UNIVERSIDADE CATÓLICA PORTUGUESA

Digital Pathways:

Towards Efficiency of Smart Cities' Mobility through Digital Transformation

by

Duarte Alexandre Azevedo Fernandes

Católica Porto Business School, Universidade Católica Portuguesa

May, 2024

UNIVERSIDADE CATÓLICA PORTUGUESA

Digital Pathways:

Towards Efficiency of Smart Cities' Mobility through Digital Transformation

Final Work in Academic Context presented to
Universidade Católica Portuguesa
in order to obtain the master's degree in business economics

by

Duarte Alexandre Azevedo Fernandes

Under the guidance of
Prof. Dr. Jorge Julião and Prof. Dr. Marcelo Gaspar

Católica Porto Business School, Universidade Católica Portuguesa
May, 2024

Acknowledgements

As I stand at this significant crossroads of my life, marking the culmination of my academic journey, the weight of gratitude in my heart is immense. At a time when my life was a complex conjunction of multifarious commitments, the firm support of those who were my pillars, served as my encouragement to proceed.

To my family, especially my parents since their boundless support and understanding have been my “safe zone”. Their understanding and care in giving me the space to immerse myself in my chores, even as I juggled full-time work, was crucial to the completion of this endeavor.

My beloved girlfriend, Eva, since her support was the calm in my storm, guiding me through this tumultuous sea of emotions and responsibilities with love and patience. Her constant belief in me was a true source of inspiration and comfort.

To my esteemed professors, as you have not only prepared me for this important task but have also equipped me with the knowledge and courage to face the future challenges that lie ahead.

And to my supervisors, your patience, accessibility, and insightful guidance have been the cornerstone of this journey. Your unwavering support was instrumental.

May the next chapters be as rewarding as the previous ones. I thank you all, from the bottom of my heart.

Resumo

Esta dissertação investiga o impacto dos avanços digitais na mobilidade urbana em cidades inteligentes em meio a uma urbanização rápida. Explora como podem melhorar a eficiência dos sistemas de mobilidade urbana, que são cruciais para reduzir o consumo de energia, emissões e melhorar a qualidade de vida em resposta aos desafios impostos pela expansão urbana.

Baseando-se numa revisão de literatura e dez entrevistas semiestruturadas com especialistas, mergulha na integração de tecnologias digitais na mobilidade urbana, identificando tanto oportunidades quanto desafios. Desta forma, conecta *insights* teóricos com experiências práticas, enfatizando o potencial das tecnologias digitais para melhorar a mobilidade urbana em *smart cities*.

Estruturada em torno dos temas de conceitos de *smart city*, mobilidade urbana e avanços digitais, a dissertação analisa a interação entre tecnologia e planeamento urbano. Os resultados pretendem informar *decision-makers*, *urban planners* e profissionais do setor da tecnologia sobre como analisar e integrar eficazmente estes avanços digitais nestes *frameworks* da mobilidade urbana.

Destaca-se então a importância de alinhar os avanços digitais com uma infraestrutura robusta e políticas abrangentes para enfrentar os desafios da mobilidade urbana, salientando-se o potencial dessas tecnologias para melhorar a eficiência em termos de tempo de viagem, segurança, acessibilidade, sustentabilidade e custo. Por fim, encontram-se então duas limitações, indicando a necessidade de estudos futuros, enquanto sugere uma estratégia holística de mobilidade urbana que integre inovação digital com elementos estruturais e políticos para atender às necessidades em rápida mudança das populações.

Palavras-chave: transformação digital, cidades inteligentes, eficiência, mobilidade urbana, planeamento urbano, sustentabilidade.

Abstract

This dissertation investigates the impact of digital advancements on urban mobility in smart cities amidst rapid urbanization. It explores how they can enhance the efficiency of urban mobility systems, which are crucial for reducing energy consumption, emissions, and improving quality of life in response to the challenges posed by urban expansion.

Drawing on a literature review and ten semi-structured interviews with experts, the study dives into the integration of digital technologies in urban mobility, identifying both opportunities and challenges. It connects theoretical insights with practical experiences, emphasizing the potential of digital technologies to enhance urban mobility in existing and emerging smart cities.

Structured around the themes of smart city concepts, urban mobility complexities, and digital advancements, the dissertation analyses the interplay between technology, urban planning, and societal needs. The findings are intended to inform policymakers, urban planners, and technologists on effectively integrating digital technologies into urban mobility frameworks.

It then underscores the importance of aligning digital advancements with robust infrastructure and comprehensive policy frameworks to tackle urban mobility challenges. It highlights the potential of these technologies to improve efficiency regarding travel time, safety, accessibility, sustainability, and cost. Nonetheless, the research then points two main limitations, indicating the need for further study, while simultaneously pointing towards a holistic urban mobility strategy that integrates digital innovation with structural and policy elements to meet the fast-changing needs of urban populations.

Keywords: digital transformation, efficiency, smart cities, sustainability, urban mobility, urban planning.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AI – Artificial Intelligence

GDP – Gross Domestic Product

ICT – Information and Communication Technology

IoT – Internet of Things

MaaS – Mobility as a Service

RFID – Radio Frequency Identification

SC – Smart City

SDG – Sustainable Development Goal

SMC – Small Mid Cap

UM – Urban Mobility

UMS – Urban Mobility Systems

UN – United Nations

WHO – World Health Organization

A Day in the Future - Welcome to Utopia

As dawn unfurls, a soft, golden light bathes the cityscape of our advanced metropolis. Stepping outside as I join the city's awakening rhythm, streets resonate with the quiet hum of electric vehicles, seamlessly navigating the intelligently orchestrated roads. Tasty, clean air, a testament to our city's commitment to sustainability, fills my lungs, infusing itself with the aroma of freshly brewed coffee from a nearby *café*. My digital assistant, discreetly nestled on my wrist, subtly outlines my day with impeccable precision.

My commute unfolds effortlessly, thanks to the knottily connected transport network. Encased in a sleek, autonomous pod, panoramic views of the evolving urban expanse captivate the travelers through vast glass windows. Advanced AI traffic management weaves us through the fabric of the city, free from congestion, in a dance of fluid motion.

Upon swiftly reaching my destination, as I sweep the keycard on my wrist, the building greets me, personalizing its environment in anticipation. Inside, holographic displays and augmented reality glasses blur the lines between digital and physical realms, showcasing important information, enhancing productivity and global collaboration, inside our work environment.

As evening descends, I wander through verdant urban gardens. There are digital art installations blending light and sound into a sensorial masterpiece. The city, with its digitally curated cultural offerings, caters to the diverse tastes and preferences of its population.

As I now retreat to my apartment after a long day of work, my couch embraces me, adapting to my form. The apartment's AI, embedded in the city's technology, now a familiar conductor of my daily symphony, selects music that echoes my mood. As I am now drifting to sleep, I reflect on the wonderful comfort and well-being brought by the seamless integration of technology and life in this digital utopia, where instead of navigating the city, the city now gently but efficiently steers me.

Chapter 1: Introduction

1.1. Background

In the ever-shifting tableau of time, the United Nations (2018) has observed a metamorphosis in the world's urban population – a leap from 751 million people to an astonishing 4.2 billion over the span of 68 years. In this landscape, where 55% of humanity now finds solace in the embrace of urbanity, a number foreseen to swell to 68% by the year 2050 (Trask, 2022; United Nations, 2018), one can't help but ponder.

Can the city administrations, those unseen hands that guide and shape our urban lives, possess the requisite capacity to embrace and manage this ceaseless tide of change in areas such as energy, waste, housing, and mobility management, while also paying close attention to the ever-growing wave of concern surrounding sustainability (Halkos & Gkampoura, 2021)?

According to the UN, occupying a scant 2% of the Earth's vast sturdy canvas, cities reveal a contradiction, since they claim dominion "over 60% of the global energy consumption, 70% of the greenhouse gas emissions, and 70% of the global waste." And, with a perplexing dualism, these same metropolises orchestrate "70% of the economy (GDP)" (United Nations, 2016).

Embracing the sustainable development goals (SDGs) mapped out by the United Nations (2015), the cultivation of an urban mobility system that intertwines both sustainability and intelligence, is of the utmost importance, in order to better optimize land usage, reduce urban sprawl and promote

densification, which is crucial in accommodating a growing population within the constraints of limited urban space (Dai Junliang & Shoushuai, 2010).

Moreover, urban mobility is closely intertwined with sustainability. According to urban planner Jan Gehl, a well-functioning urban mobility system can significantly contribute to reducing greenhouse gas emissions, air pollution, and energy consumption (Gehl, 2010).This way, within the whispers of wheels and the unspoken rhythms of traffic, urban mobility plays a pivotal role, sculpting the very core essence of the city's vitality. As urban theorist Richard Florida highlights, urban mobility is a crucial part of the city, enabling economic growth, social connectivity, and access to essential services (Florida, 2017), highlighting the fundamental role of efficient transportation systems in promoting economic development, and improving overall livability.

Meanwhile, in the shadow of this urban crescendo, technology textures its own narrative - one of rapid, relentless growth, solving issues previously thought as unsolvable (by employing technology such as IoT, AI, smart sensors, and RFID, for example). The current digital advancements now offer "the unseen hands of the city" the power to tame the widespread chaos born from the world's population knitting itself ever tighter into the urban fabric.

It is in this delicate balance, through the contemplation of two parallel threads, as if destined to converge, that a question is born: "*How can the integration of digital advancements in smart cities' urban mobility systems enhance their efficiency?*"

1.2. Motivation: Examples of urban mobility projects in smart cities

There are multiple examples that can be named on employing technology to aid in the ease of the urban mobility management issues, enabling a greater efficiency, sustainability and/or better quality of life for its citizens.

The table below lists some of the most notable examples:

Smart City	Project	Summary of the project
Barcelona	Urban Mobility Plan 2024	A project sponsoring a mobility focused on public transport, bike or by foot, including measures for healthy and sustainable transport
New York	Midtown in Motion	Recording traffic in real time using cameras and sensors to respond and adapt quickly to shifting conditions
Hamburg	Intelligent Traffic and Transportation System in the Port of Hamburg	A partnership between Hamburg Port Authority and NXP Semiconductors that aimed to develop an intelligent traffic light system that optimized the flow of truck traffic and guided the drivers in a safer manner, inside onde of the busiest ports in Europe
Amsterdam	Smart Street Lighting	Streetlights equipped with smart applications to enhance the safety of the residents
Rio de Janeiro	Partnership with IBM	In a partnership with IBM, Rio de Janeiro built a smart operations center, integrating data from 30 different city agencies, enabling weather monitoring, forecasting of the traffic conditions, and emergency responses
Seoul	Smart Transportation Initiatives	The initiative focused on augmenting the city's transportation services' convenience, reliability, and sustainability. This was achieved by integrating digital technology, notably through the deployment of 50,000 IoT sensors strategically dispersed across the cityscape
Luxembourg	Multimodal MaaS Platform	The project innovatively enhanced its mobility app, transforming it into a real-time information hub for diverse transport options. This upgrade strategically encourages commuters to embrace public transportation, effectively alleviating urban congestion
Bogotá	ParceGo	The city launched a traffic management mobile app to gather and analyze traffic data, particularly in congestion-prone areas. This effort aims to improve traffic flow and develop a more efficient urban traffic management system

Table 1 - Smart city projects around the world and their contributions.
Source: Author's own creation.

The implementation of these smart city projects demonstrates how innovative digital solutions can significantly enhance urban life.

From Barcelona's focus on sustainable mobility to Seoul's integration of IoT technology for efficient transportation, each project reflects a commitment to improving city living. Smart traffic management in cities like New York and

Bogotá showcases the use of real-time data to alleviate congestion, while Amsterdam's smart lighting promotes urban safety, highlighting the importance of this aspect.

Rio de Janeiro and Luxembourg's projects further exemplify the diverse applications of smart technologies in urban management, leading to more connected, efficient, and livable cities.

1.3. Research Aim

This dissertation embarks on a comprehensive exploration into the nuanced landscape of digital advancements within the urban mobility systems of smart cities. At the heart of this investigation lies a dual focus: to unearth the myriad opportunities that these technological innovations can unveil and to navigate the complex challenges they may introduce. It's an expedition that ventures deep into the transformative potential of digital technologies, seeking to clarify the paths through which they can revolutionize urban transport systems, enhancing their efficiency and responsiveness to the needs of the city's population, while also keeping an eye for its potential limitations.

The guiding light of this study is condensed in the research question:

"*How can the integration of digital advancements in smart cities' urban mobility systems enhance their efficiency?*"

This is a question that seeks answers that provide decision-makers with the possibility of reimagining of urban spaces as living, breathing entities, where technology and humanity converge in harmony, enhancing the quality of life.

1.3. Scope and Methodology

Given the length of this dissertation, it is rather impossible to fully address the whole complexity of its subjacent topic. This is particularly true when considering the vast array of ongoing research within this domain and its adjacent fields. The multifaceted nature of this subject matter, entangled with emerging technologies and urban development strategies, presents a rich complexity of potential questions and considerations that far exceed the limitations of a single academic work.

Thus, considering that same challenge, this dissertation is anchored upon three pivotal anchors that will guide its trajectory:

the theoretical framework of *smart cities*;
the concept of *urban mobility*;
the notion of digital advancements.

These themes are interlaced within a crucible of analysis, designed to dissect their interrelations, thereby unveiling a spectrum of opportunities and challenges inherent in their convergence. This thematic exploration serves not only as a foundation for the research itself but also as a lens through which the evolving landscape of urban development and technological innovation can be scrutinized.

To navigate this vast terrain with precision and relevance, five objectives from the following literature review will be distilled, in order to narrow the path of the investigation. These objectives serve as signposts, directing the exploration towards the elucidation of the central, core, research question. They are precisely

crafted to ensure a proper collection of expert opinions and insights, employed through a methodology of a meticulous series of ten semi-structured interviews with seasoned specialists in the field, endeavoring to forge a rich set of insights. These conversations are not merely exchanges of information but are designed as pivotal engagements to probe the depths of expertise and experience that each participant brings to the table, so that the root of these discussions is to provide a comprehensive understanding of how the digital fabric of smart cities can be alloyed together with the physical realm of urban mobility, creating a seamless mesh of reliable, efficient, responsive, and intelligent transport systems.

As the findings from these qualitative interviews are methodically processed and analyzed, a deliberate and thoughtful approach will be employed. Each piece of data, each nugget of wisdom gleaned from the experts, will be considered and placed within the broader mosaic of the research, allowing the data, and the emergence of key themes and insights to build upon the existing body of literature.

Thus, the richness of real-world experiences shared by professionals in the field will serve as a very relevant ingredient, seasoning the research to properly emphasize opportunities and challenges that lay hidden beneath the surface of conventional wisdom. It's here that the dissertation aims to make its mark, offering a beacon of insight on how smart city technologies can be implemented in order to boost the efficiency of the urban mobility systems, ensuring the urban landscape not only thrives but flourishes as a holistic living organism.

From this dissertation, several concepts can be drawn, used, and reused to construct solutions that offer the possibility to genuinely boost the quality of

living (in many fronts) of its citizens, which is a crucial feature to be considered by the cities' decision-makers.

Moreover, the assimilation of these expert perspectives lays the groundwork for an enriched discourse, extending beyond the confines of this dissertation, as intended. By digging into the findings and analyses presented herein, the way is paved for future research works. These subsequent analyses, possibly rooted in the insights gleaned from this study, will possess the specificity and focus necessary to address the unique challenges and opportunities presented by individual cities or a collective of urban environments, as per the given professional perceptions.

In essence, this dissertation does not purport to exhaustively catalog every nuance and facet of its central themes, but rather, it aspires to chart a course through the complex interplay of technology, urban planning, and societal needs. Through this exploratory journey, the primary focus is to contribute meaningfully to the ongoing dialogue surrounding smart cities, urban mobility, and digital advancements, while acknowledging the vast horizon of knowledge that remains to be discovered and studied.

Chapter 2: Literature Review

An important examination of the fundamental ideas that form the basis of this discussion on smart cities, and their changing environments will be provided in the current chapter. The goal is to clarify and disentangle the complexities of SCs, the technical advancements that power them, and the vital role that urban mobility plays in this setting, with a view supported on the respective literature review thoroughly enriching the narrative, whilst showcasing the urgent need for certain aspects to be addressed, in order to foster the fast response to the pressing needs of today's growing modern society.

2.1. Smart city concept

The concept of a smart city, an ambiguous subject that fuels a profound debate throughout the literature, tends to generally embody the integration of information and communication technologies (ICT) into urban infrastructure to enhance the quality of life for its inhabitants, improve the efficiency of urban services, and ensure a sustainable development path, leveraging digital technologies to collect data, which is then used to manage assets, resources, and services more efficiently; this includes data collected from citizens, devices, buildings, and assets that is processed and analyzed to monitor and manage traffic and transportation systems, information systems, and other community services, optimizing city functions and driving economic growth while improving the quality of life for its citizens through smart technology (Caragliu et al., 2011).

Nonetheless, the major point that the critics hold to the concept of smart city, is a focus, which they describe as too strong, on ICT, pointing out that "technology deployment alone is not sufficient to make a smarter city" (Daniel & Doran, 2013).

Nonetheless, the essence of a smart city lies in its ability to utilize digital and telecommunication technologies to enhance performance and well-being, and to engage more effectively and actively with its citizens, depending on a great length, however, on the general context of the area itself which is under analysis at that specific moment (Neirotti et al., 2014).

The smart city concept thus goes beyond the mere application of technologies; it encompasses a broad and complex ecosystem that involves the strategic use of digital advancements to solve urban issues, foster sustainable development, and create an inclusive and accessible urban environment for all residents (Kitchin, 2014) drawing the dynamics underlying an intricate notion that comprehends not only the technology, but also the key factors specific to the area under scope (Hollands, 2008).

According to Verhulsdonck et al. (2023) "smart cities connect humans to networks of information to create urban operating systems that optimize traffic management, sustainable energy use, and enact smart governance".

Al-Barhamtoshy, et al. (2023) view the "smart city" concept as a realization amid "vehicles, road networks, smart parking, smart mobility, smart environment, living, and people coupled with human populatiosn growth and needs". Reinforcing that this concept has evolved over time, using the digital transformation to improve the quality of life to its inhabitants.

This way, the generality of ideas tends to converge on the transformative potential of smart cities in redefining urban living, making them crucibles of innovation and progress (Batty et al., 2012).

2.2. Digital advancements

Schwab (2016) emphasizes the role of digital advancements as the cornerstone of the Fourth Industrial Revolution, marking a significant shift in the way we live, work, and relate to one another.

According to Albino et al. (2015), digital advancements, the new and coming technologies applied in this field, are pivotal in the context of smart cities, where they serve as the backbone for developing smart infrastructure and services, facilitate the collection, analysis, and management of data, transforming it into actionable insights that improve urban services, reduce costs, and minimize environmental impacts, which, in turn, serve as a powerful lens to perspective the concept of an efficient urban landscape.

2.3. Urban mobility

Rodrigue (2020) divides the concept of urban mobility in the three broad categories of collective, individual and freight transportation, highlighting the polygonal nature of this notion, which includes not only the physical movement but also the infrastructures, policies, and technologies that enable such mobility.

According to Banister (2008), effective urban mobility systems are vital for the economic vitality and social fabric of cities, sustaining access to employment, education, healthcare, and leisure, while greatly reducing the environmental footprint of transportation.

The advent of digital advancements and the smart city paradigm have significantly influenced the evolution of urban mobility, introducing innovative solutions that leverage various types of technology to optimize transportation networks and enhance user experiences (Giffinger et al., 2007).

In essence, UM stands at the intersection of technological innovation and urban planning, embodying the transition towards smarter, more sustainable cities. It represents a critical link in the chain of urban development, influenced by and contributing to the advancements in digital technology and the overarching smart city objectives defined for a specific geolocation.

In conclusion, these will be the three gentle pivots upon which the whole narrative delicately balances, casting light on the followed path. They will be the beacons of the exploration guiding and shaping the way the research question is addressed in this dissertation.

2.4. Common challenges in the implementation of SC projects

These projects can have major difficulties in implementation, even though they might offer great advantages (Ojo et al., 2015). Some of the core challenges in the realization of smart city projects around the world include:

2.4.1. Lack of adequate funding and resources

Smart city projects often require significant investment in infrastructure, technology, and human capital. Without adequate funding and gathering of resources (and allocation), it becomes challenging for cities to execute and sustain these projects effectively (Tabane et al., 2016).

2.4.2. Technological infrastructure

Implementing SC projects demands a robust and interconnected technological infrastructure, which needs to support data collection, analysis, and communication between various systems and stakeholders. If deprived of a solid technological infrastructure, smart city initiatives may face hurdles in integrating different systems and achieving seamless connectivity (Giffinger et al., 2007).

2.4.3. Engaging stakeholders and ensuring citizen participation

The success of smart city projects relies heavily on stakeholder engagement and the active participation of citizens (Tabane et al., 2016). Without the involvement and support of key participants, including government officials, businesses, and residents, it becomes difficult to gain traction and imprint sustainable changes (Ojo et al., 2015).

2.4.4. Data privacy and security

Smart city projects involve the collection and analysis of vast amounts of data, including personal information about residents (Ismagilova et al., 2022).

These kinds of data need to be safeguarded for ethical aspects or even attempts of exploitation.

2.4.5. Integration and standardization

To fully realize the potential of smart cities, different systems and devices also need to be integrated and work together in a seamless manner, even though implementing various technologies and systems may be complex, it mut be done in a competent manner, otherwise, it can lead to inefficiencies and limitations in achieving the desired outcomes (Batty et al., 2012).

In the nuanced journey of shaping our cities, we face a collection of challenges that need to be addressed with care and precision. It's about finding a balance in managing costs of implementation, building a solid technological foundation, engaging various stakeholders, safeguarding data privacy and security, and ensuring that the implemented systems work together seamlessly through integration and standardization.

This effort goes beyond the physical construction of cityscapes. It's an investment in the future, focusing on adopting innovative technologies and fostering sustainable urban development. It's about laying the groundwork for a future that secures the well-being of citizens and the efficiency, and resilience of the implemented frameworks.

By paying close attention to these critical elements, we move toward creating urban mobility that is not only resilient and interconnected, but it is also a place where life thrives. It’s a commitment to overcoming obstacles that stand in the way of progress, aiming to augment the quality of urban living and ensuring that cities become more than just places to reside – they become a well-spring of collective growth and harmony.

2.5. The urgency and demand for efficiency

Urban mobility systems play a crucial role in the functioning of cities, as they determine the efficiency of transportation and contribute to the overall livability of urban areas. Enhancing these systems is essential for appropriate urban development.

As seen in an article by Verizon Connect, written by Mark Wallin, in the United States, cities like Boston, Washington, DC, and Chicago experience severe traffic congestion, with commuters in Boston spending an average of 164 hours annually in traffic, leading to significant costs both in time and money. This bottleneck plays its part in the grander scheme of things, affecting the economy and the rhythm of businesses, as transport delays lead to increased costs and decreased efficiency.

Furthermore, the demand for better urban mobility systems is not limited to the inconvenience caused by jamming or lack of accessibility but also considers the broader issues of sustainability and quality of life.

A study by the World Health Organization (WHO) digs into how urban transportation affects public health. It draws attention to the detrimental effects of air pollution and the inactive lifestyle often linked with the use of private vehicles. Published in 2016, this research emphasizes the critical need for creating smarter, more sustainable cities, by improving their citizens' well-being through the promotion of walking, cycling, and the use of public transportation (World Health Organization, 2018).

2.5.1. Efficiency as safety

According to an article by Velco Tech, a technology company focused on the development of solutions that fit the smart city paradigm, safety is a paramount aspect of urban mobility systems, especially due to the crowding of various transportation modes in limited spaces. In this dynamic environment, with numerous individuals navigating through cities by foot, car, motorbike, bus, or bicycle, there's an increased likelihood of unexpected incidents that necessitate heightened alertness. These scenarios, rich with potential but fraught with danger, demand our constant vigilance. It's crucial, therefore, to craft urban landscapes that not only embrace this diverse flow of movement but also safeguard it. By thoughtfully designing our infrastructure, we can ensure the safety of all who traverse the city's veins, while also nurturing an environment that minimally impacts the world around us.

2.5.3. Efficiency as travel time

A study from Texas A&M Transportation Institute (2021) invites us to envision cities where every saved minute on the road adds to a healthier, more vibrant community life, by painting a vibrant picture of how reduced travel times can transform urban life. It suggests that less time spent commuting not only opens the door to increased economic productivity but also enriches the quality of life, by granting citizens with more time for other activities, such as social moments. However, the benefits extend beyond the personal: decreased travel times mean less greenhouse gas emissions and less fuel consumption.

2.5.3. Cost-efficiency

The cost of urban mobility is another noteworthy dimension of efficiency in smart cities. It involves minimizing the monetary resources required to operate and maintain the transportation infrastructure. According to Litman (2023), cost-efficient systems are relevant for both citizens and their cities to allocate their limited resources efficiently. This can be achieved by investing in sustainable transportation modes, such as cycling and walking infrastructure, which provide a more affordable alternative in terms of both creation and upkeep, as opposed to the hefty expenses of constructing new roads or enlarging public transit systems.

2.5.4. Efficiency as sustainability

Sustainability stands at the forefront of urban mobility advancements in smart cities, echoing the crucial point that cities account for a staggering 70% of global greenhouse gas emissions, as previously noted by the United Nations, through the publication of their referred SDGs.

According to Ewing et al. (2009) by integrating land use and transportation planning, which promotes compact, mixed-use development and reduces travel distances, city administrations can also enhance the environmental sustainability that comes from urban mobility systems.

2.5.5. Efficiency as accessibility

Accessibility efficiency in urban settings is a multifaceted concept that emphasizes the simplicity and convenience with which individuals can reach their desired destinations. This concept grasps the principle of equal access to diverse transportation options for each and every segment of society. As Corrêa et al. (2023) put it, "it is inferred that accessibility is a main attribute of the

environment, and that its implementation is fundamental, considering that through it, the improvement of the quality of life of individuals is guaranteed and positive social results are produced, since it contributes to inclusion".

It's about inclusivity, ensuring that individuals with disabilities, the elderly, and those from economically disadvantaged backgrounds can navigate the city with ease. (Litman, 2023), also defines accessibility as the capacity for individuals to easily reach the places and services they need and desire. This perspective on accessibility emphasizes the significance of incorporating inclusivity into the very core of transportation planning making it about creating a network that connects everyone to the opportunities and resources they require, which is the ultimate goal of the transport activity.

Chapter 3: Research Methodology

This section delineates the data sources and the methodology employed for the data gathering process, crucial to properly perform the subjacent analysis.

Going back to the previously appointed research question - *"How can the integration of digital advancements in smart cities' urban mobility systems enhance their efficiency?"* – it is important to mention that this inquiry greatly surpasses the academic perspective; it reflects a pressing need to reimagine urban spaces in the face of burgeoning populations, environmental challenges, and the relentless pace of technological innovation. By diving into this query, a tapestry of research objectives designed to meticulously dissect the intertwined relationship between digital technologies and urban mobility is unfolded, aiding in the quest to unlock pathways towards more livable, sustainable, and equitable urban futures.

3.1. Design Methodology

Embarking on this exploration required a methodological approach that could capture the complexity and nuance of integrating digital advancements in urban mobility. The choice of a qualitative research strategy, marked by interviews with seasoned professionals in architecture, urban planning, smart cities, technology, and related fields, was driven by a conviction in the value of experiential knowledge and insights.

This approach was chosen for its ability to delve beneath the surface of quantitative data, revealing the lived experiences, and challenges of those at the

forefront of shaping smart urban mobility and its supporting surrounding solutions, allowing for the extraction of deep and valuable perspectives about the topics under exploration.

The selection of the interviewees was orchestrated with due care, adopting adequate criteria to filter from a rich web of insights from voices deeply rooted in the transformative journey of urban landscapes, which will be described further ahead.

Then, semi-structured interviews and their respective questions (please refer to Figure 1) were crafted as conduits for capturing the nuanced reflections of these experts. By elegantly bridging the insights gleaned from the literature review to the specific objectives that were aimed to explore, this methodology allowed to brilliantly illuminate answers to the central research question.

The research objectives, sought to be explored through conversations with experts, are elaborated upon below.

Assessing the impact of digital advancements on travel time reduction

The first beacon guiding this journey is the assessment of how digital technologies are reshaping travel time within smart cities.

Real-time traffic management systems and route optimization algorithms represent the a big portion of this transformation. Technologies such as these, embedded within the very nervous system of urban mobility, attempt to alleviate the chronic congestion that throttles the arteries of our cities. By investigating their deployment and efficacy, it was aimed to uncover the extent to which they can sculpt the temporal landscape of urban travel, transforming wasted hours into moments reclaimed for life's true pursuits.

Evaluating digital technologies' contribution to user safety

Safety within urban mobility systems is a paramount concern, directly impacting the well-being and confidence of city residents.

Digital technologies, through the lens of surveillance and real-time monitoring, are some of the examples that offer unprecedented capabilities to safeguard the public realm. This objective seeks to delve into the digital domain's capacity to forewarn and forearm against the specters of accident and harm that haunt urban transport and its surrounding environment. By examining the opinions of experts on these technologies' effectiveness, the conditions are born to understand and chart a course towards safer urban voyages, where fear and uncertainty are replaced by assurance and vigilance.

Understanding how digital solutions improve the accessibility in urban mobility

The density of urban life is rich and diverse, yet the threads of accessibility and inclusivity may be frayed and neglected. The third objective centers on unraveling how (and if) digital platforms can mend these threads, creating a mobility landscape that embraces all members of society. From those with disabilities to the elderly and economically disadvantaged, the objective aims to clarify the ways digital solutions can bridge divides, ensuring that the city's pulse beats equally for every citizen. Through this lens, the potential of technology to democratize urban movement, making it a right, not a privilege, accessible to all who call the city home, is explored.

Comprehending the role of digital innovations in promoting sustainability within smart cities' transportation systems

In the intricate dance of urban development, sustainability plays a central role, acting as both a goal and a guiding principle.

This fourth objective dives into the territory of digital innovations such as carpooling and bike-sharing platforms (and other solutions that may be appointed by specialists). These solutions, relevant for a shift towards more sustainable urban transport methods, offer a dual promise: to mitigate the environmental degradation wrought by traditional modes of transport and to create a new structure of urban mobility, characterized by resilience and adaptability.

Analyzing the promotion of sustainability through digital platforms involves a nuanced examination of how these technologies not only reduce the carbon footprint of city transport but also how they reshape urban spaces and social norms. The exploration extends to understanding the impact of these innovations on public health, urban congestion, and the overall quality of life, drawing connections between environmental sustainability and the holistic well-being of urban communities.

Evaluating the Cost-Efficiency of Digital Integration

The final essential aspect characterizing the interviews, which aims to collect the necessary qualitative data, involves delving into the digital advancements within smart cities' urban mobility systems, with a particular focus on the remarkable economic dimension.

This objective marks the completion of the interview process, displaying an effort to uncover how technological innovations influence the economic aspects of transportation networks in smart cities, from the experts' points of view. Here, the cost-efficiency of embedding digital technologies into the fabric of urban mobility is critically assessed. This objective seeks to shine light on the financial viability of certain integrations, weighing the upfront investments against the long-term dividends in efficiency, sustainability, and societal benefits, and how they should be evaluated.

By meticulously examining specific cases, the answer to this research objective offers insights into how digital advancements have, and can lead to operational savings, and the optimization of resources.

3.2. Interview design

To enlighten the research objectives that directly address the research question mentioned earlier, an interview process was devised. Originally planned to consist of ten discussions with competent experts, this process was carefully structured. The design of this approach and its straight interconnections are depicted in the figure below.

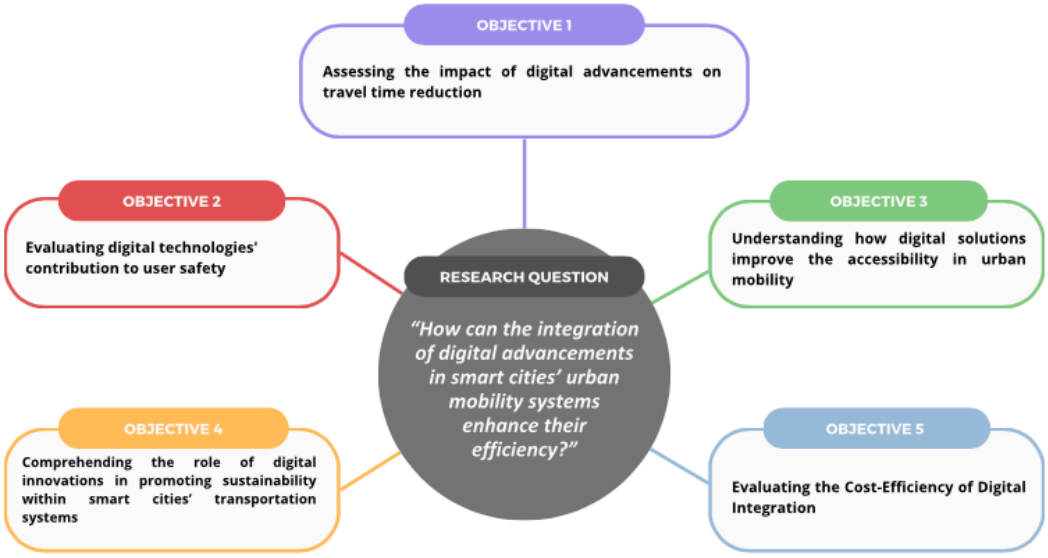

Figure 1 - Relationship between research question and research objectives.
Source: Author's own creation.

To directly address the research objectives outlined earlier, interview questions related with each objective were carefully, and individually crafted. This approach ensured that the responses collected would offer applicable insights, serving as essential pieces of information. These insights were not only aimed at fulfilling the specific objectives but also, and importantly, at consequently providing answers to the overarching research question.

Regarding objective 1, the designed questions were as it follows:

- Can you describe how real-time traffic management systems have impacted urban mobility in terms of travel time reduction?
- How do route optimization algorithms specifically address the reduction of travel times in urban environments?
- Based on your experience, what are the most significant challenges and successes in implementing these technologies in this context?

In terms of objective 2:

- Could you share examples of technologies that have been particularly effective at enhancing safety in urban mobility systems and highlight how they have actually improved it?
- What are the key factors for successfully integrating these safety-enhancing technologies into existing urban mobility systems?

When it comes to research objective number 3, these were the questions:

- Can you provide an example of a digital solution that has significantly improved mobility for a specific segment of society?
- How have digital platforms been used to improve accessibility for individuals with disabilities, the elderly and low-income groups?
- What are the main obstacles to making urban mobility systems more accessible through digital innovations, and how can they be overcome?

Considering objective 4, about sustainability, the interviewees answered the following questions:

- From your perspective, which current and future digital innovations hold the most promise for improving sustainability in urban mobility systems, and how?
- How do digital car- and bike-sharing platforms (or others that you think are significant) contribute to reducing the environmental impact of urban transport?
- What technological solutions have been implemented to promote sustainability in smart cities and what results have been observed?

Finally, these were the questions asked concerning the 5th objective:

- Can you discuss the long-term financial impacts of integrating digital technologies into urban transport systems?

- How do the initial costs of implementing digital advances compare with the economic savings achieved over time?
- Are there specific examples, of which you have direct or indirect knowledge, where the integration of new technology has led to significant cost savings in urban mobility?

3.3. Target audience and filtering criteria

Through a selection of already gathered contacts that worked in the area or had a considerable amount of knowledge by working close to this field, a detailed exploration on LinkedIn, and the identification of key speakers at smart city conferences, a diverse array of perspectives was meticulously assembled. This careful selection and filtering process played a crucial role in ensuring the research captures the depth and complexity found at the crossroads of smart cities and digital innovation. The criteria for the selected candidates for this inquiry was individuals with hands-on urban planning experience, key decision-makers knowledgeable in integrating various systems within an urban framework, and/or those with professional backgrounds in smart cities, especially those who bring a deep understanding of urban mobility and those engaged in the smart cities sector as part of their daily professional activities.

The interviews were conducted throughout the months of March and April of 2024 with individuals matching these specific criteria. Their responses were accurately transcribed into separate documents.

This process allowed for an in-depth analysis of their opinions and perspectives, significantly developing the research with their valuable perspectives.

The research objectives outlined here, coupled with a qualitative methodological framework intended to answer them and, therefore, the core research question, lay a robust foundation for an in-depth exploration of this dynamic convergence of subjects. In the chapters that follow, the insights collected from the qualitative research will be analyzed, and the implications of the respective findings will be approached and discussed.

The data analysis process was carried through a collection of answers and through the construction of a map (found in Appendix 2) with all the questions and answers from all the participants. Then, a careful comparison between them was developed, addressing their qualitative similarities and divergences, while understanding where the majority pointed, collectively.

This uncovers a pathway to understanding the potential of technology to create more efficient, safe, and sustainable urban environments, with the anticipation of revealing strategies and solutions that will not only help address the challenges of today's urban spaces but also inspire the design of the smart cities of tomorrow.

Chapter 4: Results and Data Analysis

Data alone holds little value without thoughtful analysis and consequent interpretation. Therefore, the aim of this chapter is to present and analyze the inquiries and outcomes, pinpointing the crucial findings that align with and support the achievement of the research objectives.

This chapter seeks to lay down a foundation for a comprehensive discussion, rounding out the main body of the thesis. It is structured to include an introduction, an overview of the data collection methods (along with appropriate justifications), the main results obtained, and an analysis and interpretation of these results. A conclusive summary will also be provided to seamlessly transition to the final chapter, the conclusion.

4.1. Research Approach

Due to the holistic importance of researching the topic as a whole, and not as a focused case-study approach, survey interviews were adopted to collect data through a semi-structured script.

The results of these surveys can then be useful to provide insight to future policy-makers, decision-makers and researchers. Institutional researchers, for example, can leverage survey data to inform decision-making processes at universities, demonstrating the practical utility of survey results in guiding strategic initiatives (Ehrenberg et al., 2004). Thus, by adopting a qualitative approach using semi-structured interviews, this research facilitated the exploration of diverse perspectives, enabling an in-depth understanding of the practical

applications and genuine concerns of those directly involved in shaping and dealing with urban mobility systems in smart cities and its adjacent fields. This methodology provided a fertile ground for gathering rich, varied insights from individuals who had valuable viewpoints to offer, which, according to Adams et al. (2014) provides us with the possibility of gaining important insights about reality and the challenges faced by those involved.

4.2. Data Collection Methodology

In order to gather the appropriate data, by employing a stratified random sampling technique, a set of ten interviews was conducted via either Microsoft Teams, Google Meet or Zoom between March 1st, 2024, and April 30th, 2024. The semi-structured script, composed by open-ended questions, which was used in the interview process, can be reviewed both in subchapter 3.2. and Appendix 1, for convenience purposes.

As previously mentioned, the selection of interviewees was conducted with careful consideration. Candidates were chosen based on their academic expertise in fields such as architecture, engineering, and technology, or their professional roles directly or indirectly related to urban mobility in smart cities. These specific qualifications distinguished them from the general population, ensuring they shared relevant characteristics crucial for this study. Additionally, practical criteria such as availability and willingness to participate were also essential factors in their selection, as it defined if they were, at all, reachable to be considered in the study. Other variables such as age, gender, and income were not considered in the study, since the study aims to understand universal issues or solutions that apply broadly, regardless of these unconsidered factors.

For the purposes of analyzing the data acquired and prevent inaccurate interpretations or biased facts, all ten interviews were conducted with the participants' permission to record – and subsequently delete - audio and transcribe it without any alterations.

4.3. Data Analysis

Thematic analysis was employed as a flexible method to explore and interpret the patterns within the dataset relevant to urban mobility in smart cities. This approach, recommended for its robustness in qualitative research, allows for an in-depth, flexible, examination of the data without the rigid step-by-step process often prescribed (Joffe & Yardley, 2004). The analysis was focused on distilling the essence of the interviews into coherent themes that illuminate the underlying dimensions of the topic. This was achieved by iteratively sifting through the data, identifying significant statements, and categorizing these into themes that collectively construct a comprehensive understanding of the subject matter.

The forthcoming section of this thesis will pivot from the detailed analysis of these themes to a broader interpretation of their implications, so, rather than directly linking the findings to the existing literature introduced in the first chapter, the emphasis will be placed on unpacking the understandings derived from the thematic analysis to deepen the understanding of digital advancements in urban mobility systems. This approach ensures a focused exploration of the data, highlighting its unique contribution to the discourse on smart cities.

4.4. Interviewee Characterization and Categorization

The table below is designed to provide a detailed overview of the participants involved in the interview process. It outlines the intrinsic characteristics of each individual, offering insights into their profiles and contributions, through the inclusion of key information such as the date and duration of the interview, country of residence, academic background, and current profession, enabling readers to gain a comprehensive understanding of the factors that help building each participant's perspective.

Interviewee	Interview Date	Duration of the Interview	Country of Residence	Academic Background	Current Professional Activity
1	01/03/2024	38 minutes	Portugal	Architecture	Architect - Urban Planner - Mobility Expert
2	23/03/2024	84 minutes	Portugal	Architecture	Architect - Urban Planner
3	27/03/2024	23 minutes	Portugal	Transportation & Economics	Teacher - Engineering; Owner of a Transportation Microenterprise
4	28/03/2024	35 minutes	Portugal	Economics	Smart Cities Specialist
5	09/04/2024	22 minutes	Portugal	Engineering	Board Member - Transportation Services Company
6	09/04/2024	32 minutes	Portugal	Engineering	Director - Centre of Engineering and Product Development - Smart and Sustainable Living
7	10/04/2024	30 minutes	Portugal	Engineering & Technology	ICT & Smart Cities Specialist - Multinational Enterprise
8	24/04/2024	22 minutes	Portugal	Engineering	CEO - SMC - Engineering & Technology
9	26/04/2024	15 minutes	Portugal	Engineering	CEO - Startup - Engineering & Technology
10	29/04/2024	21 minutes	Portugal	Engineering	CEO - Microenterprise - Engineering & Architecture

Table 2 - Interviewee Characterization.
Source: Author's own creation.

The interviewees primarily consisted of professionals with backgrounds in engineering and technology, encompassing 60% of the group. Architecture professionals accounted for another 20%, and the remaining 20% were professionals with expertise in management/economics.

The analysis will concentrate on the same five categories into which the concept of "efficiency" was previously segmented, reflecting the organization of the interview questions. This structure enables readers to fully comprehend the

central answers provided by professionals and their contributions to the collective pool of knowledge. In the following subchapter, the central findings for each category will be condensed and explanations for each one will be provided. For a more detailed examination of these responses, Appendix 2 serves as a complement to the subsequent chapter.

Chapter 5: Discussion and Conclusions

5.1. Discussion of the Research Objectives

5.1.1. Category Number One: Impact of Digital Advancements on Travel Time Reduction

The questions elaborated in this category were designed to reflect the experts' insights into the current state-of-the-art concerning Travel Time efficiency in Urban Mobility Systems within SCs. By compiling their collective perspectives, it was possible to gain a comprehensive understanding of how technologies applied in this area have proven to be relevant, while keeping an eye for primary successes and challenges associated with implementing existing and emerging technologies that aim to enhance this aspect.

The answers were mainly positive in the impact of technology in reducing the travel time, however, there was a pressing concern to the need of the subjacent network to be ready to receive these digital innovations (*"Digital systems cannot replace a good transportation network design"*). When confronted with the third questions, regarding core challenges and successes of implementation, not only concerns about the availability of information (and quality of the data) were raised, but also those, once again, linked to the possibility of the current physical infrastructure being able to "support" these digital innovations.

According to Ерохина & Brega (2020), the impact of digital advancements on travel time reduction within urban mobility of smart cities is highly beneficial, which goes in line with most of the answers provided by the participants.

5.1.2. Category Number Two: Impact of Digital Solutions on Urban Mobility's Safety

In this category, the questions focused on uncovering technologies that improve safety in urban transportation systems and examining the critical elements required for their effective integration. It became clear from a thorough study of participant replies that many different technologies are successfully advancing safety. Enhanced safety features on electric bicycles and scooters, well-placed non-recording cameras in Barcelona that collect information on potentially dangerous scenarios, and advanced accident notifications via traffic light analytics and ice warning systems on highways are a few examples. Furthermore, the addition of smart lampposts with cameras, high-performance sensors, and artificial intelligence-powered digital indications has improved environmental-related safety protocols.

Achieving a successful integration requires resolving privacy issues, prioritizing data quality and open data, and striking a balance between active and passive sensor utilization. In urban environments, a strong infrastructure network and well-defined risk mapping are essential. Proactively improving technology integration in urban mobility through testing and optimization of these systems is advocated, demonstrating the transformational potential of these systems when backed by well-thought-out plans and solid data management procedures.

According to Bolobonov et al. (2021), digital solutions in urban mobility have a significant impact on safety in smart cities, which corroborates the idea transmitted in the interview process.

5.1.3. Category Number Three: Usage of Digital Solutions to Improve Accessibility in Urban Mobility

Regarding category number 3, the questions modeled aimed to explore the effectiveness of digital solutions in enhancing accessibility within urban mobility systems for specific societal segments, and to identify the main obstacles faced when trying to implement and solidify them.

Participants provided varied examples of digital solutions improving accessibility, such as bike-sharing platforms that accelerate travel for young people (that do not have the possibility – financial or not – to drive other types of vehicles), real-time bus location systems enhancing certainty and ease of use for all users, and specific innovations like subway systems offering directional assistance to blind individuals via telephone.

The primary challenges to broader accessibility identified by respondents include the need for widespread adoption and awareness of these technologies, the quality and availability of information, and the necessity of underlying physical infrastructure that supports digital enhancements. Participants emphasized that improving infrastructure is crucial, with statements like "we can't develop solutions that aren't fully inclusive" and "physical structure, first of all, perhaps," highlighting the foundational role of tangible assets in enabling digital advancements.

In general, while digital solutions have palpably enhanced urban mobility for various societal segments, the efficiency of these technologies hinges on overcoming challenges related to infrastructure, information quality, and system inclusivity. As one participant succinctly put it, "it's the information and the quality of the information that is even more important than management itself."

These insights underscore the need for a holistic approach that marries robust infrastructure with innovative digital solutions to truly transform the accessibility within urban mobility.

As Loos et al. (2020) put it, "Smart transport solutions can make public transport, and community/flexible transport services more accessible by both addressing barriers to access relating to difficulties in getting information about the provision of services, as well as by enabling the signaling of demand for travel services and making viable flexible transport. In an urban context, promoting opportunities to access mobility entails both physical and social infrastructures of media and transport access", as some participants highlighted in their answers.

5.1.4. Category Number Four: Role of Digital Innovations in Promoting Sustainability

The discussions around digital innovations for enhancing sustainability in urban mobility systems highlight a significant focus on sharing-based models and integrating technology with existing public transport infrastructures to reduce environmental impact. Respondents indicated that current and future digital innovations promising the most impact include systems that promote soft mobility and sharing behaviors, intelligent waste management, and advances in vehicle technologies such as electric and hydrogen fuel vehicles. A recurring theme is the integration of digital technologies to enhance the efficiency and sustainability of public transportation systems.

Responses to the second question accentuated the environmental benefits of car-sharing and bike-sharing platforms, highlighting that their positive impact depends significantly on their integration into wider urban mobility systems and the actual reduction in vehicle use. The effectiveness of these platforms is seen as

contingent on replacing car trips rather than displacing more sustainable options like walking, suggesting a need for strategic implementation and policy support to maximize their environmental benefits.

As for the technological solutions implemented in smart cities to promote sustainability, respondents pointed to enhanced public transportation systems, smart energy management in buildings, and adaptive and smart lighting systems as key developments. These technologies have been observed to reduce energy consumption significantly and improve operational efficiency in urban environments.

According to the general opinion, enhancing sustainability in urban mobility relies on a cohesive approach that combines digital innovation with robust infrastructure and policy frameworks. Effective sharing systems, improved public transportation efficiencies, and smart energy solutions were transmitted as pivotal in moving towards more sustainable urban environments. The overarching insight is that while technology provides the tools for sustainability, its real-world impact is heavily dependent on systemic integration and supportive public policies.

According to Rosario & Dias (2022) sustainability can indeed be increased by embracing and integrating digital technologies in various activities, processes, and systems, agreeing with the majority of the participants' opinions.

5.1.5. Category Number Five: Cost Efficiency of Digital Technologies in Urban Mobility

The autopsy into the long-term financial impacts of integrating digital technologies into urban transportation systems sheds light on an intriguing aspect of urban development. The responses suggest that when cities transition

towards models favoring sharing and public transportation, the economic burden on families can decrease. Several participants highlighted that mobility systems tend to be self-sustaining financially, although the distribution of costs and benefits is not always equitable, leading to challenges in implementation. Examples such as fleet management in garbage trucks and smart lighting systems exemplify once more direct cost savings and efficiency gains by reducing energy consumption and optimizing operations.

Regarding the initial costs versus long-term savings of digital advancements, it was noted that these investments generally pay for themselves over time. In Cascais, for example, the fleet management system for trash trucks saw a return on investment within just 7-8 months. However, respondents emphasized that the benefits extend beyond mere financial savings, touching on broader societal gains such as health improvements.

When asked for specific examples where technology integration has led to significant cost savings, the traffic management system in Lisbon was mentioned as a case where urban mobility was notably optimized. Besides, the move towards mobility-as-a-service (MaaS) was discussed as a future-oriented solution that, with appropriate regulatory frameworks, can allow governments to pay solely for the actually used services, potentially leading to substantial cost efficiencies.

However, it is very noteworthy that this category received notably fewer responses compared to others, which may suggest that despite the promising potential of these technologies, there is still a lack of comprehensive data on their financial sustainability. This gap in detailed feedback underscores the need for future, more robust data collection and analysis to validate the economic impacts

of digital technologies in urban transportation. Such evidence is crucial for not only justifying investments and planning future implementations that are both economically viable and socially beneficial, but also to incentivize other players to enter the market with better and, perhaps, more efficient solutions.

5.2. Conclusions

Throughout the examination of the diverse categories assessing the impacts of digital advancements in urban mobility, it is clear that digital technologies are playing an increasingly transformative role across multiple dimensions of UMS in SCs. From enhancing travel time efficiency and safety to improving accessibility and promoting sustainability, digital solutions offer significant advantages. However, as the experts firmly pointed out, their success and efficiency are cripplingly dependent on the integration with robust, well-developed and well-thought infrastructures and comprehensive policy support.

When it came to efficiency in the plane of travel time, it was possible to understand that the general opinion was that digital technologies have positively impacted travel times, yet the effectiveness of such solutions relies on the underlying physical network's readiness to support these innovations. The need for high-quality information and compatible infrastructure is critical.

On the other hand, in the sphere of safety in UMS, safety technologies appear to have been successfully integrated into urban mobility, improving environmental and traffic safety through innovations like smart lampposts and advanced traffic management systems. Nevertheless, the balance between technology implementation and data privacy remains a grave challenge.

About accessibility, the participants paint a vivid picture in which digital solutions appear to increase urban mobility's accessibility, especially for marginalized segments of society. Yet, they highlight that widespread adoption and the integration of these technologies into existing infrastructures remain significant barriers.

When it comes to the promotion of sustainability, the commitment to through digital innovations was properly emphasized, particularly in the integration of sharing systems and public transport enhancements. However, the true environmental impact of these platforms hinges on their ability to replace more pollutive travel forms effectively.

Regarding the last topic, of cost efficiency, while digital technologies generally seem to demonstrate a capacity to pay for themselves over time, the equitable distribution of these financial benefits across different stakeholders proves challenging. The notable lack of detailed responses in this category suggests that more research is needed to conclusively determine the financial sustainability of such technologies.

This research accentuates the importance of a holistic approach in implementing digital solutions within urban mobility. Realizing the full potential of digital breakthroughs in urban transit requires deliberate policy frameworks and the cooperation of technology and infrastructure. The integration of these technologies will surely demand adaptive solutions that take into account the social, economic, and environmental implications simultaneously as urban settings continue to change. Although there are many moving parts in the process of transforming urban mobility, digital innovation has the potential to

provide more inclusive, safe, and efficient urban mobility systems, within the landscapes of current and future SCs.

5.3. Limitations and Future Research

This research encountered notable limitations that could influence the comprehensiveness and depth of the findings. Firstly, engaging with professionals in the urban mobility sector proved challenging. The difficulty in accessing and securing commitments from these specialists for interviews impacted the ability to gather a broader spectrum of insights. Their availability and willingness to participate were significant hurdles, reflecting perhaps the high demands and fast-paced nature of their professions.

Secondly, the topic of cost-efficiency within digital advancements in SCs' UMS emerged as particularly difficult to explore profoundly. As highlighted in the discussion of the fifth category, responses regarding the long-term financial sustainability of these technologies were notably sparse. This gap suggests a potential reluctance or difficulty in disclosing, accessing, or analyzing financial data related to such innovations, possibly due to the nascent stage of many digital implementations in urban mobility or the sensitive nature of financial information, which participants may not feel comfortable in disclosing.

Future research should aim to overcome these limitations by employing alternative strategies to engage more professionals within the sector. This might include leveraging professional networks, attending industry conferences, or only specifically seeking urban mobility firms for academic research. Additionally, further studies should focus on developing methodologies that can successfully quantify the financial impacts of digital technologies in urban

mobility. This could involve case studies with long-term financial tracking or, perhaps, if the possibility arises, developing models that predict the economic outcomes of digital implementations. Such efforts would provide clearer insights into the cost-efficiency of the implementation of these digital advancements, aiding stakeholders in making informed decisions about investments in smart urban mobility solutions.

Bibliography

Adam Frost. (2019). *Luxembourg upgrades travel app to full multimodal MaaS*. Traffic Technology Today. https://www.traffictechnologytoday.com/news/mobility-as-a-service/luxembourg-upgrades-travel-app-to-full-multimodal-maas.html

Adams, J., Khan, H. T., & Raeside, R. (2014). *Research methods for business and social science students*. SAGE Publications India.

Al-Barhamtoshy, H. M., Abdullah, K. K., Dauda, M. K., & Himdi, T. F. (2023). Detecting Available Parking Spaces in Smart Cities. *2023 1st International Conference on Advanced Innovations in Smart Cities (ICAISC), Advanced Innovations in Smart Cities (ICAISC), 2023 1st International Conference On*, 1–5. https://doi.org/10.1109/ICAISC56366.2023.10085386

Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart Cities: Definitions, Dimensions, Performance, and Initiatives. *Journal of Urban Technology*, *22*(1), 3–21. https://doi.org/10.1080/10630732.2014.942092

Alexander Litman, T., & Todd Litman Victoria, by. (2022). *Evaluating Transportation Equity Guidance for Incorporating Distributional Impacts in Transport Planning Evaluating Transportation Equity: Guidance for Incorporating Distributional Impacts in Transport Planning* (Vol. 92, Issue 4). https://vtpi.org/Litman_ITEJ_Equity_Apr2022.pdf.

Amsterdam Smart City. (2016). *Smart Light has been implemented at the Hoekenrodeplein in Amsterdam - Amsterdam Smart City*. https://amsterdamsmartcity.com/updates/news/smart-light-has-been-implemented-at-the-hoekenrodeplein-in-amsterdam

Banister, D. (2008). The sustainable mobility paradigm. *Transport Policy*, *15*(2), 73–80. https://doi.org/10.1016/j.tranpol.2007.10.005

Batty, M., Axhausen, K. W., Giannotti, F., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., Ouzounis, G., & Portugali, Y. (2012). Smart cities of the future. *The European Physical Journal Special Topics*, *214*(1), 481–518. https://doi.org/10.1140/epjst/e2012-01703-3

Bolobonov, D., Frolov, A., Borremans, A., & Schuur, P. (2021). Managing Public Transport Safety Using Digital Technologies. *Transportation Research Procedia*, *54*, 862–870. https://doi.org/https://doi.org/10.1016/j.trpro.2021.02.140

Caragliu, A., del Bo, C., & Nijkamp, P. (2011). Smart Cities in Europe. *Journal of Urban Technology*, *18*(2), 65–82. https://doi.org/10.1080/10630732.2011.601117

ClearRoad. (2024). *ClearRoad - Ayuda a tu ciudad a medir la congestión y gana premios*. https://bogota.clearroad.io/

Dai Junliang, G. X., & Shoushuai, D. (2010). Expansion of Urban Space and Land Use Control in the Process of Urbanization: An Overview. *Chinese Journal of Population Resources and Environment*, *8*(3), 73–82. https://doi.org/10.1080/10042857.2010.10684994

Daniel, S., & Doran, M.-A. (2013). geoSmartCity : geomatics contribution to the smart city. In *Proceedings of the 14th Annual International Conference on Digital Government Research* (pp. 65–71). https://doi.org/10.1145/2479724.2479738

Dr. Jean-Paul Rodrigue. (n.d.). *Urban Mobility | The Geography of Transport Systems*. Retrieved March 28, 2024, from https://transportgeography.org/contents/chapter8/urban-mobility/

Ehrenberg, Ronald G. (2004). *Why Universities Need Institutional Researchers More Than They Realize?*. https://core.ac.uk/download/5122099.pdf

O. V. Erokhina and A. V. Brega, "*Intelligent Transport Technologies in "Smart" Cities*" 2020 Systems of Signals Generating and Processing in the Field of on Board Communications, Moscow, Russia, 2020, pp. 1-5, doi: 10.1109/IEEECONF48371.2020.9078566.

Ewing, R., Bartholomew, K., Winkelman, S., Walters, J., & Chen, D. (2009). Growing cooler: The evidence on urban development and climate change. *Renewable Resources Journal*, *25*(4), 6–13.

Florida, R. (2017). *The New Urban Crisis : How Our Cities Are Increasing Inequality, Deepening Segregation, and Failing the Middle Class-and What We Can Do About It*. Basic Books.

Gehl, J. (2010). *Cities for people / Jan Gehl*. Island Press.

Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Milanović, N., & Meijers, E. (2007). *Smart cities - Ranking of European medium-sized cities*.

Halkos, G., & Gkampoura, E. C. (2021). Where do we stand on the 17 Sustainable Development Goals? An overview on progress. *Economic Analysis and Policy*, *70*, 94–122. https://doi.org/10.1016/j.eap.2021.02.001

Hollands, R. G. (2008). Will the real smart city please stand up? Intelligent, progressive or entrepreneurial? *City*, *12*(3), 303–320. https://doi.org/10.1080/13604810802479126

Ismagilova, E., Rana, N. P., Hughes, L., & Dwivedi, Y. K. (2022). Security, Privacy and Risks Within Smart Cities: Literature Review and Development of a Smart City Interaction Framework. *Information Systems Frontiers*, *24*(2), 393–414. https://doi.org/10.1007/s10796-020-10044-1

ITS International. (2015). *Port of Hamburg launches intelligent traffic light | ITS International*. https://www.itsinternational.com/its8/news/port-hamburg-launches-intelligent-traffic-light

Jesse Berst. (2014). *Hamburg, Germany's big vision: A smart city and a smart port | Smart Cities Council*. https://www.smartcitiescouncil.com/article/hamburg-germanys-big-vision-smart-city-and-smart-port

Joffe, H., & Yardley, L. (2004). Content and thematic analysis. In D. F. Marks & L. Yardley (Eds.), *Research methods for clinical and health psychology* (pp. 56-68). London: Sage.

Kitchin, R. (2014). The real-time city? Big data and smart urbanism. *GeoJournal*, *79*(1), 1–14.

Litman, T. A. (2023). *Evaluating Accessibility for Transport Planning Evaluating Accessibility for Transportation Planning*. www.vtpi.org

Loos, E., Sourbati, M., & Behrendt, F. (2020). The Role of Mobility Digital Ecosystems for Age-Friendly Urban Public Transport: A Narrative Literature Review. *International journal of environmental research and public health*, *17*(20), 7465. https://doi.org/10.3390/ijerph17207465

Mark Wallin. (2019). *Effects of Traffic Congestion in Urban Areas | Verizon Connect*. https://www.verizonconnect.com/resources/article/traffic-effects-urban-areas/

McKinsey & Company. (2019). *The year of future transportation: An interview with Seoul Mayor Park Wonsoon*. https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/the-year-of-future-transportation-an-interview-with-seoul-mayor-park-wonsoon

Natasha Singer. (2012). *I.B.M. Takes 'Smarter Cities' Concept to Rio de Janeiro - The New York Times*. https://www.nytimes.com/2012/03/04/business/ibm-takes-smarter-cities-concept-to-rio-de-janeiro.html

Neirotti, P., de Marco, A., Cagliano, A. C., Mangano, G., & Scorrano, F. (2014). Current trends in Smart City initiatives: Some stylised facts. *Cities*, *38*, 25–36. https://doi.org/10.1016/j.cities.2013.12.010

Ojo, A., Curry, E., Janowski, T., & Dzhusupova, Z. (2015). Designing Next Generation Smart City Initiatives - The SCID Framework. In *Public Administration and Information Technology*. https://doi.org/10.1007/978-3-319-03167-5_4

Schrank, D., Albert, L., Eisele, B., & Lomax, T. (2021). *Urban Mobility Report*.

Schwab, K. (2016). *The Fourth Industrial Revolution*. www.weforum.org

SmartCitiesWorld. (2022). *Smart Cities World - Policymaking - Barcelona progresses urban mobility plan*. https://www.smartcitiesworld.net/policymaking/barcelona-progresses-urban-mobility-plan

Tabane, E., Ngwira, S. M., & Zuva, T. (2016). Survey of smart city initiatives towards urbanization. In *2016 International Conference on Advances in Computing and Communication Engineering (ICACCE), Advances in Computing and Communication Engineering (ICACCE), 2016 International Conference on* (pp. 437–440). IEEE. https://doi.org/10.1109/ICACCE.2016.8073788

Trask, B. S. (2022). *Migration, Urbanization, and the Family Dimension Background paper prepared for the UNITED NATIONS Department of Economic and Social Affairs (UNDESA) Division for Inclusive Social Development, Focal Point on the Family*.

Teles Corrêa, I., Maki Omura, K., & da Paixão, G. M. (2023). Analysis of accessibility and perception of people with disabilities in vessels. *Brazilian Journal of Occupational Therapy / Cadernos Brasileiros de Terapia Ocupacional*, *31*, 1–20. https://doi.org/10.1590/2526-8910.ctoAO259033832

United Nations. (2017). *New Urban Agenda*. 3–48.

United Nations. (2015). *THE 17 GOALS | Sustainable Development*. https://sdgs.un.org/goals

United Nations. (2016). *The New Urban Agenda - Habitat III*. https://habitat3.org/the-new-urban-agenda/

United Nations. (2018). *68% of the world population projected to live in urban areas by 2050, says UN | UN DESA | United Nations Department of Economic and Social Affairs*. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

Velco Tech. (2020). *Urban mobility and safety: what progress has been made in recent years?* https://velco.tech/en/urban-mobility-safety/

Verhulsdonck, G., Weible, J. L., Helser, S., & Hajduk, N. (2023). Smart Cities, Playable Cities, and Cybersecurity: A Systematic Review. *International Journal of Human-Computer Interaction*, *39*(2), 378–390. https://doi.org/10.1080/10447318.2021.2012381

World Health Organization. (2018). *GLOBAL STATUS REPORT ON ROAD SAFETY 2018*.

World Highways. (2012). *New York unveils "Midtown in Motion" traffic management system | World Highways*. https://www.worldhighways.com/wh12/news/new-york-unveils-midtown-motion-traffic-management-system

Appendices

Appendix 1 – Interview Script (List of semi-structured questions)

Hello! Thank you for accepting my invite to participate in this interview. I want to thank you for both your availability and kindness. My name is Duarte Azevedo Fernandes, I am 24 years old and currently am attending the Master's Degree in Business Economics at Católica Porto Business School. For this purpose, I am writing my thesis about the characterization of the digital transition's impact on smart cities' urban mobility solutions. In order to properly address this topic I drew the following research question: "'How can the integration of digital advancements in smart cities' urban mobility systems enhance their efficiency?", consequently dividing the concept of "efficiency" in five different "blocks": travel time, user safety, accessibility, sustainability and cost-efficiency. Thus, in order to respond to these research objectives, I elaborated questions for each of these "blocks", to properly collect your perspectives and expectantly develop an answer to the research question.

This way, I will now ask you some questions, which you can refuse to answer, if they are out of your area of comfort or if they're not applicable at all.

2.1. Impact of Digital Advancements on Travel Time Reduction

- Can you describe how real-time traffic management systems have impacted urban mobility in terms of travel time reduction?
- How do route optimization algorithms specifically address the reduction of travel times in urban environments?

- Based on your experience, what are the most significant challenges and successes in implementing these technologies in this context?

2.2. Contribution of Digital Technologies to Enhancing User Safety

- Could you share examples of technologies that have been particularly effective at enhancing safety in urban mobility systems and highlight how they have actually improved it?
- What are the key factors for successfully integrating these safety-enhancing technologies into existing urban mobility systems?

2.3. Digital Solutions to Improve Accessibility in Urban Mobility

- Can you provide an example of a digital solution that has significantly improved mobility for a specific segment of society?
- How have digital platforms been used to improve accessibility for individuals with disabilities, the elderly, and low-income groups?
- What are the main obstacles to making urban mobility systems more accessible through digital innovations, and how can they be overcome?

2.4. Role of Digital Innovations in Promoting Sustainability

- In your view, which current and future digital innovations hold the most promise for improving sustainability in urban mobility systems, and how?
- How do digital car-sharing and bike-sharing platforms (or others you find significant) contribute to reducing the environmental impact of urban transportation?
- What technological solutions have been implemented to promote sustainability in smart cities, and what outcomes have been observed?

2.5. Cost Efficiency of Digital Technologies in Urban Mobility

- Can you discuss the long-term financial impacts of integrating digital technologies into urban transportation systems?
- How do the initial costs of implementing digital advancements compare with the economic savings achieved over time?
- Are there specific examples, whether you have direct or indirect knowledge of them, where the integration of new technology has led to significant cost savings in urban mobility?

Appendix 2 – Analysis of the Interviews

Interviewee's Answer / Question	Int.1	Int.2
Current Professional Activity	Architect - Urban Planner - Mobility Expert	Architect - Urban Planner
Category Number One: Impact of Digital Advancements on Travel Time Reduction		
•Can you describe how real-time traffic management systems have impacted urban mobility in terms of travel time reduction?	*"Some aspects have been positive, because if we have a diverse urban network and we spread it out, we can make better use of it"*	*"Digital systems cannot replace a good transportation network design"*
•How do route optimization algorithms specifically address the reduction of travel times in urban environments?	DNA	DNA
•Based on your experience, what are the most significant challenges and successes in implementing these technologies in this context?	*"So technology in itself can be smart, but , for example, rethinking the way we use our public space and making more room for people, for bicycles, creating less congested streets so that public transport can flow, is very important"*	*"There needs to be a significantly good network, design and planning before"*
Category Number Two: Impact of Digital Solutions on Urban Mobility's Safety		
•Could you share examples of technologies that have been particularly effective at enhancing safety in urban mobility systems and highlight how they have actually improved it?	*"I can give the example of both electric bicycles and scooters, which have been developing systems to increase its safety"*	*"Certain cameras that have been placed [in Barcelona] in strategic spots(...)"*
•What are the key factors for successfully integrating these safety-enhancing technologies into existing urban mobility systems?	DNA	DNA
Category Number Three: Usage of Digital Solutions to Improve Accessibility in Urban Mobility		
•Can you provide an example of a digital solution that has significantly improved accessibility in mobility systems for a specific segment of society?	*"The use of bike-sharing platforms is facilitated and helps young people travel faster than they previously did"*	DNA
•How have digital platforms been used to improve accessibility for individuals with disabilities, the elderly, and low-income groups?	*"Real-time bus information solutions are also helping the elderly, even though they are not yet very spread and utilized, and must be developed taking into account their digital literacy"*	DNA
•What are the main obstacles to making urban mobility systems more accessible through digital innovations, and how can they be overcome?	*"Systems have to be spread so they can be used (...) people have to be aware of them (...)"*	DNA
Category Number Four: Role of Digital Innovations in Promoting Sustainability		
•In your view, which current and future digital innovations hold the most promise for improving sustainability in urban mobility systems, and how?	*"I believe that the system has to be heavily related with sharing, essentially"*	*"Safety is very important, because [when traveling by foot] if the path is dangerous, they resort back to their vehicles (...) and technology could also aid here"*
•How do digital car-sharing and bike-sharing platforms (or others you find significant) contribute to reducing the environmental impact of urban transportation?	*"They contribute if they can easily be found (...) however, they have to be paired and complemented with political courage and measures(...)"*	*"The usage that is currently promoted is very dangerous (...) electric scooters are dangerous (...) even though they can contribute"*
•What technological solutions have been implemented to promote sustainability in smart cities, and what outcomes have been observed?	DNA	*"Sustainability is found when public transports are optimized and widely adopted"*
Category Number Five: Cost Efficiency of Digital Technologies in Urban Mobility		
•Can you discuss the long-term financial impacts of integrating digital technologies into urban transportation systems?	*"If we transform the city to one where people choose "sharing" and public means of transport, we'll have a city that is much cheaper for everyone, especially the families"*	DNA
•How do the initial costs of implementing digital advancements compare with the economic savings achieved over time?	*"The savings are not only measured financially (...) health savings are particularly relevant"*	DNA
•Are there specific examples, whether you have direct or indirect knowledge of them, where the integration of new technology has led to significant cost savings in urban mobility?	DNA	DNA

DNA : Did not answer/Did not have information.

Question \ Interviewee's Answer	Int.3	Int.4
Current Professional Activity	Teacher - Engineering; Owner of a Transportation Microenterprise	Smart Cities Specialist
Category Number One: Impact of Digital Advancements on Travel Time Reduction		
•Can you describe how real-time traffic management systems have impacted urban mobility in terms of travel time reduction?	*"These systems can help (…) reducing travel times and even identify obstacles along the way"*	*"There are situations in which it has worked (…) Amsterdam is a great example"*
•How do route optimization algorithms specifically address the reduction of travel times in urban environments?	*"I don't think that that is the great driver. I believe that information and reliability are the key factors"*	*"We can inform these algorithms that a certain event is going to happen in a certain area, during the coming day (…) it has been working out well"*
•Based on your experience, what are the most significant challenges and successes in implementing these technologies in this context?	*"I believe the great challenge is the information. People need to have more information about where public transports are (…)"*	*"The most important thing is the quality of the data"*
Category Number Two: Impact of Digital Solutions on Urban Mobility's Safety		
•Could you share examples of technologies that have been particularly effective at enhancing safety in urban mobility systems and highlight how they have actually improved it?	*"Technology that allows you to share your current location with someone who is waiting for you"*	*"Cameras that are not recording but gathering data (…) of potentially dangerous moments"*
•What are the key factors for successfully integrating these safety-enhancing technologies into existing urban mobility systems?	*"Integrating video in some of the current solutions would be important"*	*"Data [and the quality of the data]"*
Category Number Three: Usage of Digital Solutions to Improve Accessibility in Urban Mobility		
•Can you provide an example of a digital solution that has significantly improved accessibility in mobility systems for a specific segment of society?	*"So the real-time system that allows a person to know the positioning of buses, (…) is also great because (…) it removes all the uncertainty one has when using this transport system"*	*"Electric bikes have been a good example of success"*
•How have digital platforms been used to improve accessibility for individuals with disabilities, the elderly, and low-income groups?	*"Real-time bus information systems are very important (…)"*	DNA
•What are the main obstacles to making urban mobility systems more accessible through digital innovations, and how can they be overcome?	*"(…) for me, it's the information and the quality of the information that is even more important than management itself"*	*"We can't grab what's physical-related and place it in the digital world"*
Category Number Four: Role of Digital Innovations in Promoting Sustainability		
•In your view, which current and future digital innovations hold the most promise for improving sustainability in urban mobility systems, and how?	*"I believe that technology, sometimes, makes it easier for people to have access to polluting means of transport (…) however, if we utilize a public transportation system, we're being more sustainable"*	*"I believe it will have a lot to do with soft mobility"*
•How do digital car-sharing and bike-sharing platforms (or others you find significant) contribute to reducing the environmental impact of urban transportation?	*"sharing has this great advantage that we are providing services without impact (…) because the service is already there"*	*"Electric bikes have been a good example of success (…) however, we need to understand what was the transportation that someone was using before moving to these solutions"*
•What technological solutions have been implemented to promote sustainability in smart cities, and what outcomes have been observed?	DNA	DNA
Category Number Five: Cost Efficiency of Digital Technologies in Urban Mobility		
•Can you discuss the long-term financial impacts of integrating digital technologies into urban transportation systems?	*"In general, mobility systems, these technologies pay for themselves. What I notice, though, is that sometimes those who benefit are not those who pay, and therefore they are not implemented because there is no match between who pays and who benefits"*	*"If it brings benefits to the citizens, the investment is worth it"*
•How do the initial costs of implementing digital advancements compare with the economic savings achieved over time?	*"In general, mobility systems, these technologies pay for themselves. What I notice, though, is that sometimes those who benefit are not those who pay, and therefore they are not implemented because there is no match between who pays and who benefits"*	DNA
•Are there specific examples, whether you have direct or indirect knowledge of them, where the integration of new technology has led to significant cost savings in urban mobility?	*"We have an example where the integration was very simple and yielded great results [that had to do with information]"*	*"Yes, the traffic management system implemented a few years ago in Lisbon, helped in the optimization of the city"*

DNA: Did not answer/Did not have information.

Question \ Interviewee's Answer	Int.5	Int.6
Current Professional Activity	Board Member - Transportation Services Company	Director - Company Focused on Engineering and Product Development - Smart and Sustainable Living
Category Number One: Impact of Digital Advancements on Travel Time Reduction		
•Can you describe how real-time traffic management systems have impacted urban mobility in terms of travel time reduction?	*"The fact that there is real-time information in terms of traffic lights allows for more precise traffic management"*	*"Optimizing the whole procedural logic, looking at the design of the network, at a multimodal approach, very much based on the complementarity of means, is what will then allow us to apply technology"*
•How do route optimization algorithms specifically address the reduction of travel times in urban environments?	*"They still don't answer this very directly (…) they are still very restricted to the old traffic systems"*	*"I believe that, in general, it helps. Especially in places we don't know yet. It will depend, however, on the number of users of that platform"*
•Based on your experience, what are the most significant challenges and successes in implementing these technologies in this context?	*"In terms of public transportation, there are some constraints related to data privacy (…) without available information, I can't choose the travel solution that best fits me"*	*"A physical and digital structure of sensors is important (…) urban sensor networks, by digital I mean apps and the feed (…) the issue of connectivity, capacity, bandwidth, enabling ubiquity and then all the intelligence associated with the information collected by devices that people carry (…)"*
Category Number Two: Impact of Digital Solutions on Urban Mobility's Safety		
•Could you share examples of technologies that have been particularly effective at enhancing safety in urban mobility systems and highlight how they have actually improved it?	*"Limiting the speed of electric scooters in certain areas"*	*There are interesting solutions for passive security,video surveillance systems that we have in many solutions, whether in vehicles, stations, or collection points (…) the apps themselves having emergency buttons to activate whenever necessary [is also good]."*
•What are the key factors for successfully integrating these safety-enhancing technologies into existing urban mobility systems?	*"Open data is crucial"*	*"Data privacy [is a challenge]"; "The active and passive sensor component is extremely important"*
Category Number Three: Usage of Digital Solutions to Improve Accessibility in Urban Mobility		
•Can you provide an example of a digital solution that has significantly improved accessibility in mobility systems for a specific segment of society?	*"A system implemented in the subway that allows blind people to receive directions via telephone"*	*"Other situations where technology can help is clearly in school transport, where we can create specific solutions"*
•How have digital platforms been used to improve accessibility for individuals with disabilities, the elderly, and low-income groups?	*"A system implemented in the subway that allows blind people to receive directions via telephone"*	*"Tailor-made transport is often a solution that solves the problem of isolation for many people, particularly older people"*
•What are the main obstacles to making urban mobility systems more accessible through digital innovations, and how can they be overcome?	*"Sometimes the infrastructure is the problem"*	*"We can't develop solutions that aren't fully inclusive"*
Category Number Four: Role of Digital Innovations in Promoting Sustainability		
•In your view, which current and future digital innovations hold the most promise for improving sustainability in urban mobility systems, and how?	*"It's hard to answer (…) reducing the consumptions and waste of the general system, already helps making it more sustainable"*	*"Sistemas de valorização de comportamentos [ecológicos] positivos [são um exemplo]"*
•How do digital car-sharing and bike-sharing platforms (or others you find significant) contribute to reducing the environmental impact of urban transportation?	*"They contribute if they're used in a rational way (…) if we're replacing walking with these solutions, it does not contribute"*	*"These solutions can work to fulfil a certain purpose, but in order to gain scale they have to be integrated into an urban mobility system and also favour complementarity"*
•What technological solutions have been implemented to promote sustainability in smart cities, and what outcomes have been observed?	DNA	*"We are working on developing a new concept aimed at creating mobility communities to leverage their impact and sharing platforms'"*
Category Number Five: Cost Efficiency of Digital Technologies in Urban Mobility		
•Can you discuss the long-term financial impacts of integrating digital technologies into urban transportation systems?	DNA	*"Yes, there's one (…) fleet management"*
•How do the initial costs of implementing digital advancements compare with the economic savings achieved over time?	DNA	DNA
•Are there specific examples, whether you have direct or indirect knowledge of them, where the integration of new technology has led to significant cost savings in urban mobility?	DNA	*"Evolving towards mobility-as-a-service solutions that, provided they are properly regulated, legislated and governed, allow local and national governments to create optimized mobility functions in which they only pay for the actual service provided"*

***DNA**: Did not answer/Did not have information.*

Interviewee's Answer / Question	Int.7	Int.8
Current Professional Activity	ICT & Smart Cities Specialist - Multinational Enterprise	CEO - SMC - Engineering & Technology
Category Number One: Impact of Digital Advancements on Travel Time Reduction		
•Can you describe how real-time traffic management systems have impacted urban mobility in terms of travel time reduction?	*"AI, Machine Learning and other technologies impact this"*	*"I can tell you that the systems, therefore, the digital transition applied to traffic, through machine learning, involves predictive systems and that will surely reduce the time (...)"*
•How do route optimization algorithms specifically address the reduction of travel times in urban environments?	*"They address this topic, especially in the cases of business that involve fleet management (...) allows to draw optimized routes"*	DNA
•Based on your experience, what are the most significant challenges and successes in implementing these technologies in this context?	*"I believe that the resistance to change is a big topic"*	*"It's a bit of a lack of knowledge on the part of those who ultimately receive these (...) innovations and then a certain concern or, I would say, unbridled ambition about what the system can do"*
Category Number Two: Impact of Digital Solutions on Urban Mobility's Safety		
•Could you share examples of technologies that have been particularly effective at enhancing safety in urban mobility systems and highlight how they have actually improved it?	*"Technology regarding traffic lighting and videoanalytics"*	*"On highways, all systems, when they use, for example, ice warnings on the road, accidents, prior knowledge of accidents, all this will greatly reduce or increase safety"*
•What are the key factors for successfully integrating these safety-enhancing technologies into existing urban mobility systems?	*"A good network of infrastructures is very important (...) and creating awareness"*	DNA
Category Number Three: Usage of Digital Solutions to Improve Accessibility in Urban Mobility		
•Can you provide an example of a digital solution that has significantly improved accessibility in mobility systems for a specific segment of society?	*"Yes, the electric scooters offer a mobility solution (...) and other soft mobility solutions"*	*"The concept of adaptive lighting greatly improves the quality of lighting, reduces the ecological footprint, cuts costs and therefore (...) improves traffic safety"*
•How have digital platforms been used to improve accessibility for individuals with disabilities, the elderly, and low-income groups?	*"Platforms that can bring knowledge and awareness to older people"*	DNA
•What are the main obstacles to making urban mobility systems more accessible through digital innovations, and how can they be overcome?	*"I believe that the investment is often na obstacle"*	*"[One of the main obstacles to making these systems more accessible with digital innovations would perhaps be to improve the infrastructure underneath] Yes, physical structure, first of all, perhaps"*
Category Number Four: Role of Digital Innovations in Promoting Sustainability		
•In your view, which current and future digital innovations hold the most promise for improving sustainability in urban mobility systems, and how?	*"More and more intelligent waste management systems, for example"; "Initially I believe that developments regarding fuels will be the key aspects"*	*"No, I think the great innovation would be (...) to place sensors in a whole region or a whole city (...) From here, the use of various sensors, algorithms, which would surely lead to great gains. As long as this data is processed properly"*
•How do digital car-sharing and bike-sharing platforms (or others you find significant) contribute to reducing the environmental impact of urban transportation?	*"They contribute if there are actually less cars circulating"*	DNA
•What technological solutions have been implemented to promote sustainability in smart cities, and what outcomes have been observed?	*"Water management systems, energy management systems in buildings and other smart energy technologies"*	*"The concept of adaptive lighting greatly improves the quality of lighting, reduces the ecological footprint, cuts costs and therefore (...) improves traffic safety"*
Category Number Five: Cost Efficiency of Digital Technologies in Urban Mobility		
•Can you discuss the long-term financial impacts of integrating digital technologies into urban transportation systems?	*"We have not only fleet management in garbage trucks, but we also have sensors in some places, in the garbage bins, which, together with fleet management, allow us to say, well, I have here 100 garbage bins, half are at 50%, 25% are at 90% and the other 25% are still at 10% (...) this allows for [cost] optimization"*	*"Waste management has had a tremendous impact (...)"*
•How do the initial costs of implementing digital advancements compare with the economic savings achieved over time?	*"In Cascais, there has been a good return on the investment of this trash truck fleet management system (...) I believe it was in 7/8 months"*	DNA
•Are there specific examples, whether you have direct or indirect knowledge of them, where the integration of new technology has led to significant cost savings in urban mobility?	*"In Cascais, there has been a good return on the investment of this trash truck fleet management system (...) I believe it was in 7/8 months"*	DNA

DNA : Did not answer/Did not have information.

Question \ Interviewee's Answer	Int.9	Int.10
Current Professional Activity	CEO - Startup - Engineering & Technology	CEO - Microenterprise - Engineering & Architecture
Category Number One: Impact of Digital Advancements on Travel Time Reduction		
•Can you describe how real-time traffic management systems have impacted urban mobility in terms of travel time reduction?	DNA	*"The increased use of satellites (data collection and real-time monitoring) and applications has played a crucial role in improving traffic management in large urban centers"*
•How do route optimization algorithms specifically address the reduction of travel times in urban environments?	DNA	*"I believe that As technology evolves with AI, we can expect even more innovative solutions to improve urban mobility"*
•Based on your experience, what are the most significant challenges and successes in implementing these technologies in this context?	DNA	DNA
Category Number Two: Impact of Digital Solutions on Urban Mobility's Safety		
•Could you share examples of technologies that have been particularly effective at enhancing safety in urban mobility systems and highlight how they have actually improved it?	*"Yes, our flood protection system that acts very early on the process"*	*"Greater (…) public lampposts [on the roads] optimized with better performing sensors in relation to weather and environment, equipped with cameras, motion detectors, digital indications using AI"*
•What are the key factors for successfully integrating these safety-enhancing technologies into existing urban mobility systems?	*"So I think there should be a clear mapping of the underlying risks within the cities, that is, there should be knowledge of which points are going to have the greatest impact (…)"*	*"The willingness to test, and optimize"*
Category Number Three: Usage of Digital Solutions to Improve Accessibility in Urban Mobility		
•Can you provide an example of a digital solution that has significantly improved accessibility in mobility systems for a specific segment of society?	*"Audible signals at traffic lights to help blind people cross and know when it's green and when it's red"*	*"Solutions that that provide guidance for pedestrians, including wheelchair-accessible routes and information about obstacles in the way"*
•How have digital platforms been used to improve accessibility for individuals with disabilities, the elderly, and low-income groups?	*"Audible signals at traffic lights to help blind people cross and know when it's green and when it's red"*	*"Solutions that that provide guidance for pedestrians, including wheelchair-accessible routes and information about obstacles in the way"*
•What are the main obstacles to making urban mobility systems more accessible through digital innovations, and how can they be overcome?	DNA	DNA
Category Number Four: Role of Digital Innovations in Promoting Sustainability		
•In your view, which current and future digital innovations hold the most promise for improving sustainability in urban mobility systems, and how?	*"Technologies related to extending the life of electric car batteries, electric buses, perhaps hydrogen fuel technologies"*	*"The development of digital technologies that can be used to improve the efficiency of public transport and promote sustainable mobility"*
•How do digital car-sharing and bike-sharing platforms (or others you find significant) contribute to reducing the environmental impact of urban transportation?	DNA	*"I believe that they can, in fact, help, but only if they remove cars from the road"*
•What technological solutions have been implemented to promote sustainability in smart cities, and what outcomes have been observed?	DNA	*"Smart lighting systems, with sensors, allow for a reduction in energy consumption (…)"*
Category Number Five: Cost Efficiency of Digital Technologies in Urban Mobility		
•Can you discuss the long-term financial impacts of integrating digital technologies into urban transportation systems?	DNA	*"Smart lighting systems, with sensors, allow for a reduction in energy consumption, which also helps reducing costs"*
•How do the initial costs of implementing digital advancements compare with the economic savings achieved over time?	DNA	DNA
•Are there specific examples, whether you have direct or indirect knowledge of them, where the integration of new technology has led to significant cost savings in urban mobility?	DNA	DNA

DNA : Did not answer/Did not have information.