divide it into subcategories. Although they vary, they end up conveying similar messages [8].

Regarding the IoT and its evolution, they both go back to the creation of the Internet. The Internet began by connecting computers. These computers would later be connected to each other via the World Wide Web (WWW) [10]. In recent decades we have seen the possibility of integrating mobile devices, such as cell phones, into this network. Finally, and more recently, the idea of linking everyday devices to the Internet has emerged, giving rise to the IoT [10]. The 'Internet of Things' refers to a network of interconnected physical objects that are equipped with sensors, software and other technologies, allowing them to collect and exchange data via the Internet [10]. These objects can range from household electronic devices to industrial machines or even vehicles [12]. This technology has various components which, when combined, allow data to be collected, trafficked, processed and analysed, as well as access to this information by users [12]. The importance of the IoT lies in the fact that, through this technology and with minimal or no human intervention, it is possible to interconnect objects, systems and devices cheaply and efficiently [12].

2.3 ADVANCEMENTS IN INTELLIGENT PARKING SYSTEMS

Growing demand for efficient urban mobility has led to increased interest in intelligent parking systems, which aim to optimize the use of available parking spaces while reducing traffic congestion. Numerous studies have explored the use of IoT technologies, sensor networks, and data analytics to develop smart parking solutions. Geng and Cassandras (2012) propose a novel “smart parking” system that dynamically assigns and reserves optimal parking spaces for drivers based on their preferences for proximity to their destination and parking costs [6]. Idris et al. (2009) reviewed the evolution of smart parking technologies, identifying the potential for these systems to be adapted and scaled for different urban environments [7]. However, it highlights challenges related to the high cost of implementation, the need for reliable communication infrastructure, and the integration of real-time data processing capabilities. More recently, Assim and Al-Omary (2020) reviewed IoT-based smart parking systems, citing cost and implementation difficulties as existing continued barriers to scalable implementation [11].

Commercial solutions are also available. ParkMobile, ParkHelp, and Park Assist use technologies like sensors, cameras, mobile apps, and IoT platforms to enhance parking management through real-time occupancy monitoring, dynamic pricing, mobile reservations, and data analytics [13]. While these systems significantly reduce the time drivers spend searching for parking, lower traffic congestion, and improve overall urban mobility, they face limitations, including high implementation costs, reliance on robust communication infrastructure, and potential challenges with user adoption. Additionally, these systems require extensive alterations to the parking infrastructure.

While these advancements in intelligent parking systems have shown promise in various urban environments, they fall short of addressing the specific needs of historic areas. The existing literature primarily focuses on modern urban settings where infrastructure can be readily adapted or replaced to accommodate new technologies. In contrast, historic areas present unique challenges such as the need to preserve architectural integrity, navigate narrow and irregular street layouts, and comply with stringent preservation regulations. The lack of research specifically tailored to these environments highlights a significant gap in the current body of knowledge. There is a need for studies that develop and evaluate non-invasive, cost-effective smart parking solutions that are not only adaptable to the constraints of historic areas but also capable of integrating with the existing infrastructure without compromising the cultural and historical value of these spaces. This study seeks to address this gap by exploring IoT-based solutions that are specifically designed to overcome the limitations of applying modern smart parking technologies in historic urban settings.

3 CHARACTERIZATION OF THE CITY OF COVILHÃ AND PARKING OPPORTUNITIES

3.1 A BRIEF HISTORY OF THE CITY

The history of Covilhã dates back to the Romanization of the Iberian Peninsula, when the first inhabitants, mostly shepherds and cattle breeders, settled in the area due to its favourable conditions for their trades [14]. In the late 16th century, the Count of Ericeira, D. Luís de Menezes, established the first Royal Factory in the city, located in Ribeira da Carpinteira. During this period, Covilhã became a central hub for economic growth in Portugal, largely due to its thriving wool industry. The two streams that run through it, the Carpinteira and the Goldra, provided the hydraulic energy needed to run the factories, and the cattle breeding that already existed in the area made it possible to obtain raw materials in abundance, such as wool [14, 15].

The 19th century was particularly significant for Covilhã, as the city was granted official city status in 1870, largely due to the socio-cultural growth driven by industrial development [14, 16]. Covilhã continued to grow into the 20th century, with census data showing that in the first half of the century, between 1900 and 1950, the city's population grew by around 54%, from 44,427 inhabitants to 68,522 [17]. The population peaked in 1960, reaching around 72,957 residents [17]. However, the city faced a significant crisis in the early 1970s when many of its textile factories and industries were forced to close due to their inability to compete with foreign markets and failure to meet safety and compliance standards [16].

From the 1980s and 1990s onwards, Covilhã expanded to a flatter area that had previously been land and farms. This so-called "new part of town" offered good geographical characteristics for the construction of buildings, roads, and other infrastructure. It also attracted outside investment and is, to this day, where most of the modern buildings are located. Today, Covilhã is mainly a university and tourist town, serving as the largest urban center in the Serra da Estrela region [16].

3.2 POPULATION AND INFRASTRUCTURE DISTRIBUTION

The newer part of Covilhã is characterized by newer, more modern buildings, including taller, more structurally sound and better-planned residential buildings with underground garages, attics, and basements. This area features wider avenues, roads, and sidewalks, as well as more green and leisure spaces, such as gardens. This area's population tends to be younger than that of the old part of Covilhã, where most of the residents are older individuals who were born, raised, and have lived there throughout their lives. In the historic part of Covilhã, one can find buildings that date back several hundred years, reflecting the city's rich architectural heritage.

3.3 IDENTIFICATION OF SOME TRAFFIC AND PARKING PROBLEMS IN THE OLD TOWN

The Pelourinho area, often considered the center of Covilhã, is undoubtedly the main artery in the most historic part of the city. It is also from here that one can access the city's main attractions, public services, and leisure facilities. For this reason, the roads leading to Pelourinho are the ones with the most significant traffic problems. Many drivers are unaware of available parking options such as the municipal silos. As a result, they often spend excessive time searching for parking along these roads, which exacerbates traffic congestion and creates further disruption. To alleviate these issues, it is critical to invest in better informing users about parking options available to them.

There are four primary avenues that provide access to the Pelourinho: Rua Visconde da Coriscada, Rua Rui Faleiro, Rua António Augusto, and Rua Comendador Campos Melo, also known as 'Rua Direita'. While these streets share common traffic and parking challenges, each also faces specific issues unique to its location.

3.4 CHARACTERIZATION OF MUNICIPAL PARKING LOTS AND THEIR OPERATION IN THE HISTORICAL AREA OF COVILHÃ

In the historic area of Covilhã, there are three municipal parking lots. These are all within a 200-meter radius of the Pelourinho [21], which is considered the city center:

- Covilhã Municipal Market Silo: This is one of the oldest parking facilities in the city, located within the Covilhã Municipal Market building. It comprises a single floor and offers a total of 35 parking spaces;
- Sporting Shopping Silo: Inaugurated on December 8, 1993, alongside the Sporting Shopping Center, this silo plays a crucial role in the area due to its significant capacity. It is one of the largest parking facilities in the historic district, along with Praça do Município Car Parking. The Sporting Shopping Silo has three floors and can accommodate up to 150 vehicles;
- Praça do Município Car Parking: Located north of the Sporting Shopping Silo on the same street, Praça do Município Car Parking is the most modern of the three parking structures in the old town. It was inaugurated on March 8, 2002, as part of a historic redevelopment project in this area of the city. This facility has three floors and can hold up to 371 vehicles.

4 PROPOSAL AND POSSIBLE SOLUTIONS

4.1 IMPLEMENTATION OF SENSORS IN MUNICIPAL PARKING LOTS

The main aim of the proposal described in this section is to address a series of challenges related to parking in the oldest part of Covilhã. These challenges include a lack of information about the existence and operation of the auto silos in this part of the city, insufficient information regarding the availability and number of vacant spaces in each silo, the creation of queues and traffic congestion due to drivers spending excessive time looking for parking, and the issue of improperly parked vehicles around the city center, which hinders traffic flow.

To modernize the operation of the silos in Covilhã's historic area and provide users with real-time information about the availability of parking spaces, it is necessary to develop a sensor-based system that accurately counts the number of vehicles inside each facility. This data would then be displayed at the entrance of each parking lot, allowing drivers to quickly assess the availability of spaces. Additionally, signs could be installed in central locations throughout the city, displaying the three silos in the area along with the current number of available spaces in each, as shown in Figure 1.

Figure 1 – Example of the design of the described signs (Font: Authors)

The design and architecture of this system require specific materials chosen to keep the prototype's cost relatively low, ensuring that this setup or variations of it, can be easily replicated in other contexts. The materials used in the laboratory assembly to simulate a vehicle counting system include: an electronic platform (Arduino), ultrasonic sensors, an LED display, mounting boards, a variable resistor, a power supply, and connection wires (Figure 2).

These components form the core architecture of a system that will, on a smaller scale, represent the prototype intended to monitor parking space availability in real time within each of the silos in Covilhã's historic area. For practical purposes, a single universal assembly has been designed that can be applied to any of the case studies discussed in this paper. The setup, illustrated in Figure 2, utilizes three HC-SR04 ultrasonic sensors, each placed in different parking spaces. The system's assembly follows this architecture:

- The Arduino is powered via a cable connected to a computer;
- The main mounting board serves as a base for integrating the Arduino, the LCD display, and one ultrasonic sensor. The potentiometer, which adjusts the brightness of the LCD, is also mounted on this board;
- The secondary mounting board holds the remaining two ultrasonic sensors used in the system;
- The display, in addition to being connected to V_{CC} and GND, is wired to the Arduino via pins 2, 3, 4, 5, 11, and 12;
- The ultrasonic sensors, specifically their Trigger and Echo pins, are connected to pins 10, 13, 14, 15, 22, and 23 on the Arduino (two

connections per sensor). Each sensor is also connected to GND and V_{CC}.

Figure 2 – System assembly for three parking spaces (Font: Authors)

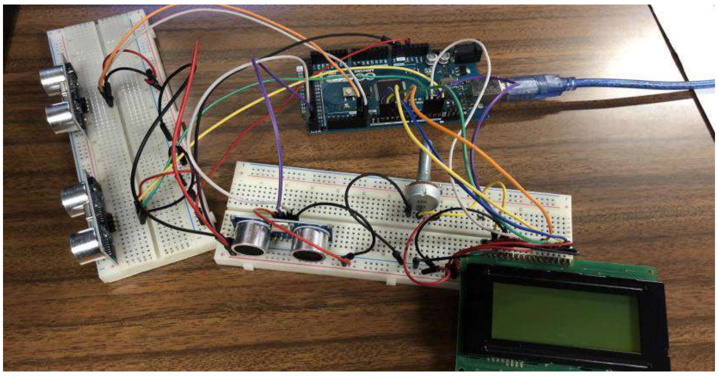

Figure 3 shows, on a small scale, the desired result when a vehicle (represented by a toy car) is parked in one of the spaces in the silo. When the sensor detects the car, it sends a signal to the Arduino platform, which then executes the command that prints the information that a parking space is occupied on the LCD (Legend: 'Vagas livr.'= Free spaces; 'Vagas ocup.'= Filled spaces).

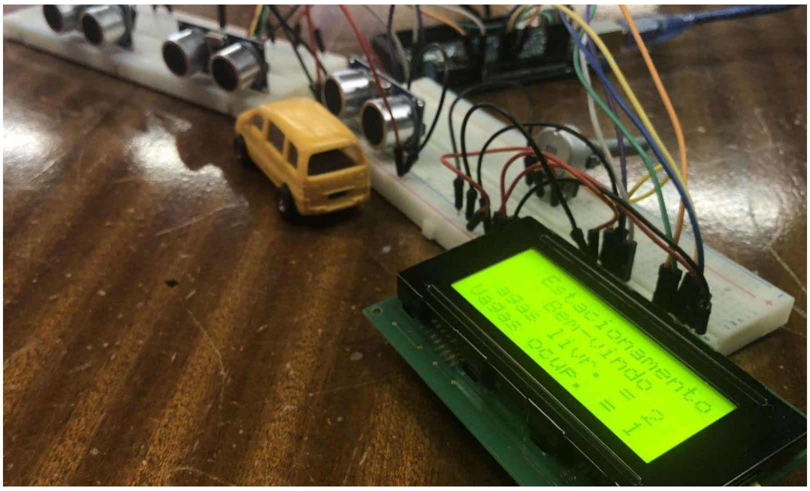

Figure 3 – Small-scale representation of how the system works when one vehicle is parked (Font: Authors)

Although the entire assembly described and represented in this section is programmed using the Arduino software, in order to carry out a larger-scale simulation it will be essential to use a tool such as CupCarbon. This open source simulation software was developed for use in the context of Smart Cities and IoT [22]. It is considered one of the most important tools in these areas of study, as it allows monitoring algorithms to be developed, visualized and validated [22]. This tool offers a very intuitive interface, using OpenStreetMap (OSM) which allows sensors to be installed directly on the map, forming sensor networks that can communicate with each other [22].

4.2 MOTIVATION FOR THE PRIORITIZATION OF NON-POLLUTING VEHICLES

In order to further modernize the silos in Covilhã's historic area, a series of measures could be implemented to encourage the use of these spaces by electric vehicle drivers. Non-polluting vehicles are a greener alternative to combustion-engine vehicles, and their adoption should be promoted through incentives that benefit their users. Below are some proposals, already in effect in other contexts, which could be applied to the case studies described in this paper:

- Provision of charging stations inside the parking facilities: Currently, none of the three silos examined in this paper are equipped with charging stations for electric vehicles. As previously noted, the only nearby charging station is located on Rua António Augusto de Aguiar and can accommodate only two cars at a time. Given the increasing number of people opting for non-polluting vehicles, this single charging station is clearly insufficient to meet the needs of the population and to encourage the adoption of electric vehicles. Installing charging stations within these parking facilities would provide a crucial incentive for electric vehicle users;
- Reserving a percentage of seats for electric vehicles: Reserving a specific percentage of parking spaces within the silos for electric vehicles would benefit those who choose to adopt this environmentally friendly option. Such a measure is important as part of a broader strategy to transition toward a greener future. In the context of the historic area silos in Covilhã, where the number of parking spaces varies, a policy could be implemented to reserve a certain percentage of spaces exclusively for electric vehicles;
- Discounts on using the parks and/or charging electric vehicles inside them: With various incentives already in place from organizations such as the European Union to promote the adoption of electric vehicles, companies managing parking facilities, such as the silos, could establish agreements with national or European government institutions to benefit from these incentives [18]. This would allow these companies to offer advantages to users of non-polluting vehicles, such as discounts on parking fees or subsidies to offset the costs of charging vehicle batteries.

5 CONCLUSIONS AND FUTURE WORK

The historic area of Covilhã, like many older urban environments, faces significant challenges in managing parking due to its narrow streets, steep terrain, and aged infrastructure. These issues are compounded by the lack of real-time information on parking availability, leading to traffic congestion and inefficiencies. This study has addressed these challenges by proposing a modern, IoT-based approach to parking management that integrates real-time data collection and dissemination through a low-cost, non-invasive sensor system. By focusing on the unique needs of historic and mountainous urban areas, this solution not only addresses immediate parking difficulties but also offers a flexible platform that can be adapted to broader urban planning initiatives.

The literature review highlighted the growing interest in intelligent parking systems, particularly in modern urban settings. However, it also underscored the gap in research and practical solutions specifically tailored to historic areas, where preserving architectural integrity and adapting to existing infrastructure are paramount. This study contributes to filling that gap by demonstrating how IoT technologies can be deployed in a way that respects the historical and cultural significance of urban environments like Covilhã while enhancing functionality and accessibility. While this report focuses on the historic area of Covilhã, many of the issues discussed are relevant to other cities at the national, European, and global levels.

In addition to the implementation of sensor-based systems, this work has proposed further modernizations to prioritize non-polluting vehicles, such as the installation of electric vehicle charging stations and the reservation of parking spaces for electric vehicles. These measures align with broader sustainability goals and reflect a commitment to promoting greener alternatives in urban transportation.

In the future, these proposals will be presented to the entity responsible for managing the parking facilities, as well as to the Covilhã City Council, with the hope that most of them, or slight variations thereof, can be implemented in the case studies addressed in this document.

Looking ahead, a potential continuation of this work could involve making the number of available parking spaces visible via a mobile application or the Covilhã municipality's website. Providing access to this information anywhere and at any time would allow users to plan their journeys more effectively, without needing to go directly to the parking sites to obtain this information. This would further reduce issues such as wasted time and excessive resource expenditure by drivers.

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