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Deliverable D3.1 – A: Requirements and Specification of the ODTF

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Glossary of terms and abbreviations

Abbreviation / Term	Description
AR	**Augmented Reality**
ARC	**Advanced Research Centre**
BIM	**Building Information Model**
BMS	**Building Management System**
DT	**Digital Twin**
ETSI	**European Telecommunications Standards Institute**
ICT	**Information and Communications Technology**
IoT	**Internet of Things**
IUDX	**India Urban Data Exchange**
JMS	**James McCune Smith Learning Hub**
MR	**Mixed Reality**
OASC	**Open & Agile Smart Cities**
ODTF	**Open Digital Twin Framework**
R&I	**Research and Innovation**
STF	**Smart Territory Framework**
VR	**Virtual Reality**

Executive Summary

METACITIES aims to develop an Open Digital Twin framework (ODTF) that will facilitate the co-development of complementary future city domains along with their corresponding Digital Twins (DTs). This deliverable (D3.1) presents the first version of the results of Task 3.1 and Task 3.2, focusing mainly on the elicitation of the socio-techno-economic requirements that will guide all the Research activities related to the specification of the Open Digital Twin Framework for the smart cities ecosystem. Its main purpose is to identify the functional and non-functional requirements and to propose a first version of the generic Digital Twin architecture. The proposal is a high-level architecture and depicts the initial blocks and requirements for the METACITIES digital architecture that can support the specific DTs and Metaverses that can lie at the core of the R&I Strategies. Layers are cleanly separated, with each serving clear purposes: Device layer, Edge Computing layer, Data Acquisition layer, Storage layer, Service layer, and Application layer. Additionally, a generic overview of all METACITIES network elements and technologies that will be exploited, is presented.

The work presented in this deliverable was carried out in four main steps. First, an extensive literature review has been conducted aiming to define DT and Metaverse, to identify characteristic DT and Metaverse solutions with a focus on their features and positive outcomes, and present architecture solutions for the available DT platforms in the state of the art. Then, taking into account the literature review, three use cases of all innovation ecosystems, Smart Mobility, Green City and Urban Planning, are analysed, introducing the input data sources and presenting high-level technical solutions for them. In the third step, a socio-techno-economic requirements analysis was elicited through questionnaires distributed to potential end-users and stakeholders. Specifically, a unique questionnaire was designed for each use-case to capture a range of perspectives, and all questionnaires were distributed to all stakeholders in the quadruple helix - industry, government, academia, and civil society - to gain diverse perspectives and insights. The questionnaire responses were analysed to identify commonalities and prioritise the most important end-users' needs. Finally, in the last step, results from the literature review and questionnaire's analysis, led to the functional and non-functional requirements for smart mobility, urban planning, and energy, considering the priorities and needs of each pilot, as well as to the first version of the proposed high-level architecture of METACITIES Digital Twin.

The main conclusions can be depicted in the identified functional and non-functional requirements. Regarding the Smart Mobility, users wish real-time information and notifications on parking availability, ability to pay using different payment methods, automatically to identify valid people with disabilities, identify and track emergency incidents, monitor traffic volume, etc. Regarding the Urban Planning, users wish real-time data such as traffic, weather, and air quality, access to historical data and future projections about the city's infrastructure and energy performance, virtual and/or augmented reality view of the city. Regarding the Energy and Green City, users also wish real-time data for energy consumption, CO_2 levels in interior spaces, consumption of electricity, water and heat, level of lighting, access to data for both public and residential buildings, and compatibility with other planning tools. Similar non-functional requirements emerged for all use cases, like privacy-preserving mechanisms to protect user's personal and financial data, AI algorithms for prediction, user-friendly interfaces and mobile applications, utilization of IoT sensors for data collection, and accessible and inclusive platforms for all.

The main purpose of this deliverable is to identify the functional and non-functional requirements and to propose a first version of the generic Digital Twin architecture. The proposal is a high-level architecture and depicts the initial blocks and requirements for the METACITIES digital architecture that can support the specific DTs and Metaverses that can lie at the core of the R&I Strategies. Layers are cleanly separated, with each serving clear purposes: Device layer, Edge Computing layer, Data

Acquisition layer, Storage layer, Service layer, and Application layer. Additionally, a generic overview of all METACITIES network elements and technologies that will be exploited, is presented.

1 Introduction

Three place-based innovation ecosystems in Cyprus, Greece and Bulgaria are joining forces to create an Excellence Hub for future cities and regions in South East Europe (SEE). The METACITIES Hub of Excellence is a sustainable network that provides a common platform for collaboration, cross-fertilisation and sharing of best practices across borders, sectors and disciplines in the production, dissemination and use of knowledge. The network's activity is based on a common R&I strategy and a nexus of cross-sectoral links between sectors, joint research, innovation and outreach activities, as well as business modelling and sustainability plans. The collaboration aims to benefit citizens, stakeholders, regional ecosystems and the entire SEE region.

Digital Twins (DT) of future cities/regions provide an accurate and reliable reference that seamlessly integrate the physical, digital and human worlds and allow stakeholders to assess the impact of changes before investments and implementations are made. METACITIES aim to develop an Open Digital Twin framework (ODTF) that will facilitate the co-development of complementary future city domains along with their corresponding DTs.

This document presents the first version of the socio-economic requirements and technical specifications of the ODTF. The socio-techno-economic requirements were elicited through questionnaires distributed to potential end-users and stakeholders. Unique questionnaires were designed for each one of the eight use-cases to capture a range of perspectives, including those of end-users, stakeholders, and experts in the fields of urban planning, management, and technology. The responses were analyzed to identify commonalities and prioritize the most important end-users' needs. In a second step, the requirements were translated into functional and non-functional specifications to guide the development and design of the ODTF.

1.1 Mapping METACITIES outputs

This section presents the METACITIES Grand Agreement (GA) commitments, as extracted from the formal deliverable and task description, in respect to their outputs and work to be performed. The purpose is to aid the reviewer in finding the specific sections of the document where the respective tasks' requirements are addressed but also to guide the author through and serve as a check list to address everything that is needed to be addressed.

Table 1: Adherence to METACITIES GA Deliverable & Tasks Descriptions

METACITIES GA Component Title	METACITIES GA Component Outline	Respective Document Chapter(s)	Justification
TASKS			
Task 3.1 Elicitation of socio-techno-economic requirements	This task will capture the functional requirements and end-user needs from the use case partners, that will guide all research activities related to the specifications of the ODTF for the smart cities' ecosystem. Requirements' definition will involve the documentation, analysis and translation of end-users needs into technical specifications considering not only the technological point of view but also the user-centric social and economic dimension. All use case partners will provide functional requirements, which will be analysed by the technological partners. The actors responsible for the data collection will also be assigned, including the definition of industry grade data collection tools and the on-line data repository.	Chapter 5 and 6	Chapter 6 presents the results of 8 questionnaires tailored for each case study that were prepared to capture the socio-techno-economic requirements and end-user needs. The survey targeted all Quadruple Helix actors. Subsequently in Chapter 7, the survey results were translated into functional and non-functional requirements to guide all research activities related to the development of the Open Digital Twin Framework.
Task 3.2 Specification of the Open Digital Twin Framework	This task will provide the specification of the ODTF, which will be used to create, maintain, and manage DT and Metaverses for future smart cities. Specifically, this task will translate the requirements elicited in Task 3.1 into functional and non-functional specification and describe a reference software architecture for smart city operation that can be used to build domain specific DT enabled by the ICT infrastructures of the smart city. It will highlight the common functions that a smart city DT should implement together with the intelligent data model. Emphasis will be given on the digital model functions and interfaces.	Chapter 7 and 8	Chapter 7 presents the functional and non-functional requirements that derived from the questionnaires and the literature review. Chapter 8 provides a high-level digital infrastructure architecture that covers the common functions of a smart city DT.
DELIVERABLE			

Deliverable D3.1 – A: Requirements and Specification of the ODTF: Requirements and Specification of the Open Digital Twin Framework. Initial version of the socio-economic requirements and technical specification of the open digital twin framework.

1.2 Deliverable Overview and Report Structure

The Deliverable 'D3.1 – A: Requirements and Specification of the ODTF' of the METACITIES project is of significant importance since it provides the first version of the socio-economic requirements and technical specifications of the ODTF. The socio-techno-economic requirements were elicited through questionnaires distributed to potential end-users and stakeholders. In a second step, the requirements were translated into functional and non-functional specifications to guide the development and design of the ODTF. A first version of the proposed architecture of METACITIES Digital Twin is also provided.

Based on the objectives and work carried out under tasks T3.1 and T3.2 this document starts with the Executive Summary followed by the introduction of the document in Chapter 1. Chapter 2 presents basic information for Digital Twins and Metaverse. An extensive literature review has been conducted in Chapter 3, as it presents the DT solutions that have already been developed and the features that are applicable to the METACITIES proposed solution. Chapter 4 provides a description of the available DT platforms as well as architecture solutions for each domain. Chapter 5 introduces the input data sources and a high technical solution for the use cases of all innovation ecosystems. Chapter 6 presents the results of 8 questionnaires tailored for each case study that were prepared to capture the socio-techno-economic requirements and end-user needs. The survey targeted all Quadruple Helix actors. Subsequently in Chapter 7, the survey results were translated into functional and non-functional requirements to guide all research activities related to the development of the ODTF. In Chapter 8 a first version of the proposed architecture of METACITIES Digital Twin is provided.

2 Background of Digital Twins and Metaverse Solutions in Smart Cities

Digital twins are part of Gartner's top 12 strategic technology trends for 2022 [1], as part of autonomic systems, and Metaverse is one of the Gartner's top 10 strategic technology trends for 2023 [2] It is mentioned that *"By 2027, over 40% of large organizations worldwide will be using a combination of Web3, spatial computing and digital twins in metaverse-based projects aimed at increasing revenue."* [2]. In 2022, the World Economic Forum has published an insight report on the framework and global practices for Digital Twin Cities [3] and the National League of Cities has published a report on Cities and the Metaverse [4].Both are highlighting that the digital twins have become a crucial component of smart cities, enabling the creation of virtual replicas of physical assets, systems, and processes and that the concept of the metaverse may transform the way we interact with smart cities creating a seamless bridge between the physical and digital worlds.

2.1 Digital Twin Definition

In 2002, the concept of the digital twin was depicted in the Mirrored Spaces Model [5] as a set of digital models constructed in the virtual space to interact with physical entities and fully describe the trajectory of physical entities throughout their life cycle. Later, a "digital twin" [6] was defined as the integration of multidisciplinary and multiscale simulation processes by making full use of physical models, sensors, operational history and other data. The digital twin acts as a mirror image of the physical product in virtual space and reflects the full life cycle of the physical entity.

The concept of a "digital twin city" [7] was introduced in the planning and construction of smart cities. Based on the information technology systems of digital identification, automated perception, networked connection, inclusive computing, intelligent control and platform services, a digital city matching the physical city is recreated in the digital space, with holographic simulation, dynamic monitoring, real-time diagnosis and accurate prediction of the state of the physical city entity in the real environment. This helps promote the digitalization and virtualization of all elements of the city, a real-time visualization of the entire metropolis, and intelligent and collaborative urban operation and management. As a result, the physical and virtual cities can be engaged in synergistic interaction and parallel operations. The concept of "smart city digital twins"[8] was proposed, from the perspective of an urban platform, as an intelligent, internet of things (IoT)-enabled, data-rich urban virtual platform that can be used to replicate and simulate changes that occur in real cities in order to improve the resilience, sustainability and liveability of cities.

2.1.1 The importance of Digital Twins in Smart Cities

Since 2019, the concept of a digital twin city has been widely promoted and regarded as a new application model that utilizes real-time data, Internet of Things (IoT) sensors, integrates data from various sources, provides real-time insights, advanced analytics to monitor, facilitates predictive analysis, and supports decision-making for urban planning and management. Following we present how digital twins can support smart cities.

- **Integration of IoT and Big Data:** Digital twins rely on IoT sensors embedded within urban infrastructure to collect data on energy consumption, traffic patterns, air quality, waste management, and more. This data is processed and analyzed using big data techniques to generate actionable insights for improving urban services, sustainability, and resource management.

- **Real-Time Monitoring and Predictive Analysis:** Digital twins enable real-time monitoring of physical assets and systems, providing a comprehensive view of their operational status. By analyzing historical and real-time data, these virtual replicas can also forecast future conditions, allowing proactive decision-making to mitigate issues and optimize resource allocation.
- **Urban Planning and Design:** Digital twins help urban planners and architects simulate the impact of new infrastructure projects or policy changes before implementation. By creating virtual replicas of proposed developments, city planners can evaluate factors such as traffic flow, energy consumption, and environmental impact, optimizing designs and reducing costly revisions.
- **Improved Operational Efficiency:** Digital twins optimize the operational efficiency of smart cities by enabling predictive maintenance. Continuously monitoring and analyzing real-time data from sensors can predict potential failures or performance issues predicted, allowing maintenance teams to address problems proactively and minimize downtime.
- **Citizen Engagement and Participation:** Digital twins foster citizen engagement by providing an interactive platform for residents to access and contribute data. Citizens can report issues, provide feedback, and access real-time information on services like transportation, waste management, and public safety, enhancing transparency and collaboration between municipalities and residents.
- **Resilience and Emergency Response:** Digital twins play a vital role in enhancing the resilience of smart cities. By simulating various scenarios and emergency situations, such as natural disasters or terrorist attacks, city authorities can better understand potential impacts, optimize emergency response plans, and allocate resources effectively.
- **Data Security and Privacy:** As digital twins rely on vast amounts of sensitive data, ensuring data security and privacy is paramount. Advanced encryption, authentication mechanisms, and data anonymization techniques are employed to protect citizen data and prevent unauthorized access.
- **Integration with Emerging Technologies:** Digital twins are increasingly integrated with emerging technologies such as artificial intelligence (AI), machine learning (ML), and augmented reality (AR). AI and ML algorithms enhance data analysis and pattern recognition capabilities, while AR provides immersive visualizations and overlays to aid decision-making and urban planning.
- **Interoperability and Standards:** To enable seamless integration and exchange of data between different digital twins and urban systems, the development of interoperable standards is crucial. Organizations and industry consortia are working towards establishing open standards and frameworks to ensure compatibility and promote collaboration.

2.1.2 Digital Twins Architecture

According to [3], developing a digital twin city requires nine elements, representing a “4+5” framework (see Figure 1). The “4” refers to the four core elements, which are: 1) infrastructure; 2) data resources; 3) platform capacity; and 4) application scenarios. These elements provide the internal power and digital base for the digital twin city. The “5” in the framework comprises the five major external supporting elements of digital twin cities. These are: 1) strategy and mechanisms; 2) stakeholders; 3) funding and business models; 4) standards and evaluation; and 5) cybersecurity.

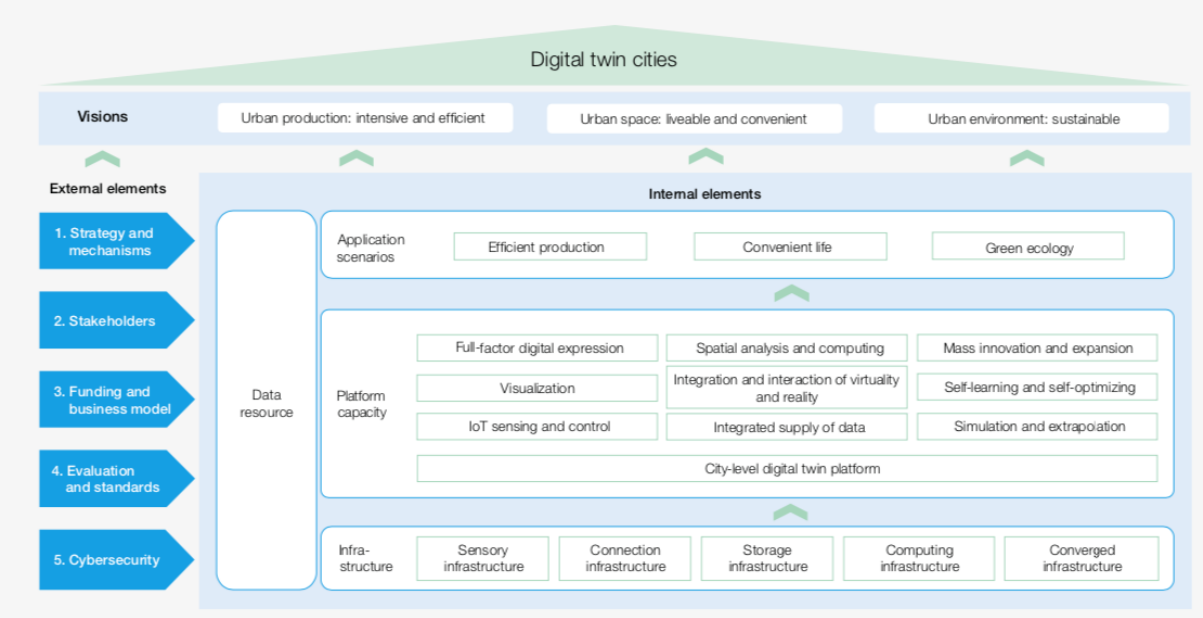

FIGURE 1: ELEMENT VIEW OF THE DIGITAL TWIN CITY (SOURCE: CAICT [3])

From an abstracted view a smart city digital twin relies on a number of layers of data (Figure 2) that build on top of each other, layering in information about the terrain, buildings, infrastructure, mobility, and IoT devices [9]. The digital twin uses the data generated in the virtual smart city layer to perform additional simulations; this information is fed back through the layers of the model, where it can be implemented in the physical world.

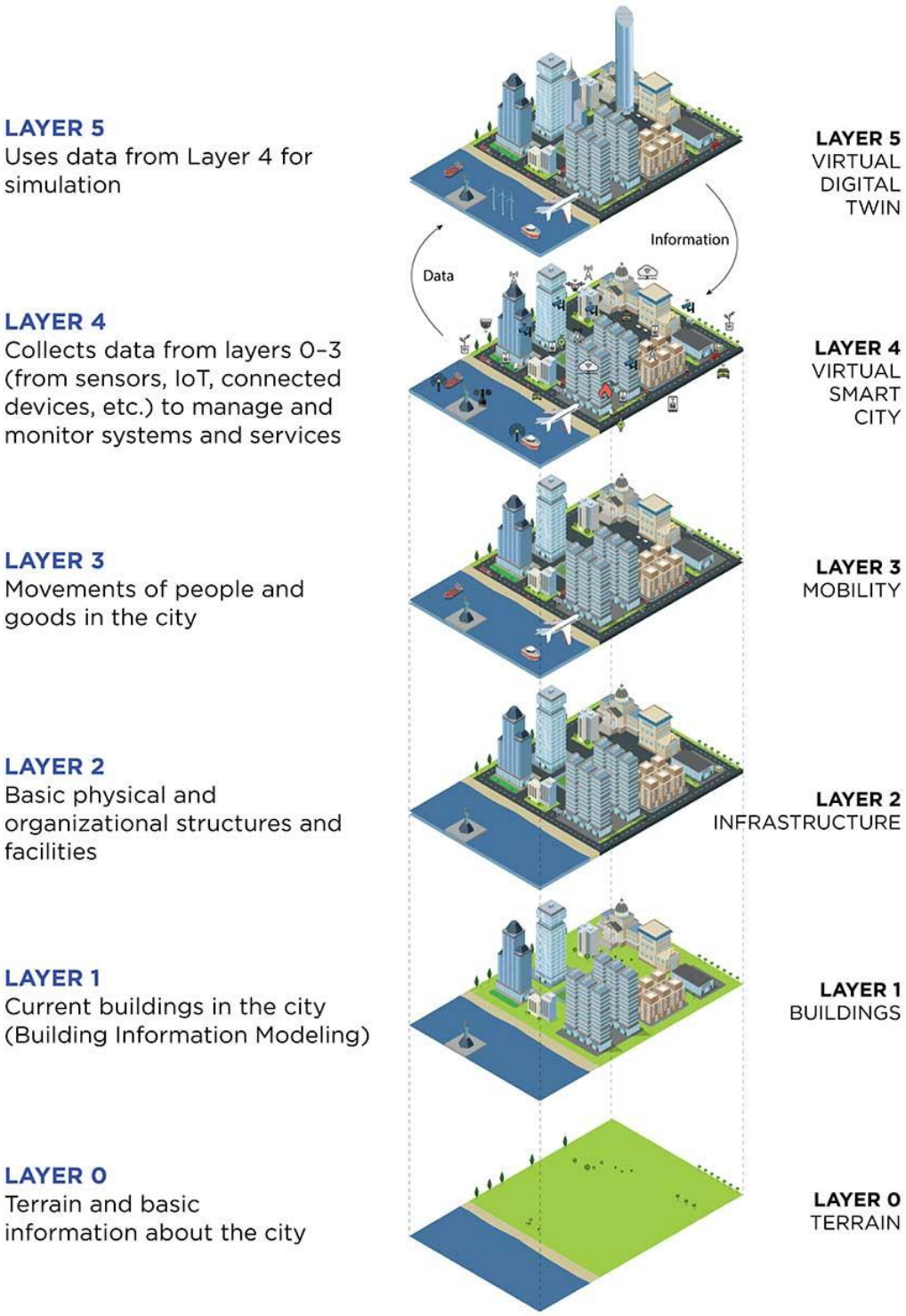

FIGURE 2: A DIGITAL TWIN SMART CITY FOR CITIZEN FEEDBACK (SOURCE: (C) TRINITY COLLEGE DUBLIN [9])

2.1.3 Digital Twins Best Practices

Digital twin solutions evolve via various levels of maturity & adoption:

1. **Descriptive Analysis:** Visualize the city in 3D and its changes over time such as new assets, roads & bridges, movement of people, demographic & economic changes.
    - Indicative use cases: 3D model of all assets, Street view and building façade, Socio-economic information, Demographic details.
2. **Predictive Modeling:** Model, predict and forecast underlying activities in sectors, such as real estate, transport, sustainability & socio-economic sectors.
    - Indicative use cases: Understand the relation between changes in demographics, immigration, Real estate, transport sector and public assets demand predictive analysis.
3. **Scenario Planning & Simulations:** Run multiple what-if scenarios and simulations by pulling levers of change and its effects on the city.
    - Indicative use cases: Model infrastructures to accommodate for changes in the city, Simulate economic activity & demographic changes.
4. **Operational Excellence:** Improve operations by making the organization proactive through live command centers and AI powered recommendations backed by real-time data integration.
    - Indicative use cases: Live command center and dashboard powered by AI, Real-time social listening & impact on real estate and asset management.

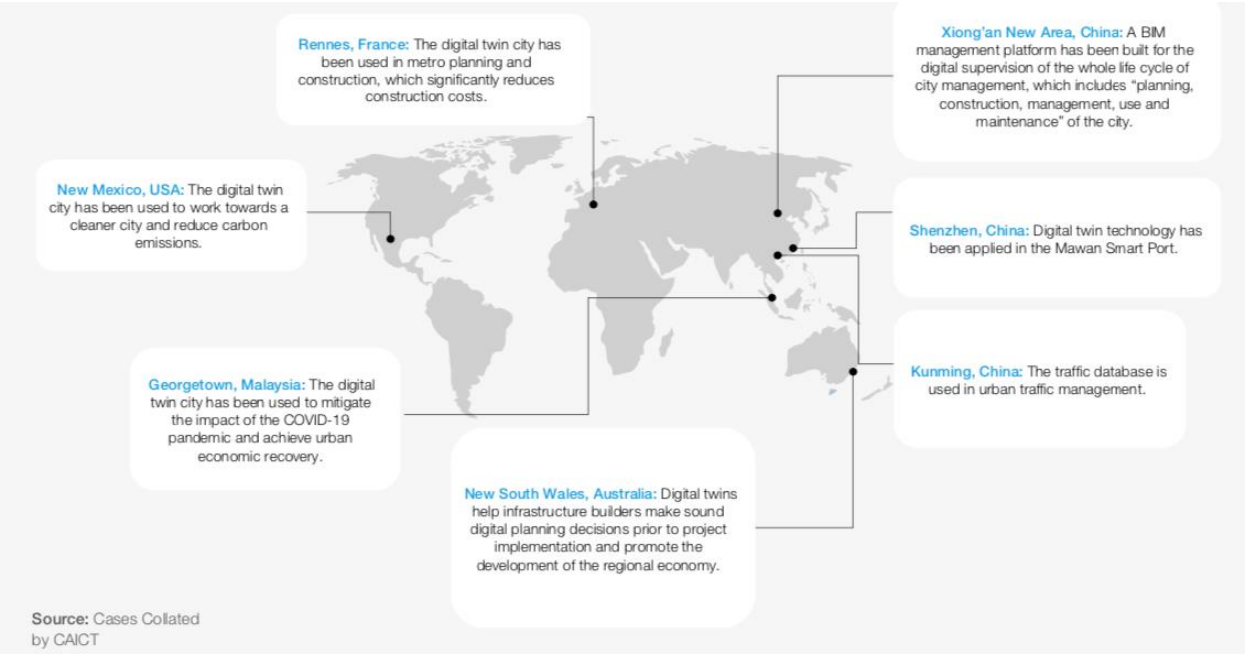

FIGURE 3: CASES OF GLOBAL DIGITAL TWIN CITIES (SOURCE: CAICT [3])

In the map shown in Figure 3, seven prime cases [3] of digital twin cities are depicted:

- **Xiong'an New Area, China.** The Xiong'an New Area is the first area in China to propose the construction of a digital twin city. According to the "Planning Outline of Xiong'an New Area in Hebei", Xiong'an New Area is required to carry out digital supervision of the whole life cycle of urban planning, construction, management, use, maintenance and repair, and create the "BIM Management Platform for planning and construction of Xiong'an New Area" to achieve the synchronous planning and construction of the digital city and the physical city.
- **Kunming, China.** Kunming is the capital city of Yunnan Province, China, and one of the most important cities in western China. In order to ease traffic congestion at rush hour and improve the city's traffic health index, Kunming built a digital twin-based urban traffic database to enable urban traffic managers to observe and control the city's traffic operations.
- **Shenzhen, China.** Located in China's Yangtze River Delta, Mawan Smart Port, established on 30 September 1986, provides a model case of how to upgrade a traditional bulk cargo terminal and transform it into an automated terminal. The port uses digital twin technology to create a 1:1 realistic recreation of static port scenes and a data-driven simulation of dynamic port operations, offering such functions as all-round real-time dynamic recreations of port operations, flexible switching of equipment operation perspectives, visualization of trailer operation paths, search and positioning of equipment and containers, 3D spatial management of yard and container services, and statistical analysis of operational efficiency.
- **Georgetown, Malaysia.** Tourism is the second largest source of revenue in Georgetown, the capital of Penang, Malaysia, but the city's tourism industry has been severely affected by the COVID-19 pandemic. To drive economic recovery, Georgetown is using a digital twin city platform to assess the feasibility of new projects, infrastructure capacity needs and sustainability, aiding in the reallocation of land use and helping to attract investment.
- **New Mexico, USA.** New Mexico is located in the southwest of the United States, covering an area of about 314,900 square kilometres. It is the fifth largest state in the United States, with a population of about 2,097,000 (2019 estimate). In 2019, the state passed the Energy Transition Act (ETA), which proposes that the state shall become a clean energy leader and achieve 100% clean energy by 2050. Founded in 2009, Cityzenith, a US software company, proposes to transform cities through digital twin technology to make them cleaner and healthier, and contribute to the "Clean Cities – Clean Future" vision. As a result, the State of New Mexico has partnered with Cityzenith to develop SmartWorldPro, a digital twin city platform, to help build new "smart infrastructure" and achieve carbon neutrality goals.
- **Rennes, France.** Rennes is the second largest city in northwest France and an important tourist destination. Metropolis Rennes and Dassault Systèmes are working together to create a virtual Rennes, a digital model of the city to be used for urban planning, decision-making and management and as a service to citizens. The 3D platform built by Metropolis Rennes and Dassault Systèmes is a collaborative environment that enables stakeholders to collaborate and communicate in designing innovative projects, products and services.
- **New South Wales, Australia.** The New South Wales (NSW) Government, in partnership with the Data61 department of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), has developed the digital twin proof-of-concept model: a complete, real-time, accurate and reliable 4D framework model that projects a physical environment that can enable real-time spatial-based data sharing and collaboration to help policy planners and project developers better design and manage the future of cities.

In [10] a systematic review on smart digital twins cities is presented (Figure 4) highlighting the notable increase in density in Europe and China. Specifically, there are works being developed in China, Bogotá, Helsinki, Brescia, Valencia, Irkutsk, Dublin, Herrenberg, Shenzhen and Zurich.

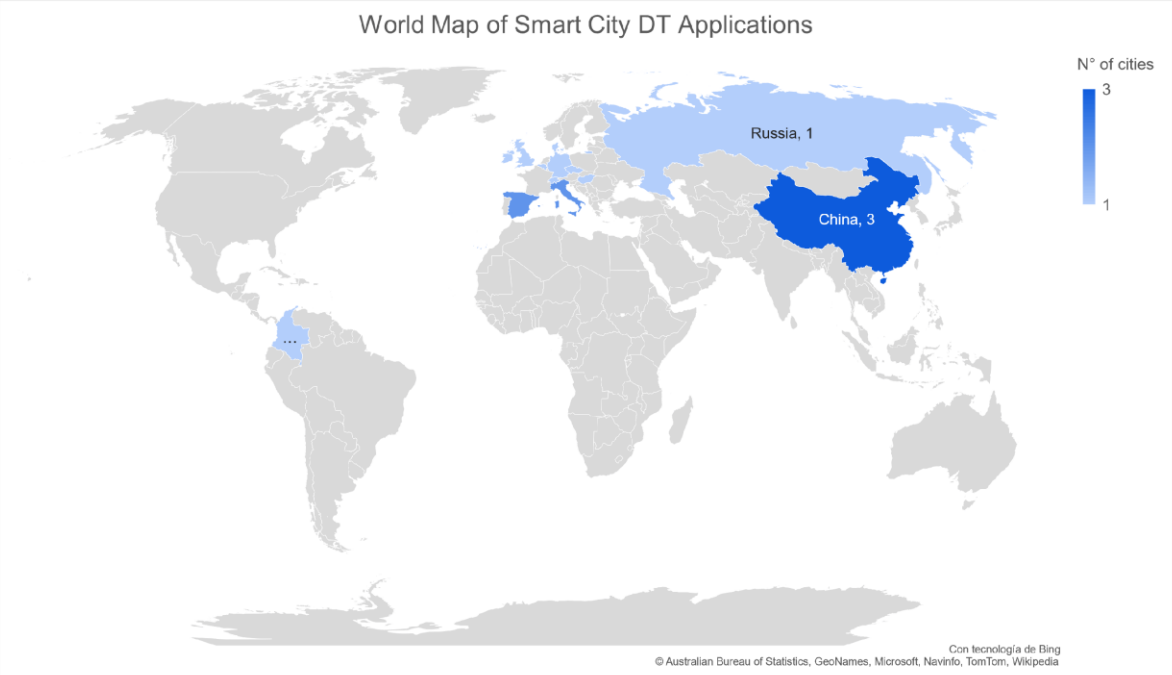

FIGURE 4: WORLD MAP OF SMART CITY DIGITAL TWIN IMPLEMENTATIONS (SOURCE: [10])

Some characteristic case studies in various domains are the following [3]] [10]:

- Virtual Singapore platform for urban environment improvement and optimization.
- Beijing builds an intelligent and advanced 'city brain' to help create a digital twin city.
- Shanghai releases minimum management unit for urban digital governance to create APPLICATION a digital twin system for buildings.
- Beijing builds a digital twin China International Services Trade Fair to support industry development.
- Tianjin Binhai digital twin processes citizens' requests in 15 minutes.

2.2 Metaverse

The concept of the metaverse has gained significant attention and holds the potential to transform the way we interact with smart cities. The metaverse refers to a virtual shared space that encompasses multiple interconnected virtual and augmented reality environments, creating a seamless bridge between the physical and digital worlds. Though there is no agreed definition of the metaverse, we regard metaverse as the next evolution of the internet, with a focus on the integration of physical and digital experiences [4]. For some users, the metaverse is an online space meant to digitally recreate the real world. For others, it is a shift in how they interact with their world, using technologies like 3D computing, augmented reality (AR), virtual reality (VR), and blockchain to form new immersive virtual world experiences that have the potential to overlay digital information on our physical world.

The metaverse can be a place to play and relax while escaping the real world, or it can be a space to do the work of life virtually. The web and how we use it continuously evolve. Each shift brings additional flexibility for users and increased capacity for engagement with others. The metaverse relies on movement towards Web 3, where users have more control over their experiences and an increased ability to engage with other users in new ways.

2.2.1 The Importance of Metaverse in Smart Cities

Various cities are beginning to explore how metaverse can benefit governmental operations and support community needs. Augmented and mixed reality, the internet of things (IoT), digital twins, and blockchain are all foundational technologies vital to the metaverse, and cities are already deploying them for uses ranging from tourism to resource management. Following we present how metaverse can support smart cities [2].

- **Immersive Experiences and Spatial Computing:** The metaverse leverages immersive technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR) to provide highly interactive and immersive experiences. Through spatial computing, users can visualize and navigate digital representations of smart cities, accessing real-time data, services, and experiences.
- **Seamless Integration of Physical and Digital Realms:** The metaverse enables a seamless integration of physical and digital environments. By overlaying virtual content onto the physical world, users can access contextual information, navigate through smart city infrastructure, and interact with virtual objects, services, and other users.
- **Enhanced Collaboration and Communication:** The metaverse facilitates enhanced collaboration and communication within smart cities. Users can connect and interact with each other, regardless of physical location, to co-create, share ideas, and solve urban challenges. This fosters citizen participation, enabling a collective approach to urban planning, decision-making, and problem-solving.
- **Smart City Simulation and Planning:** The metaverse provides a platform for simulating and visualizing smart city planning and development scenarios. Urban planners and policymakers can create digital replicas of cities, test different design options, evaluate the impact of proposed changes, and engage citizens in the decision-making process. This improves urban planning outcomes, resource allocation, and sustainability.
- **Data Visualization and Analytics:** The metaverse empowers smart cities with advanced data visualization and analytics capabilities. Real-time and historical data from various sources, such as IoT sensors, social media, and open data platforms, can be visualized in immersive ways, allowing policymakers and citizens to gain insights, identify patterns, and make data-driven decisions.
- **Virtual Citizen Services:** The metaverse enables the delivery of virtual citizen services. Residents can access a range of services, such as virtual town halls, online education, remote healthcare consultations, and virtual commerce, enhancing convenience, accessibility, and inclusivity within smart cities.
- **Digital Twin Integration:** The metaverse can integrate with digital twins of smart city infrastructure, systems, and assets. This integration allows for real-time monitoring, control, and management of physical entities through their digital representations, optimizing operational efficiency, predictive maintenance, and resource utilization.

- **Privacy and Security Considerations:** As the metaverse gathers vast amounts of data and facilitates extensive user interactions, privacy and security concerns must be addressed. Robust data protection mechanisms, privacy controls, and encryption protocols should be implemented to safeguard user information and ensure secure transactions within the metaverse.

- **Interoperability and Standards:** Establishing interoperability standards is crucial for the metaverse's widespread adoption in smart cities. Open standards that enable seamless integration and data exchange between different metaverse platforms, smart city systems, and devices are essential for creating a cohesive and interconnected digital ecosystem.

- **Ethical and Inclusive Design:** The metaverse should prioritize ethical considerations and inclusivity. Designing user-centric experiences, ensuring accessibility for individuals with disabilities, and addressing potential biases in algorithms and data sources are critical aspects to be addressed for a fair and equitable metaverse in smart cities.

2.2.2 The seven layers of the Metaverse

Jon Radoff [11] describes the metaverse as a digital environment made up of seven distinct layers (Figure 5) that represent different phases. These layers must work together, from the experiences people seek to the enabling technologies that make it possible.

- **Layer 1 – Experience:** The 'Metaverse concept' is destined to be far more than just a 3D manifestation of the physical world for our passive viewing. It'll involve the physical dematerialisation of physical space, distance, and objects, made possible by photo-realistic graphic elements.

- **Layer 2 – Discovery:** Arguably the most lucrative layer for businesses, the Discovery segment forms the discoveries that result from a constant push and pull of information that familiarises users with new, innovative experiences.

- **Layer 3 – Creator economy:** We've moved past pioneering eras of experienced creators who have to build websites from scratch by coding HTML or dedicated programmers writing directly to graphics hardware and games. The newest spaces, powered by AR, VR, and similar technologies, are specifically targeted to entice visitors who will be able to do anything they want within them. We're moving into an era where designers and creators would instead swerve the tedious coding and place their abilities more creatively. We can use tools, templates, and marketplaces that reverse development from a bottom-to-top, code-centred process to a top-to-bottom, creatively-centred one.

- **Layer 4 – Spatial Computing:** SP has already made our lives easier. It's made fashion fun and shopping more convenient by allowing shoppers to try clothes in virtual changing rooms. Eventually, we'll work, shop, and live as avatars in a 3D digital world that mimics reality. Spatial computing is a technology solution that merges virtual and augmented reality to provide a high level of authenticity to the immersive 3D experience.

- **Layer 5 – Decentralisation:** 'Decentralisation'refers to the technologies, designs, and approaches that shift power and control away from centralised authorities. This proposed framework is viewed by many as the only way to run the Metaverse effectively.

- **Layer 6 – Human Interface**: This layer describes the technologies/hardware/devices that allow users to experience the true magic of the metaverse and explore it through dynamic human-computer interaction (HCI). Think VR headsets, smart glasses, and haptic technologies where users can navigate digital worlds in real time.

- **Layer 7 – Infrastructure:** This layer pertains to the complex technological infrastructure required to create a fully functional and interoperable Metaverse that enables our devices to connect us to virtual networks and deliver content.

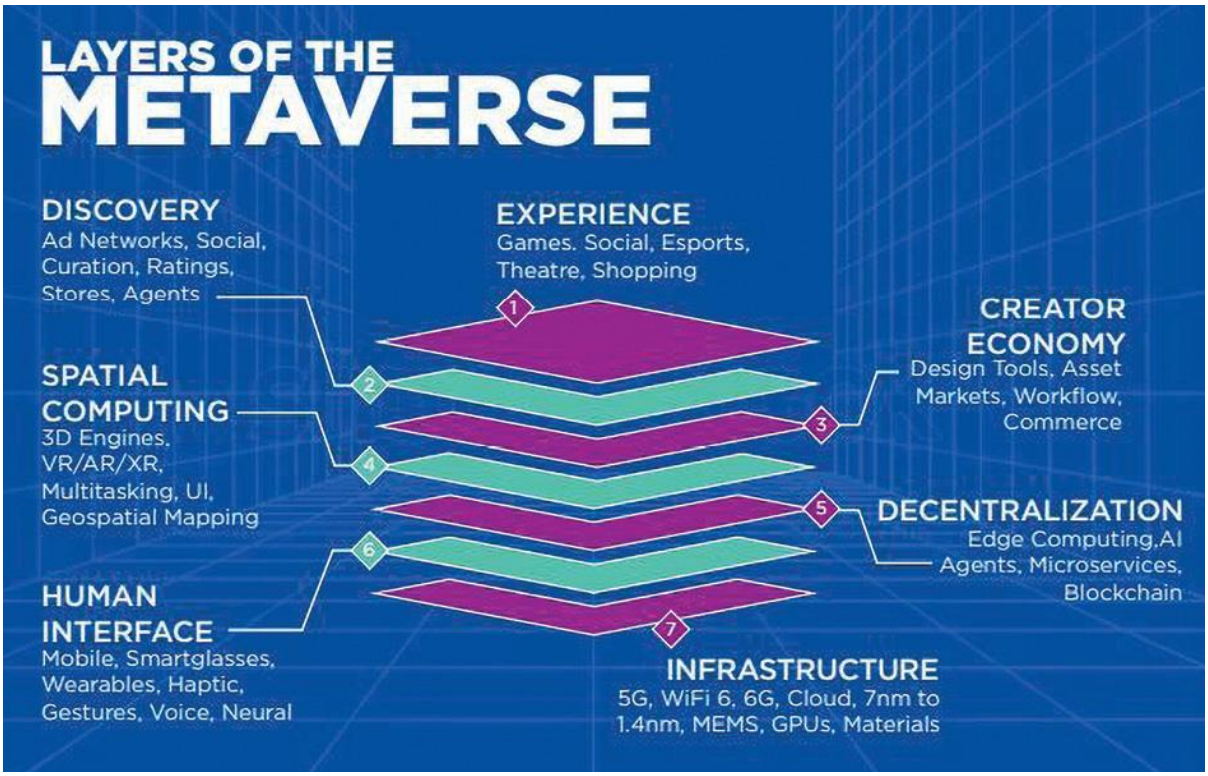

FIGURE 5: THE SEVEN LAYERS OF THE METAVERSE (SOURCE: [11])

2.2.3 Metaverse Smart Cities Case Studies

Following some of the most characteristic case studies of metaverse in smart cities are presented [4], [12]:

- **Shanghai, China:** Shanghai issued a five-year development plan that named the metaverse one of four frontiers for exploration. In 2021, the Shanghai Municipal Commission of Economy and Information Technology released a plan encouraging exploration of the metaverse across industries, both in the private sector and for public services. The commission plans to increase research and development of underlying technologies that will build the metaverse, including smart sensors and blockchain.

- **Santa Monica, CA:** Santa Monica was the first U.S. city to enter the metaverse. The city now offers a virtual way to experience its downtown district through FlickPlay, a Santa Monica-based metaverse social app company. In its partnership with Santa Monica, FlickPlay provides users an interactive map of the city's retail district where they can collect tokens as they move around the city. Some tokens can be used to unlock digital experiences in the app and others can be redeemed for physical items at retailers in the area. Santa Monica's participation in the metaverse allows users to explore this exciting new technology, but also benefits the local economy. Through the app, users are drawn to visit real world local businesses, and the app aims to increase foot traffic in underutilized spaces.

- **Seoul, South Korea:** In 2021, the Seoul Metropolitan Government announced its plan to become the first city to fully enter the metaverse. As part of the five-year metaverse Seoul promotion master plan, Seoul will invest $3.3 million to develop a communications platform

that will enable the city to provide services to its residents in the metaverse. The city's metaverse ecosystem will accommodate all areas of Seoul's municipal administration, from traffic enforcement to tourism. In Seoul's "Metaverse 120 Center" residents will meet with avatar public officials in a virtual office for public services previously only available in person at City Hall. This entirely new use of the metaverse would enable governments to provide key services and engage with residents in a lifelike way while overcoming space limitations, distance between residents and city hall, language barriers and other obstacles to in-person interactions. Along with transitioning government services to the metaverse, Seoul is introducing a virtual tourist zone which will host some of Seoul's largest tourist attractions virtually. Seoul's most popular festivals will be held in the metaverse, starting with a traditional Bosingak bell-ringing ceremony on New Year's Eve. Moving cultural events into the metaverse will allow people from around the world to connect with the city and establish Seoul as a global hub for emerging technology by displaying one of the city's most impressive technological accomplishments.

- **London:** Using spatial mapping technology powered by Nextech's ARway, the City of London is now being mapped in 3D. The software development kit maps the physical environment within minutes, thus providing incredible location-based AR experiences. This opens up a new realm for AR advertising, AR Portals, and Holograms in the future. London is also the central hub for crypto-related gatherings and conferences.

- **New York City:** Columbia University started the Hybrid Twins for Urban Transportations project in 2021 to create digital twins of various key New York City locations. The city uses real-time data obtained through sensors placed at various locations. The project aims at using machine learning to optimize the flow of traffic at key intersections.

- **Tokyo:** The Tokyo government announced in 2021 that they would commence the creation of digital twins to replicate the busy streets of Tokyo in the virtual realm. By utilizing different sensors throughout the city, they project calculated conditions for wind, traffic, sunlight, and more. The government stated that the project would be fully realized by 2030.

- **Singapore:** The concept of digital twins was embraced by Singapore in 2014, making it one of the first cities to accept this technology. With Singapore being an island nation, there are rising concerns about the impact of climate change. With the help of digital twin creation, the country could test different weather conditions to analyze whether current arrangements could withstand adverse effects. An integrated structure is already in place to analyze rising sea levels. By using various sensors, the country has been able to create a digital replica of its world. Apart from accepting the digital twin concept, Singapore is also investing heavily in Metaverse-related startups. NGC Ventures announced a $100 million fund to help boost the growth of Metaverse technology.

- **Dubai:** Besides Dubai's goal of creating over 40,000 new jobs by attracting Metaverse companies, the thriving city is also looking into starting a digital twin city to facilitate urban planning. Dubai's Road and Transport Authority (RTA) has also released plans for several intelligent initiatives. Such as using digital twins to recreate Dubai's Metro Network. The algorithm combines data gathered over time and provides valuable insights into maintenance schedules. It can also give predictions on how to avoid unforeseen accidents in the future.

- **Shanghai:** Shanghai devised a strategy to utilize the Metaverse for governmental, non-governmental, public, and private reasons over the following five years at the end of 2021. The city recently announced its interest in utilizing digital twin technology to improve city operations. This is part of China's five-year plan to use digital twins to improve capacity

management. The technology would enable Shanghai to fully recreate every building, street lamp, water sewerage pipeline, and more. A form of digital twins was also used during the COVID outbreak to limit the spread of the disease.

3 Digital Twin (DT) Solutions

In this section some of the most characteristic digital twin case studies for all METACITIES domains are presented as long as the features that are applicable to the METACITIES proposed solution [147].

3.1 DT solutions for Smart Mobility

In this section we present some of the most characteristic digital twin case studies for smart mobility focusing on their benefits and positive outcomes.

3.1.1 CityZenith DT

One notable use case that demonstrates the benefits of using Digital Twin technologies for smart mobility in the United States is the implementation of a smart transportation system in the city of Los Angeles, California [14]. Los Angeles has been actively deploying smart mobility solutions to address its traffic congestion challenges and enhance urban mobility. Using the digital twin, city officials can simulate and test different scenarios to identify potential bottlenecks, predict traffic congestion, and optimize traffic signal timings in real time. For instance, if the digital twin detects an increased flow of vehicles entering a specific area, it can automatically adjust the traffic signals to prioritize the movement of those vehicles, alleviating congestion and reducing travel times. By continuing the CityZenith platform previously deployed in Chicago, the city has achieved notable benefits, including:

- **Real-time Traffic Management:** Los Angeles utilizes a network of sensors, cameras, and connected devices placed throughout the city's transportation infrastructure to collect real-time data on traffic conditions. This data is processed using advanced analytics and AI algorithms to optimize traffic signal timings, manage lane directions, and dynamically adjust traffic flow. As a result, the city has experienced reduced congestion, improved traffic flow, and shorter travel times for commuters.

- **Integrated Public Transportation:** Los Angeles has integrated digital solutions into its public transportation system, including real-time transit tracking, electronic fare payment systems, and mobile applications for trip planning. These technologies allow commuters to access accurate information on bus and train schedules, track the arrival times of public transit vehicles, and plan their journeys efficiently. This integration has improved the overall reliability and convenience of public transportation, encouraging more people to use sustainable modes of travel.

- **Parking Optimization:** The city of Los Angeles has implemented smart parking systems that leverage sensors and mobile applications to provide real-time information on parking availability and guide drivers to vacant parking spaces. By reducing the time spent searching for parking, the city has reduced traffic congestion, enhanced urban accessibility, and improved the overall parking experience for residents and visitors.

- **Data-driven Decision-making:** Los Angeles utilizes big data analytics and real-time data to make data-driven decisions regarding transportation planning and infrastructure investments. By analyzing traffic patterns, demand trends, and user preferences, city officials can identify areas of improvement, optimize transportation networks, and allocate resources effectively. This data is then fed into a digital twin, which is a virtual replica of the physical transportation system. The digital twin constantly updates itself based on the real-time data and provides an accurate representation of the current state of the transportation network. By combining this virtual model with advanced analytics and artificial intelligence algorithms, the city's transportation authorities gain valuable insights into the system's behavior and can make data-driven decisions to optimize traffic management.

The implementation of these smart mobility technologies in Los Angeles has resulted in several benefits, including reduced traffic congestion, improved travel times, enhanced public transportation services, and optimized parking management. These advancements contribute to a more efficient and sustainable urban transportation system, making the city more livable and improving the overall quality of life for its residents.

In conclusion, the successful exploitation of smart mobility and digital twins in smart cities in the USA can revolutionize urban transportation. By leveraging real-time data and virtual simulations, cities can optimize traffic flow, reduce congestion, and enhance overall mobility, leading to improved quality of life for residents, increased sustainability, and a more efficient transportation system. Results:

1. **Improved traffic flow:** The digital twin's real-time monitoring and analysis of traffic conditions allow transportation authorities to make data-driven decisions and adjust traffic signal timings accordingly. This leads to smoother traffic flow, reduced congestion, and improved travel times.
2. **Enhanced public transportation:** Integrating digital twins with public transportation systems enables better coordination and optimization of bus and train schedules. Real-time data helps in identifying areas with high demand and allows for more efficient allocation of resources to meet passenger needs.
3. **Personalized travel recommendations:** By leveraging the digital twin and integrating it with smart mobility applications, cities can provide personalized travel recommendations to individual users. This may include suggesting alternative routes, transportation modes, or even incentivizing off-peak travel to alleviate congestion during peak hours.
4. **Increased sustainability:** Optimized traffic flow and reduced congestion result in reduced fuel consumption and lower emissions. By promoting the use of more sustainable transportation options and encouraging behavior changes, cities can work towards achieving their environmental goals and improving air quality.

3.1.2 Barcelona 15-minute city DT

In Europe, the city of Barcelona, Spain, has implemented as part of the 15-minute city initiative an innovative smart mobility system that integrates digital twins to optimize transportation networks and improve urban mobility [15]. By deploying a network of sensors, cameras, and IoT devices across the city's transportation infrastructure, Barcelona collects real-time data on traffic conditions, parking availability, and public transportation usage. This data is then fed into a digital twin, a virtual replica of the city's transportation system.

The digital twin continuously updates itself based on the real-time data, allowing city officials to monitor the current state of the transportation network accurately. Advanced analytics and AI algorithms are applied to the digital twin to gain insights into traffic patterns, identify congestion hotspots, and predict future mobility challenges. Using the digital twin, Barcelona's transportation authorities take proactive measures to optimize traffic flow and enhance mobility:

- **Intelligent traffic management:** The digital twin enables real-time monitoring of traffic conditions, allowing officials to identify bottlenecks and dynamically adjust traffic signal timings. By synchronizing traffic signals based on the current traffic flow, the city can reduce congestion and improve overall traffic efficiency.
- **Parking optimization:** The digital twin integrates data on parking availability and occupancy. This information helps city authorities direct drivers to available parking spaces and reduce the time spent searching for parking, resulting in reduced traffic congestion and improved urban accessibility.

- **Public transportation enhancements:** By analyzing real-time data on public transportation usage, the digital twin assists in optimizing bus and metro routes. The city can adjust schedules, allocate resources more efficiently, and provide accurate travel information to passengers in real time, improving the reliability and attractiveness of public transportation.

- **Mobility planning and simulation:** The digital twin serves as a valuable tool for city planners to simulate and evaluate different mobility scenarios. They can assess the impact of proposed infrastructure changes or policy interventions before implementation, ensuring more effective and informed decision-making.

The successful implementation of this smart mobility system in Barcelona has resulted in several positive outcomes:

1. Reduced congestion and improved traffic flow, leading to shorter travel times and enhanced overall mobility for residents and visitors.
2. Increased utilization of public transportation due to improved reliability, real-time information, and optimized routes, resulting in a modal shift from private vehicles to sustainable modes of transportation.
3. Enhanced urban accessibility and reduced environmental impact by reducing unnecessary vehicle kilometers traveled, lowering greenhouse gas emissions, and improving air quality.
4. Better use of infrastructure resources through optimized traffic signal control, parking management, and public transportation operations, leading to cost savings and improved resource efficiency.

3.1.3 Singapore Vizzio DT

In Asia, Singapore-based VIZZIO Technologies “cloned” all of Singapore to create the world’s biggest digital twin [16]; the 1:1 scale model of Singapore is divided into 1 square meter titles, totaling 728,000,000. As part of this effort Singapore has implemented a comprehensive smart mobility system that leverages digital twins to optimize transportation and improve urban mobility.

With an extensive network of sensors, cameras, and IoT devices deployed across the city, Singapore collects real-time data on traffic conditions, public transportation usage, and various mobility aspects. This data is fed into a digital twin, a virtual replica of the city's transportation system, to enable accurate monitoring and analysis. The digital twin integrates data from various sources and applies advanced analytics and AI algorithms to gain insights and enable smart decision-making. Here's how this use case unfolds:

- **Dynamic traffic management:** The digital twin continuously monitors traffic conditions, including congestion levels, flow patterns, and incidents. By analyzing this data in real time, Singapore's transportation authorities can dynamically adjust traffic signals, manage lane directions, and optimize road capacities to improve traffic flow and reduce congestion.

- **Integrated public transportation:** The digital twin integrates real-time data from buses, trains, and other modes of public transportation. This allows for seamless coordination of schedules, optimized route planning, and efficient resource allocation. Passengers can access real-time information, such as arrival times and service disruptions, through mobile apps, enabling a smoother and more reliable public transportation experience.

- **Multi-modal trip planning:** Leveraging the digital twin, Singapore provides a comprehensive multi-modal trip planning platform. Users can access mobile apps or websites that integrate real-time data from various transportation modes, including public transport, ride-sharing,

bike-sharing, and walking. The digital twin analyzes this data to suggest the most efficient and sustainable routes based on individual preferences and real-time conditions.

- **Predictive maintenance and safety:** The digital twin enables predictive maintenance for transportation infrastructure, such as bridges and tunnels, by analyzing sensor data and identifying potential issues before they occur. This proactive approach helps prevent disruptions and ensures safe and reliable transportation for commuters.

The successful implementation of this smart mobility system in Singapore has led to several significant outcomes:

1. Improved traffic flow and reduced congestion, resulting in shorter travel times, increased predictability, and enhanced overall mobility for residents and visitors.
2. Increased utilization of public transportation due to improved reliability, real-time information, and seamless integration of different modes, leading to a modal shift towards sustainable transportation options.
3. Enhanced safety and security through real-time monitoring, incident detection, and predictive maintenance, reducing the risk of accidents and disruptions.
4. Optimized resource allocation and reduced environmental impact through efficient transportation management, resulting in lower fuel consumption, reduced emissions, and improved air quality.

3.1.4 Greek Innovation ecosystem for Smart Mobility focus areas

The Digital Twin solutions highlighted through the examples of Los Angeles, Barcelona and Singapore presented above, offer effective Digital Twin solutions in Smart Mobility. Accordingly, the Greek innovation ecosystem will leverage Digital Twin technology for the areas of “Smart Parking”, “Environmental behavior analysis on traffic incidents” and “Emergency Management”. More specifically:

- **Smart Parking:** By integrating data like parking availability, the system can provide real-time information on available parking spaces, evaluate Estimated Arrival and suggest optimal routes to reach them. The digital twin will be able to visually exhibit the traffic situation and congestion in real time. Furthermore, the proposed digital twin should be able to run specific what-if scenarios in order to develop proposals for solving transport problems like optimization of traffic flow, pedestrian and cyclists’ flows, public transport alternatives, traffic management, parking management etc. Also, it will suggest public transportation enhancements identifying areas with high demand.

- **Environmental behavior analysis on traffic incidents:** By integrating environmental data like air quality, noise, smoke, etc. and combining them with traffic data into the Digital Twin, the system can investigate the correlation that they have and the effect that traffic and /or incidents may have on the environment in a city of the city center. In METACITIES, the digital twin will be able to visually exhibit the environmental and noise situation and congestion in real time. Finally, an application will be designed that will interoperate with the digital twin and will be able to inform the stakeholders about possible eminent incidents that may compromise air quality.

- **Emergency Management:** Based on real time collected data and analysis, the building blocks will be designed that will comprise an operating center for emergency services through which authorities can sync up their actions after a traffic incident. These actions include vehicle’s rerouting while facilitating emergency vehicles to access the incident when needed. At a later stage, this operating center will become an advanced notification system for drivers, cyclists, pedestrians and public vehicles. It will also provide solutions to what if scenario for

optimization of traffic, optimization of traffic lights, and investment justification in the construction of transport infrastructure for emergency services (for example extra lanes etc).

3.2 DT solutions for Green City

In this section we present some of the most characteristic digital twin case studies for green city focusing on their benefits and positive outcomes.

3.2.1 Cityzenith – SmartWorldPro – State of New Mexico

The State of New Mexico has partnered with Cityzenith to develop SmartWorldPro, a digital twin city platform, to help build new "smart infrastructure" and achieve carbon neutrality goals [3]. Cityzenith and its SmartWorldPro platform was presented in the previous section in the use case of Los Angeles for smart mobility, too. The focus of this infrastructure for green city is on:

- **Providing full life-cycle services for buildings:** Cityzenith's digital twin city platform, SmartWorldPro, is a tool for building planning, management and operations. The platform is used by architects, contractors and asset managers to carry out site selection, planning, design, construction, operation, maintenance and sales.
- **Solving problems in data integration and providing template tools for rapid expansion:** To overcome the difficulty of integrating data from different sources such as BIM, GIS and IoT, SmartWorldPro has significantly expanded and upgraded its data import and integration capabilities, providing the ability to import hundreds of data types into a common dashboard. Using 3D templates, users can quickly scale from a single building to a portfolio of hundreds or even thousands of buildings, including information on rooms, floors, textures and major equipment. At the same time, users can customize rendered scenes to their liking, with visualization tools such as colour palettes, preset objects and base maps.
- **Build a platform and professional community**: SmartWorldPro has built Mapalyze, an application store for building professionals, as a library of analysis tools. Mapalyze provides users with AI-based analysis such as solar analysis, viewpoint analysis, sociological analysis, traffic studies and climate impact simulations. In addition, SmartWorldPro offers a variety of deployment methods, including customized solutions, software as a service (SaaS) and software development kits (SDKs).

3.2.2 University of Southern Denmark, Campus Odense and University of Glasgow

A Digital Twin Framework was configured to control a physical room – the room U182, which is a classroom, in building OU44 at the University of Southern Denmark, Campus Odense [17]. The building constitutes part of the Smart Building Living Labs at the University of Southern Denmark and is used in ongoing research efforts to determine the optimal use of energy in buildings.

The Digital Twin Framework, which is presented for performing MPC, constitutes an architecture describing applications for building control, occupancy prediction, and a common data format implementation based on sMAP. The Digital Twin Framework contains a parameterized Zone Model which can be calibrated against (virtual or physical) controllable zones as well as a parameterized Zone Control Application which enables the configuration of targets for temperature- and CO2.

A similar digital twin pilot project to monitor building performance approach is presented in [18]. Digital twin versions of three buildings at the University of Glasgow have been created as part of a pilot project assessing how compliance models can be used to improve building performance. Funded by Innovate UK and called eDigit2Life, the project saw Glasgow-based proptech firm IES produce digital twins for the James McCune Smith Learning Hub (JMS) built in 2021, and the Advanced Research Centre (ARC) completed in 2022.

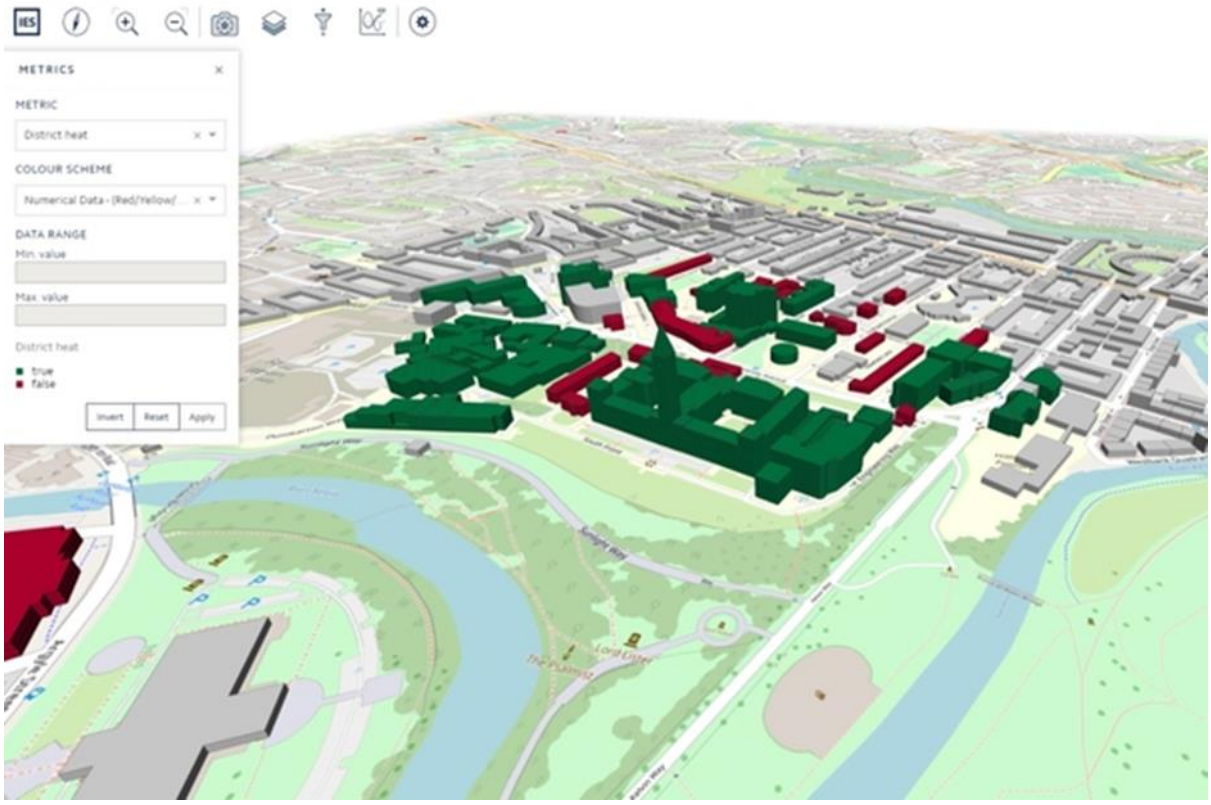

FIGURE 6: DIGITAL TWINS MONITORING BUILDING PERFORMANCE

Compliance models are created at the design stage to assess aspects like energy performance and environmental rating. However, according to IES, they cannot reliably predict real world building performance in a useful way. The project used compliance models for three buildings at different stages of their lifecycle and created calibrated models and, from those, detailed digital twins.

These digital twins enable accurate predictions of a building's operational performance (Figure 6) while repurposing existing models for further use. For the JMS and ARC buildings, a building information model (BIM) was created. These were then converted to energy models by the engineers using dynamic simulation modelling software. The models ensure that the buildings will comply with the relevant industry standards for energy performance.

The compliance models were then updated to include information on each building's energy-usage patterns, as well as unregulated loads that had not been considered originally. Occupancy profiles based on building use were also added and small power electrical equipment loads were investigated. Data collected from the Building Management System (BMS) and design profiles, such as equipment efficiencies and lighting loads, were then added to the models. The resulting models were calibrated to create building-performance digital twins.

For the library, a geometry model was created based on an existing BIM and an energy audit was carried out to create a thermal template of the model. This gathered information on the energy heat and flows, as well as the schedule for heating controls, domestic hot water consumption and heating set-points and set-back temperatures.

A calibrated model was then created using information from the energy audit. Using the resulting building-performance digital twin, three scenarios were tested for improved performance. These were: adjusting start/stop times and closing upper floors during low-occupancy periods, a basic electrical retrofit and HVAC equipment upgrades.

The digital twin predicted reductions of 15 per cent on energy and carbon emissions, with 9 per cent reductions for the electrical retrofit and 23 per cent for the HVAC upgrades. The University of Glasgow is hoping to begin the first scenario and consider the other two options alongside a range of other campus-wide energy-saving initiatives.

As a result of the project, recommendations have been made to Riba to facilitate performance digital twin adoption, with the aim of improving building performance and helping to decarbonise the built environment. Recommendations have also been outlined for governments and standard bodies to support the use of digital twins across the whole building life cycle.

3.2.3 Central Park Smart estate in Burgas

Digital Twin solutions for Central Park Smart estate in Burgas

Central Park's digital twin is a digital representation of a physical object and its systems. The proposal for the buildings described below in Central Park – gr. Burgas, consists of elements that enable management and control of processes in the building (Figure 7). The complex has several separate zones with different types of management: i) Residential buildings; ii) Office buildings; iii) Underground garages; iv) Trade Facilities; and v) Common areas.

Management and monitoring of all areas is done through a centralized SCADA system and local governments. The elements described below relate to the management of the zones indicated.

- Office building - all floors of it are divided into 4 separate offices on each floor. Each office has conditionally separated 4 zones with approximate dimensions of 8 * 8 meters. Each zone includes the management of: i) Lighting; ii) Air conditioning; iii) Ventilation; iv) Blinds; v) Access control; vi) Lifts; vii) Electrical panels; viii) Pumps and hydrophores; ix; Meters; x) Counters; and xi) Diesel generators.

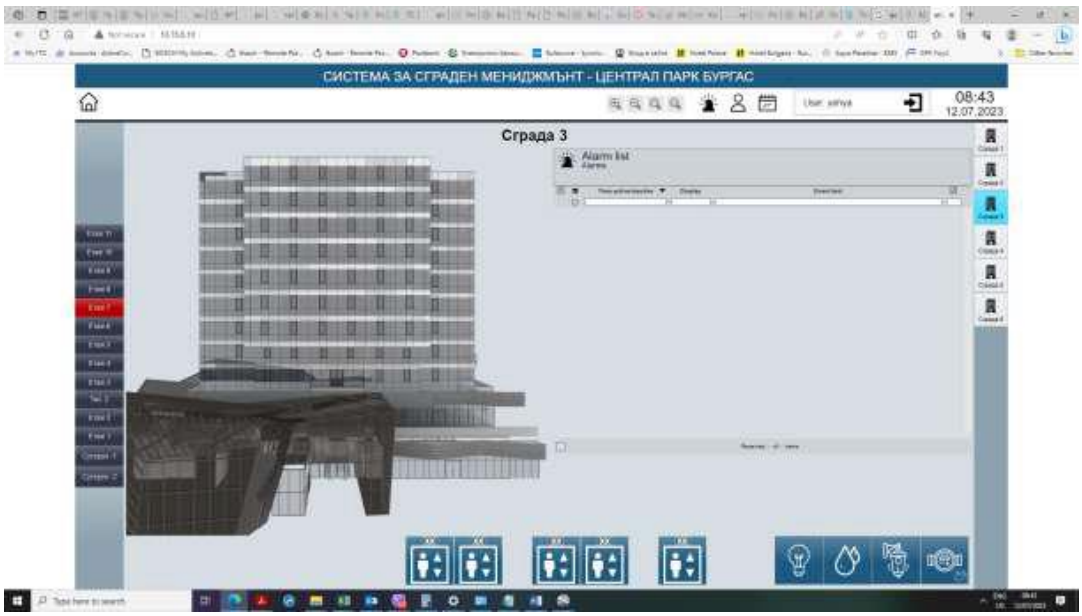

FIGURE 7: BUILDING 3 OF CENTRAL PARK SMART ESTATE

This makes it possible to independently manage each zone, as the solution is expandable and can be specified according to customer needs. The management protocols for individual systems are: Lighting Dali, Air conditioning, Ventilation, Power supply, Access control.

Air conditioning: Air conditioning for all offices is type VRF, as the manufacturer of the equipment is not yet specified [19] The system is operated through the manufacturer's ModBus or BacNet Gateway controls up to 128 addresses of indoor units. It is recommended that every gateway be on the separate ModBus or Bacnet module for system performance. Based on the internal Addressing the bodies is carried out management by zones. Each zone has a screen configured a map with the number and addresses of the air conditioners. In each room there is a separate management for the corresponding cartridge which is equal in priority to the management through the central screen or BMS but is subject to the general constraints laid down in the temperature, regime and etc. Based on the conversation with the contractor of the air conditioning site VRV the cartridges will be equipped with the possibility of connection to ventilation. It will take care of the management and the warming of the incoming air inflow. In this way, fresh air will be provided with In this way, fresh air will be provided with appropriate temperature in the premises. Alarms are displayed from the system depending on the capabilities provided by the manufacturer only on the support team's service screen.

Lighting: The lighting is controlled using the Dali protocol [20]. Management circles are merged in an office board, where a control controller with a Dali expander is installed. Each zone for control has a configured screen with a card with the number and addresses of lighting fixtures. Any there is a key or tablet next to the door or in a suitable place to control the lighting fixtures. There are also presence sensors installed on Dali that provide information for the presence of people in the room. The luminaires are combined in groups in order to make it easier to Lighting control in offices. Each control key has four groups with two programmed Scripts. The rooms are equipped with sensors for presence and measurement of illumination. Through them a certain degree of illumination in the room can be set and this can be dynamically controlled by the system.

Ventilation: The ventilation of the floors is provided by 4 fixtures [21]. Bodies do not have degrees of speed and temperature control therefore the control of each zone is done by means of manual Turn on and off through the floor control screen. Motors are monophasic and have motor protection provided. We can offer these fixtures to be equipped with devices to control the speed of single-phase motors pressure sensors and thus to control the flow of incoming air from the ventilation to the VRV cartridges. It will optimize electricity costs, will reduce noise but must be consistent with the number of the cartridges in each zone and the power of the bodies. Each zone has a configured screen with a map with the rooms and ventilation is controlled for office. There is no separate remote control for each room. At a specific time, the system can be set to turn on for a maximum of 15 minutes to provide fresh air in the Room. This time can be changed from the menu Schedules on the screen for the office. Alarms are issued on the basis of power failure, lack of flow or motor protection.

3.2.4 Bulgarian Innovation Ecosystem Green City focus areas

The Digital Twin solutions highlighted through the examples of New Mexico, University of Southern Denmark, Campus Odense and Central Park Smart estate in Burgas presented above, offer effective Digital Twin solutions in Green City. Accordingly, the Bulgarian innovation ecosystem will leverage Digital Twin technology for the areas of “Renewables (PV) potential and performance analysis tool”, “Buildings Energy Performance Analysis” and “Budget Planning for Energy Usage and Buildings”. More specifically:

- **Renewables (PV) potential and performance analysis tool:** By combining the input data, simulation models, and advanced analytics, the digital twin city model will become a dynamic and interactive platform for energy performance analysis of public buildings that enables continuous monitoring, pattern analysis, optimization, and decision-making to achieve long-

term energy efficiency goals. With the specific data sources and the proposed technical approach, the digital twin city model can in addition support policy making on general energy performance improvement at the pilot sites and future PV implementations in the city.

By integrating data like PV availability and performance into the PilotDigital Twin, the system can identify PV systems existing in the city as well as give new tool to create models to assess and determine accurately their production potential. This data can then be integrated into the Digital Twin of the city, providing users with the ability to monitor PV energy production potential, including functionalities enabling the consideration of different scenarios as to how to achieve the goals of the city for 2030, as well as to inform building owner(s) and citizens about the economic feasibility of PV installations on the buildings.

- **Buildings Energy Performance Analysis:** By integrating into the Digital Twin specific data like: energy consumption, evaluation of consumption patterns; energy benchmarking to identify energy-saving opportunities; building envelope analysis to analyze the extent of heat loss or gain through walls, roofs, windows, and doors; evaluation of the efficiency and performance of heating, ventilation, and air conditioning (HVAC) systems; analysis of the lighting systems; efficiency of lighting system, including the type of lighting technology, lighting controls, and lighting schedules; evaluation of the feasibility of integrating renewable energy photovoltaic (PV) panels; analysis of usage patterns, occupancy schedules, and user interaction with building systems; the system can provide real-time information for building performs in energy aspect.

  By inputting in the Digital Twin platform the data related to building insulation characteristics, equipment specifications, weather data, occupancy patterns, and others, the developed Digital Twin could be used to predict energy consumption, identify energy-saving measures, and evaluate their impact; evaluate the building' indoor environmental quality factors such as thermal comfort, indoor air quality, lighting levels; analyze factors that impact occupant health, productivity, and comfort; identify opportunities for improvements that enhance indoor environmental quality while maintaining energy efficiency.

- **Budget Planning for Energy Usage and Buildings:** By integrating into the Digital Twin the data related to historical costs and prices of resources, the system can help the experts of the city of Burgas to better estimate investment needs, define priorities for potential local investments, and evaluate financial mechanisms and business models aimed at improving the energy efficiency indicators and overall energy performance of the city, all these in line with its strategic goals. Through the implementation of specific IoT devices, additional data can be collected for a deeper analysis into the particular types of energy consumption in each building, assuming a future breakdown of consumption considering the equipment existing at each delivery point.

  The technical approach will follow the methodology of performing an overall life cycle cost analysis for the goal of assessing the economic viability of the proposed energy efficiency measures and PV energy systems. The upfront costs, energy savings, operational costs, maintenance requirements, and the payback period of investments should be evaluated.

3.3 DT solutions for Urban Planning

As cities continue to grow and evolve, urban planning increasingly requires innovative technologies to create sustainable, efficient, and livable environments. One such technology, the Digital Twin (DT), stands at the forefront of this digital revolution and is increasingly being recognized as an essential tool in urban planning [22], [23], offering an integrative and data-driven approach to design and manage urban areas [24], [25]. By creating a dynamic and virtual replica of a city's physical infrastructure and processes, DT facilitates in-depth analysis, simulation, and optimization of various urban planning aspects.

In the following sections we provide some examples that illustrate the application of Digital Twin Technology in urban planning [26], [27], [28], [3]. Specifically, we investigate examples from Amsterdam, Singapore and Helsinki. In a similar manner, the Cyprus innovation ecosystem will leverage Digital Twin technology to revolutionize “Smart Urban Planning” and “Smart Parking”.

3.3.1 Amsterdam, Netherlands - Sustainable Urban Development

Amsterdam has integrated Geodan's Digital Twin platform [29], [30], [31], [32], [33] into its urban-development [34] planning processes, aiming to foster sustainable and resilient urban environments. The Amsterdam's Digital Twin platform[35] offers diverse modules and features, enabling a multi-faceted approach to urban planning. For example, by using this platform the city is able to perform:

- **Simulation and Scenario Planning:** Amsterdam's Digital Twin presents a virtual replica of the city, integrating comprehensive land-use and demographic data, providing city planners a tool to explore, simulate, and evaluate diverse urban development scenarios. The platform also incorporates modules that facilitate impact assessment, including traffic simulation, shadow analysis, and environmental impact estimation.
- **Environmental Management:** The Digital Twin platform provides an advanced environmental management module that integrates real-time data from various sources, including air quality sensors, noise level monitors, and satellite imagery. This module provides city officials with the ability to monitor environmental conditions continuously and in real-time and supports the design of eco-friendly interventions to improve urban sustainability.
- **Public Participation:** A unique feature of the Amsterdam's Digital Twin is its integration with a public participation portal. This interactive interface enables citizens to visualize future developments in their neighborhoods, explore their potential impact, and provide valuable feedback. This participatory approach fosters a sense of community ownership in urban planning processes and ensures that the needs and concerns of residents are taken into consideration.

3.3.2 Singapore - Advanced Urban Planning

A note-worthy case of urban scale digital twin is ‘Virtual Singapore’ [36], [37], [38], [39], [40]. Singapore's Digital Twin platform is developed in partnership with Surbana Jurong [41], [42], a leading Asian urban and infrastructure consulting firm. This Singapore's digital twin [43] integrates a vast array of data including transportation networks, utilities and community facilities making it a crucial tool in various aspects of city planning, such as:

- **Infrastructure Planning:** The platform integrates diverse data sets, including transportation networks, utilities, and community facilities. It uses advanced AI algorithms to analyze this data, enabling optimization of infrastructure layout and design. The platform's infrastructure planning module also enables simulation and testing of various infrastructure development scenarios. The predictive capabilities of the Digital Twin also help in forecasting future

infrastructure needs based on various factors like population growth, urbanization trends, and economic development. Thus, enabling a proactive and efficient planning process.

- **Climate Resilience Planning:** The platform incorporates a climate resilience planning module that allows city planners to simulate various climate scenarios, such as sea-level rise or extreme weather events, enabling city planners to assess the potential impact on the urban environment. The module also uses predictive analytics to identify areas that are particularly vulnerable to climate change effects and supports the design of adaptive infrastructure.
- **Urban Renewal Visualization:** The platform offers 3D visualization capabilities, facilitating comprehensive understanding and communication of urban renewal proposals. This feature enables planners, stakeholders, and citizens to visualize proposed developments, whether this is a new park, a shopping complex, or a residential district, and assess their potential impacts, before the construction begins.

3.3.3 Helsinki, Finland - Smart Urban Development

The 3D City Models of Helsinki [44], [45], [46], [47], also known as the city's digital twin, are a virtual rendering of the city's environment, operations and changing circumstances. The digital twin is a combination of information technology services, open data and constantly updating information. Helsinki's city-scale Digital Twin platform, supports various aspects of smart urban planning and management. These can include:

- **3D Urban Modeling:** Through the platform's 3D visualization feature [48], city planners, architects, engineers, and even citizens can access an accurate, high-resolution 3D model of the city's physical environment. With this 3D model, providing a far greater understanding of the urban space than traditional 2D maps, urban planners and stakeholders to visualize urban spaces, infrastructure and the future development projects, thus enhancing the clarity and effectiveness of the planning process.

- **Energy Efficiency Planning:** The platform integrates building-specific data on energy consumption, to map the energy performance of different areas within the city, enabling comprehensive energy efficiency analysis. By using AI algorithms to analyze this data, city planners can identify areas and structures that are energy-inefficient and design interventions to improve energy conservation and reduce the city's overall carbon footprint. Also, its predictive capabilities enable city planners to forecast future energy needs and design strategies that align with the city's ambitious sustainability and climate goals.

- **Transport Planning:** Helsinki's Digital Twin platform, by integrating various mobility data, such as traffic flows, public transport usage, pedestrian movement, and cycling routes, enables a comprehensive view of the city's transport networks and services. The platform's transportation module uses advanced analytics that supports city planners in identifying congestion hotspots, inefficient routes, or under-serviced areas. The data can also help in optimizing transport services, designing better transport infrastructure, and promoting sustainable modes of transport, such as cycling and public transit.

3.3.4 Cyprus Innovation Ecosystem Urban Planning focus areas

The Digital Twin solutions highlighted through the examples of Amsterdam, Singapore, and Helsinki provided above, offer a wide range of applications of Digital Twin Technology in urban planning. In a similar manner, the Cyprus innovation ecosystem will leverage Digital Twin technology to revolutionize the areas of "Smart Urban Planning" and "Smart Parking". More specifically:

- **Smart Urban Planning:** By integrating a combination of terrestrial datasets, remote sensing data from sensors deployed across urban spaces, and Synthetic Aperture Radar (SAR) imagery into the Digital Twin, the system can provide meaningful insights such as trends in urban growth, building stock analysis, noise maps, real estate prices, green cover, etc. The sensors, installed strategically across the city, would capture vital data about the urban environment, further enriching the digital twin's ability to model and predict urban trends. The goal is to create an integrated system that enables accurate prediction of environmental impacts on urban areas and provides information that can be used for planning and decision-making in urban development.
- **Smart Parking:** By integrating data like parking availability and demand into the Digital Twin, the system can provide real-time information on available parking spaces and suggest optimal routes to reach them. To achieve this, sensors can be installed in parking spaces to monitor occupancy in real-time. This data can then be integrated into the Digital Twin of the city, allowing officials to understand parking patterns, predict demand, and effectively manage the allocation of parking spaces. Furthermore, this real-time data can be made accessible to citizens through a mobile application, guiding them directly to available parking spots and significantly improving the parking experience. Also, this not only saves time for drivers but also reduces congestion and pollution. However, in the context of "Smart Parking", tracking individual vehicles' movements could potentially infringe on personal privacy rights. Therefore, it is critical to establish robust data protection measures, anonymize data where possible, and secure consent for data collection where required.

4 Digital Twin Infrastructure

4.1 DT Platforms and Enablers

In this section we present some of the most representative technologies that have been used to enable digital twin platforms and case studies.

4.1.1 FIWARE

FIWARE [49] is an open-source initiative defining a universal set of standards for context data management which facilitate the development of smart solutions. It provides a framework of open-source platform components and standards for accessing and managing heterogeneous context information through open APIs.

NGSI-LD:

The adaptation of open standards plays a crucial role in the cross-domain and cross-border interoperability and replicability of smart solutions [50]. NGSI-LD [51] is an ETSI standard which defines an information model and an API for context information management. NGSI-LD is an extended subset of JSON-LD for use with context management systems.

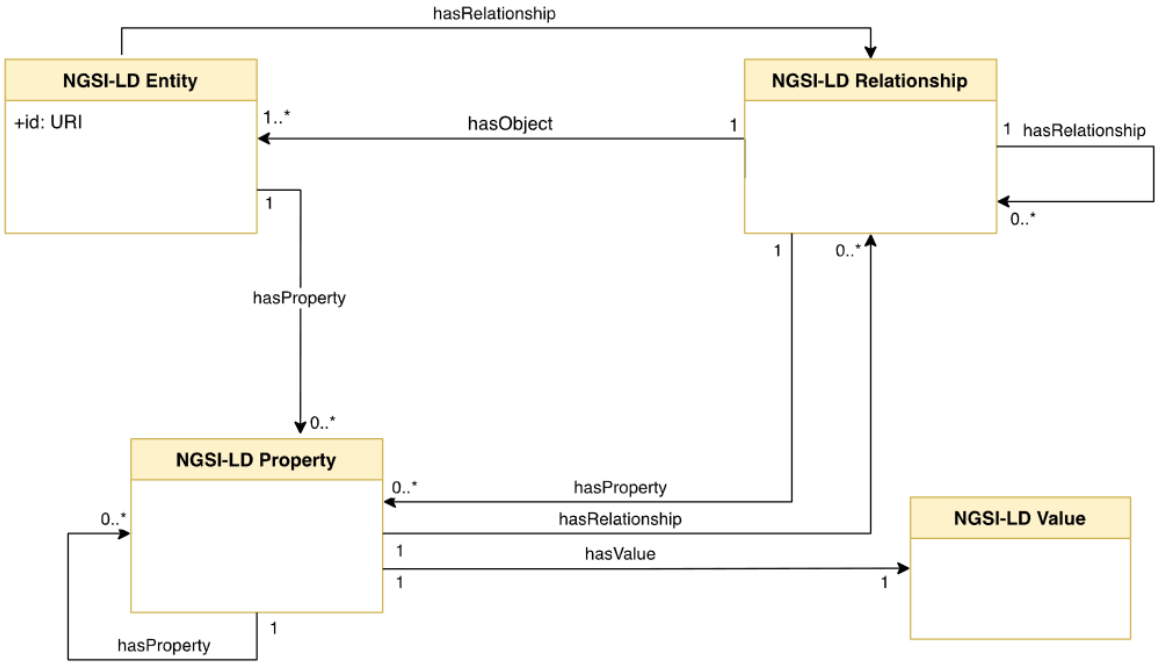

FIGURE 8: NGSI-LD INFORMATION MODEL [51]

The NGSI-LD information model [51] (Figure 8: NGSI-LD information model [51]) consists of:

- **NGSI-LD Entity**: informational representative of something that is supposed to exist in the real world, physically or conceptually.
- **NGSI-LD Property**: description instance which associates a main characteristic, i.e. an NGSI-LD Value, to either an NGSI-LD Entity, an NGSI-LD Relationship or another NGSI-LD Property and that uses the special *hasValue* property to define its target value.

- **NGSI-LD Relationship**: description of a directed link between a subject which is either an NGSI-LD Entity, an NGSI-LD Property or another NGSI-LD Relationship on one hand, and an object, which is an NGSI-LD Entity, on the other hand, and which uses the special *hasObject* property to define its target object.
- **NGSI-LD Value**: JSON value (i.e. a string, a number, true or false, an object, an array), or a JSON-LD typed value (i.e., a string as the lexical form of the value together with a type, defined by an XSD base type or more generally an IRI), or a JSON-LD structured value (i.e. a set, a list, a language-tagged string).

NGSI-LD API:

The NGSI-LD API defines a RESTful API for accessing and updating context information.

TABLE 2: THE NGSI-LD API STRUCTURE [51].

API	Functionality	Operations
CoreAPI	Context Information Provision - operations for providing or managing Entities and Attributes	Create Entity Update Attributes Append Attributes Partial Attribute Update Delete Attribute Delete Entity Batch Entity Creation Batch Entity Upsert Batch Entity Update Batch Entity Delete Merge Entity Replace Entity Attribute Replace Batch Entity Merge
	Context Information Consumption - operations for consuming Entities and checking for which Entity Types and Attributes Entities are available in the system	Retrieve Entity Query Entities Retrieve Available Entity Types Retrieve Details of Available Entity Types Retrieve Available Entity Type Information Retrieve Available Attributes Retrieve Details of Available Attributes Retrieve Available Attribute Information

	Context Information Subscription - operations for subscribing to Entities, receiving notifications and managing subscriptions	Create Subscription Update Subscription Retrieve Subscription Query Subscription Delete Subscription Notification
Temporal API	Temporal Context Information Provision - operations for providing or managing the Temporal Evolution of Entities and Attributes	Upsert Temporal Representation Add Attributes to Temporal Representation Delete Attributes from Temporal Representation Partial Update Attribute Instance Delete Attribute Instance Delete Temporal Representation
	Temporal Context Information Consumption – operations for consuming the Temporal Evolution of Entities	Retrieve Temporal Evolution of Entity Query Temporal Evolution of Entities
Registry API	Context Source Registration – operations for registering Context Sources and managing Context Source Registrations (CSRs)	Register Context Source Update CSR Delete CSR
	Context Source Discovery – operations for retrieving and discovering CSRs	Retrieve CSR Query CSRs
	Context Source Registration Subscription – operations for subscribing to CSRs, receiving notifications and managing CSRs	Create CSR Subscription Update CSR Subscription Retrieve CSR Subscription Query CSR Subscription Delete CSR Subscription CSR Notification
JSON-LD Context API	Storing, managing and serving @contexts	Add @context List @contexts Serve @context Delete and Reload @context

Context Broker:

The Context Broker is the only core and mandatory component of any "Powered by FIWARE" platform or solution. It is a software component that implements the NGSI-LD API and enables context data management. All interactions between applications or platform components and the Context Broker take place using the NGSI-LD API.

Some implementations of the Context Broker include:

- Orion-LD developed by FIWARE [52]

- Scorpio developed by NEC Laboratories Europe and NEC Technologies India [53]
- Stellio developed by EGM [54]

FIWARE Catalogue:

Building around the Context Broker, the FIWARE Catalogue (Figure 9) offers a list of components called Generic Enablers (GEs) [55] .

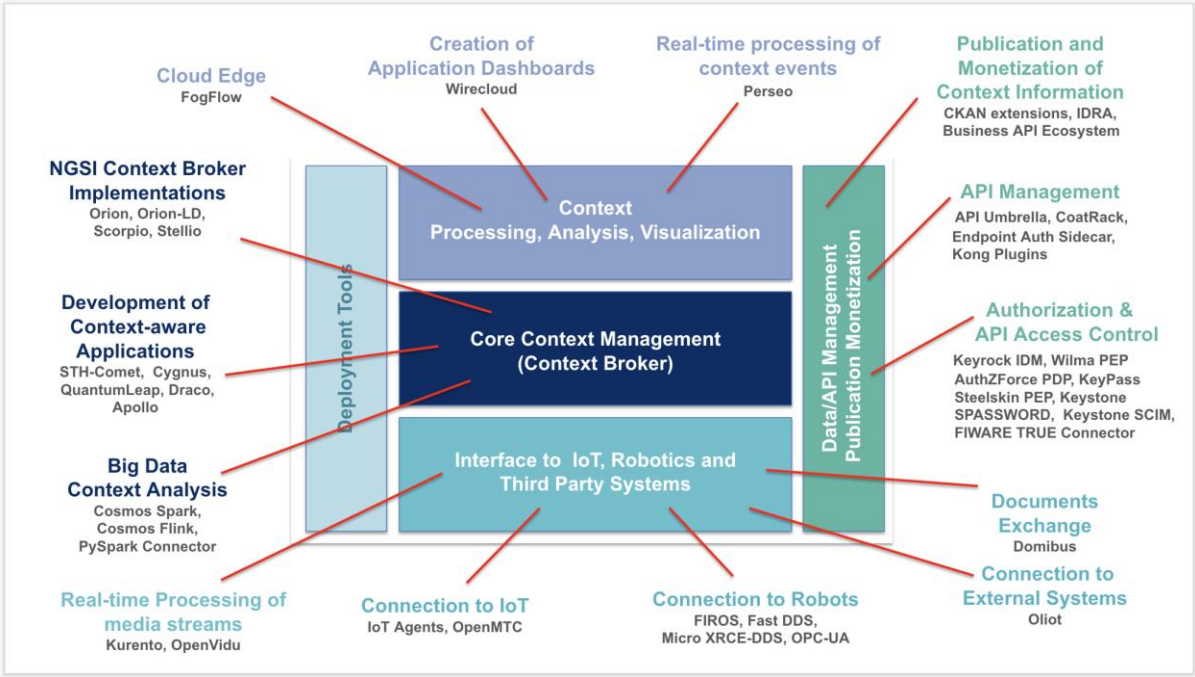

FIGURE 9: FIWARE CATALOGUE [55].

- Core Context Management manipulates and stores context data so it can be used for further processing.
- Interfacing with the Internet of Things (IoT), robots and third-party systems, for capturing updates on context information and translating required actuations.
- Processing, analysis and visualization of context information, implementing the expected smart behaviour of applications and/or assisting end users in making smart decisions.
- Context Data/API management, security, publication and monetization, bringing support to usage control and the opportunity to publish and monetize part of managed context data.

Deployment Tools such as Docker images and Helm-chart recipes are available for each Generic Enabler.

Reference architecture:

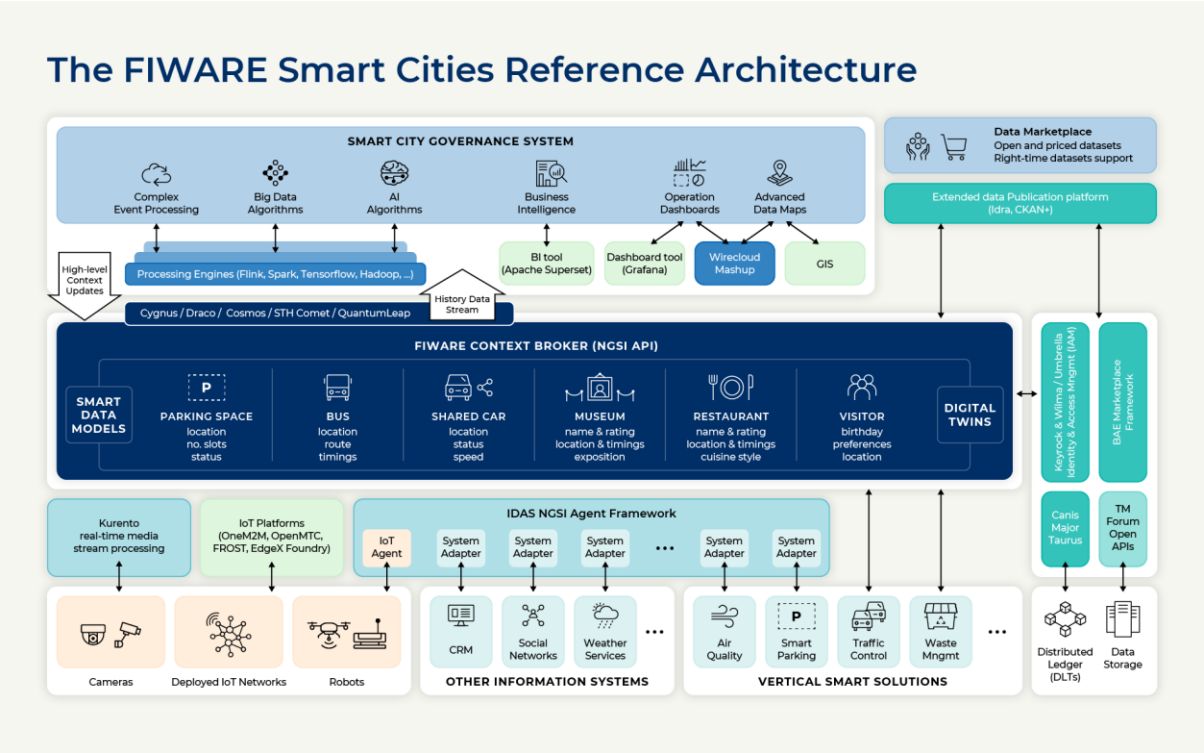

FIGURE 10: FIWARE SMART CITIES REFERENCE ARCHITECTURE [56].

Smart Data Models:

Smart Data Models [57] is a joint-collaboration program led by the FIWARE Foundation, India Urban Data Exchange (IUDX), TM Forum and Open & Agile Smart Cities (OASC), which aims to support the adoption of a reference architecture (Figure 10) and compatible common data models, underpinning a digital market of interoperable and replicable smart solutions [58].

Smart Data Models provide open-licensed shared data models for the following domains:

- Smart Cities
- Smart Agrifood
- Smart Water
- Smart Energy
- Smart Logistics
- Smart Robotics
- Smart Sensoring
- Smart Health
- Smart Destination
- Smart Environment
- Smart Aeronautics
- Smart Manufacturing
- Cross Sector

4.1.2 AWS

Amazon has been extending intelligent software solutions through its AWS platform, and offers Digital twin solutions with AWS IoT TwinMaker. This platform offers the tools to efficiently create a virtual representation of existing physical systems with real-world data integration for faster monitoring operations, as it is described in the paragraphs below.

Smart Territory Framework:

The Smart Territory Framework (STF) [59] is an open-source framework that supports the development and integration of smart solutions across multiple domains. Its high-level architecture is shown in Figure 11 The STF complies with the NGSI-LD standard and leverages the NGSI-LD compliant Smart Data Models initiative that provides open-licensed data models.

The STF Core consists of two modules:

- The STF IoT module
- The Context Broker

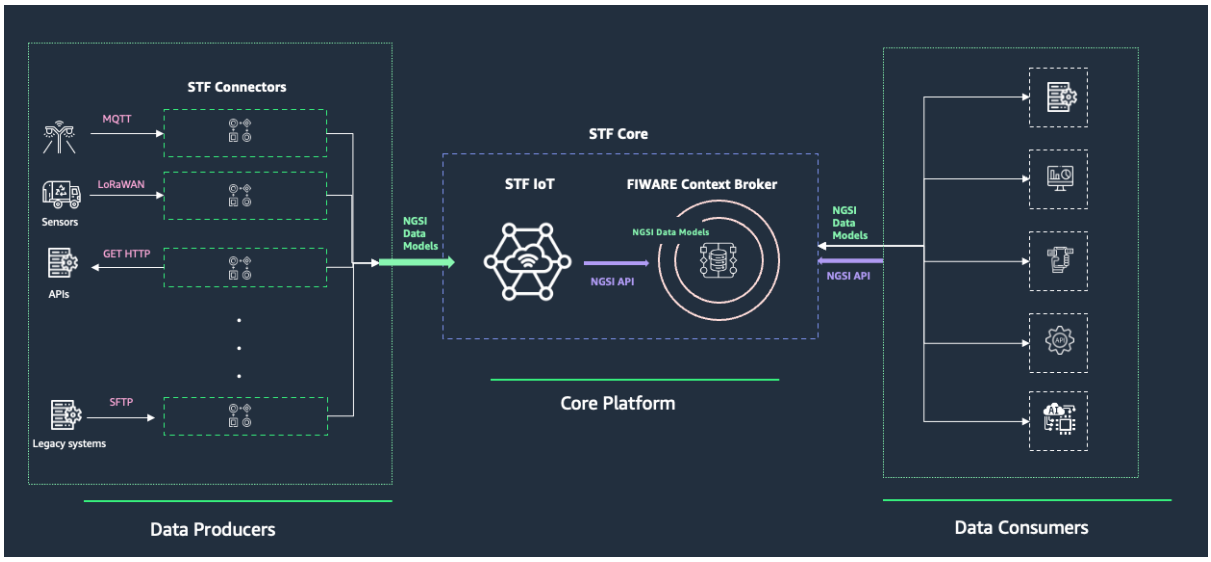

FIGURE 11: STF HIGH-LEVEL ARCHITECTURE [59].

The STF Core provides a unified API that exposes two services:

- The NGSI-LD API to interact with the FIWARE Context Broker
- The STF IoT API to provision and manage things in the STF IoT Registry

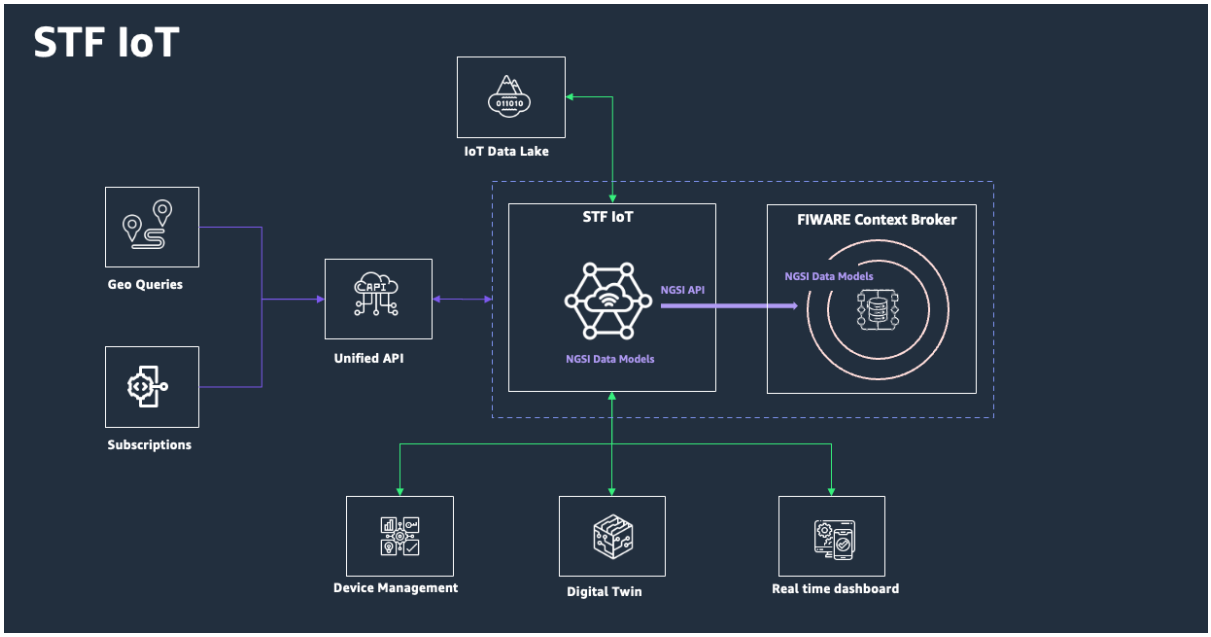

FIGURE 12: STF IOT [59].

The STF IoT module (Figure 12) is synchronized with the Context Broker in real-time. Any change that occurs in the STF IoT module is replicated in the Context Broker and is stored in the STF IoT Data Lake.

AWS IoT TwinMaker:

AWS IoT TwinMaker [60] is a service used for developing digital twins of real-world systems. The STF IoT Data Lake shown in Figure 13 can be used as a data source for creating digital twins using the AWS IoT TwinMaker.

Reference architecture:

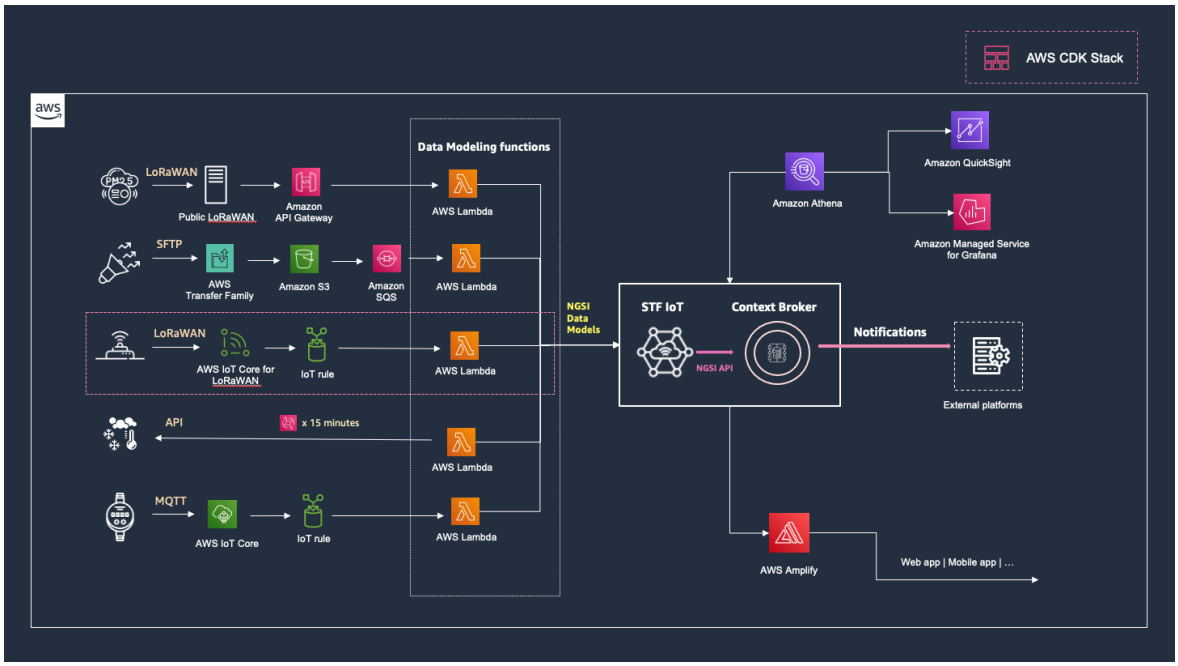

FIGURE 13: STF REFERENCE ARCHITECTURE [61].

4.1.3 Azure IoT

Azure IoT [62] is a collection of Microsoft-managed cloud services, edge components, and SDKs that enable connection, monitoring, and control of IoT assets at scale. Its architecture is shown in Figure 14.

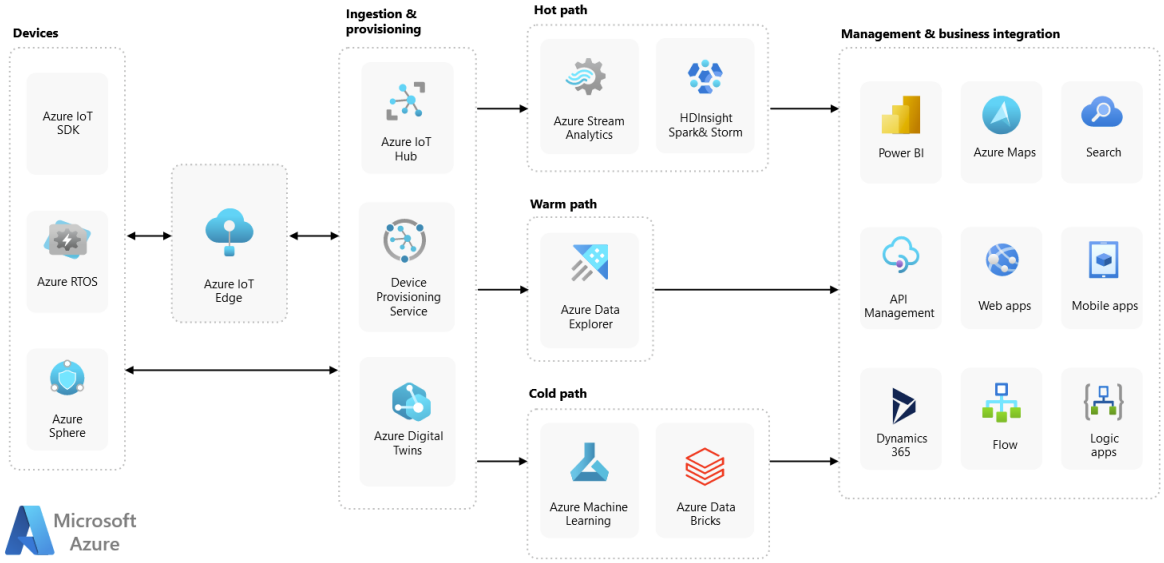

FIGURE 14: AZURE IOT REFERENCE ARCHITECTURE [63].

Azure IoT solutions consist of:

- Things, typically devices that generate data.
- Insights formed about the data.
- Actions taken based on insights.

Azure IoT supports various devices (e.g., microcontrollers, developer boards, gateways running custom software) which can either perform local processing through services such as the Azure IoT Edge [64] or connect directly to the Azure cloud.

Azure IoT Hub [65] is a managed service hosted in the cloud that acts as a central message hub for communication between an IoT application and its attached devices. It supports a wide range of devices and messaging patterns.

Azure IoT Central [66] is an IoT application platform (aPaaS) that provides a ready-to-use UX and API surface built to connect, manage, and operate fleets of devices at scale. The web UI enables users to connect devices, monitor device conditions, create rules, and manage devices and their data throughout their life cycle. Azure IoT Central applications use multiple Azure IoT hubs as part of their scalable and resilient infrastructure.

Azure IoT offers three data processing paths based on the requirements for latency and data access.

- The hot path analyzes data in near-real-time as it arrives. It typically utilizes a stream processing engine and its output can trigger alerts or can be written to a structured format.
- The warm path analyzes data that can accommodate longer delays for more detailed processing.
- The cold path performs batch processing over large volumes of data at longer intervals (e.g., hourly or daily).

Based on the insights gathered about the data, various business integration actions may be performed. Such actions include:

- Storing informational messages.
- Raising alarms.
- Sending email or SMS messages.
- Integrating with business applications such as customer relationship management (CRM) and enterprise resource planning (ERP).

Azure Digital Twins:

Azure Digital Twins [67] is a platform as a service (PaaS) offering that enables the creation of twin graphs based on digital models of various environments (e.g., buildings, factories, farms, energy networks, railways, stadiums, entire cities). A sample of Azure IoT solution in shown in Figure 15

In Azure Digital Twins, the digital entities that represent entities in a physical environment are defined using custom twin types called models. Models are defined in a JSON-like language called Digital Twins Definition Language (DTDL) [68] , and they describe types of entities according to their state properties, telemetry events, commands, components, and relationships. While models can be designed from scratch, pre-existing sets of DTDL industry ontologies [69] can also be used.

The Azure Digital Twins Explorer [70] provides an interface to build and interact with the Azure Digital Twins graph.

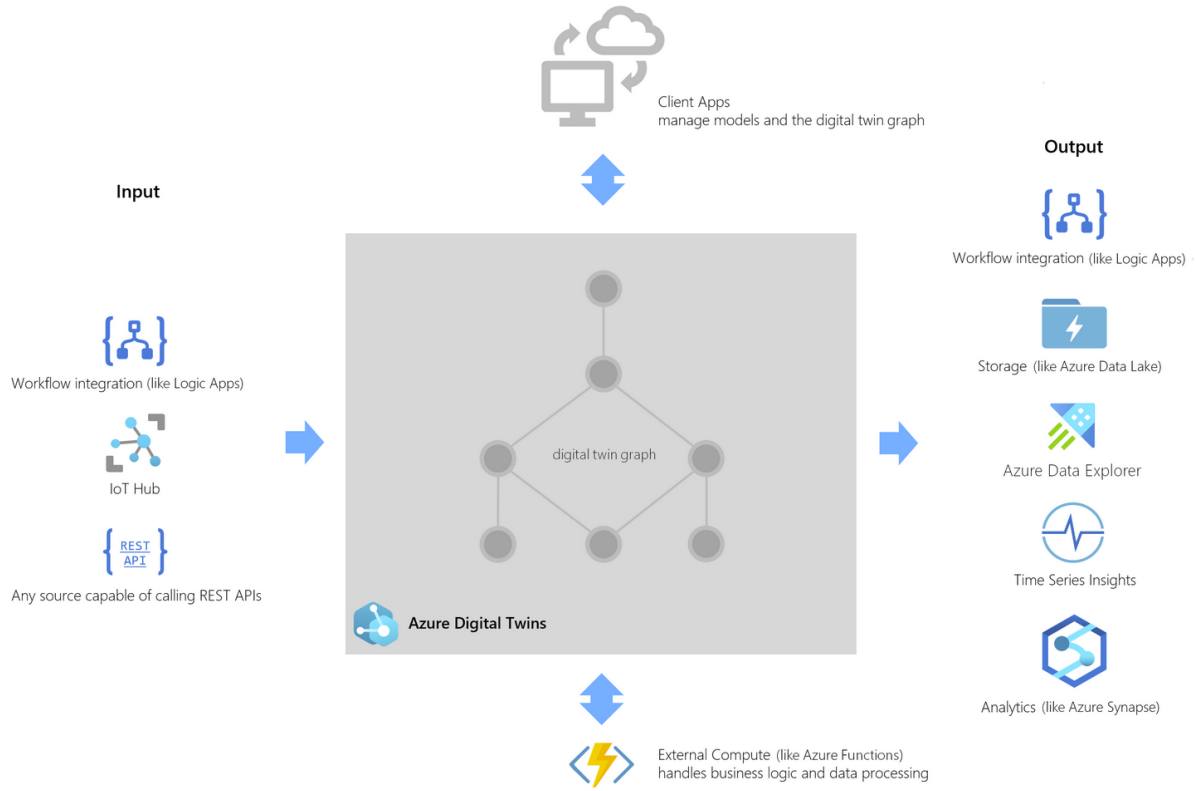

FIGURE 15: SAMPLE AZURE IOT SOLUTION [71].

4.2 Digital Infrastructure

The digital infrastructure backbone for a modern Digital-Twin or Metaverse solution in the Smart Cities context follows a 4-layer technological stratum. A comprehensive map for the general architecture of the required digital infrastructure and different options for each part follows bellow (Figure 16). It is important to note that more functionality and microservices may be added for predictive AI, analytics etc. but that lies beyond the scope of a Metacity's infrastructure itself and third-party applications, that may provide such solutions, are supported through a Digital Twin API.

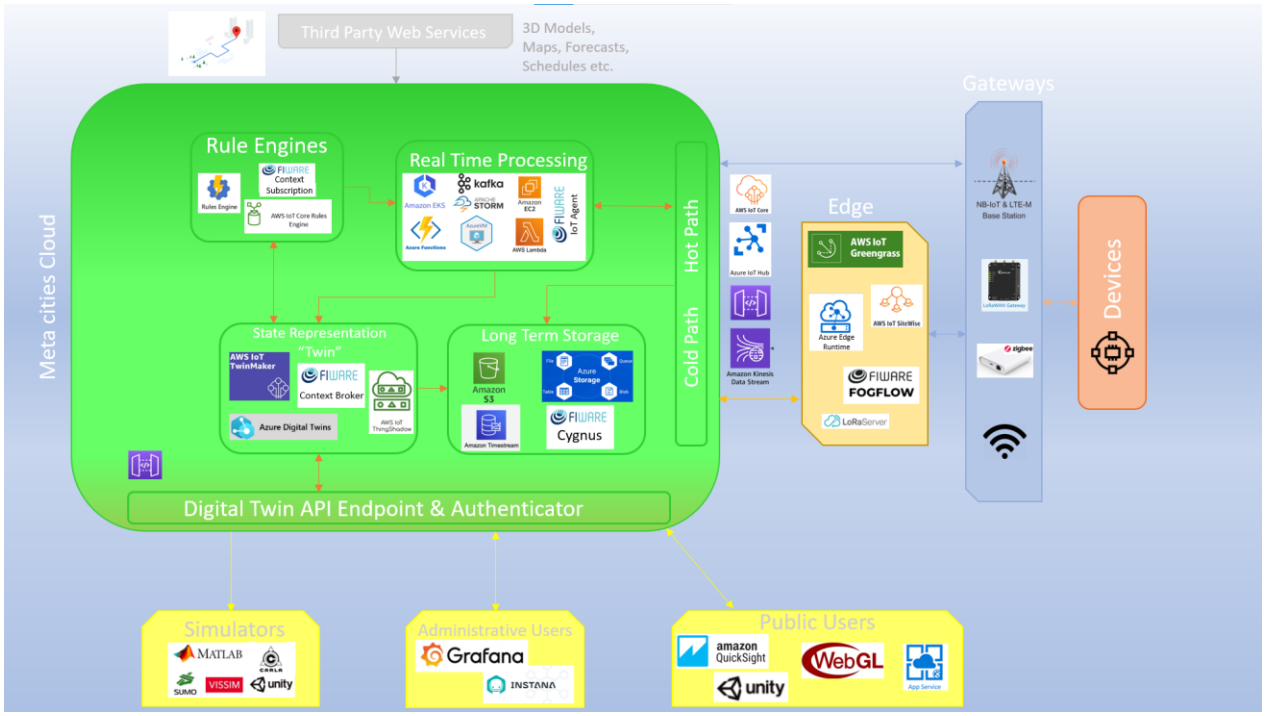

FIGURE 16: TYPICAL MODERN METACITY DIGITAL INFRASTRUCTURE.

The **First layer** (Device Layer) is the protagonist of any IoT system and the one closest to the physical twin. It is assembled by the physical devices. Said devices can be sensors, actuators, or both. Sensors collect data in different forms such as multimedia, time-series, or event-based analytics from either directly the physical plane or through existing information & management systems. Similarly, actuators provide feedback to the environment either directly (e.g., smart traffic lights, smart gates etc.) or indirectly through previously installed equipment (e.g., arming a pre-existing security system). In the classification of different solutions, the Device Layer offers significant variations in the communication protocols implemented, power & processing requirements, and the installation scheme & cost. Different installation plans can tackle a variety of challenges, grids of similar low cost and low power devices can monitor wide areas of interest and forgo reliance to signal coverage by implementing mesh communication or daisy-chain patterns. High interest points or real time interaction needs may be served by grid powered devices with high throughput and low latency connectivity. Regarding the implemented communication protocols a device may use one of several options such as Wi-Fi, Bluetooth, VSAT, ZigBee, LoRa, Cellular (5G, 6G etc.), Wi-Sun, Ethernet, NB-IoT to accommodate specific power, range, or data-rate requirements.

In the city environment the topology introduces further specialization characteristics pertaining to the communication protocols implemented. More specifically, a smart city provides close access to grid power and often physical WAN connectivity (ethernet & Wi-Fi) for most sensor placement locations, both on a city's motorways and estate. It is worthy of note that while the device's physical access to

resources may be easy to implement it may not be hustle-free to do so since jurisdictive limitations are topologically dense inside the cities. Meanwhile, cellular connectivity is rather abundant both in transmission quality and coverage while inside the city borders, driven by high consumer density. Finally, given the frequency of sensor installation inside a city, wireless communication between devices in close proximity is also attainable. Given those factors the most prevalent solutions are:

a. In applications where high data rate is required and grid power (or self-sustaining solar/wind power) is available, cellular (5G, 6G etc.) or Wi-Fi (if available) are the optimal solutions.
b. When installations are operational without need for high bandwidth connectivity but indoors or in locations under poor coverage and no Wi-Fi access, NB-IoT offers the best compromise.
c. For moving objects (vehicles or other assets) 5G & 6G, NB-IoT and LoRa provide connectivity with descending order regarding data-rate and power consumption. A LoRa mobile device will also require a sufficiently dense LoRa Gateway installation in the area or routes where the assets are predicted to move but also means the device attached to the tracked element will be less intrusive (without needs for external power).
d. In per-floor systems or small areas of a building, often the combination of a LoRa or ZigBee Gateway with a full ecosystem of the appropriate devices may provide easy low bandwidth connectivity without interfering with the already saturated Wi-Fi local network.
e. In open spaces where no power is easily available or intrusive action is to be avoided (parks, squares, highways etc.) LoRa devices and Gateway(s) offer easy installation and low maintenance.

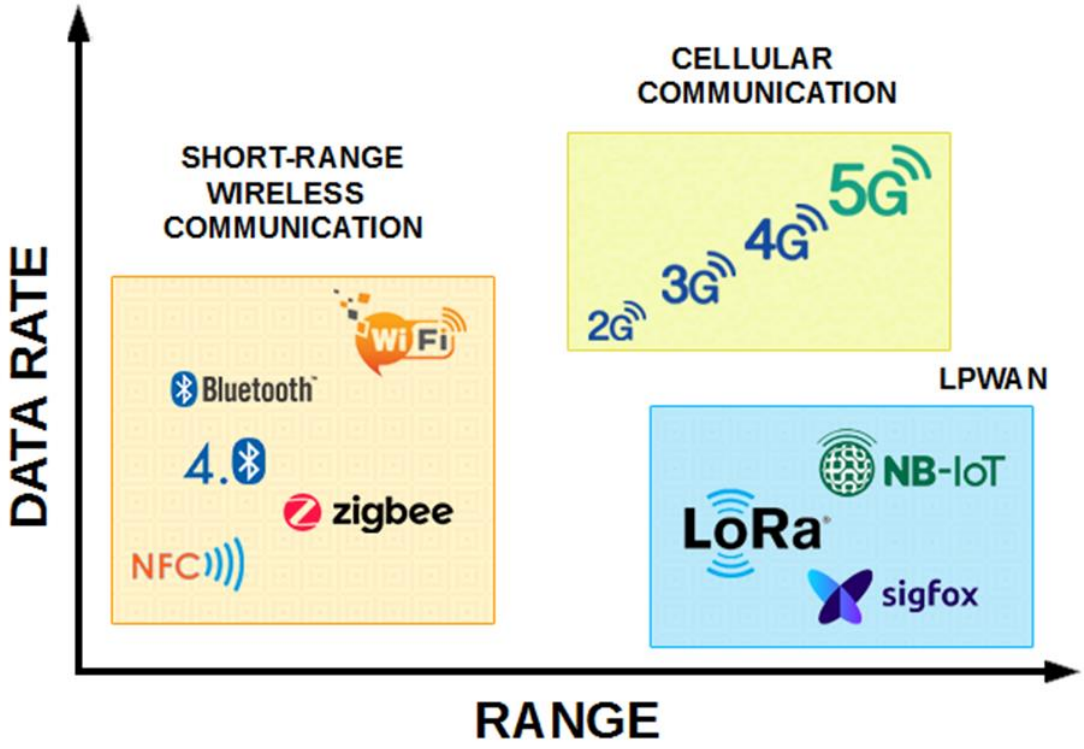

FIGURE 17: IOT WIRELESS PROTOCOLS, DATA-RATE AND RANGE GRAPH [72].

The **Second Layer (Gateway Layer)** takes the role of bridging the Device Layer with an IP stack or directly to the Internet. On the device layer side, a multitude of protocols, encodings and encryption standards transfer information, above the Gateway Layer all information passes through the OSI Transport Level (either TCP or UDP) so the Second Layer is also responsible for encoding and decoding traffic. Each device may provide a corresponding decoder code snippet to be run in the Edge or Gateway layer to decode and decrypt the produced packets since those may be compressed (for transmission energy savings) and/or encrypted (the device layer is exposed to cyber-attacks such as Man-in-the-Middle and Sniffing). The infrastructure of the Second Layer is heavily influenced by design choices in the First Layer. This part of the infrastructure often is grouped together with the First Layer.

The **Third Layer** often called Edge-Mist Cloud is a distributed processing layer between the Cloud and the Gateway Layers. It is tasked with distributed computing, real time workloads where latency is important, high throughput data flows where bandwidth optimization provides significant efficiency benefits and critical application processing when offline operation is a security requirement. All major Cloud operators currently provide Edge options (e.g., AWS Outposts, Azure Stack Edge etc.).

The **Fourth Layer** is the Cloud where all aspects of a Digital Twin lie. Long term data collection flows are separated from real-time streams either from or to equipment and users. Information is processed, stored in the Twin State, and forwarded to rule-engines that facilitate the corresponding actions (cloud actions, actuator feedback, user responses etc.). Twin States may also provide 3D Visual representations. Long term stored data are utilized in analytics and machine learning microservices. The cloud architecture can also interact with third party services through a multitude of Web APIs to request information useful to its operation such as maps and visual assets (Google's 3D Tiles API), schedules, weather forecasts and more. Both raw data and processed models can either be visualized through microservices or incorporated in simulators to provide insights and testing frameworks. Administrative users or the public may access the twin either through visualization/control panels , directly through the 3D views available or though websites incorporating insights from the Twin's state.

4.3 DT Generic Architecture

In this section we present various architecture solutions based on the literature review proposed for each targeted domain; smart mobility, green city and urban planning. We notice that the majority of solutions follow similar approaches and entail the same main cores.

4.3.1 Architecture for Smart Mobility

A typical Digital Twin architecture for Smart Mobility is shown in the next diagram, Figure 18Figure 18, and consists of three planes: the lower plane (in blue) stands for the physical world where humans, vehicles, and traffic infrastructures reside; the upper plane (in yellow) represents the digital space where the digital replicas of those physical entities are found; and the space between the physical and the logical planes, the communication plane plays a crucial role in this framework to allow real-time and non-real-time data streaming, both upstream and downstream.

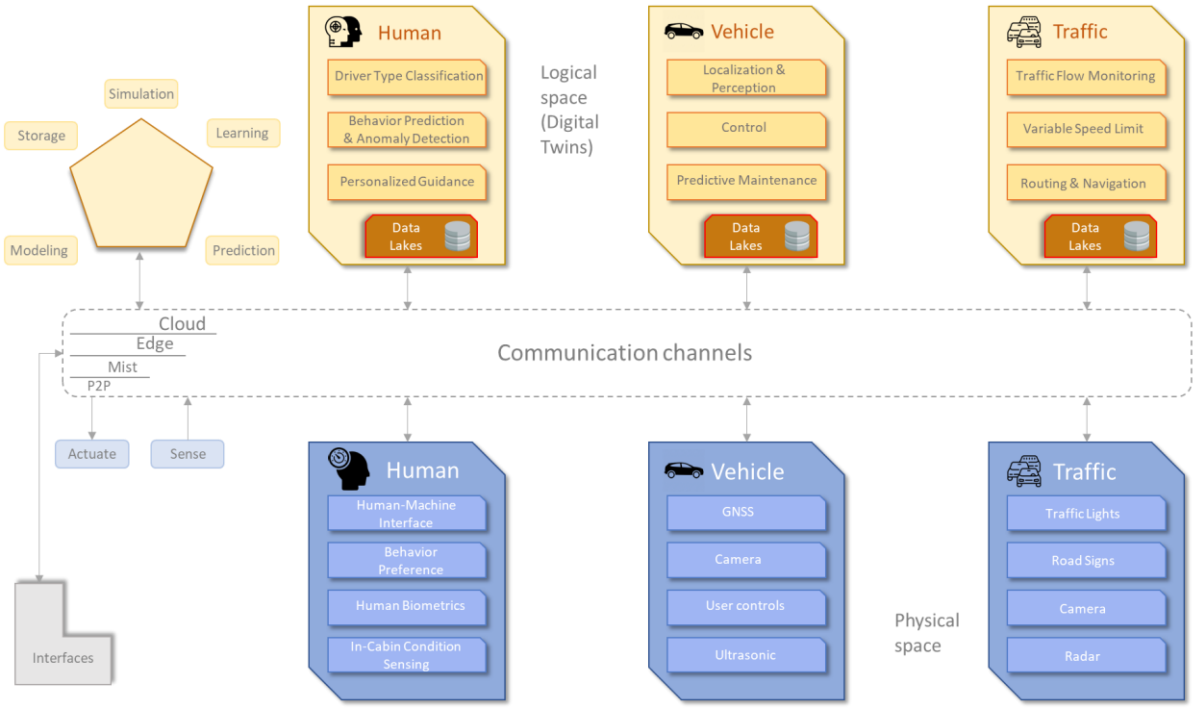

FIGURE 18: A TYPICAL DIGITAL TWIN ARCHITECTURE FOR SMART MOBILITY.

The three main entities in this architecture are: Humans, Vehicles and Traffic. Given the existence of the communication plane, each of the physical entities can be connected to their respective counterpart in the digital space and exchange data with each other, thereby continually strengthening their respective Digital Twins.

4.3.2 Architecture for Green City

The three main aspects of Digital Twins are **data acquisition, data modeling, and data application**. A typical Digital Twin architecture can use **four technologies to collect and store real-time data, obtain information to provide valuable insights, and create a digital representation of a physical object** [73].

These technologies include the Internet of Things (IoT), Artificial Intelligence (AI), Extended Reality (XR), and Cloud, Figure 19 . In addition, each specific Digital Twin uses a particular technology, depending on the application type, to a greater or lesser extent.

1. **Internet of Things (IoT):** IoT refers to a giant network of connected ‘‘things’’. The connection is between things–things, people–things, or people–people. Digital Twins use IoT as its primary technology in every application. By 2027, more than 90 percent of all IoT platforms will have Digital Twinning capability. IoT uses sensors to collect data from real-world objects. The data transmitted by IoT is used to create a digital duplication of a physical object. The digital version then can then be analyzed, manipulated, and optimized. IoT constantly updates data and helps Digital Twin applications create a real-time virtual representation of a physical object. Therefore, every Digital Twin application uses IoT as a primary technology.
2. **Cloud Computing:** Cloud computing refers to delivering hosted services over the Internet. The technology efficiently stores and accesses data over the Internet. Cloud computing provides Digital Twins with data computing technology and cloud data storage technology. Cloud computing allows Digital Twin, with large volumes of data, to store data in the virtual Cloud and easily access the required information from any location. Cloud computing enables Digital

Twins to effectively reduce the computation time of complex systems and overcome the difficulties of storing large amounts of data.

3. **Artificial Intelligence (AI):** As a discipline of computer science, AI seeks to mimic the basis of intelligence to create a new intelligent machine capable of responding like human-to-human intelligence. Areas of AI study include Robotics, image recognition, and language recognition. Neural Networks, Machine Learning, Deep Learning, and expert systems, AI can assist Digital Twins by providing an advanced analytical tool capable of automatically analyzing obtained data and providing valuable insights, making predictions about outcomes, and giving suggestions as to how to avoid potential problems.
4. **Extended Reality (XR)** is an umbrella term used to describe immersive technologies like Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). These technologies can merge the physical and virtual worlds and extend the reality we experience. XR creates digital representations of objects where digital and real-world objects co-exist and interact in real-time. Digital Twins utilize XR capabilities to digitally model physical objects, allowing users to interact with digital content.

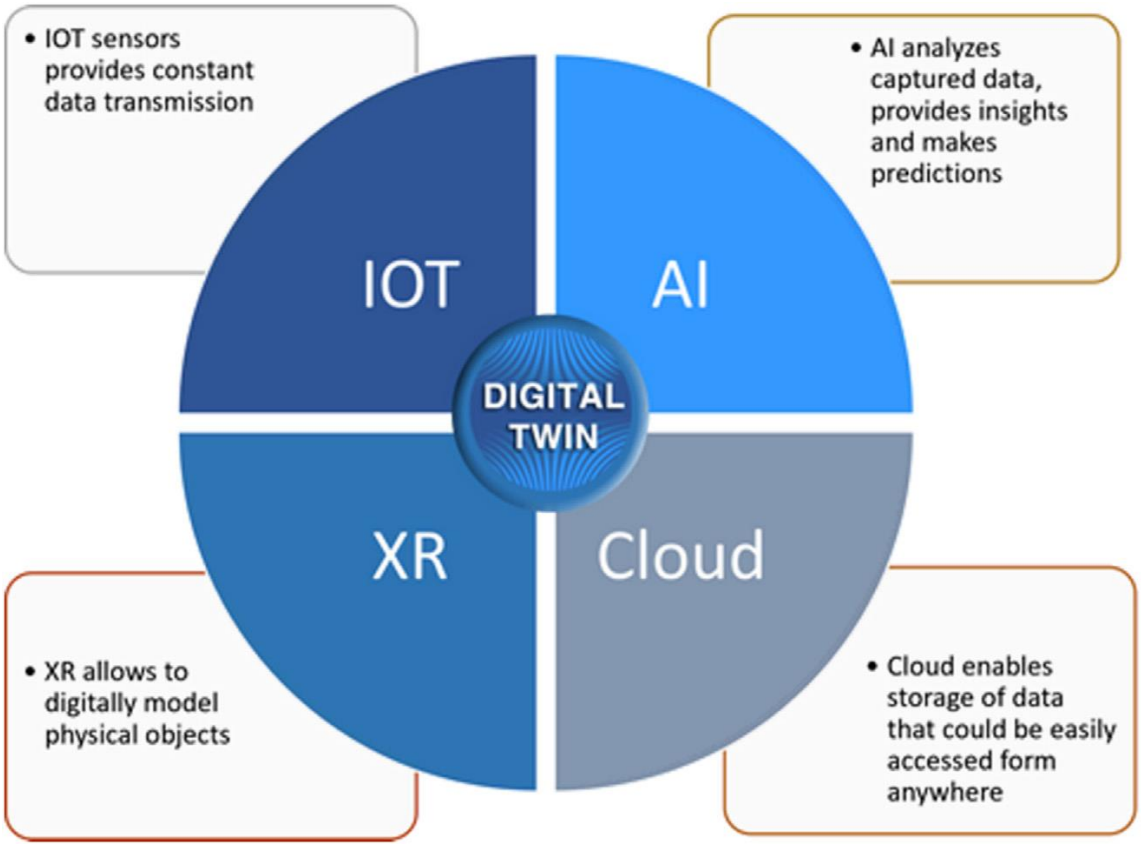

FIGURE 19: TECHNOLOGIES OF DIGITAL TWINS.

Up-scaling the Smart Burgas Urban Platform

The digital twin city is a new application model of the "digital twin" concept in smart city construction - that is, recreating a complex, giant system in digital space that maps and interacts with the real world **to realize the interaction between the physical and digital dimensions of the city.**

The understanding of the Green city digital twin city operational mechanism contains following steps:

1. Through IoT, information modeling and a ubiquitous network, real-time **data is collected,** making it possible to connect and map from reality to virtuality;
2. Based on the knowledge map of a city's operation patterns and big data analysis algorithms, problems in the digital space can be analyzed and scientific guidance established for policy-makers.;
3. Through the remote control and interactive interface of the IoT, the real city can be controlled by a virtual mechanism and establish: 1) the whole life-cycle management service of the physical city; 2) the optimization and improvement of the city's operations; 3) and its sustainable economic development.

The digital twin city has four major technical characteristics: 1) Precise mapping of the physical and digital city; 2) Analysis of and insights from the digital city; 3) The virtual-real integration of the digital city and the physical city 4) The intelligent application of insights from the digital city to the physical city.

Main visions of the Green city digital twin are: Intensive and efficient urban production and operations; liveable and convenient urban living spaces; sustainable urban environment.

The philosophy of up-scaling the Smart Burgas Urban Platform with digital twin application in the Green Cities domain is to use the already excising architecture framework which consists of four core elements (infrastructure in place; data resources in local cloud infrastructure; exploitable platform capacity, newly implemented application scenarios) and involve five external elements (strategy and implementation mechanisms, stakeholders, funding and business models, standards and evaluation, cybersecurity).

The SmartBurgas urban platform has well-established GIS databases which contain geospatial model of the city and base map layer imported each year after precise photogrametric surveys. Data models related to Green city domain as energy efficiency, green system of the city, heat islands etc., based on AI processed IoT Services and registry data and other supporting data are easily added to virtual objects. The new pilot implementations related to energy efficiency management and policy use cases are expected to up-scale the city digital twin to a new level.

4.3.3 Architecture for Urban Planning

A Digital Twin, as a comprehensive, data-driven representation of urban environments, can support city planners and other related stakeholders to simulate, visualize, and analyze various aspects of urban ecosystem; from assessing the impact of new developments to tracking real-time changes and predicting future trends. However, the effectiveness of a Digital Twin system is based on its underlying architecture [74] which involves numerous Hardware and Software components, with Middleware for data management in between, orchestrated to work as a uniform system [75]

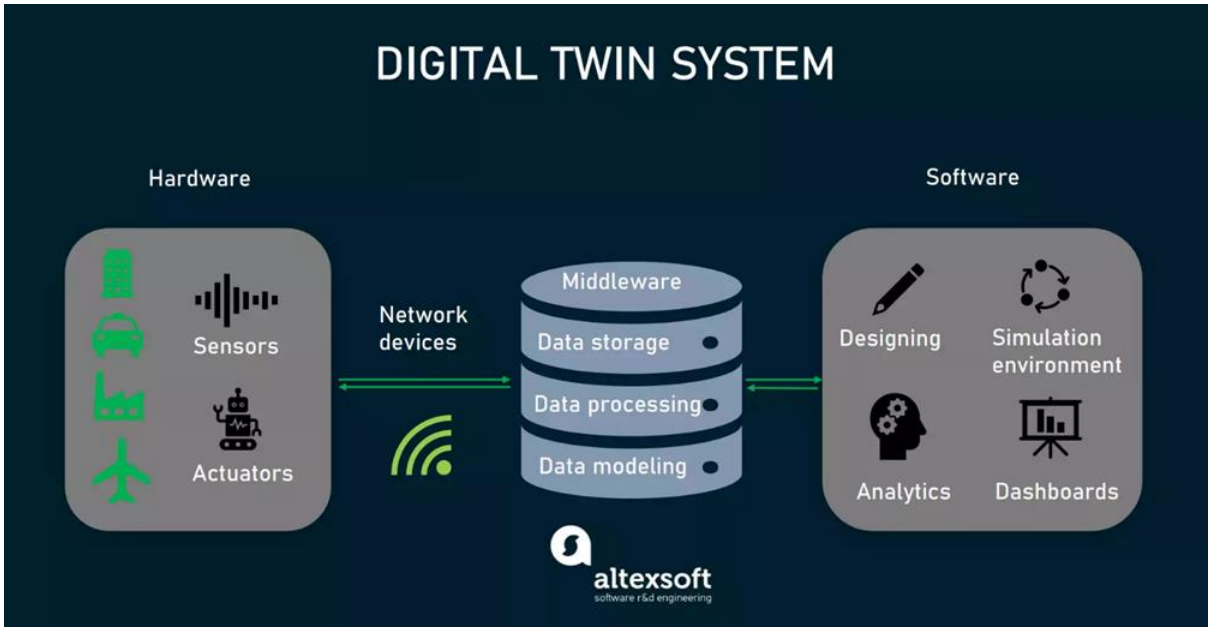

FIGURE 20: COMPONENTS OF A DIGITAL TWIN SYSTEM [75].

Based on Figure 20Figure , the system architecture of a Digital Twin for Urban Planning can typically comprised the following group of components: i) Hardware Components; ii) Data Management Middleware; and iii) Software Components.

4.3.3.1 Hardware components

The core elements forming the fundamental basis of DTs is its Hardware Components serving as the primary Data Sources that initiate the exchange of information between physical assets and their virtual counterparts. Each hardware component serves a specific purpose in the construction and operation of a Digital Twin, ensuring a continuous flow of data that drives insights, decisions, and actions. In the context of Urban Planning, the hardware components can be:

- **Internet of Things (IoT) Sensors:** These are embedded within urban infrastructure and are essential in providing real-time data about the city's operations. Examples include traffic sensors installed on roads and bridges for traffic flow data, weather sensors for real-time climate data, air quality monitors to track environmental health indicators, and energy usage meters on buildings to monitor power consumption.
- **Actuators:** These devices convert digital commands into physical actions and are critical in automating responses to certain situations based on the insights derived from the Digital Twin. For instance, actuators can be utilized in adaptive traffic control systems where they modify traffic light durations in response to live traffic data, facilitating smoother traffic flow.
- **Networking Hardware:** Devices such as routers, edge servers, and IoT gateways enable the vast amount of data collected by IoT sensors and other sources to be communicated effectively and processed in a timely manner. They form a crucial part of the data infrastructure underpinning the Digital Twin.
- **GIS Databases:** These contain a wealth of geospatial and demographic data that provide additional context to the real-time data collected by IoT sensors. Data stored can include demographic statistics, land use data, economic indicators, detailed information about the built environment, satellite and drone imagery revealing changes in land cover, the presence of urban heat islands, and other important geospatial parameters.
- **Public Services and Utilities Data:** This encompasses crucial datasets about the operations of various public services such as waste collection schedules, water and electricity usage, public

transportation routes and schedules, etc. While not a hardware component in the traditional sense, this data source plays a vital role in enriching the Digital Twin. It adds more layers of detail, allowing for a comprehensive representation of the city and thereby enabling more effective planning and management of urban services within the Digital Twin framework.

4.3.3.2 Data Management Middleware

This part of the system architecture mainly comprises a centralized repository to accumulate data from different sources. This includes components for:

- **Data Processing, Modelling and Integration:** All data collected from the various sources described above will be provided to the Data Management Midleware to be processed, modelled into a unified format and integrated into the Digital Twin. During this stage the collected data undergoes various preprocessing steps like cleaning, normalization, and error handling. The aim is to ensure the integrity and usability of the data and its integration into a common format and database that can be utilized in the Digital Twin model. The efficiency and reliability of this stage are paramount to ensuring the Digital Twin's real-time responsiveness and the validity of the insights it generates.
- **Data Storage and Management:** Given the extreme amounts and varied types of data involved, the Digital Twin requires robust, scalable, and efficient data storage and management solutions. These often involve distributed databases or cloud storage solutions that can handle the large volumes of data, support fast data retrieval, and provide necessary scalability. Spatial databases might be used to store and manage GIS data, while time-series databases could handle sensor data. Managing these databases, ensuring data security, and maintaining data quality are essential elements of this component.

4.3.3.3 Software Components

These serve as the foundation, facilitating the analysis, simulation, and visualization of urban planning data. Can include components for:

- **Modeling and Simulation**: These act as the digital mirror of the physical city, capturing its intricacies and operational dynamics. They host the algorithms and mathematical models that simulate various aspects of urban planning. These models transform raw data into actionable insights and offer scenario-based predictions, leveraging either physics-based, data-driven, or hybrid approaches, depending on the application.
- **Data Analytics and AI**: These form the intelligence layer of the Digital Twin architecture. Utilizing sophisticated techniques such as machine learning and deep learning, these components parse huge amount of urban data, identify patterns, and generate predictions. In an urban planning context, these insights could range from trends in urban growth and real estate prices to environmental quality indices. They serve an essential role in anomaly detection, such as sudden spikes in traffic or energy usage, and predictive analysis, like forecasting future urban growth patterns.
- **Visualization and Interaction Tools (Dashboard):** These tools provide a user-friendly interface, promoting stakeholder engagement with the Digital Twin. They enable the comprehensive visualization of the city's data, facilitating the running of simulations and the assessment of outcomes. GIS platforms such as ArcGIS or QGIS may be employed to map urban data, while 3D modeling software like SketchUp or Blender can visualize the city’s-built environment. Web-based dashboards present real-time data and analytics results, and interactive tools offer stakeholders the capability to manipulate data and explore 'what-if' scenarios. These tools foster a more engaging, intuitive, and effective approach to urban planning with Digital Twins."

4.3.3.4 A layered view of the Architecture

A digital twin is a virtual representation of a physical object or system that enables real-time monitoring, analysis, and simulation. The architecture of a digital twin typically consists of several layered components, as described below.

- **Data Acquisition Layer:** This layer is responsible for collecting data from various sources, such as sensors, IoT devices, and external databases. The data is typically in the form of measurements, images, or textual information [76].
- **Data Processing Layer:** In this layer, the collected data undergoes preprocessing and filtering to remove noise and irrelevant information. It also includes data fusion techniques to integrate data from multiple sources [77].
- **Data Storage Layer:** This layer stores the processed data in a structured format that facilitates efficient retrieval and analysis. It may employ technologies such as relational databases, data lakes, or distributed file systems [78].
- **Analytics and Modeling Layer:** Here, advanced analytics techniques are applied to gain insights from the collected data. This layer may include statistical analysis, machine learning algorithms, or simulation models to predict system behavior and identify anomalies [79].
- **Visualization Layer:** This layer provides user-friendly interfaces to visualize the digital twin and its associated data. It may include 2D/3D visualizations, dashboards, or augmented reality interfaces for effective data interpretation [80].
- **Communication Layer:** This layer facilitates communication between the digital twin and external systems, such as control systems or human operators. It may use protocols like MQTT or RESTful APIs for data exchange [81].
- **Security Layer:** Ensuring the security and integrity of the digital twin is crucial. This layer includes mechanisms for authentication, access control, data encryption, and monitoring for potential cybersecurity threats [82].
- **Decision Support Layer:** This layer leverages the insights derived from the digital twin to support decision-making processes. It may include recommendation systems, optimization algorithms, or decision support tools [83].

5 Use Cases Description

5.1 DT for Smart Mobility

Traffic management problems in any city are acute. The modernization of legacy traffic control centers is necessary due to the increase in the information load on operators. The complexity of these transport management systems however increases with the number of people and modes of transport. Especially when the density of vehicle and people increase the effect of small incidents on traffic congestion is unpredictable and taking actions becomes very significant on handling large amount of traffic of vehicles and people. **This issue compromises the accessibility goals set by the METACITIES Smart City** R&I strategy (elaborated in D2.1).

Specifically, short response time on traffic incidents is crucial to minimize the impact on congestion. In economic terms, the annual cost of congestion in the EU has been estimated to be 1% of GDP [84] . Congestion also has other negative externalities, such as increased levels of noise, pollution and the potential for accidents and reductions in the useful life of vehicles (OECD, 1999) and the capacity of the network to cope with incidents (its resiliency).

Furthermore, according to the European Commission, in 2020, 18800 people lost their lives on European roads; this number equates to about 360 people tragically dying every week [85].

These unacceptable numbers, both in absolute and relative terms, have remained largely unchanged for the past 20 years, despite the painstaking work of the United Nations and other road safety bodies. Recognizing the importance of the problem and the need to act, governments from around the world declared unanimously — through UN General Assembly Resolution 74/299 — a Second Decade of Action for Road Safety 2021–2030 with the explicit target to reduce road deaths and injuries by at least 50% during that period. Even more, in case of accidents, shorter response time can significantly reduce people's permanent disability and death rates. [86]

The above evidently compromise the safety and quality of life but also the environmental goals set by the METACITIES Smart City R&I strategy as elaborated in D2.1.

The response time does not only rely on the timely identification and classification of the incident but also on the actions that should be taken to effectively alleviate the influence of these incidents. Therefore, it is crucial that a modern Traffic Management system should be Intelligent enough to predict the impact of an incident in the broader area and help operators, police authorities and other emergency services execute an effective action plan.

The proof-of-concept experiments that will run on the Municipality of Patras digital infrastructure will set up the base for the implementation of an Intelligent Transport and Incident Management System (ITIMS). According to the METACITIES methodologies, policies that may assist in dealing with the Transport issues in the City of Patras will rely on the design of an efficient Smart Transport digital twin, that will monitor the necessary data and provide the" testbed" for various policies and solutions before actually implementing them.

The goal is to help vehicles, pedestrians and bicycles move safely and smoothly through complex urban environments, serving the goals that are set for the Smart Transport priority for Safety, Quality of Life, Green, Accessibility and Inclusivity goals for the City of Patras.

5.1.1 Use case 1: Smart mobility and Parking behavior analysis in relation to the Excellence hub priorities and goals

One of the main problems in the City of Patras that affects **the quality of life, safety and accessibility** of various significant points of interest in the city center are the limited parking spaces and limited short term parking solutions, large number of people living in the outskirts of the city and bad parking behavior with respect to short term parking. In order to propose solutions and policies that will overcome the problem of the illegal parking induced congestions compromising the safety and the accessibility of cyclists, pedestrians and drivers that visit or work at the city center, one need to understand the problem.

In order to provide efficient and sufficient solutions the first step is to monitor the traffic patterns and characteristics, various parking related incidents and drivers/pedestrian behavior, in order to investigate and built an intelligent transport management system that may predict the effects of such illegal parking behaviors on the overall traffic and congestion. Hence from the list of the existing sensors and data sources provided above, there are numerous combined and stand alone data that can be used.

The specific use case will deal with the **Goal of Accessibility at the Smart City priority of Smart Transport.**

5.1.1.1 Input data sources and preconditions

We will collect data from roadway sensor and cameras to study the impact of illegal parking behavior on traffic congestion. Such behavior includes, among others, violations of restricted parking zones, double parking and violation of maximum allowed parking time. Furthermore, crowd sourcing incident reporting may be sought to that respect. These conditions will be monitored and identified by advanced sensor networks with edge analytics.

At a second stage, we will investigate the effect of various policies on the traffic patterns and congestions for example we will seek the relation of the response time of traffic operators and municipal police and we will evaluate the impact of this time on traffic congestion.

At a final stage various applications that will be able to interface with the digital infrastructure to provide various solutions to the Smart mobility problems.

5.1.1.2 High Level Technical Approach

In METACITIES we will provide the design for the functional blocks and respective interfaces for a Digital Twin that will evaluate all the data mentioned in the previous section, combining traffic data , parking solutions and data, illegal parking behavior and the effect that these will have on the traffic in the city center (eg a specific street). All the functional requirements will be defined and described.

The Digital twin will be at the core of the Intelligent Transport and Incident Management System which will in turn show in a visual way the traffic situation of specific roads.

In METACITIES, the digital twin will be able to visually exhibit the traffic situation and congestion in real time. Furthermore, the proposed digital twin should be able in the future to interface functional models and algorithms that may be able to train the behavioral models so that It will also be able to run specific what if scenarios in order to develop proposals for solving transport problems like optimization of traffic flow, pedestrian and cyclists flows, public transport alternatives, traffic management, parking management etc. In METACITIES the exact data flow, standards and interfaces will be sought and defined.

Finally the ultimate goal is to show how innovative applications that exactly deal with the priorities under discussion will be interfacing the DTs, for example we will design an application that will interoperate with the digital twin and will ultimately be able to give stake holders valuable real time info with respect to the following

- evaluate Estimated Arrival Time combined with free parking slots in the area of interest for drivers.
- Suggest alternative transportation /intermodal transport for the places of interest
- provide alerts and perform incident reporting to first responders/police for incidents that may potentially turn into traffic blockage incident

5.1.2 Use Case 2: Environmental behaviour analysis on traffic incidents in relation to the R&I priorities and goals

One of the main problems faced by the big cities that compromise the quality of life of its citizens relates to the Green dimension of the city life. Especially for Smart Mobility priority it has been identified as a compromising factor that needs to be dealt with for specific stakeholders (cyclists, pedestrians) but for all the citizens at large.

Monitoring the environmental indexes, it is a very important factor when trying to apply policies and actions that will make a City greener, healthier, more sustainable and more attractive for its citizens and visitors.

The impact of traffic incidents on environmental indexes needs to be thoroughly analyzed by correlating traffic conditions with environmental (air quality, noise, smoke, etc.) measurements. As presented in the METACITIES R&I strategies the Smart Transport priority would become green and environmentally friendly.

5.1.2.1 Input data sources and preconditions

By monitoring specific indexes through sensors and crowd source means, and making use of the air quality forecasting models already applied to the city of Patras one can correlate and understand the expected environmental conditions after an incident on a certain city location.

This may involve also footage from specific cameras and other data sources from the list in previous sections.

5.1.2.2 High Level Technical Approach

In METACITIES we will design the main functional blocks that will comprise a Digital Twin that will evaluate all the environmental (air quality, noise, smoke, etc) data, and traffic data in order to investigate the correlation that they have and the effect that traffic and /or incidents may have on the environment in a city of the city center (e.g. a specific street).

In METACITIES, the digital twin will be able to visually exhibit the environmental and noise situation and congestion in real time. However, the digital twin will be able to train air quality forecasting models and will be able to run specific what if scenarios in order to develop proposals for compromising the effect on environment. The second use case will rely on the functional blocks that will assume a specific data flow from the sensors and data sources to the visualitions of the environmental issues in real time, while interfacing environmental models. All elements will be described and designed.

Finally, we will design an application that will interoperate with the digital twin and will be able to inform the stakeholders about possible eminent incidents that may compromise air quality.

5.1.3 Use Case 3: Emergency Management with respect to Safety Goal

One main problem in large cities that affects the quality of life and the safety of the citizents relates to the road deaths and injuries that through UN General Assembly Resolution 74/299 — a Second Decade of Action for Road Safety 2021–2030 are set to be reduced by at least 50%. It has become evident that for injuries, in case of road accidents, shorter response times can significantly reduce people's permanent disability and death rates. To that respect an Intelligent Transport and Incident Management System (ITIMS) of a smart City, according to the METACITIES R&I strategies and goals for Smart Transport priorities should alleviate the issues of traffic congestion for emergency services.

As it is analysed for the specific goal, the following actions should be a priority and support the Safety goal of the Smart Transport priority.

5.1.3.1 Input data sources and preconditions

The data that are required will be similar to the ones mentioned in use case 1 and 3. Data from from roadway sensor and cameras may be used for traffic prediction and blockage.

5.1.3.2 High Level Technical Approach

Based on real time collected data and analysis, we will design the building blocks, interoperability centre and interfaces that are required to be built for the Digital Twin that will comprise an operating center for emergency services through which authorities can sync up their actions after a traffic incident. These actions include vehicle's rerouting while facilitating emergency vehicles to access the incident when needed. At a later stage, this operating center will become an advanced notification system for drivers, cyclists, pedestrians and public vehicles.

Similarly, to Use case 1, data will be used to train traffic models that will enable quick decision making in case of incidents that affect the traffic.

The Digital twin will be at the core of the Intelligent Transport and Incident Management System which will in turn show in a visual way the traffic situation of specific roads, transport network and develop proposals for solving transport problems. Specific solutions will be run as what if scenarios when specific infrastructure changes will be made.

It will also provide solutions to what if scenario for optimization of traffic, optimization of traffic lights, and investment justification in the construction of transport infrastructure for emergency services (for example extra lanes etc.).

5.2 DT for Green City

As stated in the DIGITAL Europe Program "making Europe greener and more digital are the twin challenges for our generation, and our success in meeting them will define our future." At the same time, the European Green Deal has set out an ambitious plan to reduce GHG emissions by 55% by 2030 and reach net zero emissions by 2050. These goals are reflected in the following strategic documents of the city of Burgas:

- Plan for Integrated Urban Development, 2021-2027. This is the main development strategy of the city and it provides the framework for all the other plans and strategies. Its priority 6: Successful Management of Natural and Urban ecosystems envision measures to improve the adaptation potential of the city including increasing the share of RES, increasing the energy efficiency of buildings and the development of platforms to track environmental indicators.

- Sustainable Energy Strategy and Climate Action Plan 2021-2030 (SESCAP). Elaborated under the Global Covenant of Mayors methodology, it sets the following specific goals for the city for 2030
    - reduction of CO2 emissions by 40%
    - decrease the primary energy use by 32.5%
    - increase the share of RES in the energy mix of the city by 32%

The SESCAP also includes an energy and emissions inventory for 2020. According to it, the building sector accounts for the largest share of primary energy use and GHG emissions 50% of the total primary energy use of the city and for 54% of total GHG emissions in the city. At the same time, as of 2020 (last available data) the share of RES in the energy mix of the city is only 12%.

These goals were behind the rationale for the Municipality focus on energy efficiency (EE) in the building stock and the increase of the RES potential of the city, which amounts to PV installations due to the restrictions on wind turbines because of geographical location of Burgas on one of the biggest avian migration routes in Europe. The BG/Burgas pilot will implement three use cases in the development of the ODTF in order to automate the analysis and improve its investment decision making into EE solutions.

The Bulgarian partners in METACITIES will use the DT for green city pilot to upgrade the existing GIS of the city and the Integrated Urban Platform SmartBurgas, with tools related to the solar potential of the city. This will allow for the upscaling of the existing digital platform for energy efficiency with new 3D functionalities to help better manage resources and utilize unused roof spaces of public and non-public ownership. The pilot will focus on gathering relevant and valid data sources to make 3D digital twins of one or more public buildings. Those will then be developed by using different approaches as AI and machine learning algorithms to detect patterns and provide solutions regarding energy efficiency, air quality or climate conditions monitoring and control. Further in time, data collection will enable formulation of data driven decisions for applying investment strategies to ensure a more sustainable and efficient urban environment. The DT for Green City will be applied and evaluated focusing on the following three use cases.

5.2.1 Use Case 1: PV potential and performance analysis tool

The DT will identify PV systems existing in the city as well as give new tool to create models to assess and determine accurately their production potential. This use case should provide users with the ability to monitor PV energy production potential, including functionalities enabling the consideration of different scenarios as to how to achieve the goals of the city for 2030, as well as to inform building owner(s) and citizens about the economic feasibility of PV installations on the buildings.

5.2.1.1 Input data sources and preconditions

For this use case in METACITIES, the goal will be to identify and locate the PV systems installed in the city, register and estimate their current energy production performance, and model the city's PV adoption curve through time. This will be made by using different data sets, including orthophotomaps, satellite images, as well as data provided by existing platforms.

5.2.1.2 High Level Technical Approach

In METACITIES the approach for this use case will include a general feasibility study, performance analysis, and consideration of key aspects related to the installation of PV systems (resource assessment, site location, building architecture, design, etc.). The feasibility study and performance analysis of PV systems is essential to assess the overall system energy consumption, to look for approaches for optimization of energy utilization, and for ensuring reliable electricity supply [87]. The

analysis will also involve estimation of the combined efficiency and effectiveness of solar power generation and energy storage. The results from this analysis, the estimation of some of the technical performance indicators as a key functionality of the PV system, the data collected from the input data sources, and the application of data analytics, will be the base for the digital twin modeling and development [88].

The estimation of the technical performance indicators will be one key functionality of the digital twin, in addition with optimization of the energy consumption based on real-time monitoring, fault detection and condition forecasting. Existing simulation tools will also be analyzed in order to be applied for the assessment of the performance of the PV systems and aid the digital twin construction. Trough the digital twin, the feasibility of the PV installations in terms of the energy, cost and design features will be mapped, and performance prediction algorithms researched [89]. By combining the input data, simulation models, and advanced analytics, the digital twin city model will become a dynamic and interactive platform for energy performance analysis of public buildings that enables continuous monitoring, pattern analysis, optimization, and decision-making to achieve long-term energy efficiency goals. With these data sources and the proposed technical approach, the digital twin city model can in addition support policy making on general energy performance improvement of the pilot and future PV implementations in the city.

5.2.2 Use Case 2: Buildings Energy Performance Analysis

By using a digital twin for a newly built public building (kinder garden) in METACITIES we will showcase the users of the energy section of the smart city platform of Burgas how a building performs in energy aspect. By analyzing and visualization of the gathered data we will provide users with the ability to better understand the buildings' energy performance.

Considering the data availability, the focus will be on defining buildings insulation capacity at the roof level (i.e., thermal insulation performance) and the assessment of how external variables (e.g. temperature, humidity, solar exposure) influence the building energy performance/consumption. The goals are manifold and include: understanding energy performance of buildings, that will drive the analysis on city's investment needs, and (possibly) support definition of potential financial mechanisms; to understand how energy consumption varies with meteorological variables through root cause analysis; and to better understand about the impacts of different energy related interventions performed in the buildings (monitoring analysis), which can be used to better plan future interventions for public buildings and buildings with non-public ownership.

5.2.2.1 Input data sources and preconditions

In METACITIES the solution will involve gathering information on energy usage patterns, and relevant parameters of the building's energy systems. Gathering data for energy consumption analysis, will be based on the recording of energy consumption data from various systems, such as HVAC, lighting, and the application of pilot IoT and smart metering technologies. Data regarding energy consumption will be gathered using smart meters and IoT devices in real time and matched with external variables (e.g. temperature, humidity, solar exposure). With the implementation of the IoT devices, a deeper analysis can be made into the specific types of energy consumption in the building and the definition of the thermal insulation performance of the building. If necessary for specific data, on-site metering will also be conducted. This involves installing temporary energy meters or data loggers to measure energy consumption in particular areas at roof level.

Information about the building's equipment, such as HVAC systems, lighting fixtures, and appliances will also be included in the energy performance analysis. This includes equipment specifications, rated capacities, efficiency ratings, and operating schedules. This information will be available from the

manufacturer data sheets, equipment manuals, or if available maintenance records. The overall goal is to integrate data from various sources to build up a comprehensive dataset that provides a holistic view of the building's energy consumption patterns.

5.2.2.2 High Level Technical Approach

The energy performance of buildings depends on their physical features, including the overall insulation performance, climatic conditions, and business or other public activities, such as operating hours and occupancy characteristics. In METACITIES, a digital twin platform for energy performance analysis of this public building will be developed. For this, it is necessary to implement an adequate data collection methodology and perform fair assessment of the energy consumption considering relevant public activities taking place in the building.

In METACITIES the technical approach for this use case will start with a state of art review of various energy performance assessment methodologies and choice of the specific approach that has to be applied and implemented in the digital twin platform. Results will vary depending on how much the assessment reflects the features and conditions of the building. In many countries, various assessment methods for existing buildings can be selectively utilized, and insufficient data can be compensated for by using different simplified input data or data estimation methods. Many classification and review of assessment methods could be found in the literature, that could be used for proper design of the technical implementation of this use case [90]], [91]], [92]], [93]], [94]], [95]. Based on this study a respective performance assessment methodology will be chosen and implemented in the digital twin. In addition, methodologies for analysis of the thermal insulation of buildings will also be considered, for the correct estimation of the thermal insulation at roof level [96]], [97]], [98]], [99]], [100].

Example of key aspects that could be included in the digital twin based energy performance analysis include: the energy consumption, and evaluation of consumption patterns; energy benchmarking to identify energy-saving opportunities; building envelope analysis to analyze the extent of heat loss or gain through walls, roofs, windows, and doors; evaluation of the efficiency and performance of heating, ventilation, and air conditioning (HVAC) systems; analysis of the lighting system's efficiency, including the type of lighting technology, lighting controls, and lighting schedules; evaluation of the feasibility of integrating renewable energy photovoltaic (PV) panels; analysis of usage patterns, occupancy schedules, and user interaction with building systems;

Moreover, by inputting in the digital twin platform data related to the building insulation characteristics, equipment specifications, weather data, and occupancy patterns, the developed digital twin in METACITIES could be used to predict energy consumption, identify energy-saving measures, and evaluate their impact; evaluate the building's indoor environmental quality factors such as thermal comfort, indoor air quality, acoustics, and lighting levels; analyze factors that impact occupant health, productivity, and comfort; identify opportunities for improvements that enhance indoor environmental quality while maintaining energy efficiency.

5.2.3 Use Case 3: Budget Planning for Energy Usage and Buildings

Following the results from Use case 2 the digital twin model can be upgraded to become a valuable tool for policy making decisions on budget planning and effective use of resources, recoupment of initial investments and managing the costs of energy use both for public and private users. For the purpose data related to historical costs and prices of resources should be added preferably in separate dashboard. In time, when data for more buildings is being constantly accumulated, it will help the experts of the city of Burgas to better estimate investment needs, define priorities for potential local

investments, and evaluate financial mechanisms and business models aimed at improving the energy efficiency indicators and overall energy performance of the city, all these in line with its strategic goals.

5.2.3.1 Input data sources and preconditions

Data regarding energy consumption gathered from Use Case 2. If necessary, through the implementation of specific IoT devices, additional data will be collected for a deeper analysis into the particular types of energy consumption in each building, assuming a future breakdown of consumption considering the equipment existing at each delivery point.

5.2.3.2 High Level Technical Approach

The technical approach will follow the methodology of performing an overall life cycle cost analysis for the goal of assessing the economic viability of the proposed energy efficiency measures and PV energy systems. The upfront costs, energy savings, operational costs, maintenance requirements, and the payback period of investments will be evaluated.

5.3 DT for Urban Planning

Massive twinning, i.e., the application of the more fundamental Digital Twin (DT) concept in a wide set of use cases, will gain importance. Massive twinning is designed to lead us towards a full digital representation of our environment, extending the use in production/manufacturing (as it has started today), but also, for example, in the management of our environment, in transportation, logistics, entertainment, social interactions, digital health, defense and public safety.

In all cases, a fully synchronized and accurate digital representation of the physical and human worlds is key. This is costly in resources, as it requires precise representations of the physical world, enhanced means for generating insights and predictions, as well as for experimenting with “what-if” scenarios; furthermore, means to impact the environment are imperative. All these need the transfer of vast volumes of data, extreme performance (capacity, bit rates, low latency, compute power) and reliability, as well as sustainability, and also trustworthiness, at unprecedented levels. City liveability is a concept that is determined by large parameter sets, which are weighted. The sets correspond to wide application areas, relevant to the city infrastructure (for example, roads, rails, buildings, networks), the ambience/environment (for example, climate, air quality), healthcare aspects (for example, management of health system, quantified self), education and culture issues, the stability/safety, and many others.

High-resolution and interactive 4D (spatio-temporal) mapping is needed, in conjunction with means to influence the physical world. High-resolution indoor and outdoor mapping will drive use case scenarios of dynamic DTs and virtual worlds in conjunction with real-time, multi-sensory mapping and rendering, movement prediction and real- time analytics. The availability of both the virtual and physical worlds will allow mapping and analysis of data and monitoring of systems to predict performance and operational issues to minimize downtime (predictive maintenance), and improve contextual awareness.

Digital Twinning is essential in various use cases. The main area that is addressed by the Cyprus innovation ecosystem is drastic enhancement of liveability of our cities (urban quality of life assessment based on various criteria), while maximizing the sustainability and the transformation of sectors like health or public security. More specifically, the Cyprus innovation ecosystem will leverage Digital Twin technology to revolutionize the areas of “Smart Urban Planning” and “Smart Parking”. Solutions should be characterized by sustainability, empower trustworthiness, and most often be suitable for global coverage.

- For the 'Smart Urban Planning' case, our objective is to develop an integrated platform for analysing and predicting large-scale geospatial information (GIS), local demographic data, and

other geo-critical datasets from multiple sources, and extracting meaningful insights such as trends in urban growth, building stock analysis, noise maps, real estate prices, green cover, etc. The overall goal is to facilitate accurate environmental impact predictions on urban areas, thereby providing valuable data that can be utilized for informed urban development planning and decision-making.

- For the 'Smart Parking' case, our objective is to develop a platform that will provide real-time information on parking availability, busy hours, and other related metrics to parking lot owners and individuals seeking parking aiming to enhance the accuracy of predictions related to parking availability. The overarching goal is to reduce time spent on searching for parking, thus creating a less stressful and more environmentally friendly urban atmosphere, contributing to the development of sustainable cities.

The knowledge and infrastructure available in smart city projects in Cyprus (mainly Nicosia and Paphos) and the iNicosia platform (see section 5.3.3) developed by METACITIES project partner CYENS will be leveraged and enhanced with new 4D functionalities. This will allow the existing digital platform to be extended with new 4D functionalities that will help to efficiently integrate smart city data. A digital replica of the real traffic scenario, automated transport operations and control of utilities such as energy, water, gas and air quality will be implemented with the aim of creating an interactive 4D map that will be used to manage, among other things, public transport, waste, pipes, cables, buildings and heating in the cities. Optimized and data-driven management can help transform cities towards sustainability. However, this pilot requires the transfer of large amounts of data within specific time constraints. This is critical to enable actions that will impact the operation of the city and improve its quality of life.

5.3.1 Use Case 1- Smart Urban Planning

The EU focus is on modeling and tracking of the interplay between natural and societal systems, for example on how policies and economics modeling predict human behaviors' impact on the environment, how explicit or implicit incentives and social norms interact with the environment's evolution and exploitation, how real-time environmental awareness and intelligence can improve behavior towards more sustainability, or how the decisions based on changes in the environment in turn affect the state of the natural environment.

This use-case will focus on the development of: i) an integrated urban environmental monitoring and sensing tool with remote sensing and IoT sensors; ii) a database with analytics and predictions for large-scale urban data collected from different sources; and iii) the use of positioning as a tool for environmental decision making, assessment, and urban impact analysis. The goal is to create an integrated system that enables accurate prediction of environmental impacts on urban areas and provides information that can be used for planning and decision-making in urban development. The platform's use of advanced machine learning and deep learning techniques will facilitate the analysis and interpretation of large data sets, enabling a better understanding of urbanization and environmental trends and promoting the development of more sustainable cities.

The specific use case will deal with the goals of Safety for Citizens (e.g., Priorities of Smart Mobility and Smart Buildings and critical infrastructure), Green (e.g., Priorities of Smart Mobility and Smart Environment), and Economic Sustainability (e.g., Priorities of Smart Mobility and Smart City priority of Smart Transport).

5.3.1.1 Input Data Sources and Preconditions

By integrating a combination of terrestrial datasets, remote sensing data from sensors deployed across urban spaces, and Synthetic Aperture Radar (SAR) imagery into the Digital Twin, the system can provide meaningful insights such as trends in urban growth, building stock analysis, noise maps, real

estate prices, green cover, etc. The sensors, installed strategically across the city, would capture vital data about the urban environment, further enriching the digital twin's ability to model and predict urban trends.

5.3.1.2 High Level Technical Approach

For this use case we will develop an integrated platform for analysing and predicting large-scale geospatial information (GIS), local demographic data, and other geo-critical datasets from multiple sources. This platform will use advanced machine learning and deep learning techniques to perform geospatial object detection by combining terrestrial datasets, remote sensing data, and Synthetic Aperture Radar (SAR) imagery. The primary focus is to extract meaningful information such as building stock analysis, noise maps, real estate prices, green cover, urbanization, sprawl, and other critical markers to estimate urban growth trends. It will also explore the potential of real-time environmental awareness and information in promoting sustainable behaviour.

5.3.2 Use case 2 - Smart Parking

People struggle to find parking on a daily basis, particularly in densely populated cities. Driving in circles around the metropolis for a parking spot is a daily occurrence. Any destination, whether for work, personal meetings at specific locations, recreation, or emergency visits to places such as hospitals, must be reached for the least amount of money possible. The increasing number of automobiles and vehicles in a city also contributes to the difficulty and expense of finding a parking space. Frequently, people enter a parking lot without knowing if a spot is available, making navigation problematic. In addition, the incorrect location may be chosen without the driver's knowledge based on cost considerations such as time, money, or fuel consumption. Another significant issue is the driver's disregard for parking spaces that are closer to his or her destination or have a lower cost in terms of price, distance from the vehicle's current location, or distance to be walked from the parking space. In addition, parking is a $25 billion industry that has been stagnant for decades! Moreover, urban traffic is responsible for 40% of CO2 emissions and 70% of other pollutant emissions from road transport, and over 30% of urban traffic is caused by drivers looking for a parking space.

Our aim is to solve these problems by significantly reducing parking time, thus playing a major role in creating a better, less stressful and environment-friendly urban environment. Smart parking targets to offer a mobile and a web application that: i) acts as a Smart Parking assistant to help drivers find the best available parking spot, reserve it, guide them there, act as an authentication measure and let them pay in the end; and ii) assist parking lot owners and parking seekers to fully automating this procedure. A further objective is to take into account the user's preferences as they are set, as well as any other necessary data such as the desired destination and the user's current location, as well as the data manipulation and use of all the available resources, which will then be processed by a machine learning algorithm based on the user's preferences and provide the user with a list of the best available options.

The specific use case will deal with the goals Green (e.g., Priority of Smart Mobility), Accessibility (e.g., Priority of Smart Mobility) and Economic Sustainability (e.g., Priority of Smart Mobility).

5.3.2.1 Input Data Sources and Preconditions

By integrating data like parking availability and demand into the Digital Twin, the system can provide real-time information on available parking spaces and suggest optimal routes to reach them to system users. Additionally, smart parking will allow the system’s users to use specific preferences, such as cost and distance to the destination, to minimize the choices of parking places according to their preferences. To achieve the aforementioned goals, sensors can be installed in parking spaces to monitor occupancy in real-time. This data can then be integrated into the Digital Twin of the city, allowing officials to understand parking patterns, predict demand, and effectively manage the allocation of parking spaces. Furthermore, this real-time data can be made accessible to citizens

through a mobile application, guiding them directly to available and preferable parking spots resulting in a significantly improved parking experience. Also, this not only saves time for drivers but also reduces congestion and pollution. However, in the context of "Smart Parking", tracking individual vehicles' movements could potentially infringe on personal privacy rights. Therefore, it is critical to establish robust data protection measures, anonymize data where possible, and secure consent for data collection where required. The sensors, installed strategically across the city parkings, would capture vital data about the parking information, further enriching the digital twin's ability to provide to the users significant and meaningful information related to parking.

5.3.2.2 High Level Technical Approach

The integration of mobile and web applications, along with an interactive 4D Map (time and space dimensions), can provide parking lot owners and parking seekers with real-time information on parking availability, busy hours, and other metrics. Furthermore, the use of AI/ML tools can enhance the accuracy of predictions related to parking availability and other factors, such as identifying the best suitable parking location for a user according to specific preferences (such as cost, distance to destination). Overall, the Smart Parking application has the potential to transform the parking industry and contribute to the creation of more sustainable cities.

5.3.3 INicosia - Nicosias digital twin overview and vision

The iNicosia project is a digital twin of the city of Nicosia consisting of an "accurate" (as required) 3D model of the city, with representations of actual buildings and monuments (such as the walls and the old city), the road network, parking places, various metadata about the environment, possibly traffic lights and their status, street lights, the power grid/water network, vegetation, etc. Such a model would be of limited utility without the incorporation of real-world data; rich time-series data will be collected by various sensors (camera feeds, thermal/humidity/motion sensors, etc.) located throughout the city of Nicosia, government open data portal, and other private and public initiatives. Together with the digital counterpart, these data will be geolocated and timestamped, collected, associated, and stored.

This platform should benefit both the citizens and the CYENS research groups. It paves the way for the development of real-world applications that could be enriched by the cutting-edge research at CYENS, as well as the opening of multiple research opportunities and collaborations for the members of CYENS, opportunities for the municipality to help improve the quality of life in Nicosia, and many potential business applications. Researchers in the visual sciences, for instance, will have the opportunity to develop methods for reproducing and visualising the city, its collected data, its inhabitants, and its traffic. They will be able to devise immersive systems where users are immersed in the model and able to experience changes in the city before they occur, as well as visualise the city's past, present, and future. Human factor researchers will be able to observe and possibly attempt to comprehend the relationship between citizens and the city, as well as their psychology, as well as design HCI methods for effectively communicating data to stakeholders and the general public. Researchers in the field of telecommunications will need to design and integrate sensor networks that collect and process data in an efficient (and secure) manner, while specialists in artificial intelligence can help interpret, comprehend, and exploit these data.

A project of this nature permits the creation of gamification applications for the education and training of students, stakeholders, visitors, and security officers. Museums can benefit from applications built on top of the 3D model, and the municipality can visualise changes in the city and how the introduction of contemporary infrastructure affects the culturally rich centre. In addition, this type of digital sibling

project can serve as a model for larger cities that share a similar context, a culturally rich city centre (which is difficult and prohibitive to modify to accommodate modern requirements) surrounded by a modern portion of the city with numerous offices, stores, and parks.

FIGURE 21: INICOSIA – DIGITAL TWIN PROJECT.

6 Requirements' analysis of the Open Digital Twins Framework

6.1 Methodology for requirements elicitation

A digital twin is a virtual representation of a physical object, system or process, and can be used for a variety of purposes such as simulation, analysis, testing, maintenance and control [[101]]. The socio-techno-economic requirements for a digital twin can vary depending on the specific application and use case. However, some general requirements include:

- **Technical requirements:** The digital twin must be able to accurately and efficiently simulate the behavior of the physical object or system it represents. This may require the use of advanced sensors, modelling and simulation software.
- **Data requirements:** Access to accurate and up-to-date data about the physical object or system it represents. This may include data from sensors, control systems, and other sources.
- **Infrastructure requirements:** The digital twin may require a dedicated infrastructure for data storage, processing, and analysis. This may include hardware such as servers, storage systems, and networking equipment, as well as software such as databases and analytics tools.
- **Economic requirements:** The digital twin must be cost-effective to develop, maintain, and use. This may include a cost-benefit analysis of the digital twin's potential benefits and costs, as well as the development of a business case for the project.
- **Socio-cultural requirements:** The digital twin will likely require a shift in the way people work, and interact with technology, so it must be designed to be user-friendly and easy to use.

In order to develop a digital twin that serves a specific purpose, it is crucial to gather socio-techno-economic requirements from end-users to ensure that the system meets their needs and expectations. There are several techniques that can be used to elicit requirements, including workshops, questionnaires, interviews, brainstorming, user stories and focus groups. A combination of these techniques can be also used for a more comprehensive understanding of their needs and preferences.

- **Workshops:** Collaborative workshops with end-users to gather requirements and feedback on the development of the digital twin. Workshops can be structured to include group discussions, design exercises, and feedback sessions.
- **Questionnaires:** Questionnaires distribution to end-users to gather their opinions, preferences, and feedback on the development of the digital twin. Questionnaires can be designed to gather both qualitative and quantitative data and can be consisting of questions that can have a number of finite choices or be open-ended.
- **Interviews:** Interviews with end-users to gain in-depth insights into their experiences, needs, and preferences.
- **Brainstorming:** Open conversation on innovative ideas and solutions while ensuring that the conversation stays on topic and ideas are recorded.
- **User stories:** A user story is a brief, written description of a feature, requirement, or need that the user has for a product or system. User stories are usually written in a specific format, often referred to as the *"As a (user), I want (need), so that (feature)"* format. This format ensures that each user story is focused on a specific need and feature, making it easier to prioritize and plan development efforts.

- **Focus groups:** When more information about specific aspects of the project is needed specific groups can be gathered to discuss.

To gather socio-techno-economic requirements for the Open Digital Twin Framework, a questionnaire-based approach was utilized. At the end of the questionnaire, the end-users were asked to create a user story following the format *"As a <ROLE>, I want to <GOAL>, so that <REASON>"* in order to further clarify their needs and objectives. A user story represents a specific user's desired feature or functionality, which is then discussed among relevant stakeholders to ensure a clear understanding of the required functionality from the user's perspective, and how it can be implemented technically.

Questionnaires can be a good technique for requirements elicitation for several reasons:

1. **Scalability:** Questionnaires are highly scalable, meaning that they can be distributed to a large number of stakeholders simultaneously, and the responses can be easily collected and analyzed.
2. **Standardization:** Questionnaires allow for a standardized set of questions to be asked of all stakeholders, ensuring that everyone is providing feedback on the same topics and issues.
3. **Anonymity:** Questionnaires can be completed anonymously, which can encourage stakeholders to provide more honest and open feedback.
4. **Time efficiency**: Questionnaires can be completed relatively quickly at the stakeholder's convenience, which can be helpful when gathering feedback from a large number of stakeholders.
5. **Cost-effectiveness:** Compared to other elicitation techniques, such as interviews or focus groups, questionnaires can be a cost-effective way to gather feedback.

To gather information and insights from each of the three-pilot use-cases in the METACITIES project, a unique questionnaire was designed for each use-case. The questionnaires were prepared to capture a range of perspectives, including those of end-users, stakeholders, and experts in the fields of urban planning, management, and technology. To ensure that the questionnaires were both technically feasible and aligned with the goals of the project, the technical partners provided feedback and suggestions. Once the questionnaires were finalized, they were converted into user-friendly Google Forms to make distribution simple and straightforward. Two out of the three innovation ecosystems (Bulgarian and Greek) translated the questions in their native language to easily gather responses from a wider range of citizens. After the questionnaires were completed, the project team conducted a thorough statistical analysis of the responses received. This analysis identified the most important and relevant requirements for the project, while considering the priorities and needs of each pilot. Overall, the METACITIES project methodology was designed to be inclusive of diverse perspectives and requirements, while also ensuring technical feasibility and alignment with the project objectives.

6.1.1 Target Groups –End Users/Stakeholders

In discussions surrounding smart cities, the primary focus is on cooperation. The recommended approach involves including all society parties in the process of ideating, planning, executing, testing,

and assessing solutions for urban issues. This method is seen as the most effective way to implement innovative solutions [5].

The Quadruple Helix is a collaborative model that brings together four key groups in society (government, industry, academia, civil society), each bringing unique skills, knowledge and resources to address societal challenges and drive innovation. The government helix includes policymakers and regulators who provide the framework for innovation and support initiatives that promote economic growth and social well-being. The industry helix includes companies, entrepreneurs, and investors who are responsible for developing and commercializing new products and services that contribute to economic growth. The academic helix consists of universities, research institutions, and academic experts who generate knowledge and support research and development to drive innovation. Finally, the civil society helix represents the general public, NGOs, and other community-based organizations that provide input on societal needs, promote social inclusion, and ensure that innovation benefits all members of society. The model recognizes that different stakeholders have different needs and interests, and that addressing societal challenges requires the input and collaboration of a wide range of actors.

To this end, questionnaires were distributed to all stakeholders in the quadruple helix - industry, government, academia and civil society - to gain diverse perspectives and insights. By engaging with a broad range of stakeholders, the project aimed to gather comprehensive data and insights that would enable the development of effective and sustainable smart city solutions. The following Tables (Table 3-5) summarize the end-users /stakeholders who completed the METACITIES questionnaires.

TABLE 3: CATEGORIZATION OF END USERS/STAKEHOLDERS WHO ANSWERED THE CYPRIOT PILOT QUESTIONNAIRES BASED ON THE QUADRUPLE HELIX MODEL.

Cypriot Pilot			
Smart Parking (UC1)		**Urban Planning (UC2)**	
End Users/ Stakeholders	**Quadruple Helix**	**End Users/ Stakeholders**	**Quadruple Helix**
Professors-Researchers	Academia	**Educational Institutions (mainly Higher Ed)**	Academia
General Public	Civil Society	**Cyprus Scientific and Technical Chamber**	Academia
Motorist Associations	Civil Society	**Associations of Civil Engineers**	Civil Society
Motorcycle Associations	Civil Society	**Associations of Architects**	Civil Society
Bicyclist Associations	Civil Society	**Association of Urban Planners/Designers**	Civil Society
Associations of People with Disabilities	Civil Society	**Residents**	Civil Society
Cypriot Municipalities / Engineers	Government	**Environmental and Sustainability Advocates**	Civil Society
Ministry of Transportation	Government	**Community Organizations**	Civil Society
Ministry of Labour, Welfare and Social Insurance (Air Quality Dept.)	Government	**Municipalities (Directors, Department Heads)**	Government

Private Parking Owners	Industry	**Department of Town Planning and Housing**	Government
ICT companies	Industry	**Ministry of Interior**	Government
		Department of Environment	Government
		Transportation Departments	Government
		Public Health Agencies	Government
		Real Estate Businesses	Industry
		Property Developers	Industry

TABLE 4: CATEGORIZATION OF END USERS/STAKEHOLDERS WHO ANSWERED THE BULGARIAN PILOT QUESTIONNAIRES BASED ON THE QUADRUPLE HELIX MODEL.

Bulgarian Cluster					
UC1: Buildings Energy Performance Analysis		**UC2: Budget Planning for Energy Usage and Buildings Renovation**		**UC3: Renewables (PV) potential and performance analysis**	
End Users/Stakeholders	**Quadruple Helix**	**End Users/Stakeholders**	**Quadruple Helix**	**End Users/Stakeholders**	**Quadruple Helix**
Residents	Civil Society	**Residents**	Civil Society	**Residents**	Civil Society
Homeowners' association	Civil Society	**Homeowners' association**	Civil Society	**Homeowners' association**	Civil Society
Municipalities	Government	**Municipalities**	Government	**Municipalities**	Government
Ministry of the Environment and Waters	Government	**Ministry of the Environment and Waters**	Government	**Ministry of the Environment and Waters**	Government
Ministry of Regional Development	Government	**Ministry of Regional Development**	Government	**Ministry of Regional Development**	Government
Energy Efficiency Agency	Industry	**Energy Efficiency Agency**	Industry	**National Energy Efficiency Agency**	Industry
Construction Companies	Industry	**Construction Companies**	Industry	**Construction Companies**	Industry

Architectural Studios	Industry	**Architectural Studios**	Industry	**Architectural Studios**	Industry
Environmental Protection NGOs	civil society	**Environmental Protection NGOs**	Civil Society	**Environmental Protection NGOs**	Civil Society
Universities	Academia	**Universities**	Academia	**Universities**	Academia
ICT clusters	Civil Society	**ICT clusters**	Civil Society	**ICT clusters**	Civil Society
Researchers	Academia	**Banks**	Industry	**Researchers**	Academia
Union of Architects	Civil Society	**Lending Institutions**	Industry	**Union of Architects**	Civil Society
Regional Energy Office	Government	**Union of Architects**	Government	**Regional Energy Office**	Government
Solar panels providers	Industry	**Regional Energy Office**	Government	**Solar panels providers**	Industry
Architecture and Construction Vocational Schools	Academia	**Solar panels providers**	business/industry	**Architecture and Construction Vocational Schools**	Academia
		Architecture and Construction Vocational Schools	Academia		

TABLE 5: CATEGORIZATION OF END USERS/STAKEHOLDERS WHO ANSWERED THE GREEK PILOT QUESTIONNAIRES BASED ON THE QUADRUPLE HELIX MODEL.

Greek Pilot			
Parking Behavior Analysis – Emergency Management – Environmental Behavior			
End Users/Stakeholders	**Quadruple Helix**	**End Users/Stakeholders**	**Quadruple Helix**
Teachers – Professors -Researchers	Academia	**Educational Institutions (mainly Higher Education - Universities)**	Academia
General Public	Civil Society	**University Students**	Civil Society
Civil Engineers	Civil Society	**Residents**	Civil Society
Associations of People with Disabilities	Civil Society	**Road Safety NGOs**	Civil Society
Municipality of Patras	Government	**Region of Western Greece**	Government
Transportation Departments	Government	**Port Authority**	Government
Public Health Agencies	Government	**Civil Engineers companies**	Industry
Business development companies	Industry	**ICT companies**	Industry

6.2 Socio-Techno-Economic Requirements

In order to better understand the level of interest of our respondents, we have translated the results of the **questionnaires** from a scale of 1 (not important) to 5 (extremely important) into the categories of "must have," "should have," "could have," "won't have". This allowed us to more clearly identify the priorities of our stakeholders and determine which features and functionalities are essential for our project. By using these categories, we were able to present the results in a more user-friendly and understandable way for our team and other stakeholders, and to make informed decisions about the requirements for our project moving forward.

1. **Must Have" - Score of 5:** These are the features, requirements, or items that are essential and highly desired. They are critical for the success and functionality of the project. These are the top priorities and should be given the highest consideration.
2. **"Should Have" - Score of 4:** These are important features or requirements that would greatly enhance the project or provide significant value. While they may not be as critical as "Must Have" items, they should still be considered as high priorities and included if possible.
3. **"Could Have" - Score of 3:** These are nice-to-have features or requirements that may provide additional value or improve the project but are not essential for its core functionality. They can be considered if resources and time permit but can be deprioritized if necessary.

4. **"Won't Have" - Scores of 1 or 2:** These are features or requirements that are deemed less important or not relevant to the project's objectives. They can be excluded from the immediate scope or future considerations.

6.2.1 Cypriot Pilot: Immersive and Interactive Smart City Data Representation for Urban Planning

In this section, the results of the smart parking questionnaire are being presented, reflecting insights and opinions obtained from a diverse group of individuals. A total of 179 participants were reached for the smart parking questionnaire and 80 participants were reached for the urban planning questionnaire, encompassing individuals of different age, gender, and profession. With this diverse sample, a comprehensive understanding of stakeholder perspectives on smart parking can be achieved, ensuring a well-rounded analysis of the collected data. In this report, the questionnaire findings will be explored, emphasizing key trends and preferences among the participants.

6.2.1.1 Use Case 1: Smart Parking

The results of the smart parking questionnaire are being presented, reflecting insights and opinions obtained from a diverse group of individuals. The survey results show that most people, excluding academics, have never heard about the digital twin concept, with the percentage being higher for the general public (66%). As expected, most respondents mentioned that they use their cars daily for travel and have encountered difficulties such as:

1. Difficulty finding parking spots
2. Circling around in search of a spot
3. Having to park far away from their destination
4. Paying excessive parking fees
5. Receiving parking tickets

In response to the question, "How satisfied are you with the current parking situation in your city or town?" on a scale of 1 to 5, the majority of people answered 3, with the lowest percentage (2%) selecting 5 (extremely satisfied). All stakeholders in the quadruple helix expressed their willingness to use a smart parking application that incorporates digital twin and metaverse technologies if it were available. Regarding their concerns when searching for a parking spot, all groups mentioned time and cost efficiency, convenience, and safety. The major concerns about using a smart parking application that incorporated digital twin or metaverse technologies are privacy, security, technical issues and cost (Figure 22). All stakeholders indicated that they are willing to spend less than 5 minutes searching for a parking spot. However, the majority of them expressed hesitation or uncertainty about paying a fee for using a smart parking digital twin (Figure 23). Conversely, all stakeholders would be willing to pay if they could reserve a parking spot in advance (Figure 24). When asked about the importance of a Smart Parking application being accessible and usable by people with disabilities, such as those who are deaf or have mobility challenges, all respondents answered 'extremely important'. Furthermore, when asked to identify the most important feature in a smart parking system, all stakeholders voted for 'Real-time availability information' as the top priority.

Regarding security and privacy features in a Smart Parking application, data encryption and protection received the highest percentage of stakeholder votes (Figure 25).

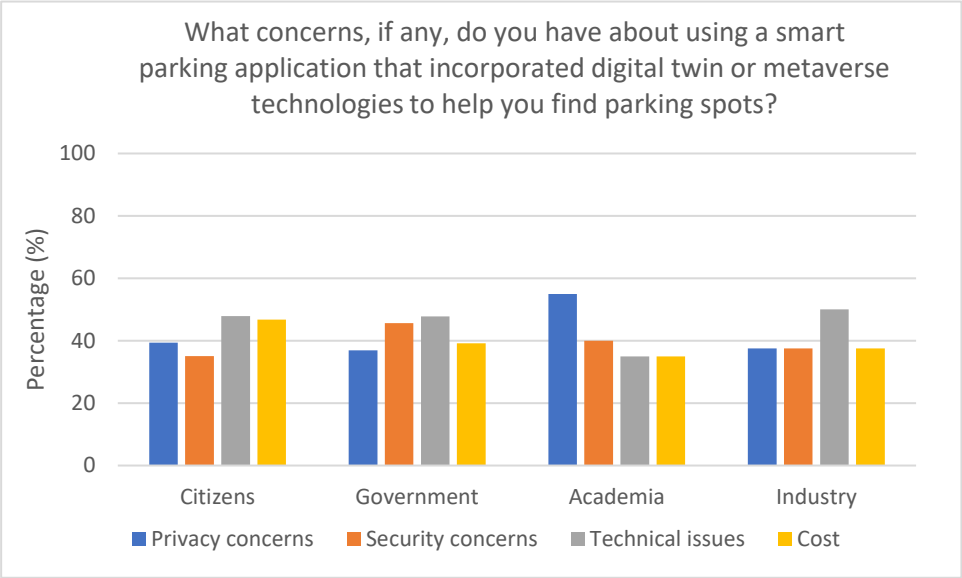

FIGURE 22: CONCERNS ABOUT USING A USING A SMART PARKING APPLICATION THAT INCORPORATED DIGITAL TWIN OR METAVERSE TECHNOLOGIES ACROSS THE QUADRUPLE HELIX GROUPS.

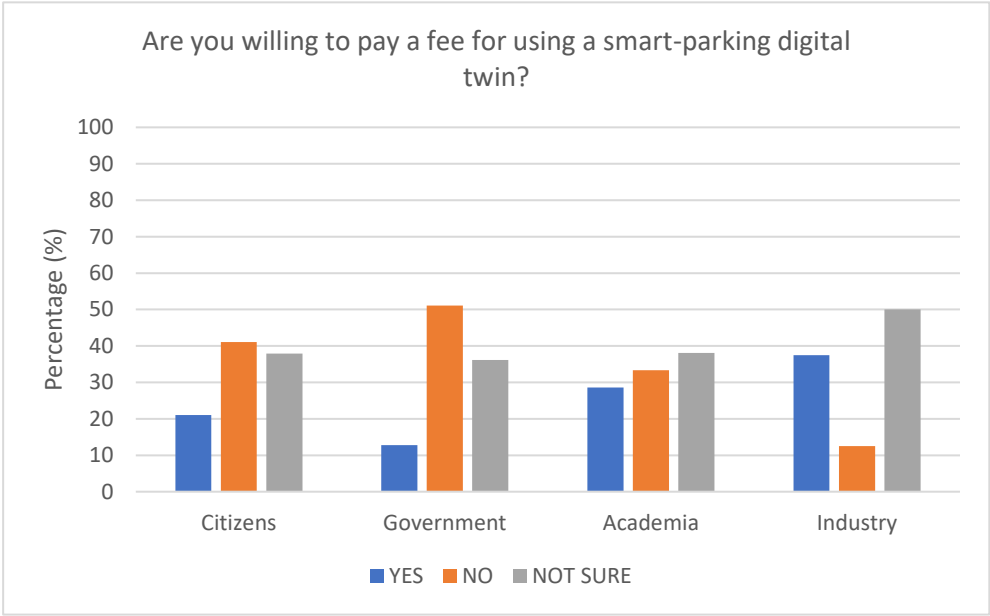

FIGURE 23: ANSWERS TO THE QUESTION ' ARE YOU WILLING TO PAY A FEE FOR USING A SMART-PARKING DIGITAL TWIN?'.

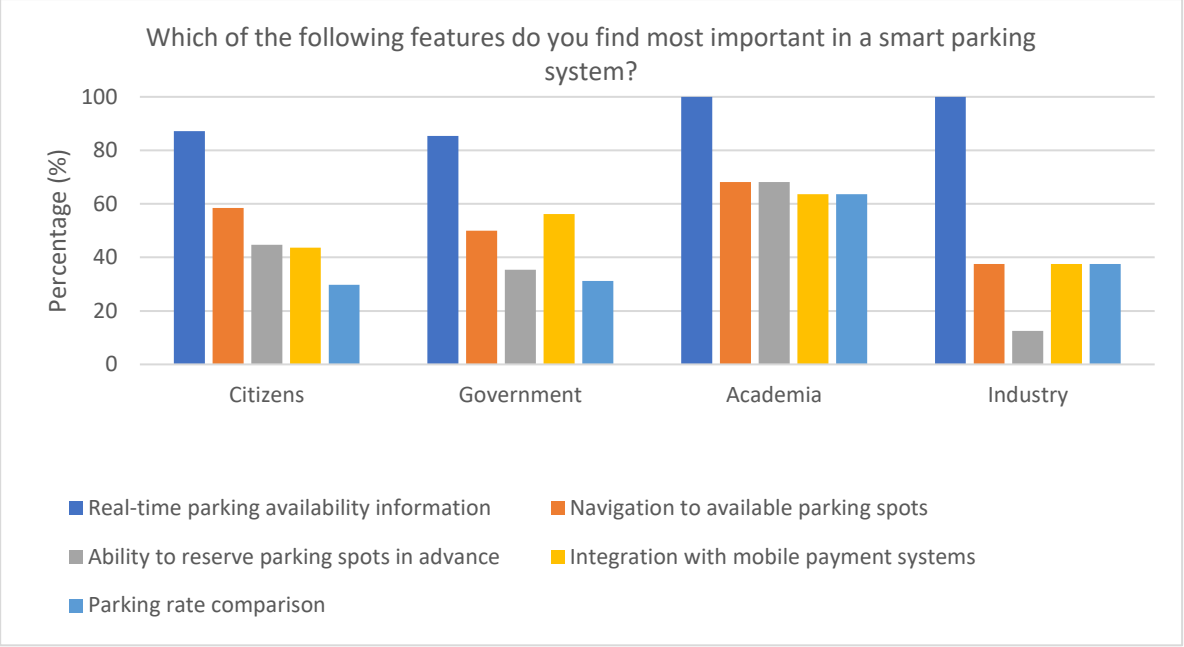

FIGURE 24: STAKEHOLDERS' VOTES ON MOST IMPORTANT SMART PARKING SYSTEM FEATURES.

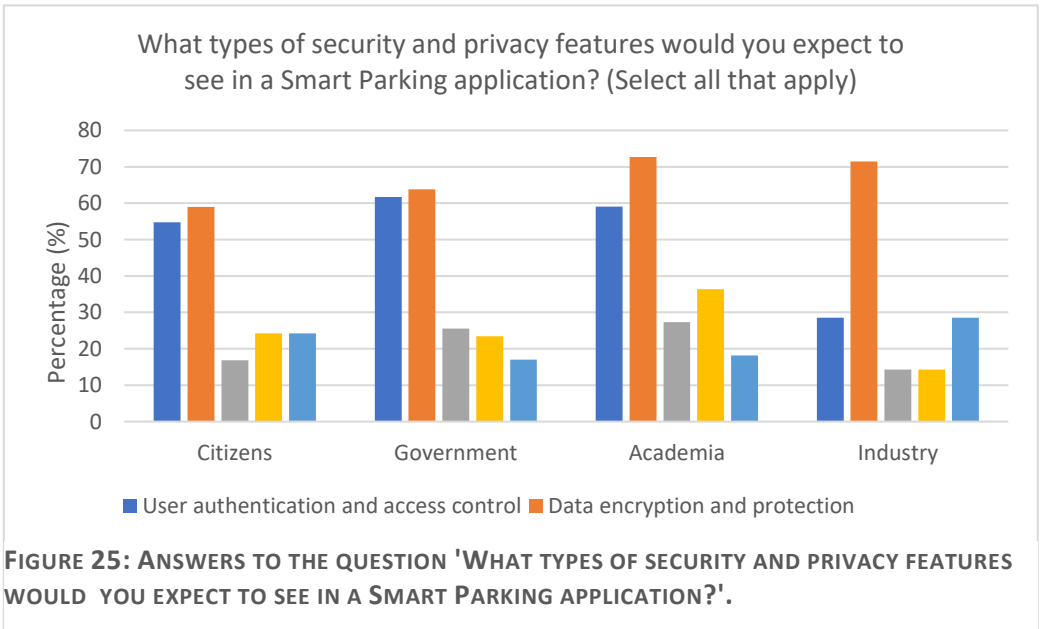

FIGURE 25: ANSWERS TO THE QUESTION 'WHAT TYPES OF SECURITY AND PRIVACY FEATURES WOULD YOU EXPECT TO SEE IN A SMART PARKING APPLICATION?'.

End-users and stakeholders were asked to vote on the technologies they consider most important to be incorporated into a smart parking digital twin (Figure 26). The results were as follows:

- Citizens voted Internet of Things (IoT) sensors for real-time parking availability monitoring and Mobile Applications that guide users to available parking spots as the most important technology.
- Government representatives voted for Mobile applications that guide users to available parking spots and enable mobile payments.
- Academia prioritized Artificial Intelligence (AI) algorithms for predicting parking demand and optimizing parking space usage.
- Industry stakeholders also voted for Mobile applications that guide users to available parking spots and enable mobile payments.

Furthermore, all four groups expressed a strong preference for accessing a smart parking digital twin through a mobile application (Figure 27). However, when it comes to the digital twin interface, only academia provided a clear preference for a 2D interface (Figure 28).

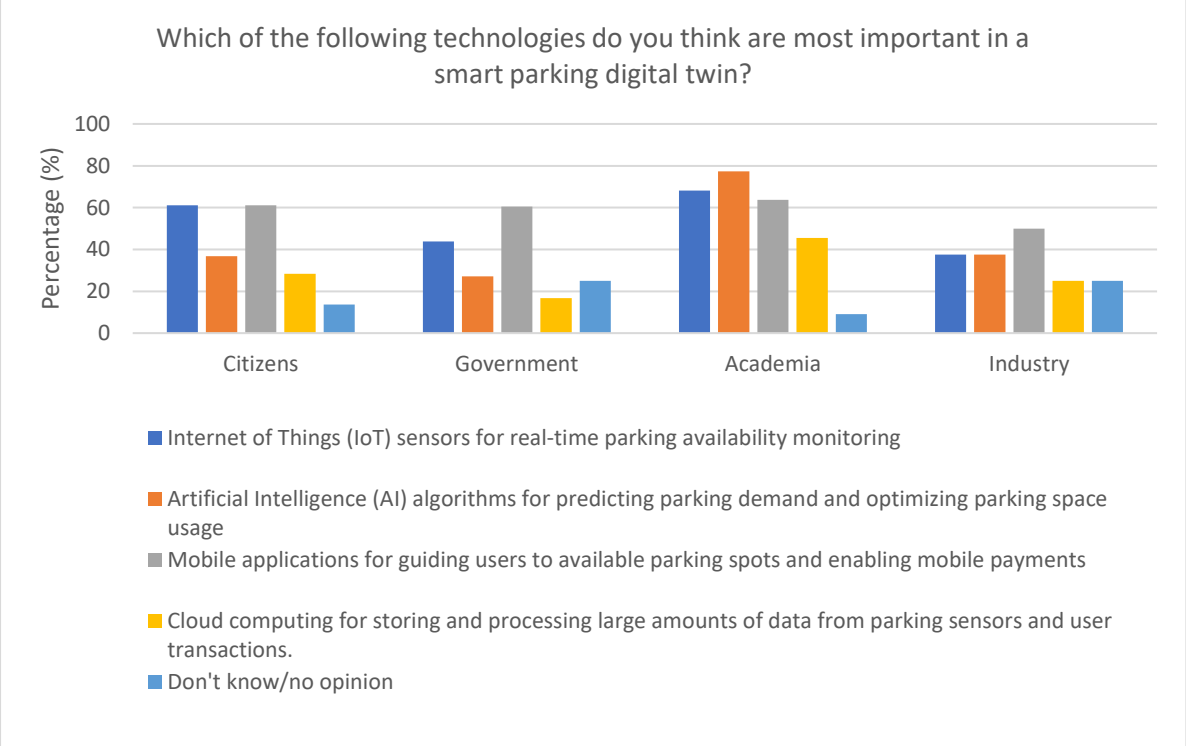

FIGURE 26: MOST IMPORTANT TECHNOLOGIES IN A SMART PARKING DIGITAL TWIN.

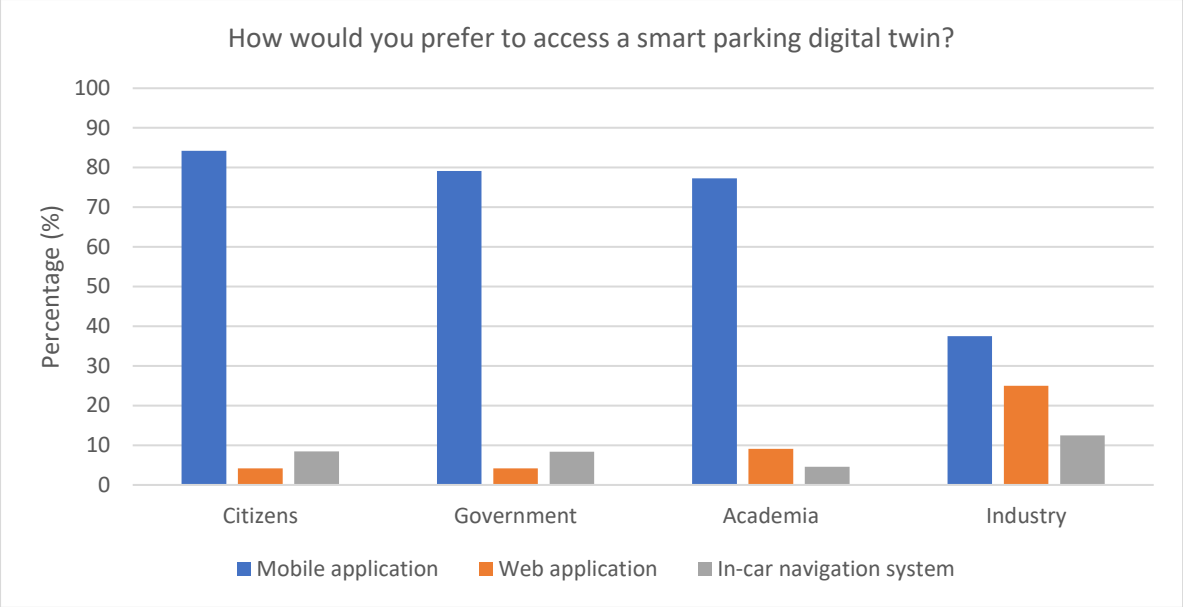

FIGURE 27: MOST PREFERABLE METHOD TO ACCESS A SMART PARKING APPLICATION.

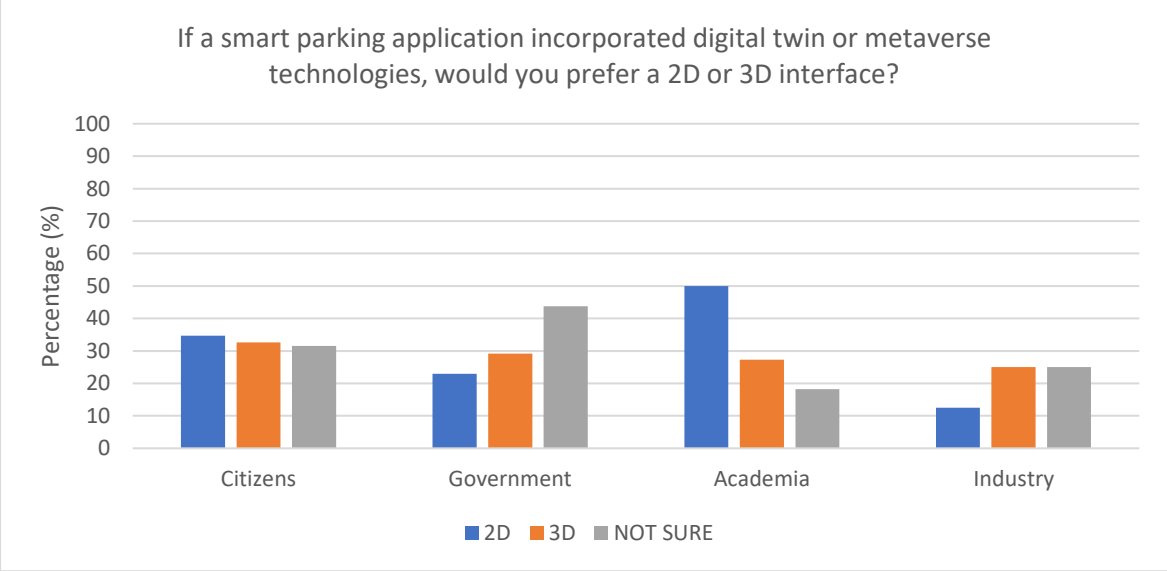

FIGURE 28: ANSWERS TO THE QUESTION 'IF A SMART PARKING APPLICATION INCORPORATED DIGITAL TWIN OR METAVERSE TECHNOLOGIES, WOULD YOU PREFER A 2D OR 3D INTERFACE? '.

To identify and prioritize the most important stakeholder needs, respondents were asked to vote on various application features using a scale from 1 (not important) to 5 (extremely important). Among other features stakeholders were asked about:

- Real-time information
- Integration with other transportation and urban planning systems, such as public transportation or traffic management systems
- Ability of the platform to work across different parking systems and providers
- Ability to pay using different payment methods

- Ability to receive notifications about parking spot availability in user's desired location
- Protection of personal and financial information
- Privacy-preserving mechanism to safeguard drivers' information about their visited locations
- User-friendly interface
- Reminders about parking time expiration
- Ability to extend parking time remotely
- Ability to view parking history and receipts
- Showing location of handicap-accessible parking spots

Table 6 summarizes the requirements and their priority.

TABLE 6: REQUIREMENTS' DESCRIPTION AND SCORING (SCALE OF 1 TO 5 TRANSLATED INTO THE CATEGORIES OF "MUST HAVE," "SHOULD HAVE," "COULD HAVE," "WON'T HAVE").

REQUIREMENT	DESCRIPTION	QUADRUPLE HELIX GROUP			
		Citizens	Government	Academia	Industry
SP01	Secure payment system to protect your personal and financial information.	Must have (86%)	Must have (91%)	Must have (82%)	Must have (100%)
SP02	Accessed via mobile application.	Must have (84%)	Must have (79%)	Must have (77%)	Must have (37%)
SP03	User-friendly interface	Must have (62%)	Must have (58%)	Must have (73%)	Must have (87%)
SP04	Privacy-preserving mechanism to protect drivers' information about their visited locations.	Must have (62%)	Must have (62%)	Must have (68%)	Must have (100%)
SP05	Real-time information about parking spot availability	Must have (62%)	Must have (67%)	Must have (77%)	Must have (87%)
SP06	Ability to extend the parking time remotely.	Must have (66%)	Must have (73%)	Must have (73%)	Must have (63%)
SP07	Ability to pay for parking using different payment	Must have (56%)	Must have (66%)	Must have (59%)	Must have (100%)

	methods (e.g. credit/debit card, mobile wallet, etc.)				
SP08	Smart Parking application to be able to work across different parking systems and providers.	Must have (59%)	Must have (57%)	Must have (64%)	Must have (63%)
SP09	Reminders about parking time expiration.	Must have (50%)	Must have (62.5%)	Must have (55%)	Must have (50%)
SP10	Showing location of handicap-accessible parking spots.	Must have (45%)	Must have (45%)	Must have (55%)	Must have (88%)
SP11	Notifications about parking spot availability in user's desired location.	Must have (42%)	Must have (29%)	Must have (36%)	Must have (63%)
SP12	Integration with other transportation and urban planning systems, such as public transportation or traffic management systems.	Must have (35%)	Should have (33%)	Must have (45%)	Must have (37%)
SP13	Parking history and receipts.	Could have (35%)	Could have (36%)	Could have (36%)	Must have (50%)

6.2.1.1.1 User Stories

In order to capture the ideal use-scenarios and requirements of various stakeholders, user stories were utilized to describe their specific goals and motivations. The user stories follow the format of 'I, as <A ROLE>, want to <GOAL>, so that <REASON>'. These user stories provide valuable insights into the desired functionalities and benefits which stakeholders seek in a smart parking solution. Below, some examples of user stories that were gathered from representatives of the quadruple helix are presented:

Citizens:

- As a person who always runs late, I want to be able to monitor parking availability close to my destination so that I can plan my route ahead and save time.
- As a physician, I want to easily find parking when driving to work so that I don't waste time searching for a parking spot.
- As someone visiting a public service building in the city center at a specific time, I want to ensure that I can find available parking close to the building within a short time. I would like the option to find and book a parking spot in advance, preferably within a 1 km radius of the building, and reserve it for at least 1 hour with the possibility of extending the reservation in case of a meeting delay.
- As a director, I would like to book a parking spot close to my office using a mobile app for added convenience.

Government:

- As a government official, I want access to real-time data on parking usage and demand so that I can make informed decisions about parking infrastructure and effectively allocate resources.
- As an Administrative Officer, I want a mobile application that allows me to easily find affordable parking spots for my car every morning.

Academia:

- As an employee, I want the ability to easily find a parking spot near my workplace during my workdays, eliminating the struggle of searching for one every morning.
- As a professional, I want to efficiently park my car without wasting time and energy resources searching for a convenient parking spot near my destination.
- As a parent of two children, I want the convenience of paying for parking through a mobile app, eliminating the need to leave my kids unattended while I go to a payment kiosk for ticket payment.

Industry:

- As an industry stakeholder, I want a seamless mobile payment system to be integrated into the smart parking solution. This will enable customers to conveniently pay for parking using different payment methods, enhancing the overall user experience.
- As a parking employee, I want to have the capability to manage parking availability and spaces through a digital platform. This platform should provide real-time information on parking availability and offer the option for drivers to reserve a parking space, streamlining the parking management process.

6.2.1.1.2 Conclusion

In conclusion, the survey results shed light on the level of awareness and challenges surrounding the digital twin concept in the context of smart parking. It is evident that there is limited familiarity with the concept among the general public, emphasizing the need for education and awareness campaigns. The daily experiences of respondents highlighted common difficulties in finding parking spots and associated issues. Stakeholders across the quadruple helix expressed their willingness to use a smart parking application incorporating digital twin and metaverse technologies, with a strong emphasis on time and cost efficiency, convenience, and safety. Privacy, security, technical aspects, and cost were identified as crucial concerns when considering such applications. Stakeholders also provided valuable insights into the desired features, including real-time information, integration with other systems, diverse payment methods, privacy protection, and user-friendly interfaces. The preference for mobile applications and the importance of accessibility for people with disabilities were notable findings. The survey findings contribute to a comprehensive understanding of stakeholder needs and expectations, providing a solid foundation for the development of effective smart parking solutions.

6.2.1.2 Use Case 2: Urban Planning

In this section, the results of the 'urban planning questionnaire' are being presented. Similar to the previous survey, a significant proportion of citizens (56%) and governmental representatives (58%) reported being unfamiliar with the digital twin concept. In contrast, the majority of academia (80%) and industry representatives (55%) stated that they were either familiar with the concept or had utilized it in the past.

Participants were asked to rate the current state of their cities on a scale of 1 to 5. The majority of respondents provided ratings of 2 to 3, indicating an average to slightly above-average state (Not Bad-Good). Commonly reported issues included traffic congestion, lack of green spaces, inefficient public transportation, inadequate pedestrian infrastructure, poor air quality, and a shortage of affordable housing (Figure 29). Traffic congestion and inefficient public transportation were consistently selected as the most significant issues.

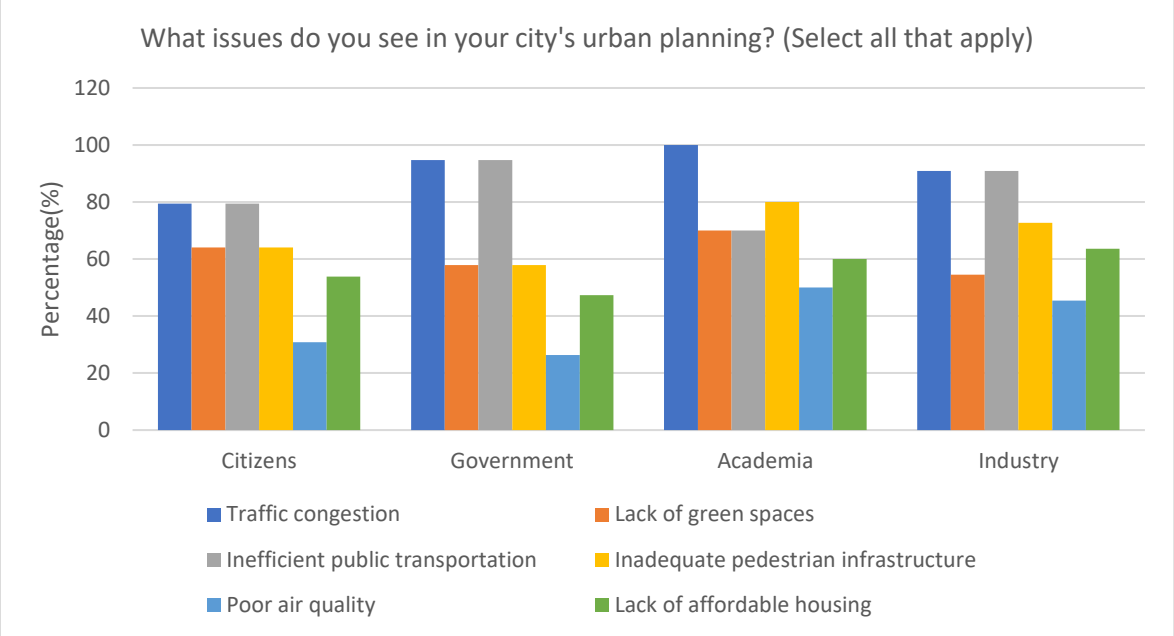

FIGURE 29:COMMONLY REPORTED ISSUES IN CITY'S URBAN PLANNING.

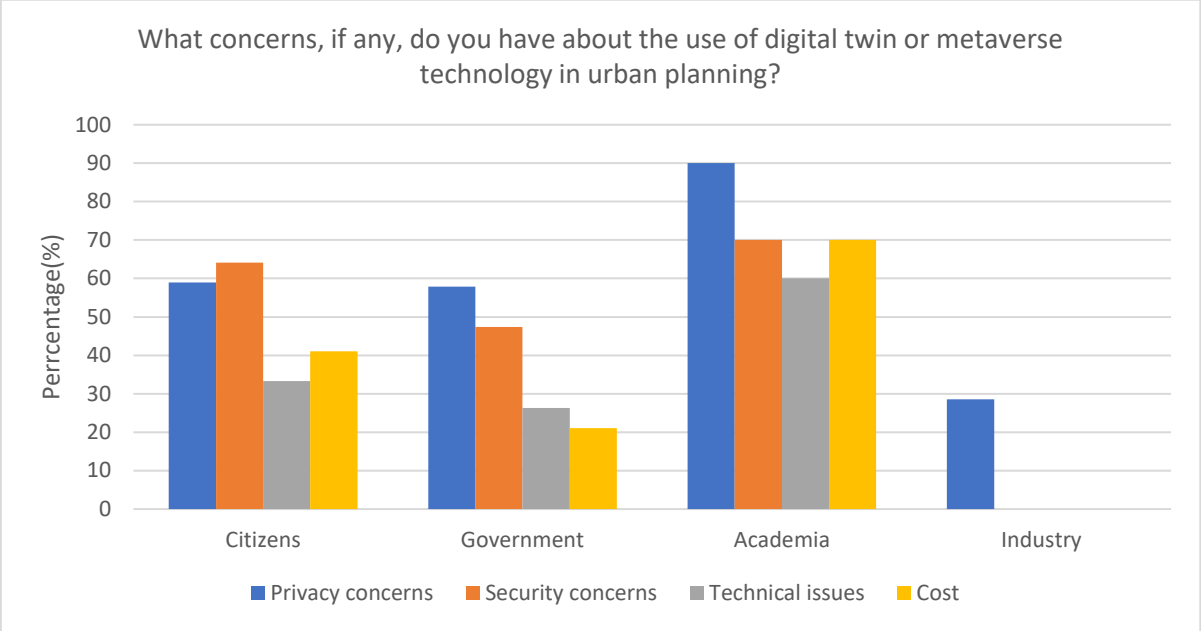

FIGURE 30: CONCERNS ABOUT THE USE OF DIGITAL TWIN OR METAVERSE TECHNOLOGY IN URBAN PLANNING.

All stakeholder groups responded positively when asked whether they believed the use of digital twin or metaverse technology in urban planning could benefit their communities. However, concerns regarding security and privacy associated with these technologies were also expressed (Figure 30)

Participants expressed the desire for a digital twin platform that provides real-time updates, particularly in relation to traffic and public transportation schedules and routes (Figure 31). Furthermore, key aspects of urban growth were identified, including building stock analysis, noise maps, real-estate prices, green cover, urbanization, and urban sprawl. Among these, green cover and real-estate prices were considered top priorities. Respondents agreed that the platform should be capable of estimating the trend of urban growth. This could be achieved by analyzing changes in the number and types of buildings over time, evaluating building density and distribution, and assessing the environmental impact of new construction projects. Furthermore, participants emphasized the importance of using green cover data to inform environmental decisions. The platform should identify areas with low green cover that require increased conservation efforts and explore the relationship between green cover and other environmental factors.

Citizens and academia both emphasized the importance of assessing air quality as the primary environmental factor for the platform to consider. Conversely, governmental representatives prioritized green cover, while industry representatives expressed equal interest in air and water quality, biodiversity and ecosystems, and green cover (Figure 32). However, all stakeholders agreed the platform should have the ability to predict and analyze the environmental impact of urban growth (Figure 33).

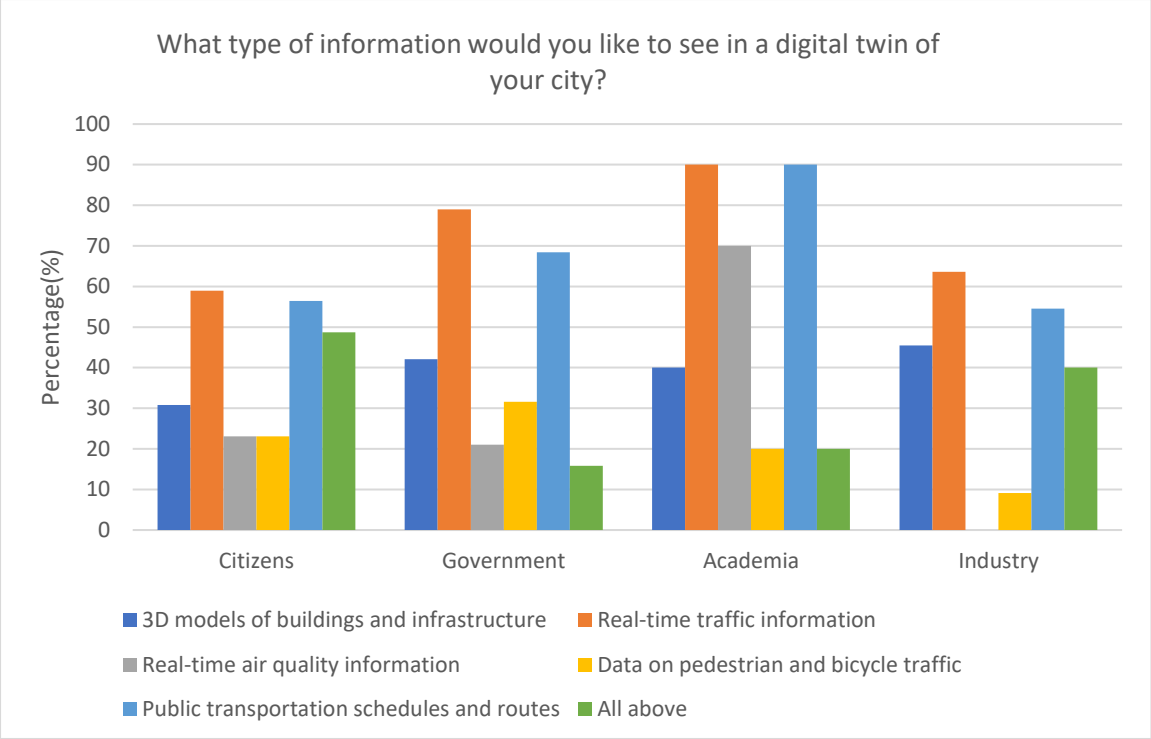

FIGURE 31: TYPE OF INFORMATION THAT STAKEHOLDERS WOULD LIKE TO SEE IN A DIGITAL TWIN OF THEIR CITY.

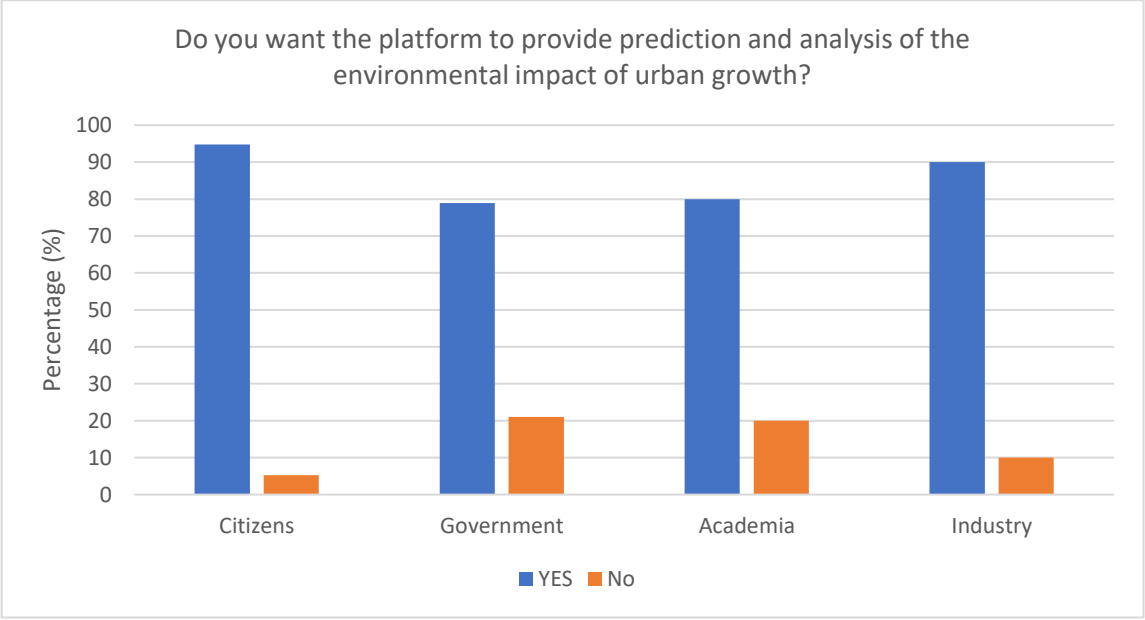

FIGURE 32: RESPONSES TO THE QUESTION 'DO YOU WANT THE PLATFORM TO PROVIDE PREDICTION AND ANALYSIS OF THE ENVIRONMENTAL IMPACT OF URBAN GROWTH?' BY THE FOUR GROUPS OF THE QUADRUPLE HELIX.

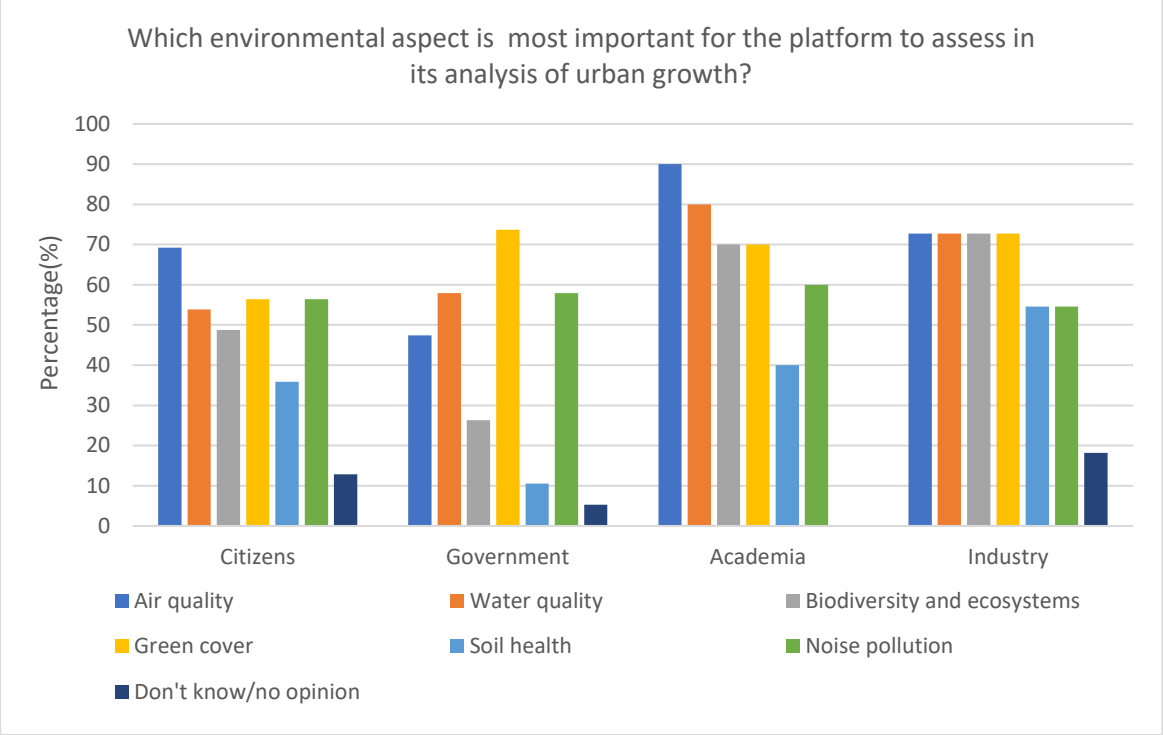

FIGURE 33: MOST IMPORTANT ENVIRONMENTAL ASPECTS FOR THE PLATFORM TO ASSESS IN ITS ANALYSIS OF URBAN GROWTH.

Regarding noise maps, the platform should incorporate factors such as population density, land use patterns, and transportation systems to provide accurate assessments.
All stakeholder groups agreed that the digital twin must possess the capability to seamlessly integrate remote sensing and in-situ monitoring, utilizing IoT sensors for environmental data collection. Furthermore, the majority of participants expressed a preference for visual representations (e.g., maps, graphs) of the data, emphasizing the importance of user-friendliness.
When asked to choose between a mobile application, web-based application, or a desktop software, respondents chose the mobile application (Figure 34).

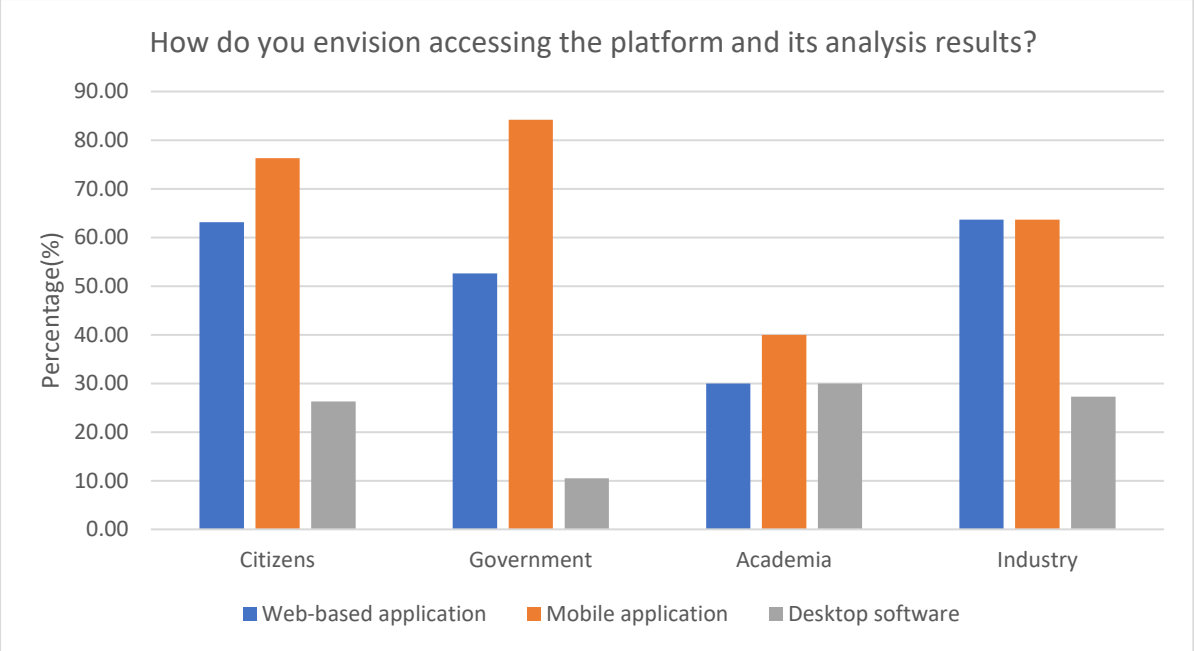

FIGURE 34: PREFERENCES ON DIFFERENT TYPES OF APPLICATIONS.

To identify and prioritize the most important stakeholder needs, respondents were asked to vote on various application features using a scale from 1 (not important) to 5 (extremely important). Among other features stakeholders were asked about:

- Real-time data such as traffic, weather, and air quality
- Access to detailed data about your city's infrastructure, such as roads, buildings, and utilities
- Accessibility and usability by people with disabilities, such as those who are deaf or handicap
- Ability to interact with a digital twin of the city and make changes
- Access to historical data about your city's infrastructure
- Access to future projections about your city's infrastructure, such as population growth and economic development
- Compatibility with other planning tools and software used by city officials and planners
- Ability to view the digital twin of the city in virtual reality or augmented reality

The following table summarizes the requirements and their priority.

TABLE 7: REQUIREMENTS' DESCRIPTION AND SCORING (SCALE OF 1 TO 5 TRANSLATED INTO THE CATEGORIES OF "MUST HAVE," "SHOULD HAVE," "COULD HAVE," "WON'T HAVE") FOR THE CYPRIOT URBAN PLANNING USE CASE.

Requirement	Description	Quadruple helix group			
		Citizens	Government	Academia	Industry
UP01	Accessibility and usability by people with disabilities, such as those who are deaf or handicap	Must have (63%)	Must have (63%)	Must have (80%)	Must have (78%)
UP02	Access to detailed data about your city's infrastructure, such as roads, buildings, and utilities	Must have (44%)	Must have (42%)	Must have (50%)	Should have (45%)
UP03	Real-time data such as traffic, weather, and air quality	Must have (39%)	Must have (32%)	Must have (50%)	Should have (45%)
UP04	Compatibility with other planning tools and software used by city officials and planners	Must have (46%)	Should have (47%)	Could have (40%)	Should have (64%)
UP05	Ability to interact with a digital twin of the city and make changes	Should have (44%)	Could have (47%)	Should have (50%)	Should have (37%)
UP06	Access to historical data about your city's infrastructure	Should have (36%)	Should have (53%)	Should have (30%)	Should have (37%)
UP07	Access to future projections about your city's infrastructure, such as population growth and economic development	Should have (50%)	Should have (37%)	Should have (40%)	Should have (73%)
UP08	Ability to view the digital twin of the city in virtual reality or augmented reality	Could have (32%)	Should have (42%)	Won't have (30%)	Should have (82%)

During the information gathering phase, individuals were asked to provide input on the **essential information and data required for their work**. The most frequently mentioned responses included:

- Town Planning
- Infrastructure
- Public Transportation
- Land Occupation
- GIS (Geographic Information System)
- Traffic Analysis
- Environmental Data
- Sociodemographics
- Green Areas
- Heritage, History & Culture
- Impact of New Construction Projects on the Environment
- Building Types and Density
- Public Transport
- Bike and Pedestrian Pathways

- Urban Growth
- Air Quality
- Data Related to Architecture, such as Building Density, Air and Microclimate Quality, Green Cover, Infrastructure, etc.

In addition, individuals identified several **existing systems or databases** that they believed should be integrated with the digital twin platform for urban planning. Here are the mentioned systems along with a brief explanation of how they would enhance the functionality of the platform:

- **Information concerning materials and structural status of existing buildings:** Integration of this data would provide crucial insights into the safety and condition of older structures, enabling better analysis and decision-making regarding urban planning initiatives.
- **Department of Land and Survey Database[1]:** This database holds valuable information related to land ownership, boundaries, and topography. Integrating it with the digital twin platform would enhance the accuracy and completeness of land-related data, aiding in more comprehensive urban planning.
- **Planned public utility projects:** Including information about upcoming public utility projects within the digital twin platform would allow urban planners to consider these projects' impact on the overall city infrastructure and plan accordingly for better coordination and efficiency.
- **Database of Land Registry and Urban Planning, Ministry of Interior:** Integrating this database would provide access to official records, regulations, and guidelines related to land use and urban planning. It would serve as a valuable resource for urban planners in making informed decisions and ensuring compliance with existing policies.
- **iNaturalist:** The inclusion of iNaturalist[2], a citizen science platform for documenting biodiversity, would contribute to the platform's environmental and ecological aspects. It would enable urban planners to access and analyse data related to species distribution, ecological corridors, and biodiversity hotspots, supporting more sustainable and nature-friendly urban planning.

6.2.1.2.1 User Stories

Citizens:

- ❖ As a cycling commuter, I want to know which route has the least congestion, noise, and air pollution, so that I can reach my destination in a fast, efficient, and healthy way.
- ❖ As a citizen, I want to have a better understanding of my city, its infrastructure, and amenities, so that I can feel more comfortable and connected to my surroundings.
- ❖ As an architect, I want to be able to visualize the current use of public spaces in our city, so that policy-making and bottom-up initiatives can effectively address problems and provide solutions for improving the utilization and design of these spaces.
- ❖ As a citizen, I want to have access to information about the government's goals and plans regarding urban planning, so that I can understand the direction in which the city is heading and actively participate in shaping its future development.

[1] DLS Portal (moi.gov.cy)

[2] https://www.inaturalist.org/

Government:

- As a professional in the public sector and the technical department of my city, I want smarter, quicker, and more effective solutions that can predict and address all aspects of the city's infrastructure, enabling maximum sustainability and efficient development.
- As a Local Government representative, I want to implement a digital twin platform to enhance city planning capabilities and enable better decision-making processes based on comprehensive and real-time data analysis.

Academia:

- As a citizen, I want to be able to view the current status of air pollution in the city so that I can make informed decisions about which areas to avoid and protect my health.
- As a citizen, I want an Urban Planning Digital Twin that provides me with access to real-time or near real-time data about my city whenever I need it. This way, I can stay informed about various aspects of the city's functioning, leading to a significant improvement in my overall quality of life.

Industry:

- As an urban developer, I want to utilize a digital twin platform that seamlessly integrates social and demographic databases, energy management systems, and geographic information systems. This integration will allow me to gain a comprehensive understanding of the needs and preferences of communities, optimize energy usage, and design efficient urban infrastructure. Ultimately, my goal is to contribute to a better quality of life for residents.
- I as project manager want to obtain real time information on developments in certain domains like transport and logistics and infrastructure so that any decision taken are informed by this data to achieve realistic analysis of parameters in place.

6.2.1.2.2 Conclusion

The survey results showed that while there is still limited awareness of the digital twin concept among citizens and governmental representatives, academia and industry have a higher level of familiarity. Participants rated their cities as average to slightly above average, with common issues including traffic congestion, lack of green spaces, and poor air quality. Stakeholders expressed positive views on the potential benefits of digital twin technology in urban planning but raised concerns about security and privacy. Key features desired in a digital twin platform include real-time data, accessibility, integration of remote sensing, and visual representations. Existing systems such as building information, land registry, and citizen science databases were identified as valuable additions. The survey highlighted the importance of addressing air quality, urban growth, and noise maps. Overall, the survey demonstrated the importance of a digital twin platform in addressing urban planning challenges and improving the quality of life for citizens.

6.2.2 Greek Pilot: Immersive and Interactive Smart City Data Representation for Smart Mobility

This part presents the results of the questionnaires regarding the parking behavior analysis , the environmental behavior analysis as well as the emergency management performance for the Greek pilot. We were able to reach 162 participants, including people of all ages, genders, and professions. With this diverse sample, it is possible to gain a thorough grasp of stakeholder perspectives on parking and environmental behavior as well as emergency management performance. The questionnaire results will be presented here, with an emphasis on significant patterns and preferences.

6.2.2.1 Use Case 1: Parking Behavior Analysis

The survey results show that most people, excluding academics and people in Industry, have never heard about the digital twin concept, with the percentage being higher for the general public (76%). Over the half of the respondents assessed the access to alternative forms of transportation (e.g., bike-sharing, carpooling, public transit) in the area they park, as extremely important (51%).

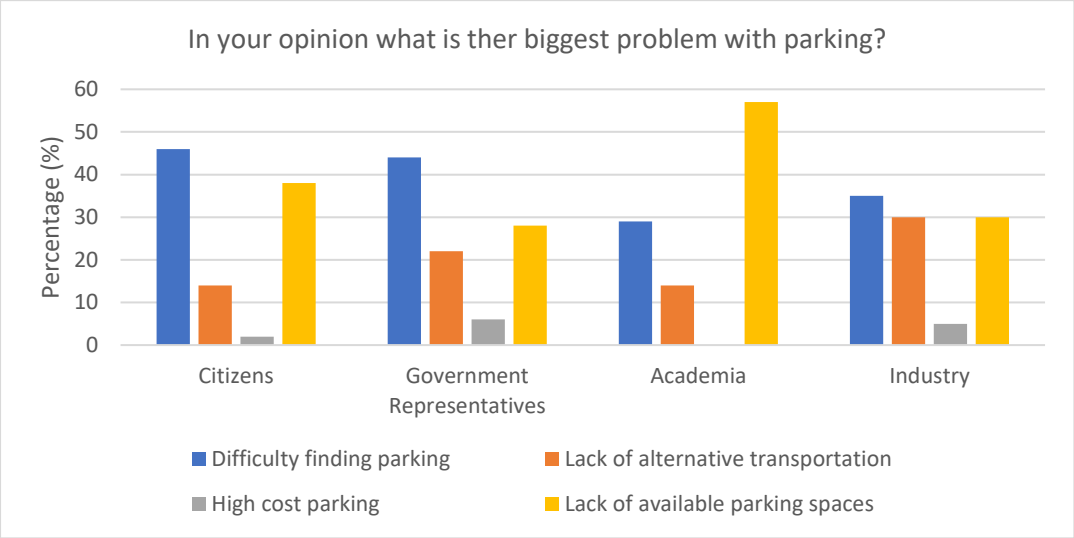

FIGURE 35: BIGGEST PROBLEM RELATED TO PARKING.

Respondents emphasized the difficulty finding parking, which was primarily noted by citizens (46%) and government representatives (44%) as well as the lack of available parking spaces, which was primarily noted by academics (57%) and citizens (38%) (Figure 35). The majority of academics (43%) and residents (31%) stated their reluctance in response to the question of whether they would be willing to pay more for a parking spot if it were closer to their destination. Government representatives were neutral (33%) or thought it was extremely unlikely (33%) that people would pay for parking, whereas a significant portion of stakeholders in the industry (30%) said they would be likely to pay for a spot if it was closer to their destination. Even while a majority of citizens and industry representatives said they would not spend more than 5 minutes looking for parking, the majority of academia and government stakeholders said they are willing to spend between 5 and 10 minutes doing so (Figure 36). All stakeholders – except for academics - agreed that the digital twin will contribute in monitoring illegal behaviors such as violations of restricted parking zones and double parking (Figure 38).

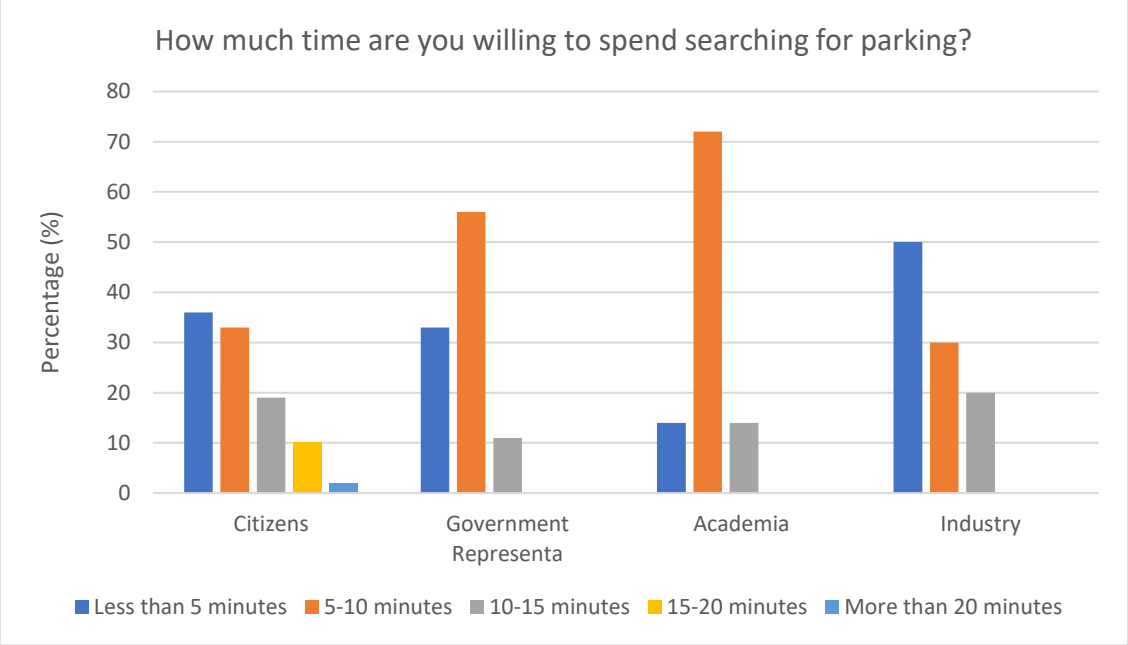

FIGURE 36: TIME THEY ARE WILLING TO SPEND LOOKING FOR PARKING

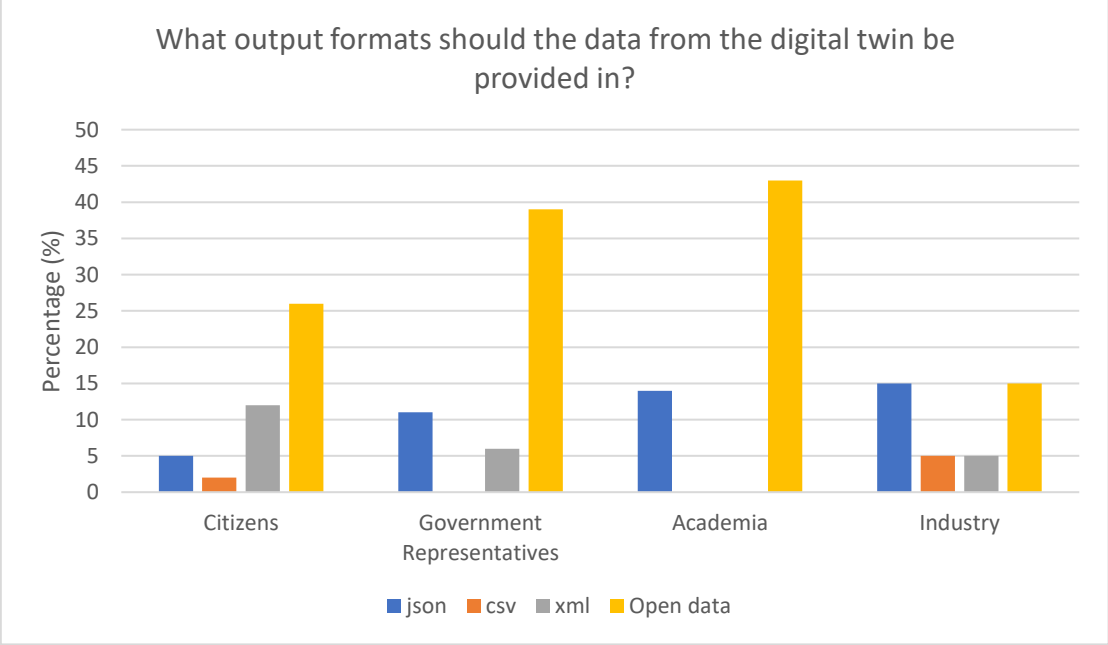

FIGURE 37: ANSWERS TO THE QUESTION "WHAT OUTPUT FORMATS SHOULD THE DATA FROM THE DIGITAL TWIN BE PROVIDED IN?"

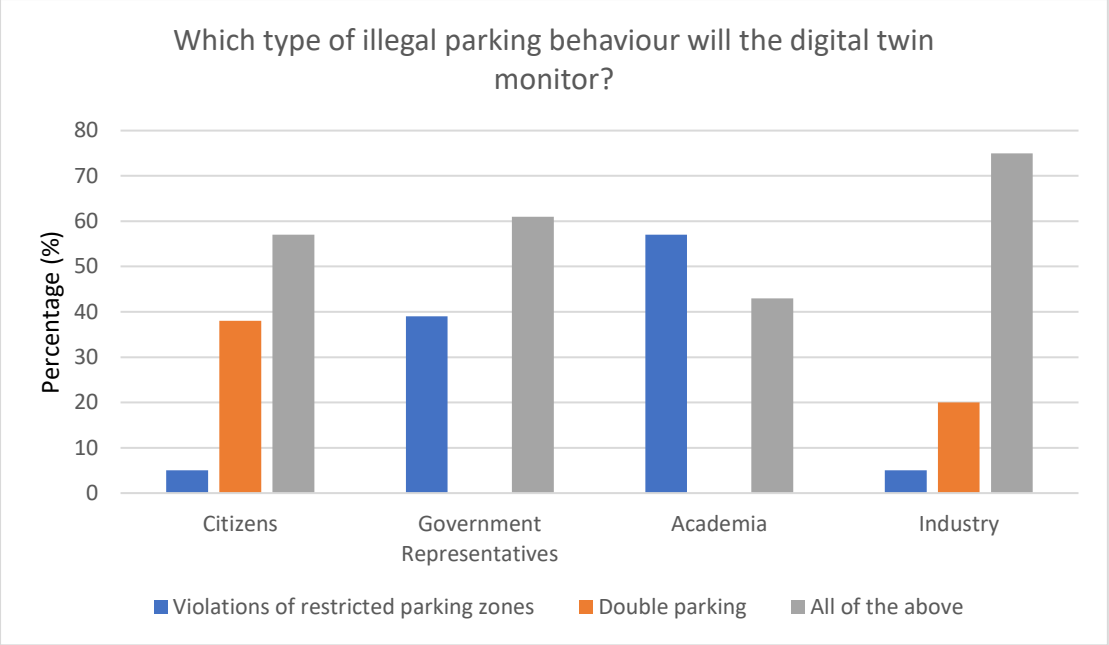

FIGURE 38: ANSWERS TO THE QUESTION "WHICH TYPE OF ILLEGAL PARKING BEHAVIOUR WILL THE DIGITAL TWIN MONITOR?"

Furthermore, all stakeholders agreed that the data gathered by the digital twins will be applied to reduce traffic congestion in the following ways (Figure 39):

- By identifying hotspots of illegal parking behavior
- By implementing enforcement and deterrent measures
- By creating dynamic parking regulations
- Dynamic planning to prevent more vehicles from congesting

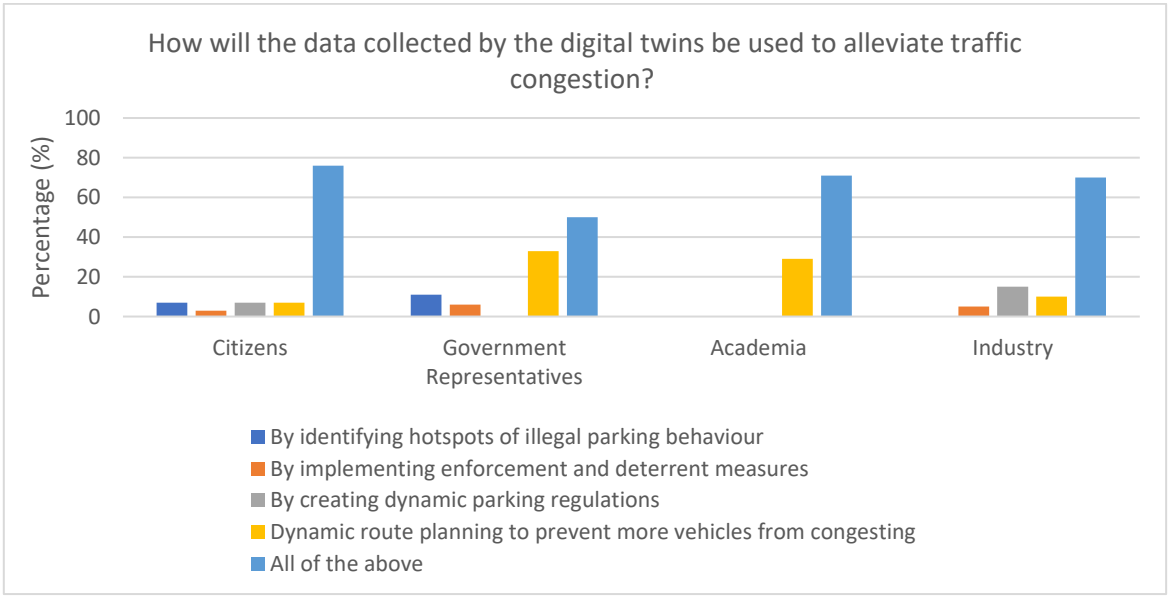

FIGURE 39: WAYS THAT DATA COLLECTED BY THE DIGITAL TWINS WILL BE USED TO ALLEVIATE TRAFFIC CONGESTION.

To identify and prioritize the most important stakeholder needs, respondents were asked to vote on various digital twin features using a scale from 1 (not important) to 5 (extremely important). Among other features, stakeholders were asked to assess the following digital twins' abilities:

- Distinguishing different types of vehicles (e.g., cars, trucks, motorcycles, buses, bicycles, electric scooters, or even pedestrians) and track their movements
- Identification of specific license plate numbers and matching them to registered owner information
- Identification and tracking parked vehicles that are in violation of parking regulations (e.g., overstaying time limit, parked in restricted zones)
- Generating real-time and historical reports on parking and traffic data
- Prediction of traffic congestion and adjustment of traffic signals accordingly
- Integration of other smart city systems, such as public transportation schedules and traffic cameras
- Real time information about public transportation schedules
- Providing dynamic optimal routing for traveling by bicycle by suggesting routes with shadow, low air pollution values, low traffic and avoiding sharp inclines
- Real-time data on available parking spaces

TABLE 8: REQUIREMENTS' DESCRIPTION AND SCORING (SCALE OF 1 TO 5 TRANSLATED INTO THE CATEGORIES OF "MUST HAVE," "SHOULD HAVE," "COULD HAVE," "WON'T HAVE").

Requirement	Description of Digital Twin's Abilities	Quadruple Helix			
		Citizens	Government	Academia	Industry
SP01	Providing dynamic optimal routing for traveling by bicycle by suggesting routes with shadow, low air pollution values, low traffic and avoiding sharp inclines	Must Have (64%)	Must Have (83%)	Must Have (100%)	Must Have (80%)
SP02	Real time information about public transportation schedules	Must Have (71%)	Must Have (78%)	Must Have (100%)	Must Have (75%)
SP03	Integration of other smart city systems, such as public transportation schedules and traffic cameras	Must Have (63%)	Must Have (72%)	Must Have (86%)	Must Have (75%)
SP04	Prediction of traffic congestion and adjustment of traffic signals accordingly	Must Have (62%)	Must Have (61%)	Must Have (72%)	Must Have(70%)
SP05	Distinguishing different types of vehicles (e.g., cars, trucks, motorcycles, buses, bicycles, electric scooters, or even pedestrians) and track their movements	Must Have (43%)	Must Have (72%)	Must Have (43%)	Must Have (50%)

SP06	Identification and tracking parked vehicles that are in violation of parking regulations (e.g., overstaying time limit, parked in restricted zones)	Must Have (57%)	Must Have (56%)	Must Have (43%)	Must Have (60%)
SP07	Providing dynamic optimal routing for traveling by bicycle by suggesting routes with shadow, low air pollution values, low traffic and avoiding sharp inclines	Must Have (45%)	Should Have (33%) – Must Have (33%)	Must Have (57%)	Must Have (65%)
SP08	Generating real-time and historical reports on parking and traffic data	Must Have (48%)	Must Have (44%)	Should Have (43%)	Must Have (45%)
SP09	Identification of specific license plate numbers and matching them to registered owner information	Must Have (36%)	Should Have (28%)	Won't Have (29%) – Could Have (29%) – Should Have (29%)	Must Have (32%)

6.2.2.1.1 User Stories

Multiple user stories were created ensuring a comprehensive understanding of stakeholders' visions and needs. Below, some examples of user stories that were gathered from representatives of the quadruple helix are presented:

Citizens

- I, as a car driver want to find a parking slot easily, so that I arrive timely.
- I, as a car driver want to find a parking slot easily, so that I pollute less.
- I, as a bicycle driver want to be able to ride in a dedicated bicycle road.
- I as a citizen would like to reduce time searching for parking so that I perform my tasks more efficiently
- I, as a citizen want to be able to reach the city center by different means (bicycle, car, public transportation), so that I can schedule the transportation time faster and easier

Government Representatives

- I, as a region employee, would like to be informed about available parking spots in order to be able to reach various civil services easily.

Industry

- I, as Civil Engineer with a focus on Environmental Impact Assessment, I would be interested in traffic loads data depicted on a map and their temporal variation, with the aim to assess the air pollution impact on various ecosystems (river and lake ecosystems).

6.2.2.1.2 Conclusion

In conclusion, the survey results shed light on the level of awareness and challenges surrounding the concept of a digital twin in the context of parking behaviour. Stakeholders from various sectors expressed their opinions on the major problems in finding parking spots and their willingness to spend time searching for parking. They also agreed that a digital twin could help monitor illegal behaviours, such as violations of restricted parking zones. Furthermore, they expressed their preferences regarding the output format of data from the digital twin and how it should be used to alleviate traffic congestion. The stakeholders also provided valuable insights into the desired features and capabilities of a digital twin, such as providing dynamic optimal routing, real-time information about public transportation schedules, integration with other smart city systems, and prediction of traffic congestion. The survey findings contribute to a comprehensive understanding of stakeholder needs and expectations, providing a clear view of various aspects of their parking behaviour. This information serves as a solid foundation for the development of effective parking solutions.

6.2.2.2 Use case 2: Emergency Management

In this section, stakeholders' attitudes and beliefs regarding the application of Digital Twins in Emergency Management are discussed. Initially, when asked about the top three goals of the operating center for emergency services digital twin for the transport network, academics emphasized Emergency Response (100%), while government representatives and citizens voted for Optimization of traffic flows (85% and 89% respectively) (Figure 40).

Furthermore, the majority of stakeholders, especially academics, mentioned that Emergency Services and Traffic Management would be the primary users of the digital twins (Figure 41). Regarding the Key Performance Indicators (KPIs) that will be used to measure the success of the digital twin, all stakeholders considered 'Reduced Incident of the Traffic Congestion' as an important indicator. Additionally, while citizens and people in industry highlighted 'Improved Traffic Flow' as crucial (100% in both cases). Academics underlined 'Reduced number of Accidents' as an important KPI (100%).

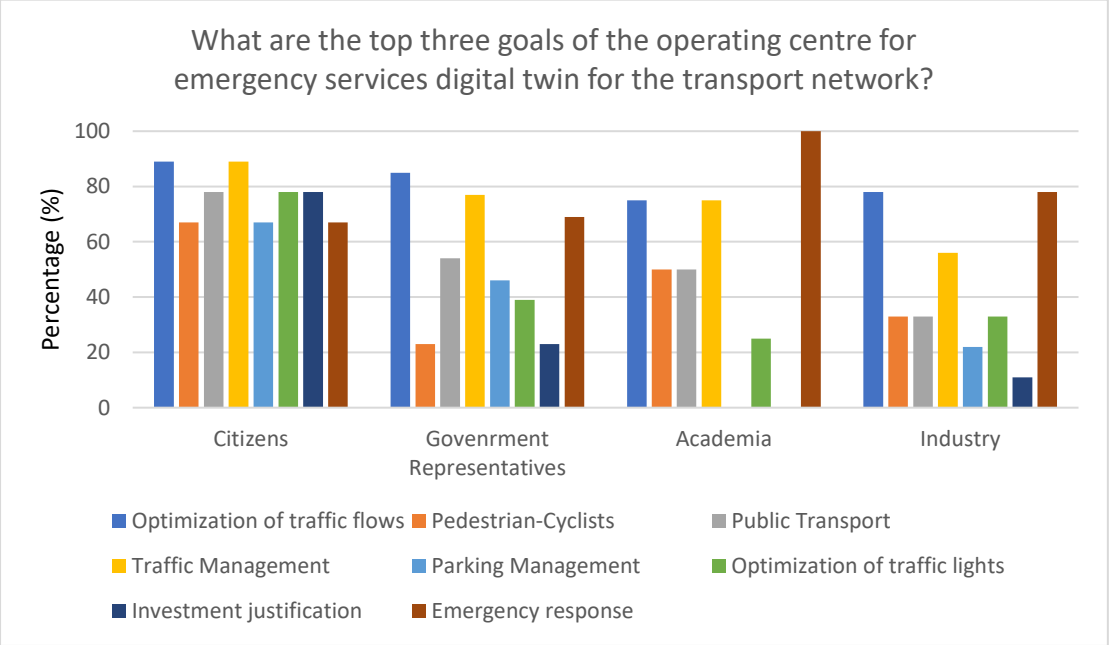

FIGURE 40: GOALS OF THE OPERATING CENTER FOR EMERGENCY SERVICES DIGITAL TWIN FOR THE TRANSPORT NETWORK.

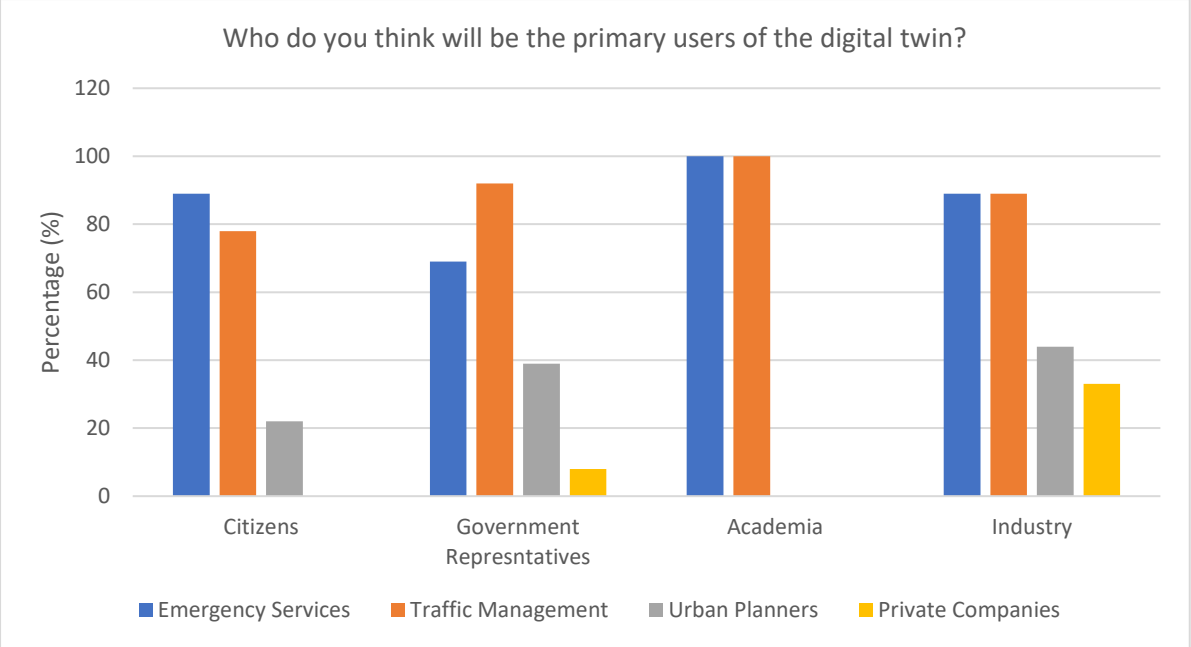

FIGURE 41: PRIMARY USERS OF THE DT.

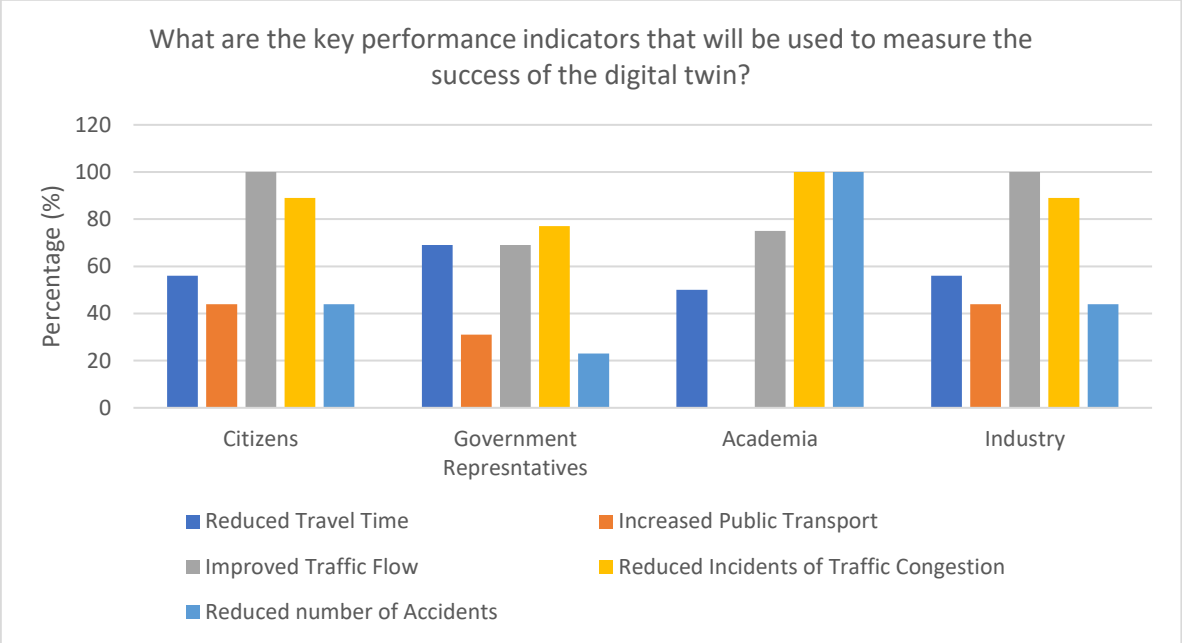

FIGURE 42: KPIS TO MEASURE THE SUCCESS OF THE DT.

Furthermore, stakeholders expressed their preference for receiving notifications about traffic incidents and road closures, with the majority choosing Mobile App among other types of receiving notifications (Figure 42). Moreover, a significant portion of the respondents, particularly citizens (56%) and government representatives (69%), mentioned their desire to be notified about traffic incidents and road closures as soon as possible (Figure 43). Regarding the frequency of notifications for traffic incidents and road closures, citizens and government representatives expressed a preference for receiving them every time there is an incident or closure (78% and 58% respectively). However, academics and individuals in the industry stated that they would like to receive notifications only for major incidents or closures (70% and 51% respectively) (Figure 44).

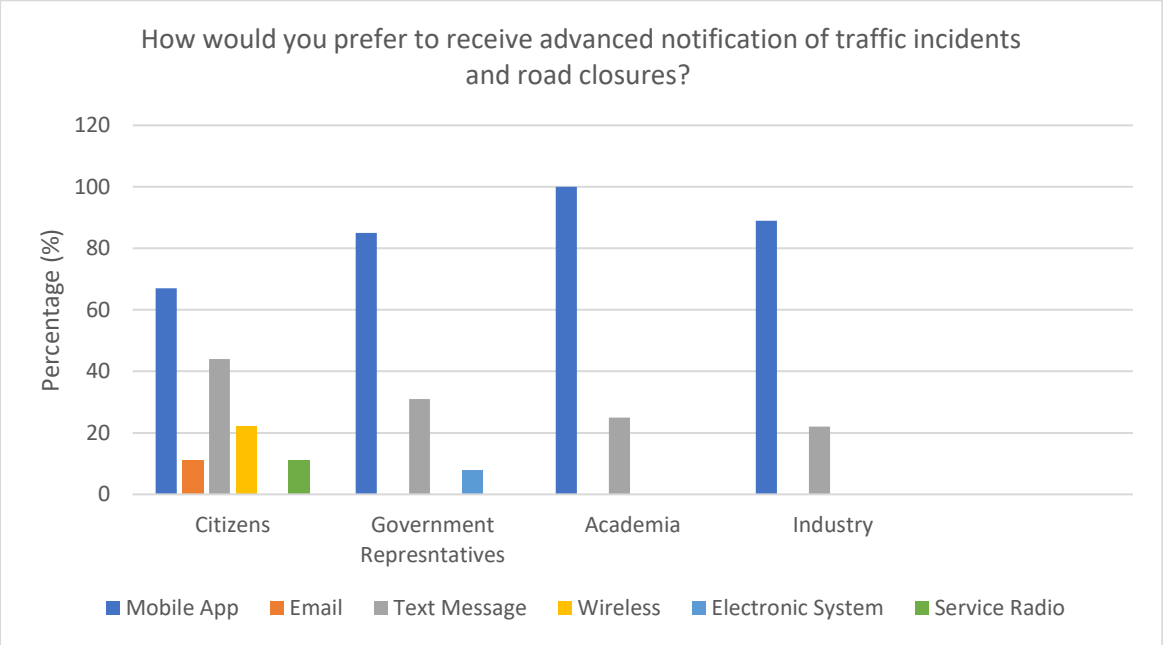

FIGURE 43: PREFERENCES ON DIFFERENT NOTIFICATION METHODS.

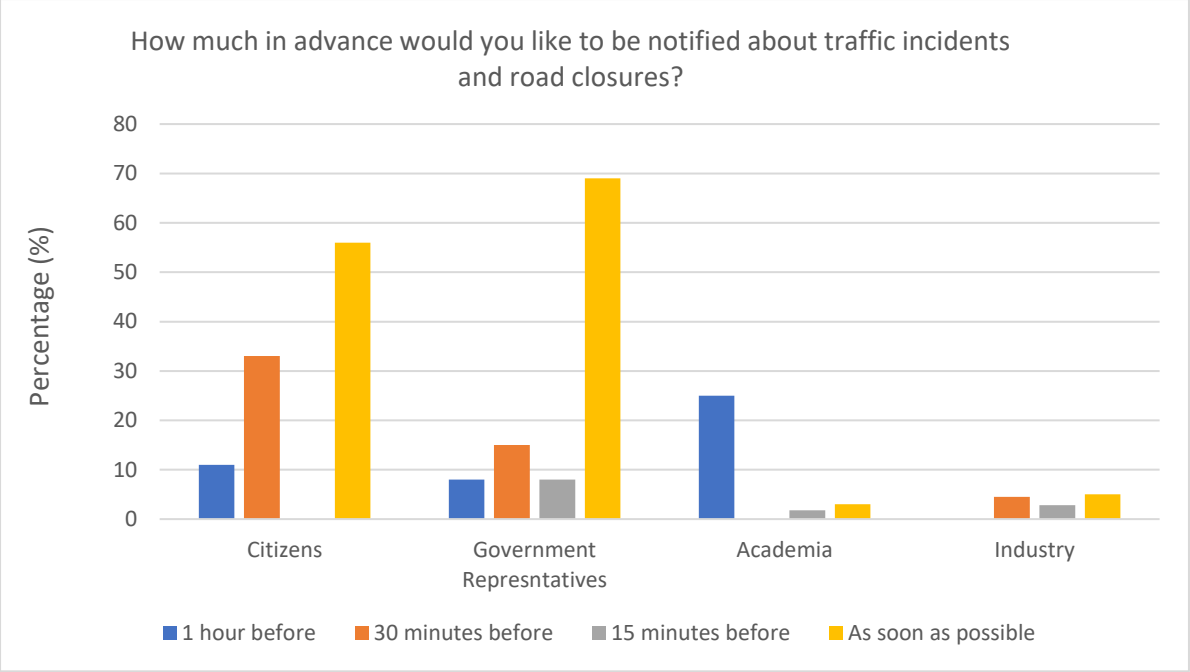

FIGURE 44: ANSWERS TO THE QUESTION 'HOW MUCH IN ADVANCE WOULD YOU LIKE TO BE NOTIFIED ABOUT TRAFFIC INCIDENTS AND ROAD CLOSURES?'

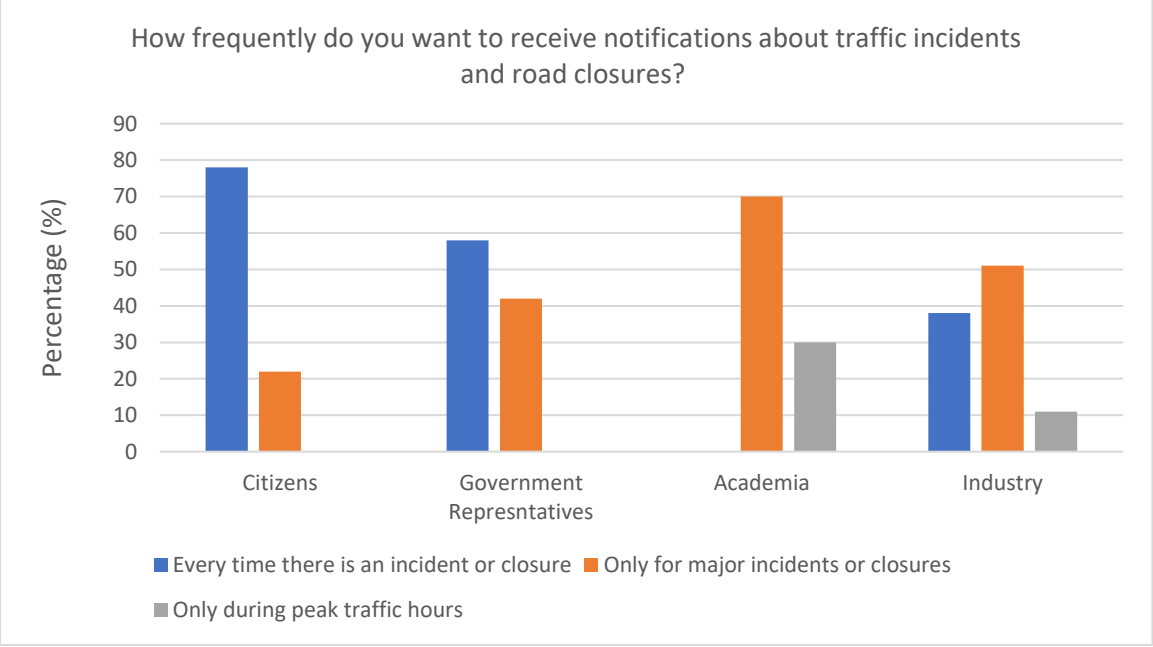

FIGURE 45: FREQUENCY OF NOTIFICATIONS ABOUT TRAFFIC INCIDENTS AND ROAD CLOSURES?

Concerning the organizations who should be responsible for sharing traffic and incident information, Traffic Management Authorities were chosen by the majority of stakeholders (Figure 46). Furthermore, all the stakeholders mentioned that traffic and incident information should be shared

in real-time. When stakeholders were asked about specific features of the digital twin emergency services coordination system, the majority expressed a preference for Real-Time Traffic Information, Rerouting Capabilities, and Advanced Notifications (Figure 46). Regarding the type of data that will be used as input by the digital twin, government representatives mentioned Traffic Sensor Data (62%). On the other hand, individuals in the industry equally voted for Traffic Sensor Data (67%), Real-Time Data (67%), and Traffic Incidents (67%) (Figure 47).

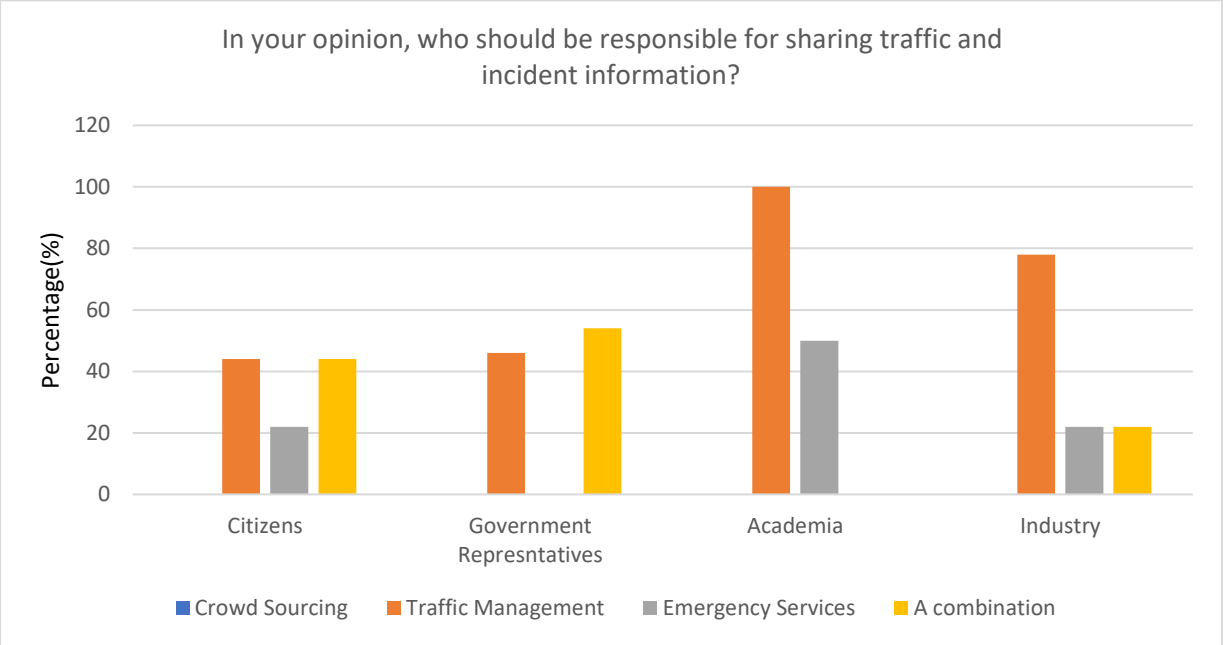

FIGURE 46: ORGANIZATIONS RESPONSIBLE FOR SHARING TRAFFIC AND INCIDENT INFORMATION.

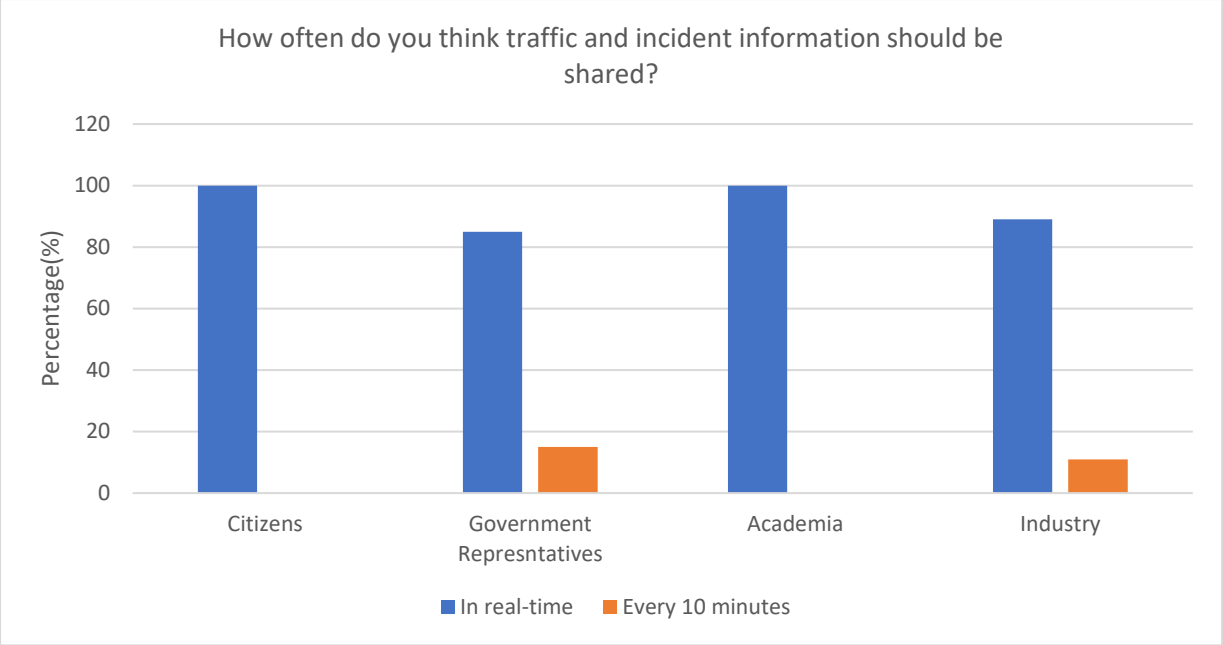

FIGURE 47: ANSWERS TO THE QUESTION "HOW OFTEN DO YOU THINK TRAFFIC AND INCIDENT INFORMATION SHOULD BE SHARED?".

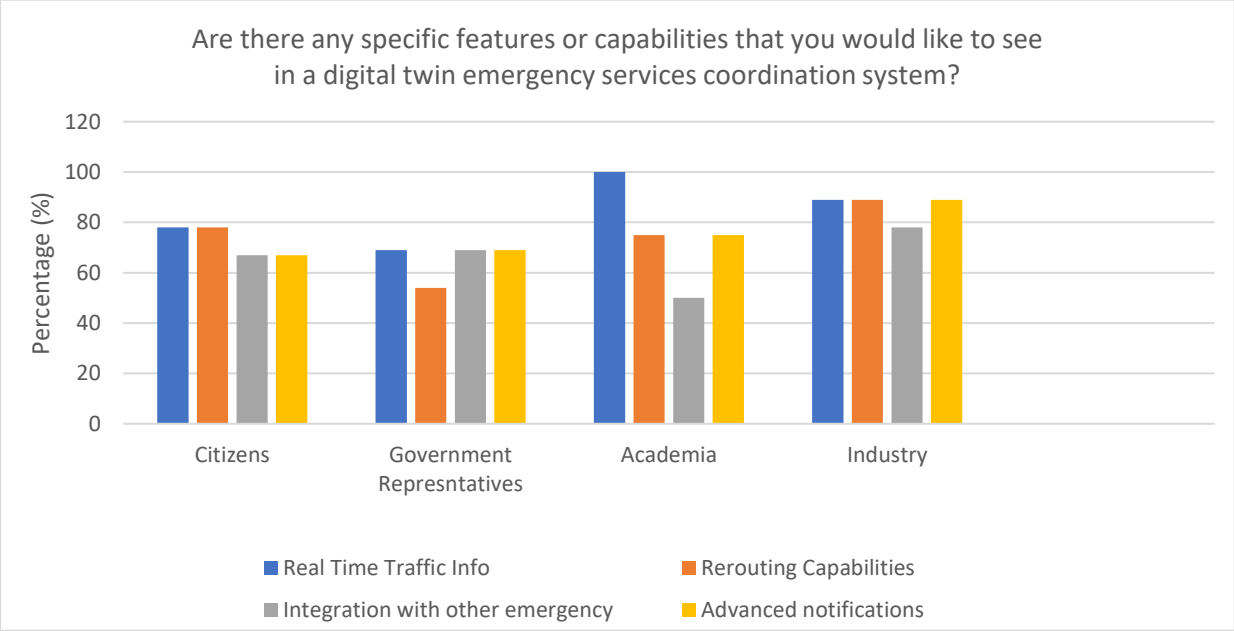

FIGURE 48: FEATURES OF DIGITAL TWIN EMERGENCY SERVICES COORDINATION SYSTEM.

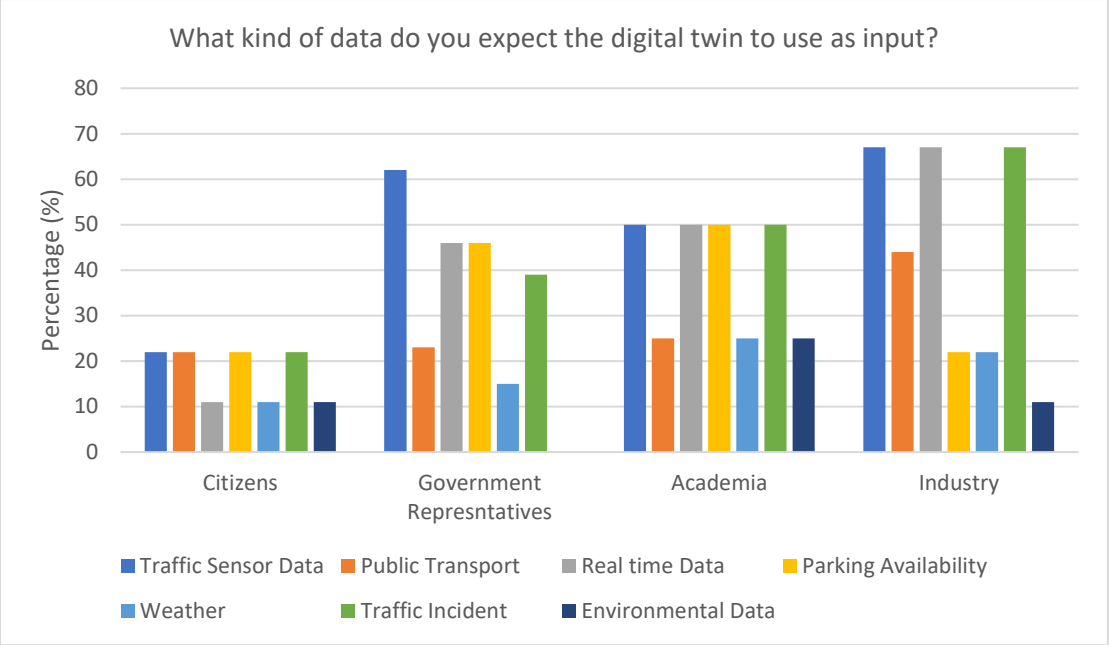

FIGURE 49: ANSWERS TO THE QUESTION "WHAT KIND OF DATA DO YOU EXPECT THE DIGITAL TWIN TO USE AS INPUT?".

When asked about the output formats which are required by the digital twin systems, government representatives chose Batch Data (4.4%), academics Real-Time Streaming (3.5%) and Industry Open Data (5%) (Figure 48). In addition, the majority of stakeholders prefer Web Based Dashboards for the visualization of the outputs of the digital twin system (Figure 49). It is important to acknowledge that the response rates for these questions were relatively low, likely due to their technical nature. Many participants may not have been fully aware or knowledgeable about the specific details, leading them to skip these questions and proceed to the next ones. These findings highlight the diverse perspectives and preferences among stakeholders regarding the output formats and visualization tools for digital twin systems. Despite the lower response rates in certain areas, the collected data still provide valuable insights into the priorities and interests of different stakeholder groups.

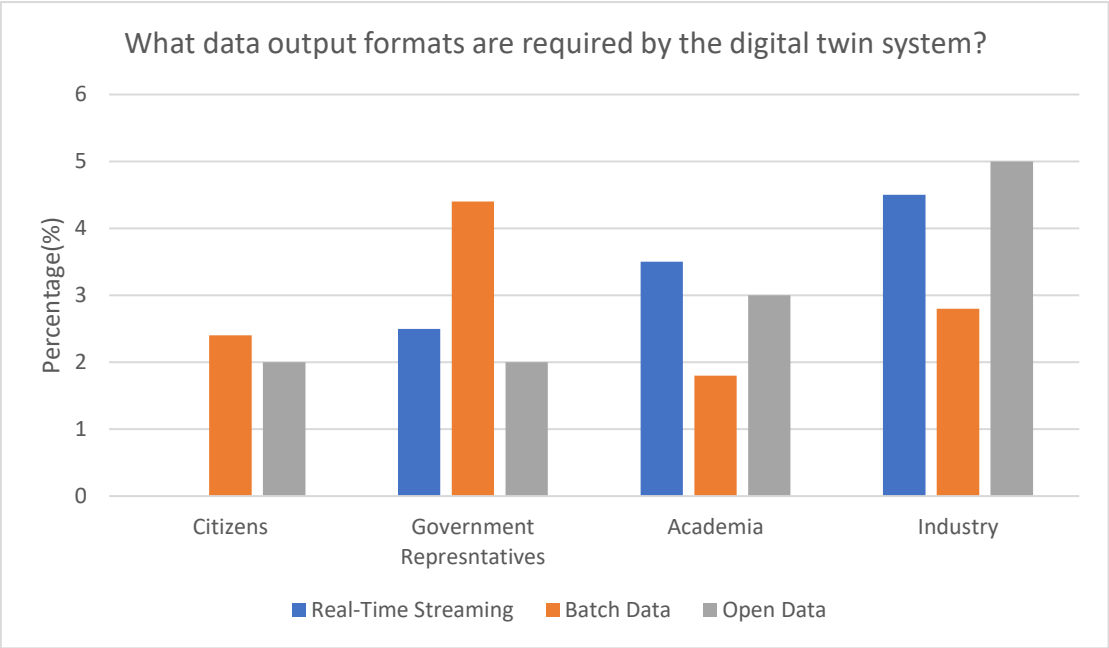

FIGURE 51: OUTPUT FORMATS REQUIRED BY THE DIGITAL TWIN SYSTEM.

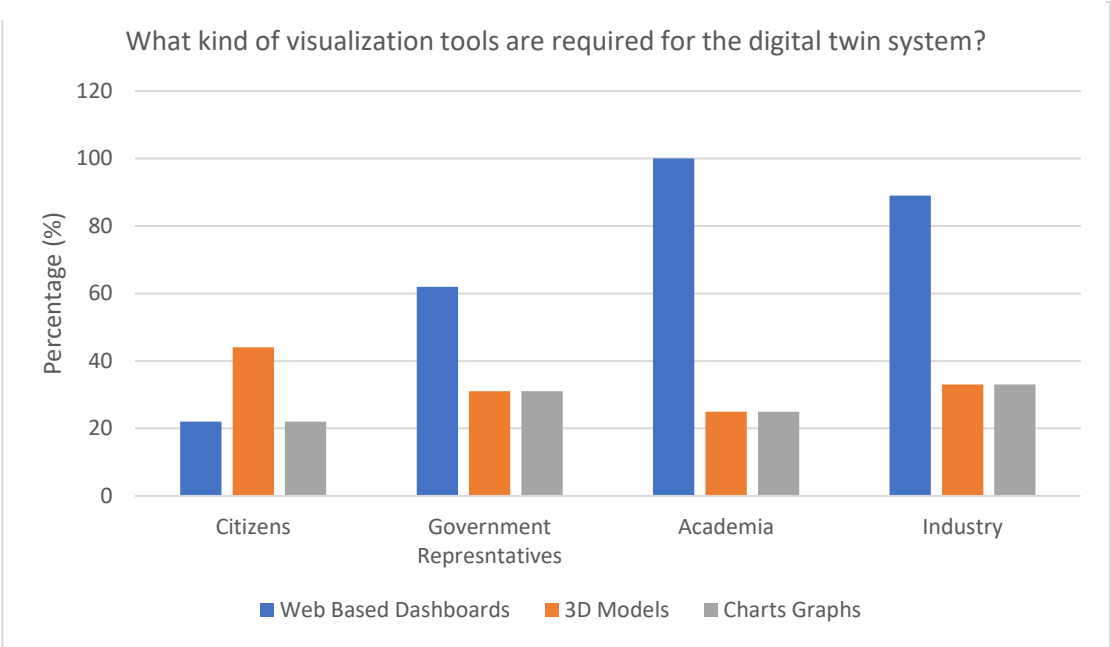

FIGURE 50: VISUALIZATION TOOLS REQUIRED FOR THE DT SYSTEM.

To identify and prioritize the most important aspects of Emergency Management Performance, respondents were asked to vote on various Social and Economic Requirements of an emergency management system. A scale was used, extending from 1 (not important) to 5 (extremely important). Among other features, stakeholders were asked to assess the following Emergency Management Performance abilities:

- Ability to predict the quickest route for emergency vehicles to access an incident Identification of specific license plate numbers and matching them to registered
- Real-time traffic information during an emergency situation
- Advanced notification about traffic incidents and road closures
- Ability to predict the impact of vehicles rerouting during an emergency situation
- Ability to share traffic and incident information with other drivers and emergency services personnel

Table 9 summarizes the requirements and their priority.

TABLE 9: REQUIREMENTS' DESCRIPTION AND SCORING (SCALE OF 1 TO 5 TRANSLATED INTO THE CATEGORIES OF "MUST HAVE," "SHOULD HAVE," "COULD HAVE," "WON'T HAVE".

Requirement	Description	Quadruple Helix			
		Citizens	Government	Academia	Industry
EM01	Ability to predict the quickest route for emergency vehicles to access an incident	Must Have (100%)	Must Have (92%)	Must Have (100%)	Must Have (100%)
EM02	Real-time traffic information during an emergency situation	Must Have (100%)	Must Have (69%)	Must Have (100%)	Must Have (55%)
EM03	Advanced notification about traffic incidents and road closures	Must Have (100%)	Must Have (77%)	Must Have (75%)	Must Have (67%)
EM04	Ability to share traffic and incident information with other drivers and emergency services personnel.	Must Have (100%)	Must Have (69%)	Must Have (75%)	Should Have (44%) Must Have (44%)
EM05	Ability to predict the impact of vehicles rerouting during an emergency situation	Won't Have (100%)	Must Have (69%)	Should Have (50%) - Must Have (50%)	Should Have (67%)

6.2.2.2.1 User Stories

Citizens

- I, as citizen want to live a safe city and be as productive as possible, avoiding traffic congestion.

Government Representatives

- I, as a region employee, would like to know that a system has availability and precision in order for accurate data to be provided and emergency incidents be processed.

Industry

- I, as lifeguard member of Red Cross would like to know the best route for an emergency incident in order to reach it out on time

6.2.2.2.2 Conclusion

In conclusion, the survey results have provided valuable insights into the level of awareness and challenges surrounding the concept of a digital twin in the context of emergency management. The respondents' answers expressed their attitudes and preferences regarding various aspects of the emergency management system, including its goals, the stakeholders who would utilize the data, the key performance indicators for measuring success, and the methods and frequency of information sharing. Additionally, the survey findings have revealed a consensus among stakeholders that a digital twin emergency system could effectively utilize Traffic Sensor Data, Real-Time Data, and Traffic Incident data. Stakeholders have also expressed their desire for specific features and capabilities, such as the ability to predict the quickest route for emergency vehicles, real-time traffic information during emergency situations, and advanced notifications about traffic incidents and road closures.

6.2.2.3 Use Case 3: Environmental behavior analysis on traffic incidents

In this section, data are presented regrading stakeholders' needs, expectations, and concerns related to a digital twin that will have the ability to analyze the impact of traffic incident on the environment. Initially, answering to the question "What are the primary goals of implementing a digital twin for analyzing the impact of traffic incidents on environmental indexes in your city?", the majority of stakeholders agreed that all the following are important (Figure 52):

- Inform Citizen
- Identify trends
- Develop Strategies

Furthermore, the majority of stakeholders, especially academics (80%) but also citizens (78%) and people in industry (75%), answered that all the following ways could be used in order for a digital twin to inform decision-making related to traffic incidents (Figure 53):

- By providing real-time updates on traffic conditions and their impact on the environment
- By identifying hotspots for traffic incidents and implementing preventative measures
- By analyzing the impact of different traffic management strategies on the environment

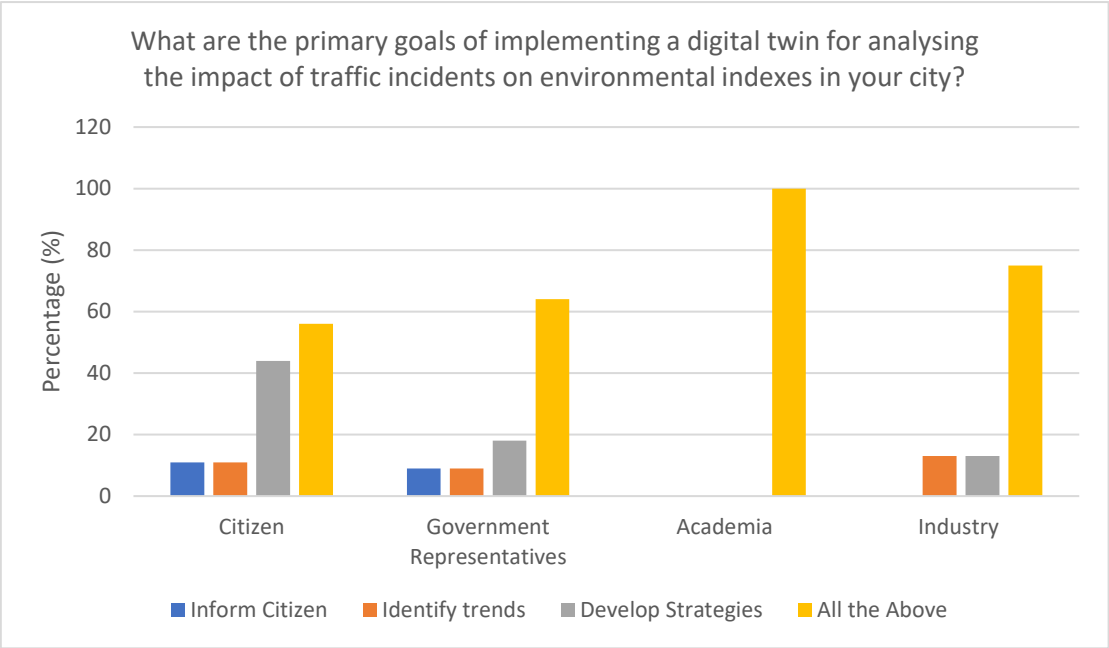

FIGURE 52: PRIMARY GOALS OF IMPLEMENTING A DIGITAL TWIN FOR ANALYZING THE IMPACT OF TRAFFIC INCIDENTS ON ENVIRONMENTAL INDEXES

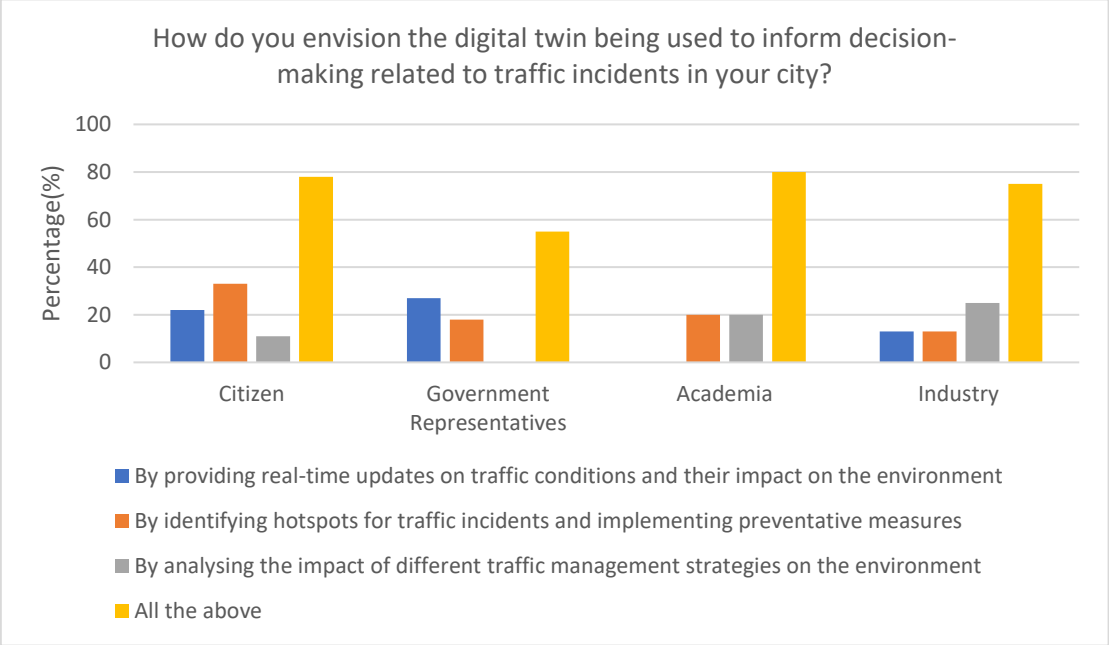

FIGURE 53: WAYS FOR A DIGITAL TWIN TO BE USED IN INFORMING DECISION-MAKING RELATED TO TRAFFIC INCIDENTS.

When utilizing a digital twin for the aforementioned purposes, the majority of stakeholders reached a consensus that updates with new data and forecasts should occur in real time (Figure 54). As for the use of the digital twin, a significant portion of stakeholders, including citizens (78%), government representatives (36%), and academics (40%), agreed that all three ways mentioned below are important (Figure 55):

- As an informational tool for planning daily activities and routes
- As a means of tracking progress towards environmental goals
- As a source of data for research and analysis

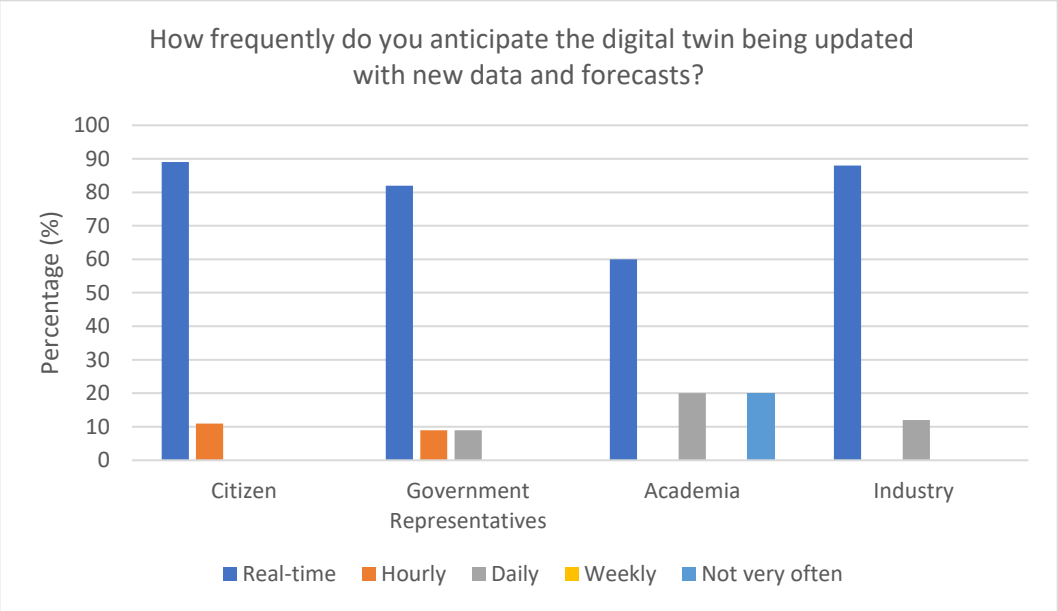

FIGURE 54: DIGITAL TWIN'S UPDATES FREQUENCY.

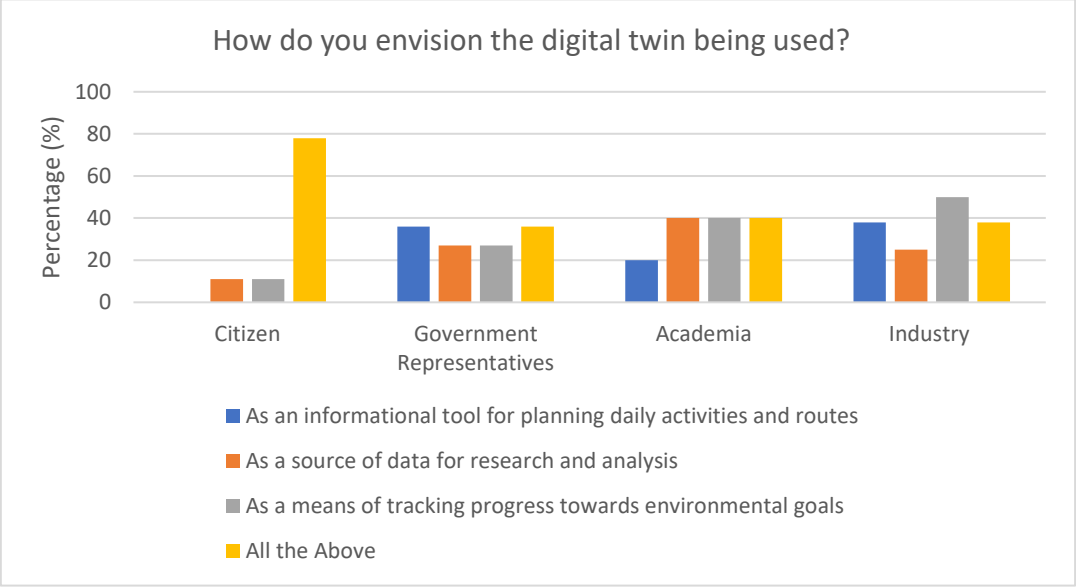

FIGURE 55: DIGITAL TWIN'S WAYS OF USE.

When it comes to environmental indexes for analyzing the impact of traffic incidents, all stakeholders rated Air Quality and Noise Pollution as the most important factors (Figure 56). A majority of stakeholders (51%) expressed the importance of receiving notifications about the expected environmental conditions following a traffic incident. Specifically, people in the industry (63%) and a smaller percentage of government representatives (36%) considered this ability to be very important. However, citizens (44%), academics (40%), and a small portion of government representatives (36%) rated this ability as neutral on the Likert scale (Table 10).

In terms of receiving information, all stakeholders (excluding citizens) preferred mobile app notifications. Citizens, on the other hand, preferred SMS text messages (33%) and public information displays (34%) (Figure 57).

Furthermore, citizens (67%) and government representatives (63%) found traffic flow, air quality, noise pollution, and weather to be useful data for inclusion in the digital twin when analyzing the environmental impact of traffic incidents. However, the majority of academics (60%) and individuals in the industry (63%) rated traffic flow as the most important factor (Figure 58).

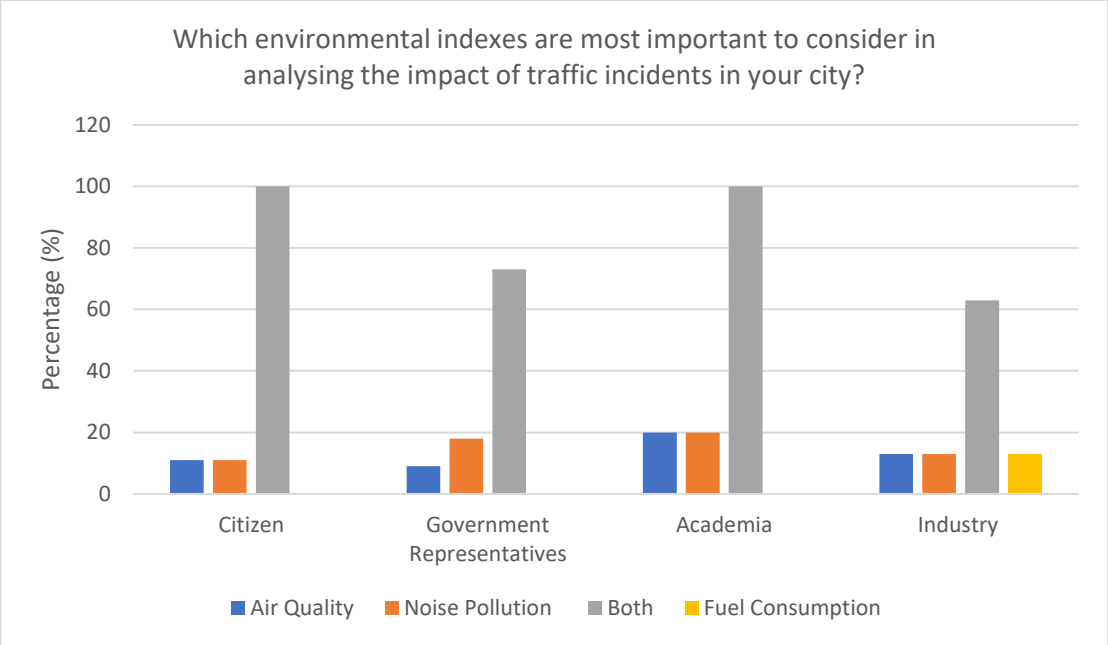

FIGURE 56: ENVIRONMENTAL INDEXES IN ANALYZING THE IMPACT OF TRAFFIC INCIDENTS.

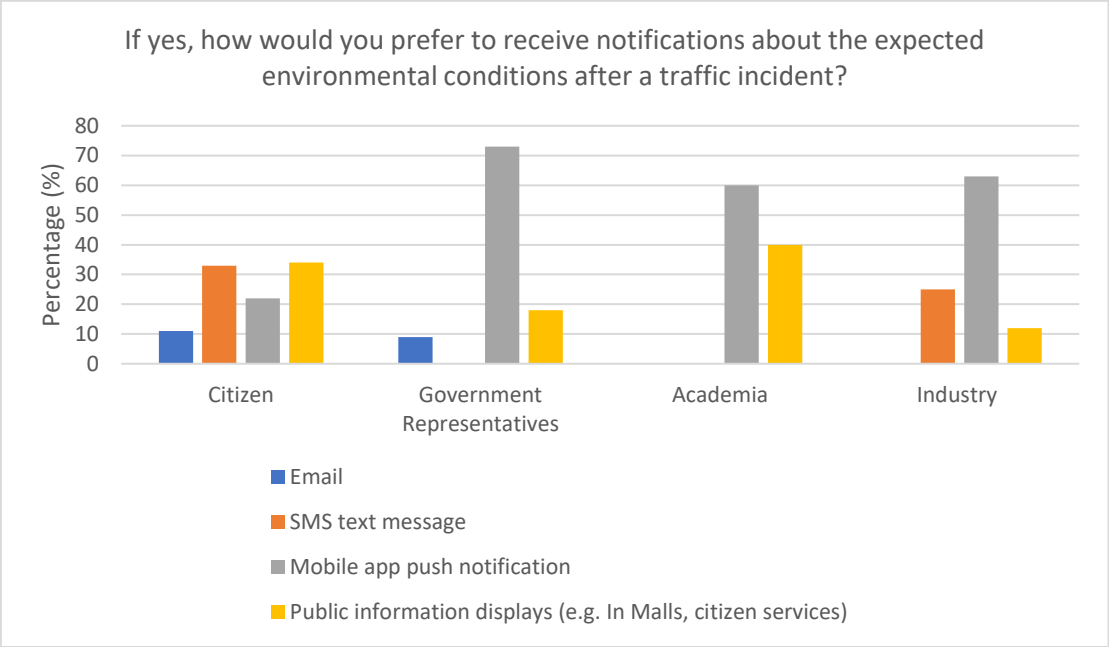

FIGURE 57: WAYS FOR RECEIVING NOTIFICATIONS ABOUT THE EXPECTED ENVIRONMENTAL CONDITIONS AFTER A TRAFFIC INCIDENT.

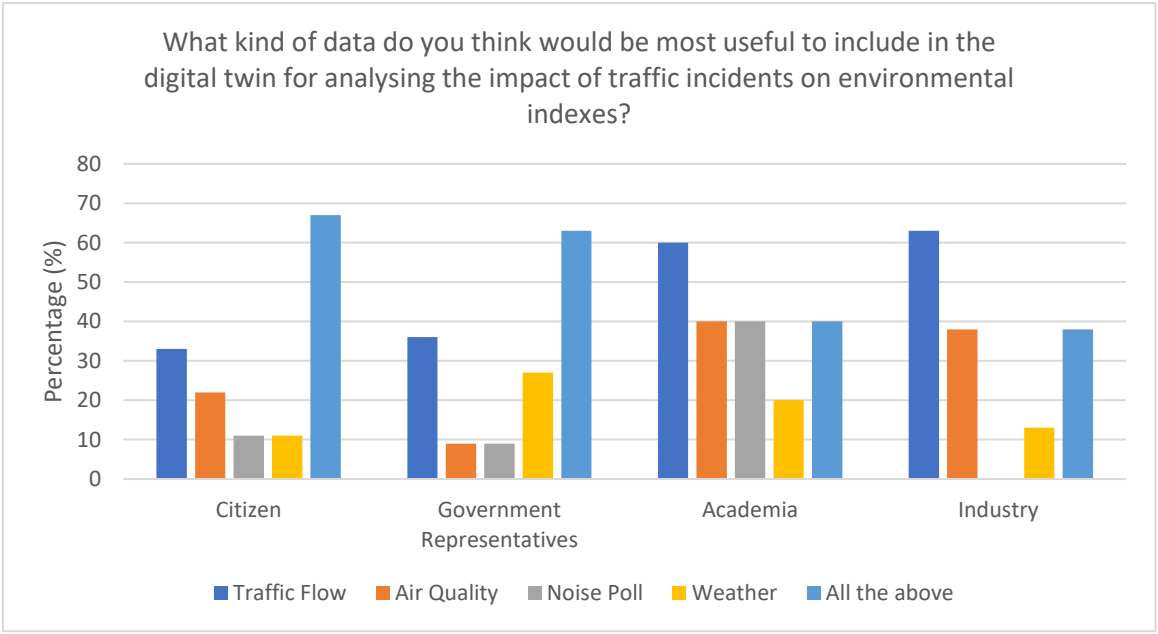

FIGURE 58: USEFUL DATA TO BE INCLUDED IN THE DIGITAL TWIN FOR ANALYZING THE ENVIRONMENTAL IMPACT OF TRAFFIC INCIDENTS.

Respondents were also asked to rate on a scale from 1 (not important) to 5 (extremely important) the ability to receive notifications about the expected environmental conditions after a traffic incident. The results are shown in the following table.

TABLE 10: IMPORTANCE OF THE ABILITY TO RECEIVE NOTIFICATIONS ABOUT THE EXPECTED ENVIRONMENTAL CONDITIONS AFTER A TRAFFIC INCIDENT.

Requirement	Description	Quadruble helix group			
		Citizens	Government	Academia	Industry
EBA01	Ability to receive notifications about the expected environmental conditions after a traffic incident	Could Have (44%)	Could Have (36%) – Should Have (36%)	Could Have (40%)	Should Have (63%)

Participants were also asked the kind of data that is vital to their work and their answers entail the following:

- Information about pollution levels and traffic congestions
- Vehicle traffic measurements Vehicle traffic measurements
- Traffic regulations, traffic incidents, black spots, type of road users, offences,
- Traffic data, pollution measurements
- Air pollution data, Meteorological data, Traffic density

In addition, stakeholders were asked about the existing systems or databases that should be integrated with the digital twin platform for urban planning. They reviewed the following as important:

- Existing map systems
- ELSTAT, google maps, meteorological data, google maps, land use mapping (commercial, residential, etc.) with detailed recording of activities affecting mobility (loading, peak hours per use, e.g., school, nightlife, etc.), parking spaces, types of road users, quantitative traffic recording
- https://aqicn.org/map/europe/, http://emy.gr/emy/en/observation/sa_xartis_paron_kairos_perioxes
- https://meteo.gr/Gmap.cfm
- Goggle maps / traffic data on roads
- Prohibition with signage and mobile notification in some way, parking in prohibited areas, e.g., parking in a disabled zone.
- Environmental pollution measuring stations controlled by the PDB.

6.2.2.3.1 User Stories

Citizens:

- As a user, I want to be informed so as to avoid serious traffic incident

Government Representatives:

- I would like to promote communication to citizens in order to make them more aware of the need to reduce emissions in the city by using (applying) relevant techniques that every citizen can apply

Academia:

- I, as Civil Engineer with focus on Environmental Impact Assessment, would be interested to know the air and noise pollution levels and the zone of impact in order to develop a strategy plan for reducing the environmental impact

Industry

- I, as a safety engineer, would like to be informed about increased levels of pollution so that I can take appropriate measures for workers in a nearby area"

6.2.2.3.2 Conclusion

In conclusion, the survey results have provided valuable insights into the level of awareness and challenges surrounding the concept of a digital twin in the context of analyzing the environmental impact of traffic incidents. The stakeholders agreed that a digital twin should provide real-time updates on traffic conditions and their environmental impact. They emphasized the importance of identifying hotspots for traffic incidents and implementing preventive measures. Additionally, stakeholders expressed the need for the digital twin to analyze the impact of different traffic management strategies on the environment.

Air Quality and Noise Pollution were rated as the most significant environmental indexes in analyzing the impact of traffic incidents. The majority of stakeholders preferred real-time updates and forecasts from the digital twin. Mobile application notifications emerged as the preferred method for receiving data on the expected environmental conditions following a traffic incident. These findings contribute to a comprehensive understanding of stakeholder attitudes, providing a clear view of the needs and expectations for a digital twin focused on analyzing the environmental behavior related to traffic incidents.

6.2.3 The Bulgarian Pilot: Digital Twins for Energy Efficiency and Renewable Energy applications

The Bulgarian pilot: Digital Twins for Energy Efficiency (EE) and Renewable Energy applications will c consider three use cases:

- Use Case 1: Building Energy Performance
- Use Case 2: Budget Planning for Energy Use and Building Renovation
- Use Case 3: Renewables' potential and performance analysis

In order to determine the socio-economic needs and technical requirements, the pilot designed 3 questionnaires, one for each use case, which were sent to 150 stakeholders, including representatives from all four groups of the quadruple helix. What follows is an analysis of the responses to each questionnaire. The answers have been both analyzed both in general terms and by looking at the responses by each group from the QH.

6.2.3.1 Use Case 1: Building Energy Performance

The survey was designed in order to gather information regarding the socio-economic and technical needs as related to buildings' energy performance. It was answered by 36 members of the target group with the following profiles according to the QH model as shown in Figure 59.

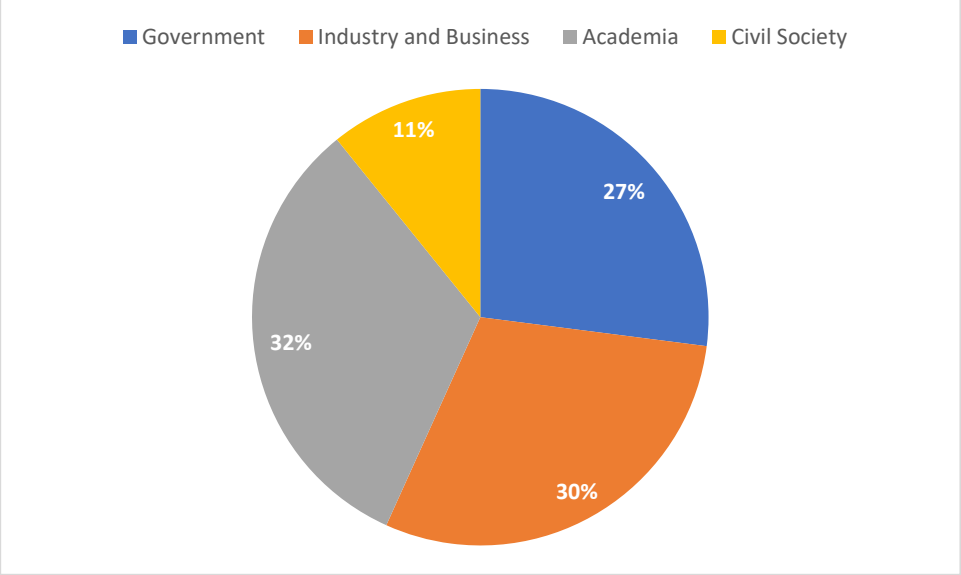

FIGURE 59: PERCENTAGE OF QH GROUPS THAT ANSWERED THE QUESTIONNAIRE.

The first part of the survey considered the benefits of DT both in terms of the energy use of the city and the impact to the local economy.

The areas of urban planning in which DTs could be beneficial are budget planning and infrastructure investment (89% of stakeholders), as well as general decision-making governmental processes (70%). On the other hand, stakeholders consider digital twins to be less beneficial when it comes to offering improved access to information and building community resilience, including adaptation to climate changes and other disasters, with only 35% and 32% of stakeholders believing digital twins can be helpful in these aspects (Figure 60).

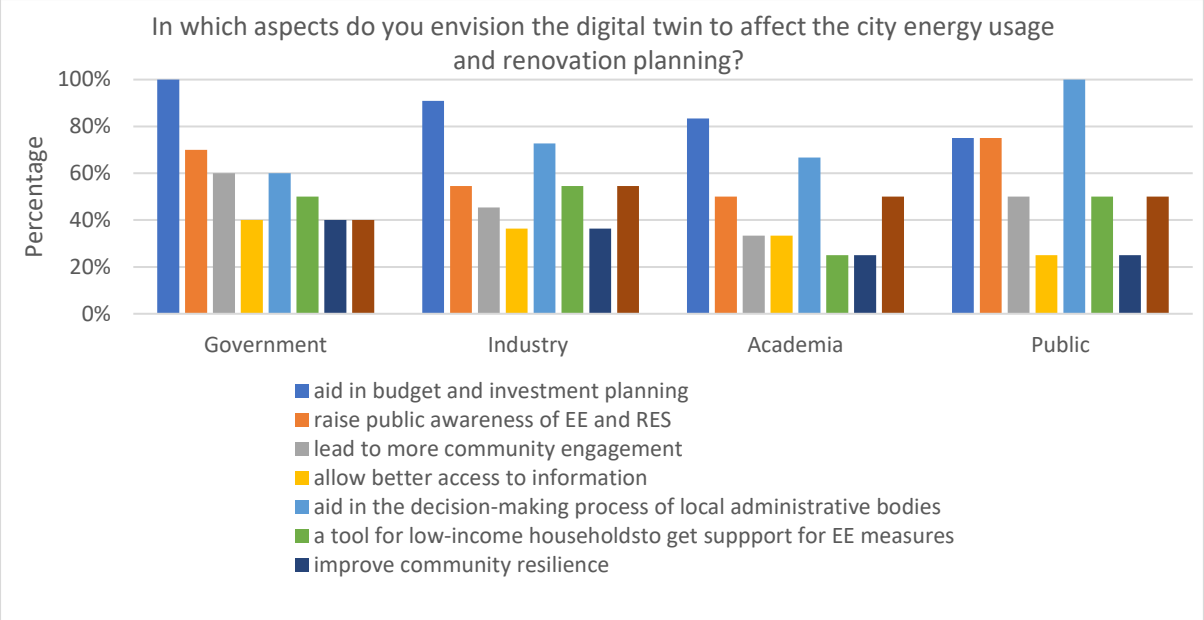

FIGURE 60: BUILDINGS ENERGY EFFICIENCY DIGITAL TWIN BENEFITS.

Looking at the results across QH groups, it is evident that Government Stakeholders perceive Digital Twins (DTs) as offering the most benefits in terms of budget and investment planning. However, only 40% of these stakeholders believe that DTs will provide similar benefits in terms of facilitating better access to information, enhancing community resilience to climate change, or reducing carbon emissions.

Similar trends are observed among industry and business stakeholders, with 91% of them expecting DTs to assist in budget planning. Yet, only 36% of these stakeholders recognize such advantages in terms of improved access to information and enhanced community resilience. Among academia representatives, the value of DTs is primarily seen in budget planning (83% of such stakeholders), while the least value is placed on building greater community resilience to climate change (25%). In the case of civil society members, the most significant potential of DTs lies in improving the decision-making process of local administrative bodies (100%). However, only 25% of them anticipate that DTs will enable better access to information or enhance community resilience.

Turning to the impact on the local economy, 86% of potential stakeholders believe that DTs can lead to cost savings for building owners and operators. A smaller percentage (70% and 62%, respectively) sees potential benefits in terms of improving the marketability of buildings, raising awareness among building owners and operators, and aiding in the decision-making process for investing in energy performance measures. Finally, only 49% of stakeholders believe that DT tools have the potential to create new jobs.

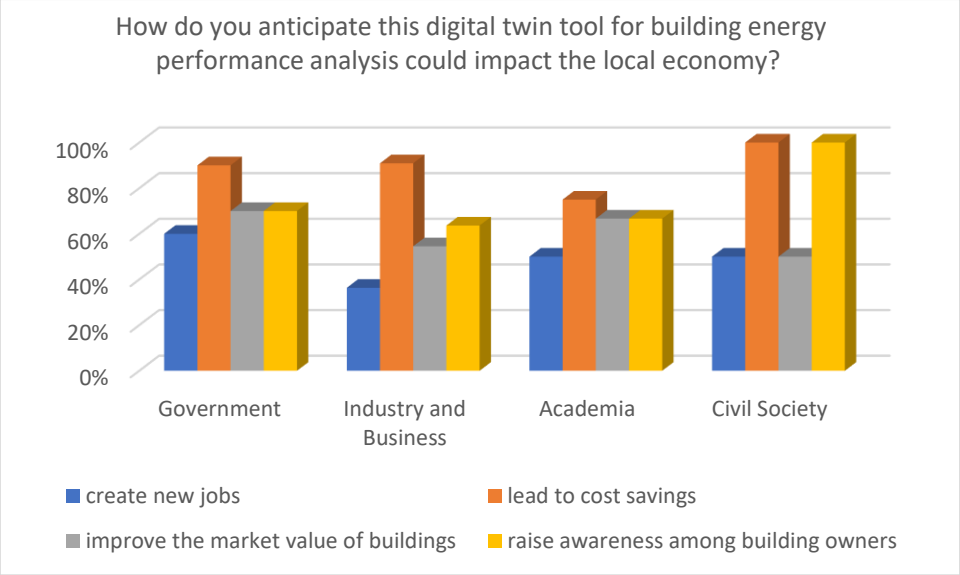

FIGURE 61: IMPACT OF THE DTS ON THE LOCAL ECONOMY.

Regarding funding sources, all respondents indicated their interest in grant-type funding, while only 32% expressed interest in low-interest loans, and 24% in tax incentives. Low-interest loans are considerably more attractive to all groups, except for the industry and business group, where 45% are interested in tax incentive schemes, and only 18% in low-interest loans.

While grants are more preferable compared to other ways of financing DTs, which would involve some level of co-payment, it is essential to acknowledge that this type of funding is often awarded to only a small percentage of applicants, and its future availability is uncertain as well. This observation indicates that stakeholders do not perceive any urgency in the creation of digital twins and consider it a luxury item with very low priority.

To address this situation, efforts need to be focused on two directions:

1. Showcasing the benefits of DTs: It is crucial to demonstrate the value and advantages that digital twins bring to various stakeholders. Highlighting the positive impacts on cost savings, improved decision-making processes, enhanced access to information, and community resilience will help stakeholders recognize the significance and relevance of DTs in their specific domains.
2. Working with all stakeholders to ensure that options such as low-interest loans and tax incentives are attractive and affordable to end-users: By collaborating with stakeholders, policymakers and industry players can design financing models that make DT adoption more accessible and appealing. Reducing barriers to entry, promoting favorable financial incentives, and providing support to end-users will foster greater interest and participation in adopting DT technology.

In the first set of questions regarding technical requirements, respondents were asked to evaluate which type of buildings they considered most suitable for implementing a DT. Nearly all of them (97%) believed that public buildings are more suitable to DT technology. Residential buildings were prioritized by 54% of stakeholders overall and were also high on the list for civil society respondents and local authorities. Commercial or industrial buildings were mostly a priority for representatives from the respective sector (64%) (Figure 62).

Regarding the applications of DT in various building upgrades, the most popular options were ventilation and air-conditioning of buildings, with 89% of stakeholders showing interest in them, followed by Renewable Energy Source (RES) installations, in which 81% were interested. Smart lighting and thermal insulation were priorities for significantly fewer stakeholders, 68% and 57% respectively (Figure 63).

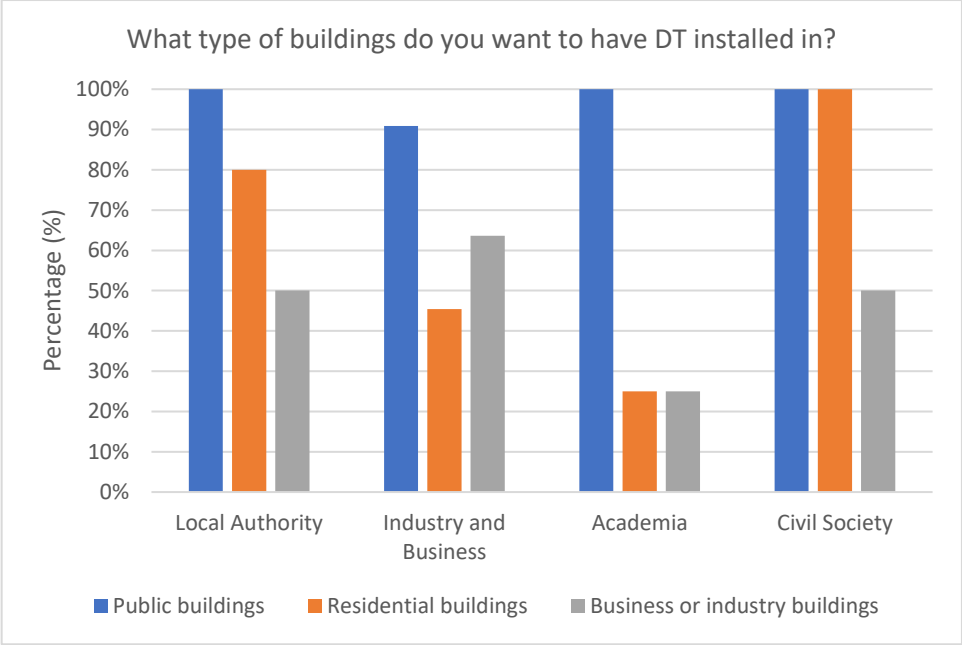

FIGURE 62: TYPES OF BUILDING SUITABLE TO INSTALLED IN DIGITAL TWIN.

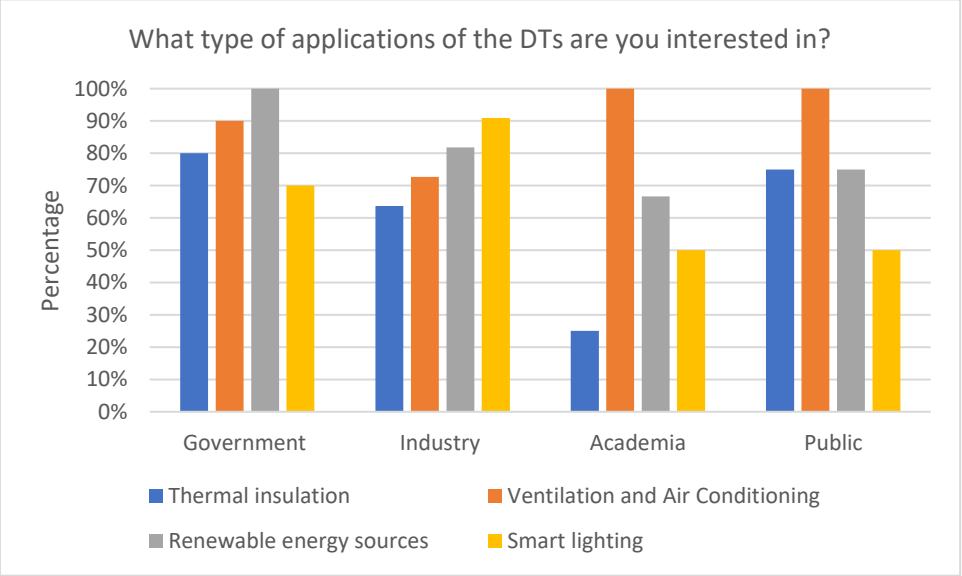

FIGURE 63: APPLICATIONS OF DT TO VARIOUS BUILDING UPGRADES

Digital twins offer various types of visualization, including real-time analytics, historical performance analysis, interactive 3D building models with energy performance metrics, and building performance dashboards. Among these options, stakeholders valued real-time analytics and historical performance analysis the most (68% and 59% respectively), while the remaining visualization types were a priority for 46% and 30% of respondents (Figure 64).

Both historical performance models and simulations to predict future changes were perceived as equally important and preferred by a large percentage of stakeholders (86% and 97% respectively), with little variation between Quadruple Helix groups.

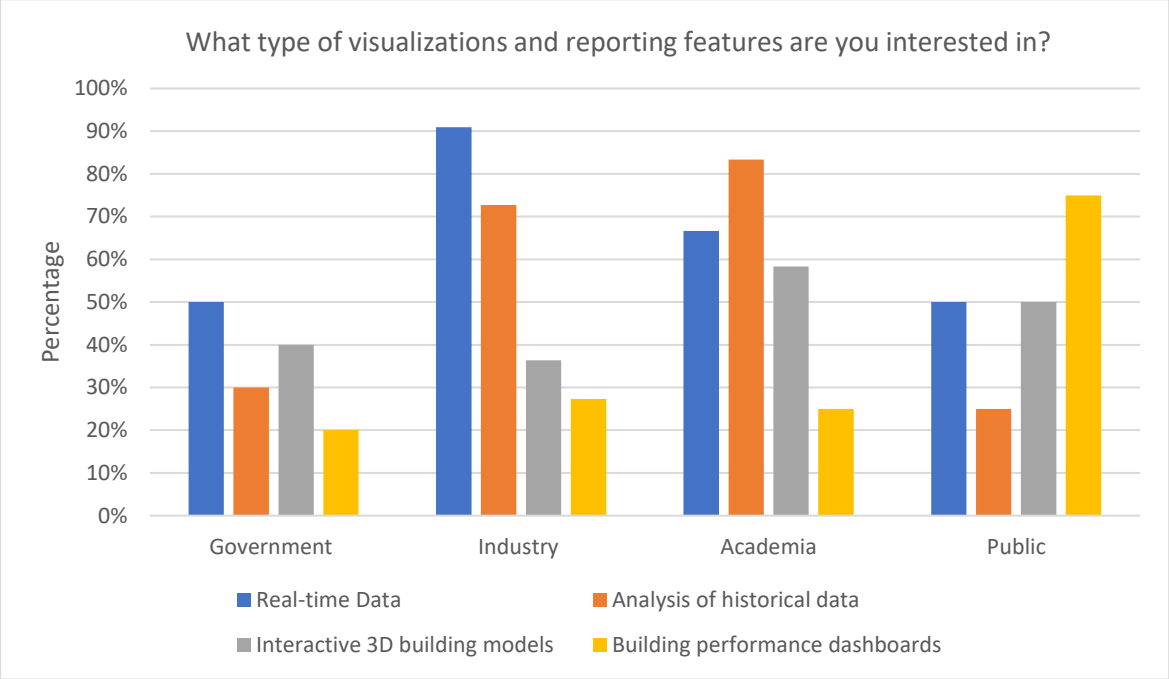

FIGURE 64: DT TYPES OF VISUALIZATION.

Regarding the frequency of data updates (Figure 65), the majority of stakeholders prefer daily or weekly updates (35% and 32% respectively). Daily updates are preferred by Academia and Citizens, while weekly updates are favored by Local Authorities and Industrial/Business representatives. Monthly updates are of some interest to commercial (27%) and academic (25%) stakeholders, whereas quarterly updates are only significantly interesting to 25% of civil society members. Finally, respondents were asked what types of data they would like to be analyzed by DTs, and the answers are summarized in Figure 66. It can be seen that energy consumption data are required by all sectors of the Quadruple Helix, while the rest of the data types show considerable variation.

Given that the pilot activities in Bulgaria will focus on energy efficiency and RES installations, the type of data deemed most useful (by 76%) was energy consumption data. This was followed by data on CO_2 levels in interior spaces, in which 59% of stakeholders expressed interest. Data on thermal insulation capacity and environmental factors such as temperature, humidity, and insolation were not of particular interest, as only 22% and 27% of respondents indicated interest in them.

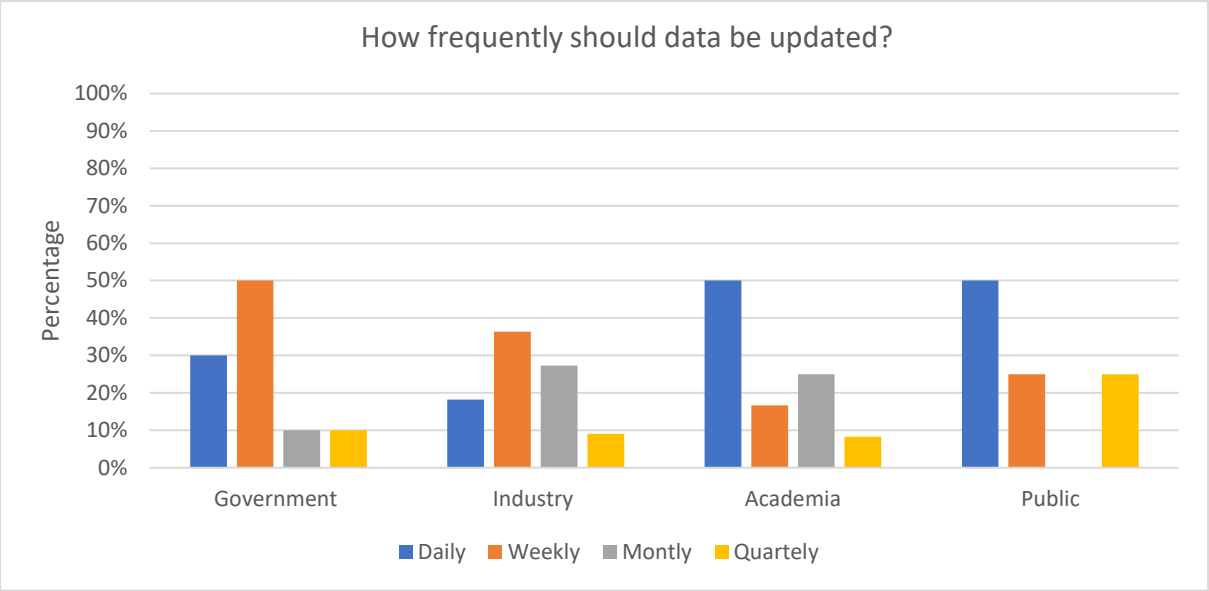

FIGURE 65: FREQUENCY OF DATA UPDATES.

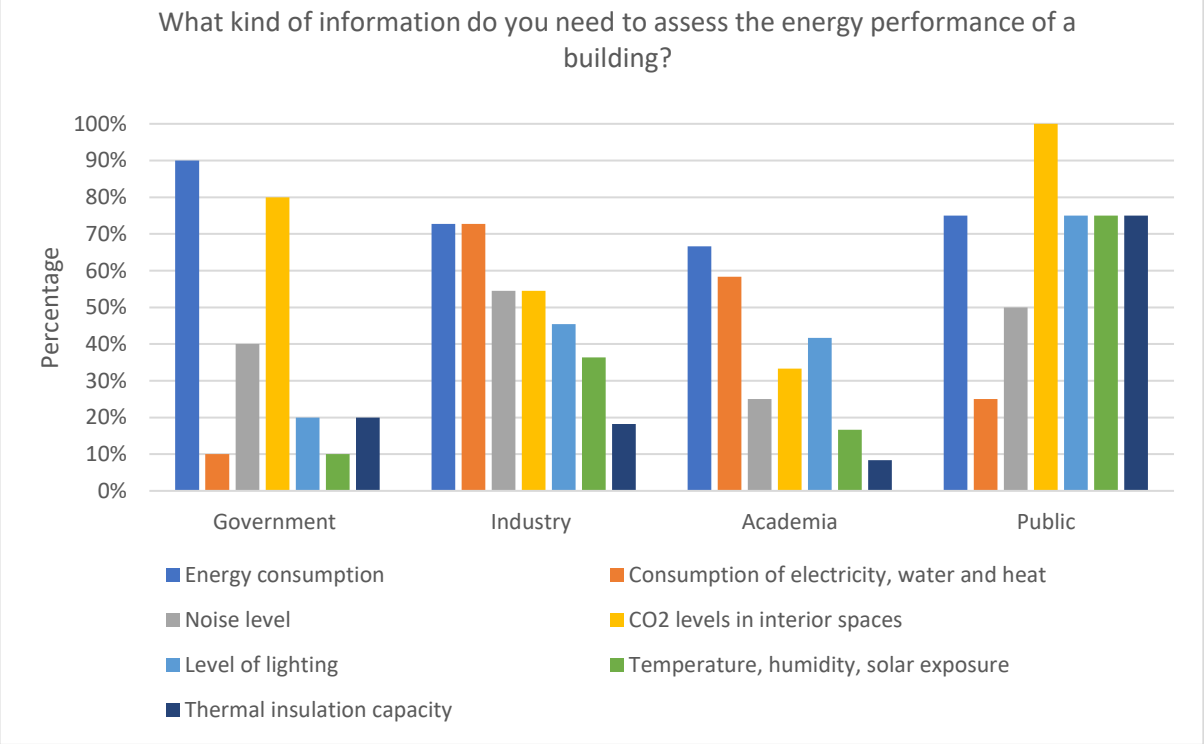

FIGURE 66: INFORMATION NEEDED FOR THE ASSESSMENT OF BUILDINGS ENERGY PERFORMANCE.

6.2.3.1.1 User stories

Citizens:

- As a building resident and visitor, I would like to know whether the building offers thermal conditions for me and my family members, especially for my children.
- As a building resident, I would like to be able to control my environment from a distance, in order to optimize energy usage.
- As an NGO member, it is important for me to have access on data on the energy use, so I can do more informed advocacy work.

Government Representatives:

- As a municipal expert, I would like to know the parameters of the energy use in buildings.
- As a policy maker, I would like to know the parameters of energy use so that I can make data-driven decisions.
- As a policy maker, it is important to have a good emissions inventory of the building stock, in order to know whether the city is meeting climate adaptation goals.

Academia:

- As a researcher I would like to know to have better data about the energy performance of buildings in order to create better models of energy use.
- As a designer, I would like to know what type of energy systems and insulation to use to provide optimum thermal conditions for building occupancy.
- As a business owner, I would like to have control over the building environment in order to provide better working conditions for my staff, while minimizing my costs.

6.2.3.1.2 Conclusion

The information gathered can be useful when creating a digital twin for specific buildings for specific stakeholders. By optimizing resources and deploying different types of sensors, various models can be created depending on the type of building or stakeholders involved. Furthermore, given the large variability in the data, it is recommended that potential users and stakeholders are involved in a co-design process to efficiently meet their needs. For local authorities, this means more accurate and efficient planning of new public buildings, refurbishment, and renovation of existing buildings, as well as preparation of technical specifications for potential contractors. The use of digital twins prior to the publication of technical specifications for tender procedures and/or the evaluation of proposals for designing, constructing, and renovating buildings can optimize energy efficiency. Local authorities should seek, implement, and promote externally funded digital twin projects. The low level of public awareness and interest requires a more active and attractive campaign to make citizens aware of the advantages and benefits of digital twins. The high level of interest from academia, industry, and business is essential for establishing fruitful cooperation. It capitalizes on the scientific knowledge of academia, the practical experience of industry, and the interest of businesses in using and offering energy-efficient buildings.

6.2.3.2 Use Case 2: Budget Planning for Energy Usage and Building Renovation.

The survey was designed to gather information regarding the socio-economic and technical needs related to Use Case 2: Budget Planning for Energy Usage and Building Renovation. We received responses from 40 members, representing various profiles according to the Quadruple Helix (QH) model.

Regarding funding sources, all respondents indicated their interest in grant-type funding, while only 30% expressed interest in other types of funding, such as low-interest loans or tax incentives. Between the two options given, tax incentives are slightly more popular, with 23% of respondents expressing interest in them. When it comes to stakeholders' willingness to pay for DTs, only 23% of all respondents are very willing or willing to pay for a DT, while 30% are either completely unwilling or to a very low extent (Figure 67).

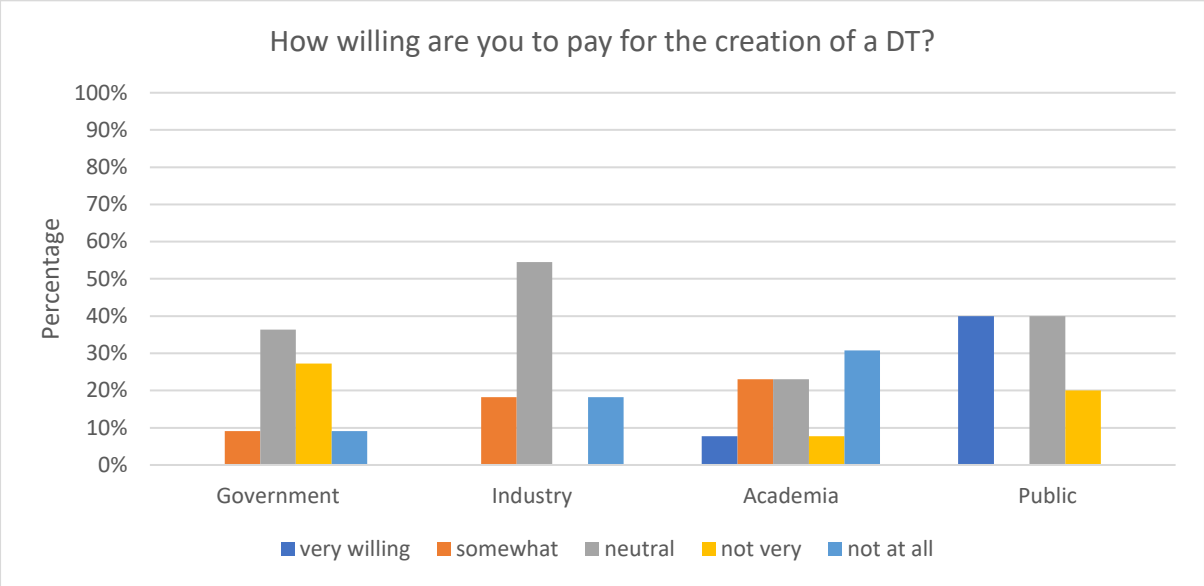

FIGURE 67: WILLINGNESS OF QH ACTORS TO PAY FOR A DT.

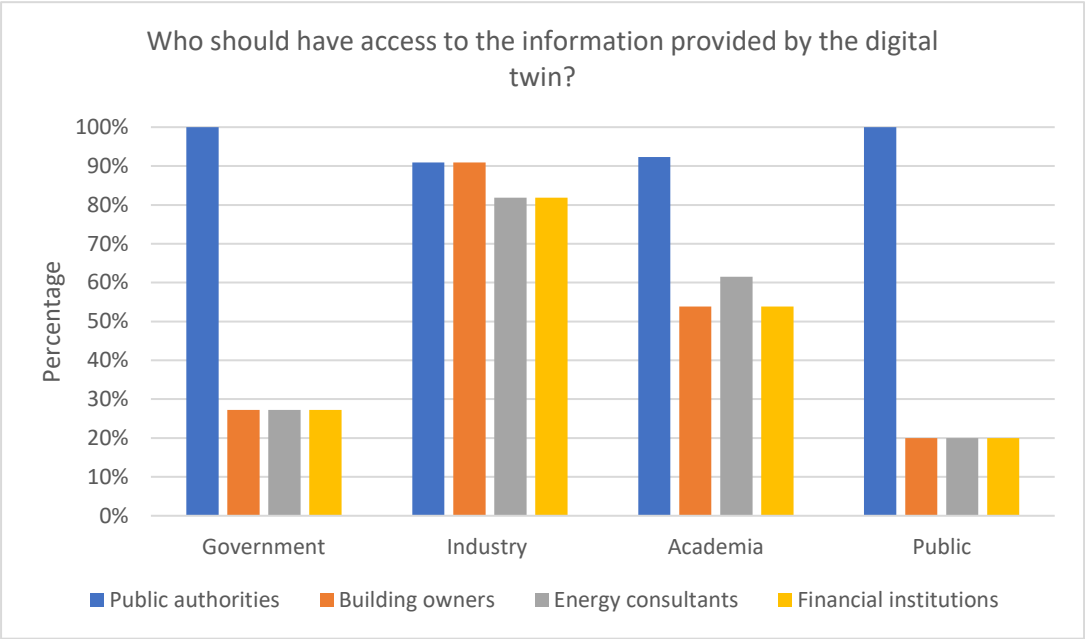

FIGURE 68: POTENTIAL BENEFITS OF THE DIGITAL TWIN.

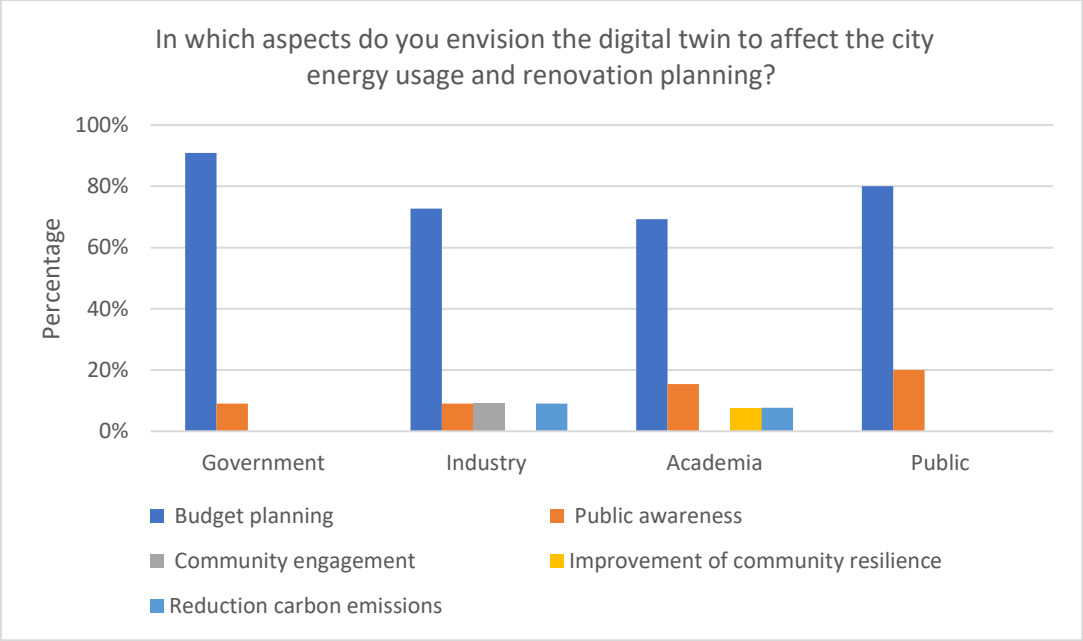

FIGURE 69: GROUPS THAT SHOULD HAVE ACCESS TO THE DT.

Regarding the potential applications of Digital Twins, the graph in Figure 68 illustrates that the vast majority of users (78%) see it mainly as a tool to improve budgeting resources. Only 13% of survey respondents view its potential as a tool to increase public awareness on renewable energy usage. Everyone believes that public authorities should have access to the information provided by digital twins. Additionally, 53% of all respondents believe that access should be provided to building owners and energy consultants, while 50% stated that access should be provided to financial institutions as well.

Digital twins offer various types of information, and when respondents were asked about their preferences, 70% of them indicated their interest in accessing real-time energy usage statistics, while 23% wanted to have benchmark indicators for future projects. On the other hand, there was minimal interest in accessing estimates on building renovation costs, with only the academia showing some interest. This preference for specific information is also reflected in the frequency of access desired by different stakeholders. Overall, most of the respondents preferred to have weekly access (28%) or monthly access (30%) to the data. Only a fifth of them expressed a preference for daily access, and even fewer (13%) wanted to access it every three months. The responses from different QH groups are illustrated in Figure 70.

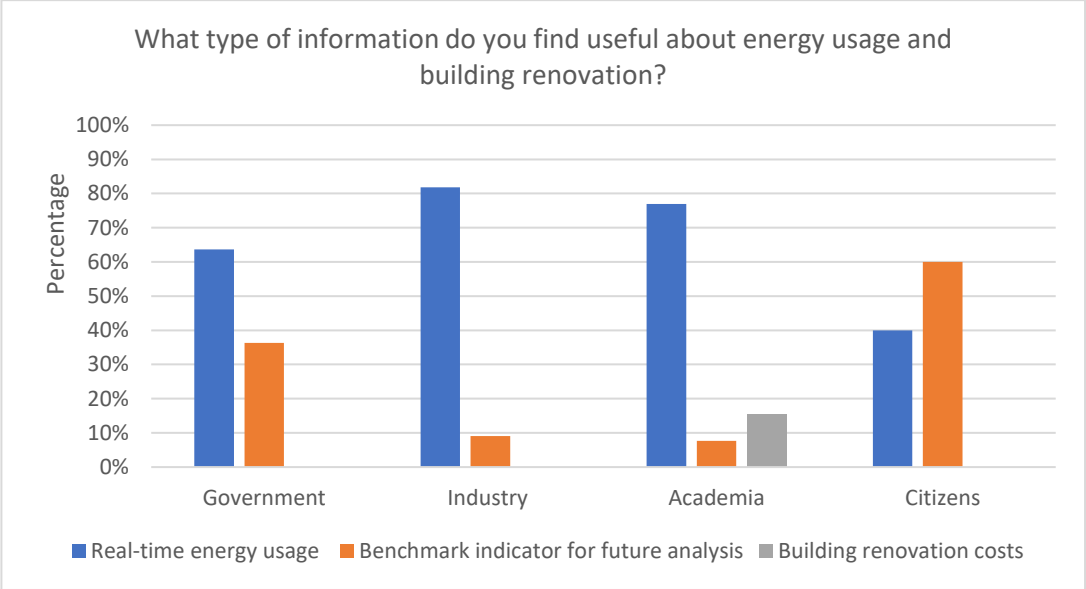

FIGURE 71: USEFUL INFORMATION ABOUT ENERGY USAGE AND BUILDING RENOVATION.

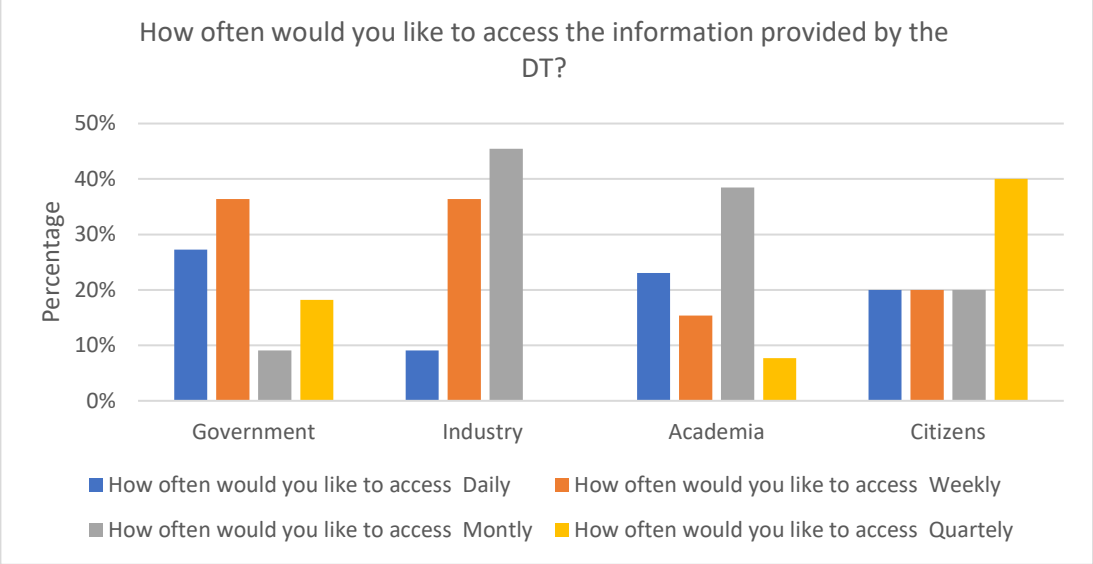

FIGURE 70: FREQUENCY OF ACCESS TO INFORMATION.

When asked about the types of features that Digital Twins (DTs) can offer, 55% of all respondents expressed their interest in having access to policies and best practices for energy usage and building renovation in Burgas, while 73% wanted the ability to compare energy usage and renovation options across buildings in the same area (Figure 72).

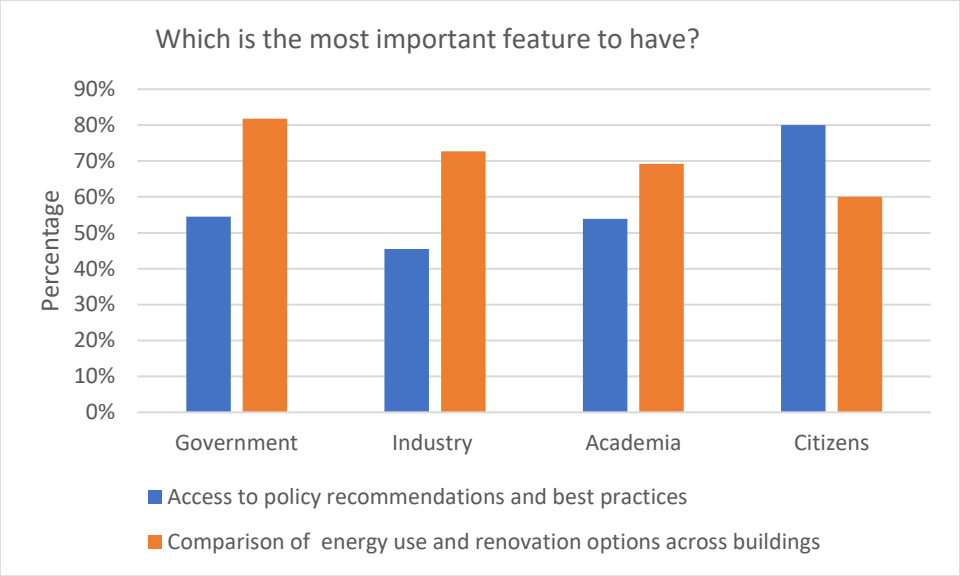

FIGURE 72: MOST IMPORTANT FEATURE BETWEEN A) ACCESS TO POLICY RECOMMENDATIONS AND BEST PRACTICES AND B) COMPARISON OF ENERGY USE AND RENOVATION OPTIONS ACROSS BUILDINGS.

One of the primary areas of application for DTs is to find potential improvements in the energy efficiency characteristics of buildings, and 82.5% of potential users expressed their desire for this functionality. Concerning the type of energy efficiency measures they would like to see included, thermal insulation options were preferred by 53% of respondents, and air-conditioning and ventilation options were chosen by 40%, while only 5% of overall users expressed interest in assessing a building's Renewable Energy Source (RES) potential. Figure 73 provides an overview of the results across QH groups. It is worth noting that thermal insulation upgrade possibilities matter most to Local Authorities and Industry and Business stakeholders, while for the other two types of stakeholders, air-conditioning and ventilation upgrades are considered the most important. The final question focused on the type of visualizations that users wished to see, with 65% of users wanting to access real-time energy usage data and 18% expressing interest in interactive 3D display options. Less than 10% showed interest in the other visualization options (Figure 74). It is interesting to note that while historical energy usage data and cost-benefit analyses were not a priority overall, 20% of civil society

representatives considered them useful. Similarly, interactive 3D display options were desired mostly by Local Authorities (36%) and Industry.

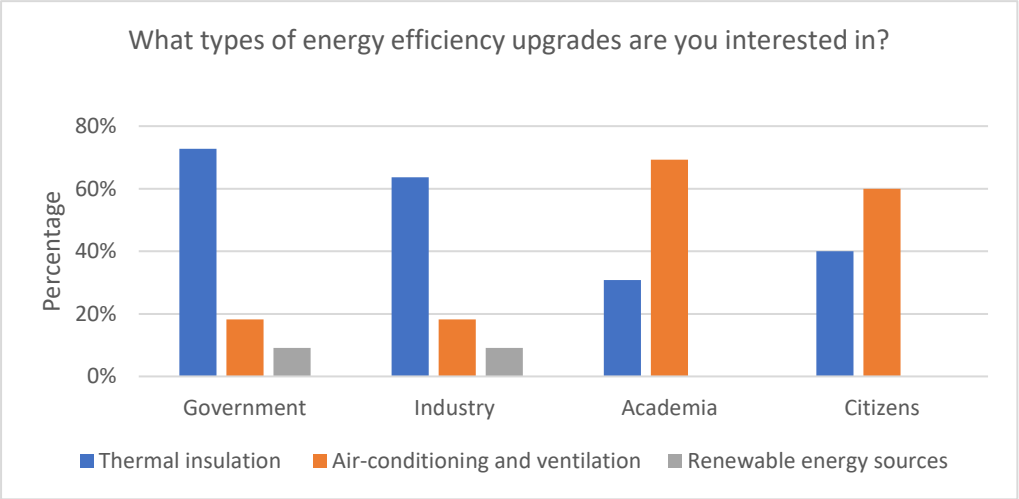

FIGURE 73: TYPES OF ENERGY EFFICIENCY UPGRADES.

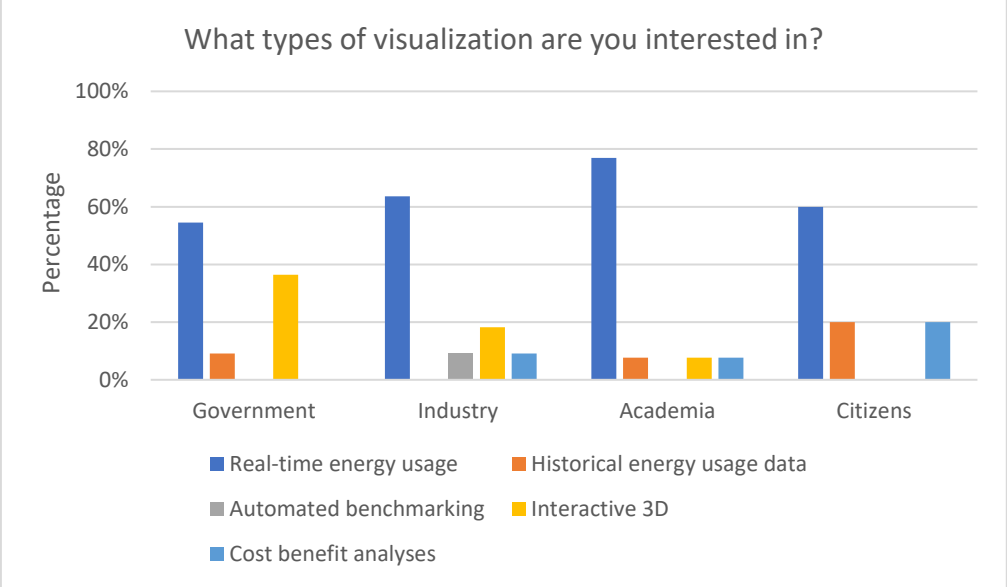

FIGURE 74: DIGITAL TWIN'S VISUALIZATIONS THAT ARE IMPORTANT FOR BUDGET PLANNING FOR ENERGY USAGE AND BUILDING RENOVATION.

6.2.3.2.1 User stories

Citizens:

- As a building user, I would like to have a good model for energy use, so I can optimize costs and plan upgrades.
- As an NGO representative, I would like to have a good budget planning method, so I can better advise my clients/members on potential actions.
- As a building user, I would like to have real-time data models so that I can adjust my behavior accordingly.

Government Representatives:

- As an officer, I would like to have a good model for energy use, so I can optimize costs and plan upgrades.

Industry

- As a building manager I would like to know what the heating/cooling costs would be so that building visitors feel comfortable and healthy.
- As a funding expert, I would like to have simulations on how energy upgrades affect costs, so that I can make more informed decisions on funding applications.

6.2.3.2.2 Conclusions

The substantial number of respondents expressing their interest in accessing real-time energy usage statistics serves as strong evidence supporting the implementation of dashboard-type information boards on relevant buildings. Furthermore, the high percentage of respondents recognizing the potential of digital twins to improve the energy efficiency of buildings should serve as a motivating factor for stakeholders such as local authorities, academic institutions, and businesses to continuously seek and develop innovative solutions in this field. It is crucial that all stakeholders work collaboratively to harness the full potential of digital twins and drive positive changes in energy consumption patterns, thereby creating a more sustainable and environmentally friendly urban environment.

6.2.3.3 Use case 3: Renewable's potential and performance analysis

The survey was designed to collect information related to the socio-economic and technical needs concerning Use Case 3: Renewable's potential and performance analysis. It was distributed to 150 stakeholders and received responses from 30 members (Figure 75). Once again, we observe the low levels of the general public/ citizens interest, which highlights a gap that should be addressed in future communication and engagement efforts. Due to their limited participation, the answers provided by this group cannot be considered fully representative and will only be included in the overall totals and excluded to the presentation of the results' analysis.

It is noteworthy to mention that in the local context of the city of Burgas, renewable energy sources (RES) primarily refer to photovoltaic installations. This is due to the city's location on an important avian migration route. To safeguard the region's numerous nesting birds, environmental authorities have imposed limitations on the construction of wind turbines in the area. Consequently, other RES, such as wind power, have not been explored or developed in the region either.

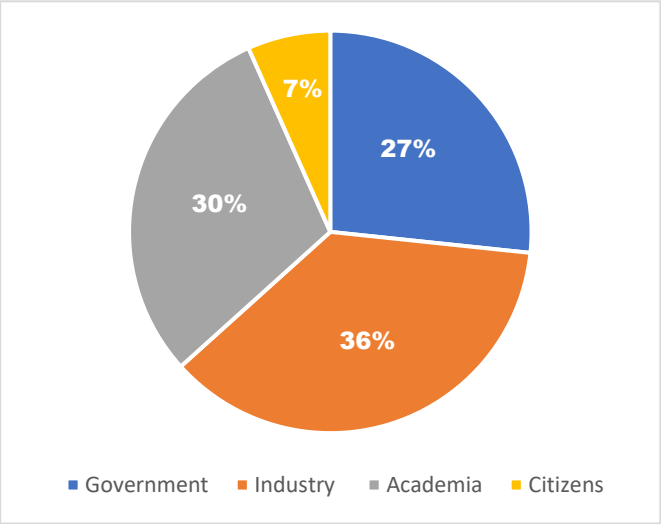

FIGURE 75: PERCENTAGE OF QH STAKEHOLDERS WHO PARTICIPATED IN THE SURVEY FOR THE RENEWABLES POTENTIAL AND PERFORMANCE ANALYSIS' USE CASE.

In terms of potential benefits, the majority of stakeholders (87%) identified Budget Planning as the most useful application of DTs, followed by Community Engagement (60%). On the other hand, the two least popular applications, with only 40% of stakeholders recognizing their potential, were support to low-income households and building up community resilience. It is evident that budget planning is the most important application for all groups of the QH (Figure 76).

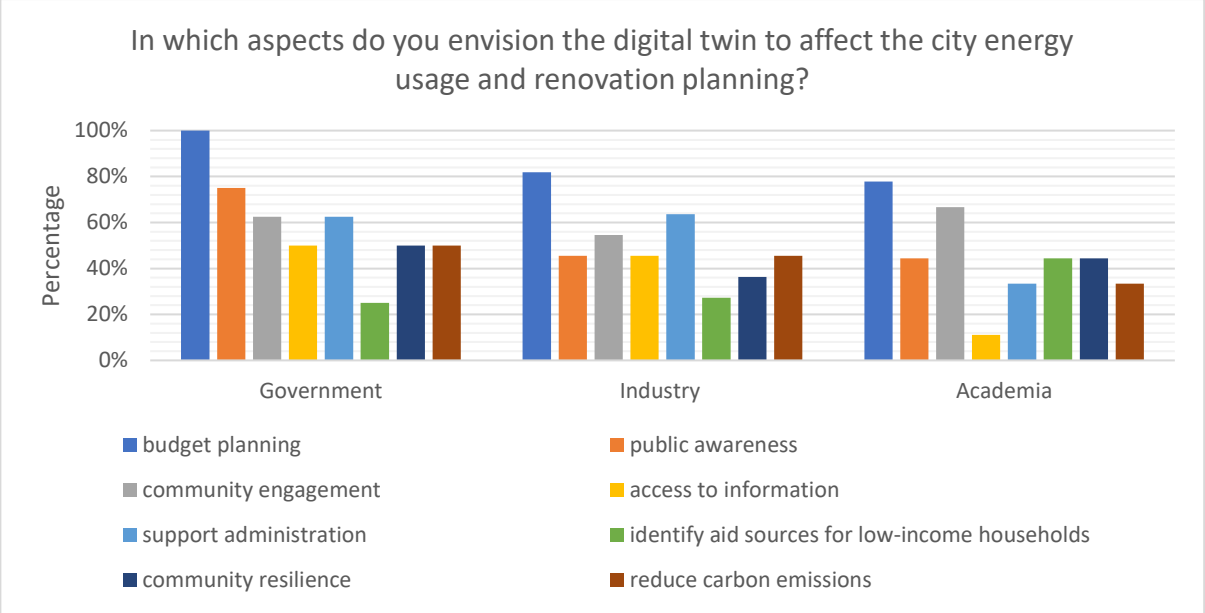

FIGURE 76: BENEFITS OFFERED BY THE DT.

Regarding funding sources, all of the respondents expressed their interest in grant-type funding, while only 20% showed interest in low-interest loans, and 30% considered tax incentives. When examining the preferences based on the Quadruple Helix (QH) groups, we observed that low-interest loans are favored by Government stakeholders, while industry and academia stakeholders showed a preference for tax incentives. This variation in funding preferences reflects the diverse needs and priorities of different QH groups. While grant-type funding remains universally attractive, the differences in the appeal of low-interest loans and tax incentives among the stakeholders highlight the importance of tailoring funding strategies to address the specific requirements and objectives of each group. Taking these preferences into account, we can optimize the effectiveness of funding initiatives and encourage greater participation and engagement across all sectors. Furthermore, the survey results indicated that economic and technical factors, which are areas where DTs can provide significant benefits, had the highest impact on the number of Photovoltaic (PV) installations in a city. In contrast, social factors, such as national and local strategies, policies, and community involvement, were not as influential in promoting PV installations (Figure 78). By understanding these factors, stakeholders can strategically focus on leveraging DTs to address economic and technical aspects, thereby maximizing their impact on the promotion and adoption of renewable energy solutions such as PV installations in urban areas.

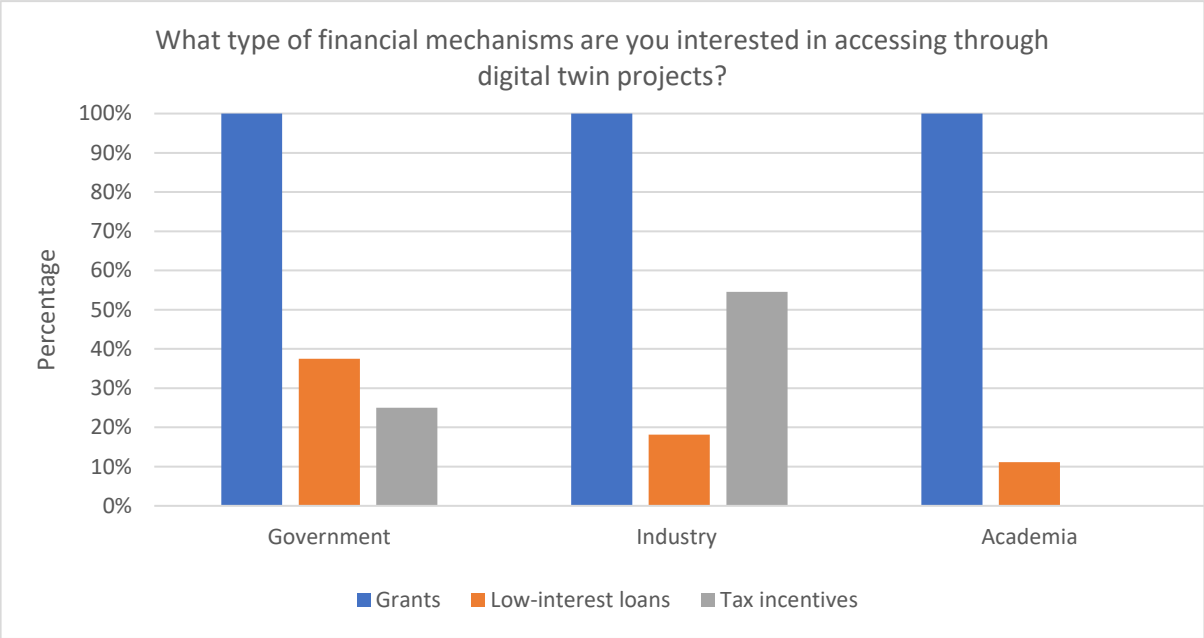

FIGURE 77: FINANCIAL MECHANISMS TO BE ACCESSED BY THE DT.

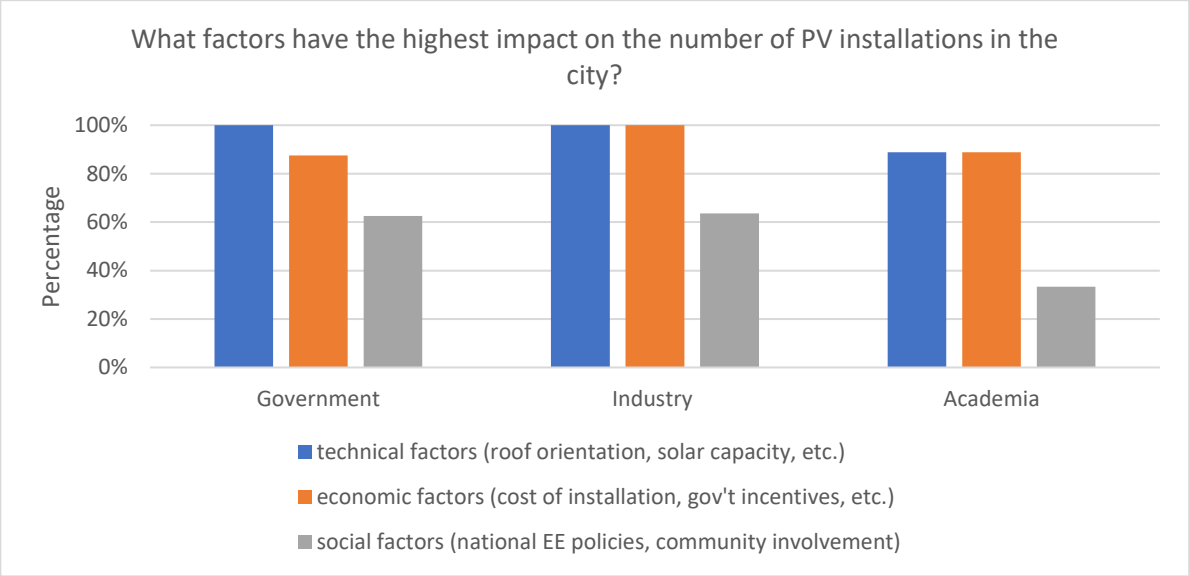

FIGURE 78: FACTORS IMPACTING ON THE NUMBER OF PV INSTALLATIONS

In the first set of questions regarding the technical requirements, respondents were asked to identify potential use cases of Digital Twins (DTs). These use cases included the identification of PV installations, the evaluation of their performance, and the study of the city's PV adoption rate over time. Approximately two-thirds of all respondents considered each of these cases as possible applications of DTs. It is also observed that government representatives found the identification of PV installations as the most attractive potential application (100%). Industry members showed a higher interest in evaluating the performance of PV installations (73%), while academics were particularly intrigued by studying the adoption rate Figure 81.

The next question focused on the potential benefits of Digital Twins (DTs) concerning PV installations. Modelling the production of energy from PV was considered important by 80% of respondents, closely followed by monitoring the production of energy from PV and assessing the economic feasibility of PV installations, both of which were indicated by 77% of respondents. Figure 81 provides the breakdown of responses by Quadruple Helix (QH) actors.

Regarding the evaluation of PV system performance in terms of energy production, the majority of respondents preferred this assessment to be done by city zones (80%) rather than by individual buildings (60%) or for the entire city (40%). This preference remained consistent across all QH groups (Figure 80). In terms of the adoption rate, the most useful indicators, preferred by 70% of all respondents, were the percentage of buildings with PV installations, followed by the total number of PV systems installed (63%) and the number of PV installations per building (57%). The preferences of QH groups varied slightly, with government representatives expressing the most interest in the total and per-building number of installations (88%), while industry members prioritized the total number of installations and the percentage of buildings with PV installations (73%). Academia members displayed a significant interest in the percentage of buildings with PV installations (Figure 81).

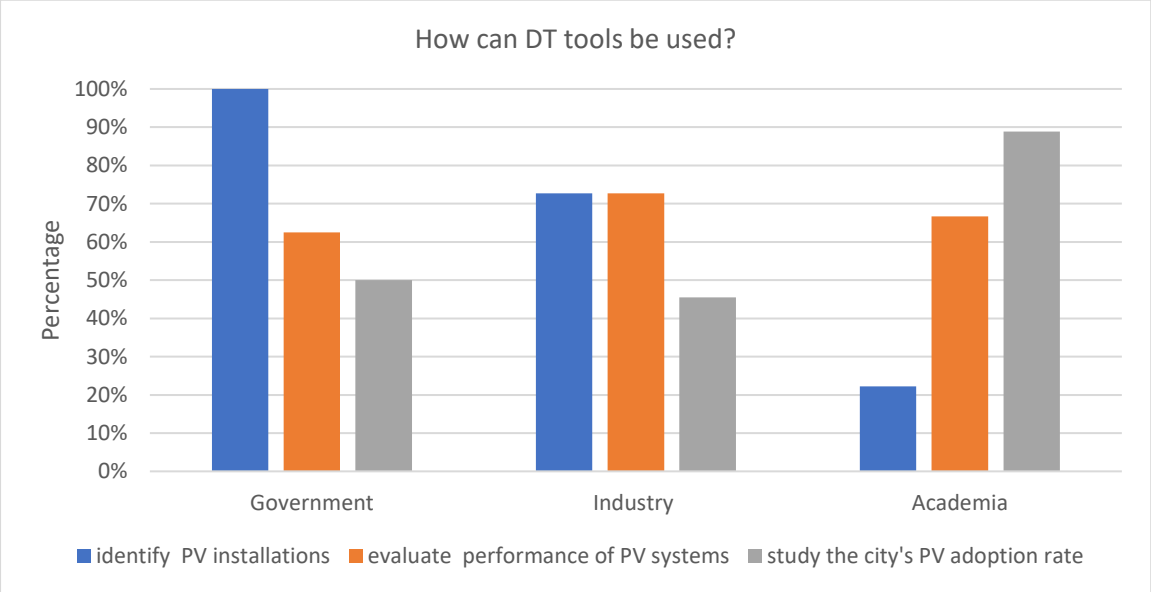

FIGURE 79: POTENTIAL USES OF DTS IN BURGAS CITY.

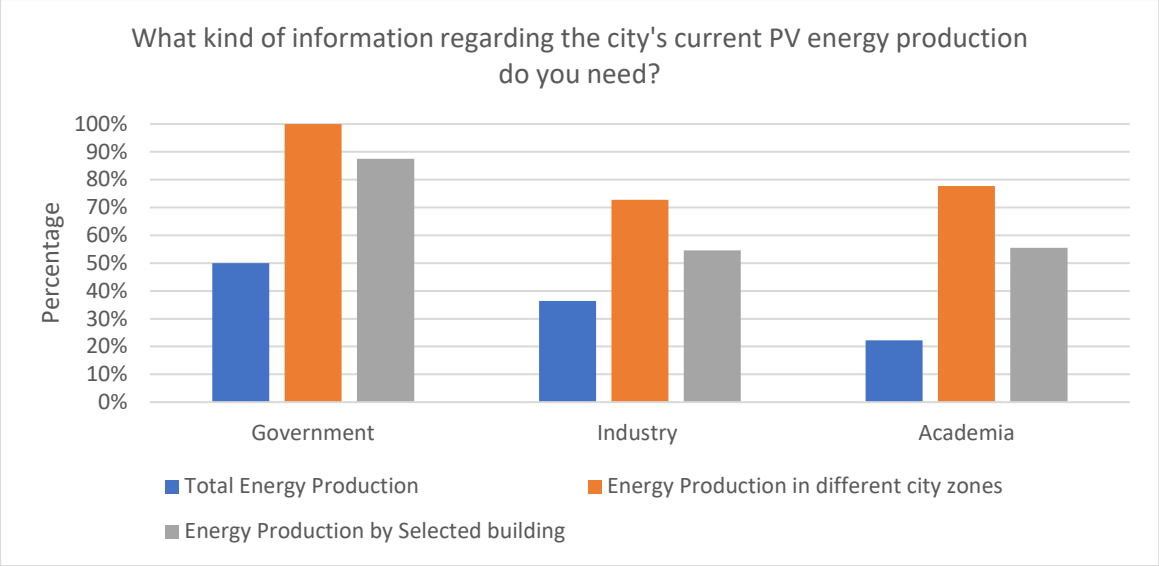

FIGURE 80: INFORMATION THAT SHOULD BE PROVIDED REGARDING THE CITY'S PV ADOPTION RATE.

When it comes to monitoring the energy production, respondents did not express a clear overall preference for the frequency of updating information. The is an almost equal split between the daily, weekly, and monthly options, with 33%, 30%, and 27% of respondents indicating these preferences, respectively (Figure 81).

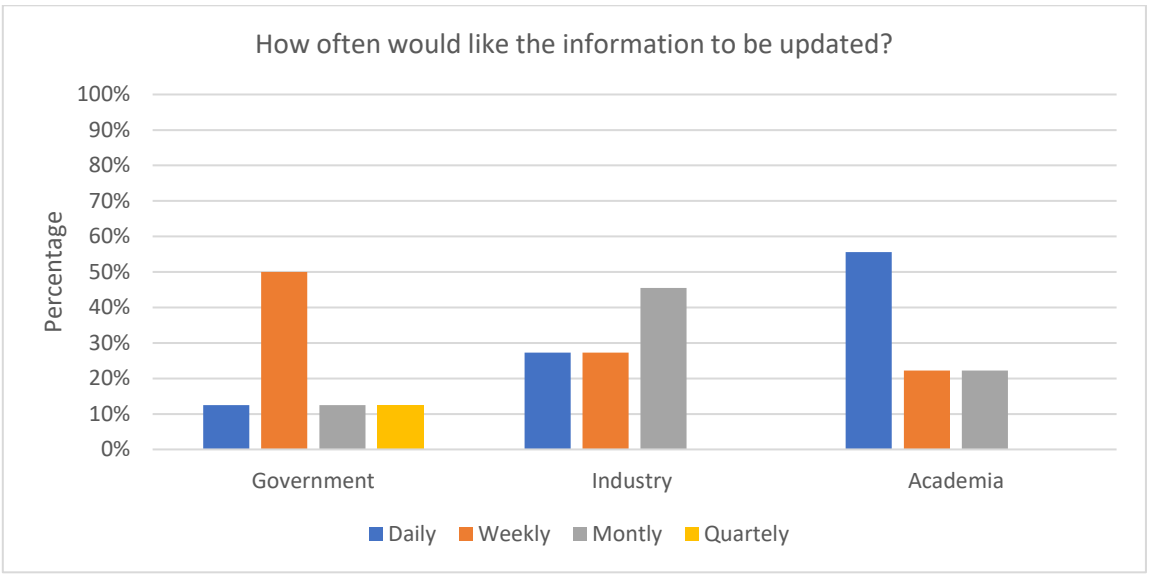

FIGURE 81: FREQUENCY OF UPDATES.

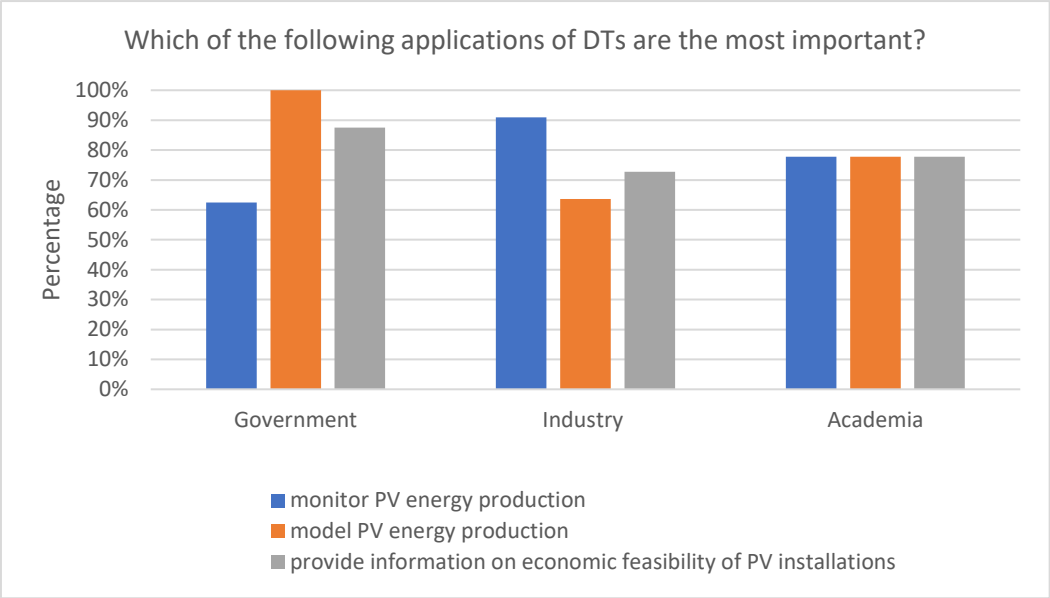

FIGURE 82: RELATIVE IMPORTANCE OF THE DIFFERENT APPLICATIONS OF THE DT.

When it comes to using DTs for modelling purposes, the majority (90%) of all respondents expressed their interest in having access to both historical and predictive models. Additionally, 37% of them indicated that they would like DTs to include forecasts of PV energy output (Figure 83). Stakeholders were also asked about the type of data that are important to be provided regarding the economic feasibility of PV installations. The most preferred option was the return on investment, chosen by 83% of respondents. Other popular metrics included the total lifetime of installations (73%) and the installation cost per building (67%). The distribution of these preferences across the Quadruple Helix (QH) groups is shown in Figure 84.

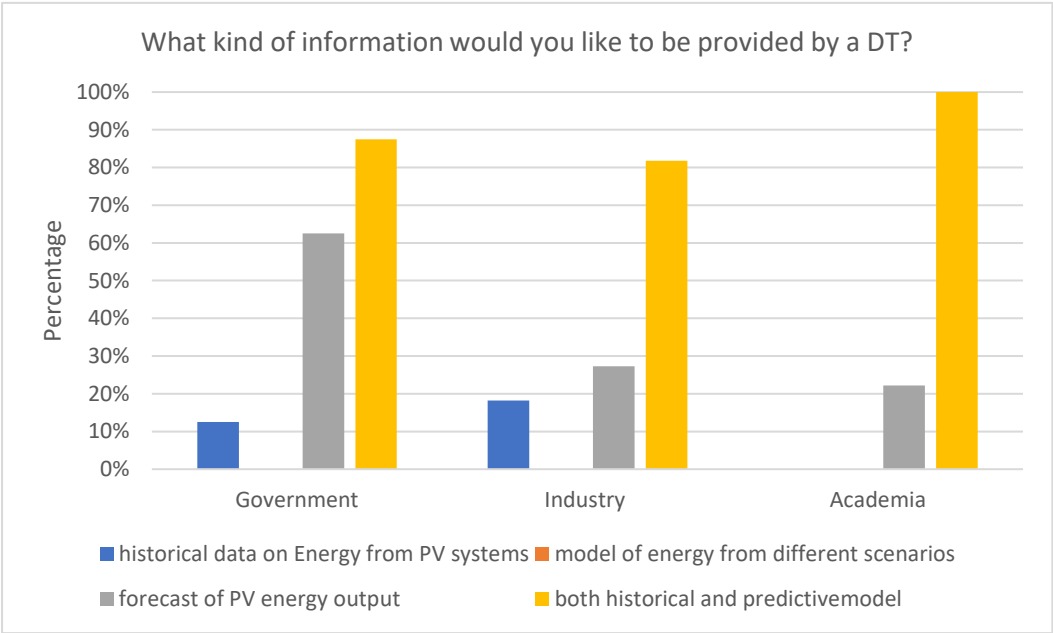

FIGURE 83: INFORMATION/MODELS TO BE PROVIDED BY THE DT.

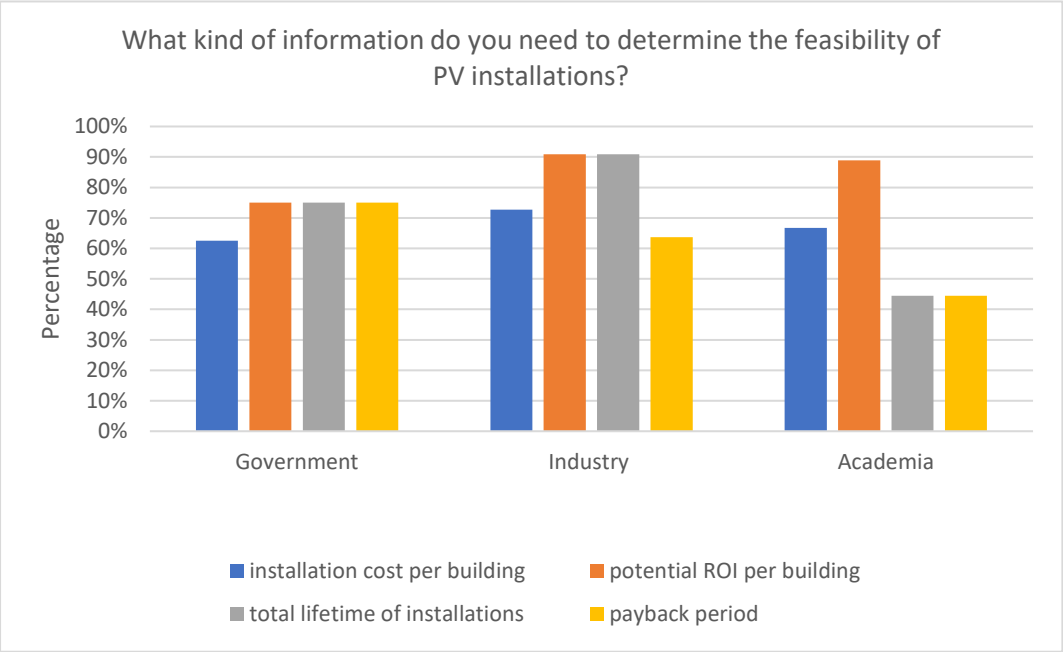

FIGURE 84: INFORMATION TO BE PROVIDED BY DTS REGARDING THE FEASIBILITY OF PV INSTALLATIONS.

6.2.3.3.1 User stories

Citizens:

- As a citizen I would like to know how quickly I can recuperate my investment in PV so I can make more sound decisions.

Government Representatives:

- As a policy maker, I would like to have a good model of PV uptake, so I know whether the city is meeting its goals of energy from RES
- As policy maker, I would like to have good data on the feasibility of PV installations, so that I can find better ways to motivate the citizens to install PVs.

Academia:

- As a researcher, I would like to have good models of RES use and performance in order to find ways to improve it.

Industry

- As a building user I would like to know how quickly I can recuperate my investment in PV so I can make more sound decisions.
- As a PV manufacturer, I would like to have more information on potential clients and on their needs, so as to better plan my operations.

6.2.3.3.2 Conclusion

In conclusion, the survey results highlight the significant interest and potential benefits of utilizing Digital Twins (DTs) in the context of Photovoltaic (PV) installations. Stakeholders expressed enthusiasm for using DTs to identify PV installations, evaluate their performance, and study PV adoption rates over time. The findings also underscore the importance of historical and predictive models in DTs, along with the need for data on economic feasibility, particularly return on investment metrics. By tailoring DT technologies to meet the diverse needs of stakeholders, we can harness their potential to optimize PV installations and drive sustainable renewable energy adoption in urban areas.

7 Requirements of Metacities

In this chapter, we present a comprehensive requirements analysis for three pilots focusing on smart mobility, urban planning, and energy efficiency and renewable energy applications. These requirements have been extracted from the previous chapter, where we analysed the results of the questionnaires answered by the QH stakeholders. By understanding the specific needs and expectations of citizens, government officials, academia, and industry representatives, we aim to develop innovative solutions that fulfill their diverse requirements.

The requirements identified in this chapter will be categorized into functional and non-functional aspects, allowing us to prioritize and design effective solutions. Functional requirements will define the specific functionalities and capabilities that the technical outcome must offer to achieve its goals, while non-functional requirements will focus on ensuring high performance, usability, and security. By leveraging the insights gathered from the Quadruple Helix actors, we can create tailored solutions that optimize smart mobility, streamline urban planning processes, and enhance energy efficiency and renewable energy applications. The integration of these requirements into the development process ensures that the resulting solutions align with the stakeholders' needs and contribute to the sustainable development and growth of the cities and communities involved.

7.1 Functional and non-functional Requirements for Smart Mobility

TABLE 11: FUNCTIONAL AND NON-FUNCTIONAL REQUIREMENTS FOR TRANSPORT.

RQ-ID	RQ Cluster/Use Case	RQ-TITLE
F-RQ-T-1	CY/GR	Real-time information on parking availability
F-RQ-T-2	CY/GR	Integration with other transportation and urban planning systems
F-RQ-T-3	CY/GR	Ability to work across different parking systems and providers
F-RQ-T-4	GR	Ability to work with multiple parking sensor vendors
F-RQ-T-5	CY/GR	Ability to pay using different payment methods
F-RQ-T-6	CY/GR	Ability to receive notifications about parking spot availability
F-RQ-T-7	GR	Ability to receive navigation instructions to available parking spots
F-RQ-T-8	CY/GR	User-friendly interface
F-RQ-T-9	CY/GR	Reminders about parking time expiration
F-RQ-T-10	GR	Automatic creation of parking tickets (fines) in cases of violating parking time expiration
F-RQ-T-11	CY/GR	Ability to extend parking time remotely

F-RQ-T-12	CY/GR	Ability to view parking history and receipts
F-RQ-T-13	CY/GR	Showing location of handicap-accessible parking spots
F-RQ-T-14	GR	Automatically identify valid PwD (People with Disabilities) badge holders via use of Tags
F-RQ-T-15	GR	Issue parking ticket when vehicle without appropriate Tag parks in PwD spot
F-RQ-T-16	CY/GR	Integration of mobile payment system
F-RQ-T-17	CY/GR	Capability to manage parking availability and spaces through a digital platform
F-RQ-T-18	GR	Notifications to emergency services
F-RQ-T-19	GR	Identify type of emergency and number of injured persons
F-RQ-T-20	GR	Keep track of the available emergency vehicles and personel
F-RQ-T-21	GR	Real time dispatch of emergency services based on the severity of the incident
F-RQ-T-22	GR	Calculate shortest paths to the incident
F-RQ-T-23	GR	Assist traffic controllers to optimally reroute traffic to minimize disruption
F-RQ-T-24	GR	Automatically monitor traffic volume via appropriate sensors
F-RQ-T-25	GR	Monitor air quality (pm rate)
F-RQ-T-26	GR	Measure noise
F-RQ-T-27	GR	Keep a record of environmental and traffic volume of time series data
F-RQ-T-28	GR	Correlate environmetal indices with traffic volume measurements
NF-RQ-T-1	CY/GR	Privacy-preserving mechanism to safeguard drivers' information
NF-RQ-T-2	CY/GR	Protection of personal and financial information
NF-RQ-T-3	CY/GR	Accessibility and usability for people with disabilities
NF-RQ-T-4	CY/GR	Real-time parking availability monitoring using IoT sensors
NF-RQ-T-5	CY/GR	AI algorithms for predicting parking demand and optimizing space usage
NF-RQ-T-6	CY/GR	Data encryption and protection for security and privacy

NF-RQ-T-7	GR	Data must be encrypted in-transit and at-rest
NF-RQ-T-8	GR	All API endpoints must employ authentication and must mandate encryption
NF-RQ-T-9	CY/GR	Mobile application interface for accessing the smart parking digital twin
NF-RQ-T-10	CY/GR	Preference for a 2D interface for academia
NF-RQ-T-11	GR	Users must uniquely authenticate with the Digital Platform
NF-RQ-T-12	GR	Digital Platform must employ Role-Based Access Controls (RBAC) for logged in users

7.2 Functional and non-functional Requirements for Urban Planning

TABLE 12: FUNCTIONAL AND NON-FUNCTIONAL REQUIREMENTS FOR URBAN PLANNING.

RQ-ID	RQ Cluster/Use Case	RQ-TITLE
F-RQ-U-1	CY/BG	Real-time data such as traffic, weather, and air quality
F-RQ-U-2	CY	Access to detailed data about the city's infrastructure, including roads, buildings, and utilities
F-RQ-U-3	CY	Ability to interact with a digital twin of the city and make changes
F-RQ-U-4	CY	Access to historical data about the city's infrastructure
F-RQ-U-5	CY	Access to future projections about the city's infrastructure, such as population growth and economic development
F-RQ-U-6	BG	Compatibility with other planning tools and software used by city officials and planners
F-RQ-U-7	CY	Ability to view the digital twin of the city in virtual reality or augmented reality
F-RQ-U-8	BG	Real-time energy usage data and interactive 3D display options
F-RQ-U-9	BG	Data to improve budgeting resources and planning
F-RQ-U-10	CY	Access to real – time energy usage statistics and to benchmark indicators for future projects
F-RQ-U-11	BG	Access to policies and best practices for energy usage and building renovation in Burgas and ability to compare

		energy usage and renovation options across buildings in the same area
F-RQ-U-12	BG	Type of energy efficiency measures - thermal insulation options and air-conditioning and ventilation options
F-RQ-U-13	CY	Data updates on weekly/monthly basis
F-RQ-U-14	BG	Access to detailed data for managing the costs of energy use both for public and private users
F-RQ-U-15	CY	Ability to interact with a digital twin of the city and make changes
F-RQ-U-16	BG	Access to future projections about the city's overall energy performance
F-RQ-U-17	BG	Compatibility with other planning tools and software used by city officials and planners
F-RQ-U-18	CY	Ability to view the digital twin of the city in virtual reality or augmented reality
NF-RQ-U-1	BG	Accessibility and usability for people with disabilities, such as those who are deaf or have mobility limitations
NF-RQ-U-2	CY	Security and privacy measures to protect user data
NF-RQ-U-3	BG	User-friendliness of the platform, emphasizing visual representations and ease of use
NF-RQ-U-4	CY	Seamless integration of remote sensing and in-situ monitoring, utilizing IoT sensors for data collection
NF-RQ-U-5	BG	Security and privacy measures to protect user data and the data of the city

7.3 Functional and non-functional Requirements for Energy Efficiency and Renewable Energy application.

TABLE 13: FUNCTIONAL AND NON-FUNCTIONAL REQUIREMENTS FOR ENERGY.

RQ-ID	RQ Cluster/Use Case	RQ-TITLE
F-RQ-E-1	BG	Real-time data such as energy consumption, CO2 levels in interior spaces, consumption of electricity, water and heat, level of lighting
F-RQ-E-2	BG	Historical data representing time-line

F-RQ-E-3	BG	data updates on daily/weekly basis which appropriate
F-RQ-E-4	BG	Application areas: renewable energy sources, smart lighting and ventilation and air conditioning
F-RQ-E-5	BG	Public buildings and residential buildings are in the focus of interest for the city digital twin
F-RQ-E-6	BG	Real-time data such as PV energy production potential, weather, and air quality
F-RQ-E-7	BG	Access to detailed data about the city's infrastructure, existing PV systems in the city
F-RQ-E-8	BG	Ability to interact with a digital twin of the city and make changes
F-RQ-E-9	BG	Access to future projections about the city's infrastructure, such as PV installations on the buildings, energy management data
F-RQ-E-10	BG	Compatibility with other planning tools and software used by city officials and planners
F-RQ-E-11	BG	Ability to view the digital twin of the city in virtual reality or augmented reality
F-RQ-E-12	BG	Real-time data such as PV energy production potential, temperature, humidity, solar exposure
F-RQ-E-13	BG	Access to detailed data about the city's infrastructure, the buildings' energy performance, buildings insulation capacity at the roof level
F-RQ-E-14	BG	Ability to interact with a digital twin of the city and make changes
F-RQ-E-15	BG	Access to historical data about the city's infrastructure, buildings energy performance/consumption
F-RQ-E-16	BG	Access to future projections about the city's infrastructure, such buildings energy performance/consumption, energy management data
F-RQ-E-17	BG	Compatibility with other planning tools and software used by city officials and planners
F-RQ-E-18	BG	Ability to view the digital twin of the city in virtual reality or augmented reality
NF-RQ-E-1	BG	Security and privacy measures to protect user data and the data of the city

NF-RQ-E-2	BG	User-friendliness of the platform, emphasizing visual representations and ease of use
NF-RQ-E-3	BG	Seamless integration of remote sensing and in-situ monitoring, utilizing IoT sensors for data collection

8 METACITIES Initial Architecture

The METACITIES proposed digital infrastructure that will be able to support the evolution of a Smart City to a Meta-City is the outcome of multi-dimensional function, as it will rely on several socio-economic, business and technical aspects. In this section, we illustrate the high-level digital infrastructure architecture that comprises both the data related infrastructure and the network technologies. This high-level digital infrastructure architecture will be elaborated in the next version of the deliverable with interfaces to the smart city application layers/metaverse technologies and specific network technology options with respect to the business models and application areas for the cities.

8.1 DT Architecture

The generic Digital Twin overall architecture proposed is shown in the next diagram:

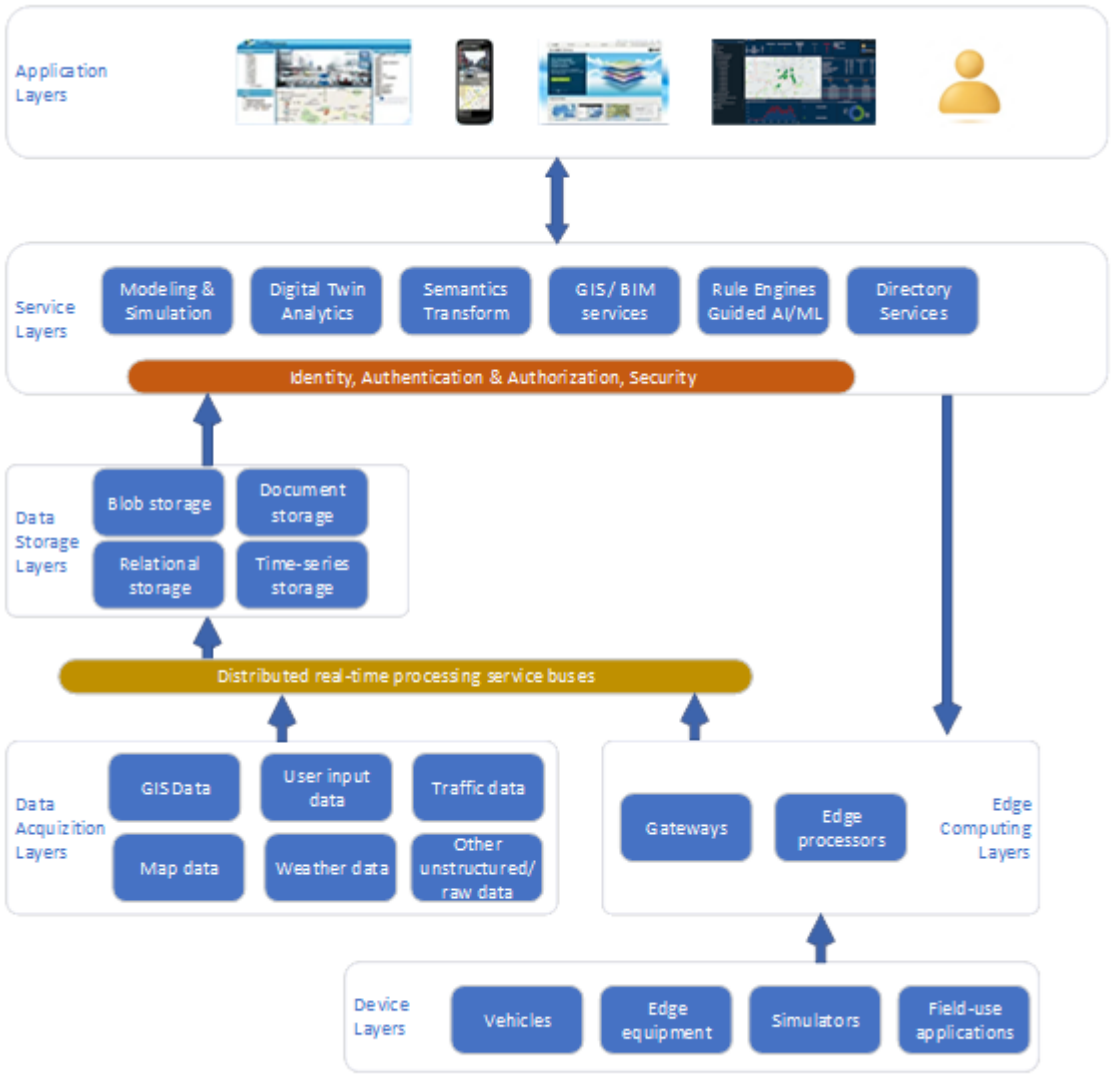

FIGURE 85: A PROPOSED DIGITAL TWIN ARCHITECTURE.

The architectural diagram is high level and depicts the initial blocks and requirements for the METACITIES digital architecture that can support the specific DTs and Metaverses that can lie at the core of the R&I Strategies. Layers are cleanly separated with each serving clear purposes.

The Device layer includes actual (real) devices and equipment, but also covers the necessary simulators and field-use applications such as mobile apps for problem reporting, configuration and similar use cases. Devices interact with API Gateways and/or Edge processors that handle forwarding, especially for non-IP-aware devices such as IoT sensors.

The Edge Computing layer also effectively handles actuation towards devices allowing decisions taken at the Service Layer to reliably reach the devices.

The Data Acquisition layer handles reception of data from 3rd party services, using cloud to cloud service data such as weather, raw text/CSV, GIS and BIM, etc. Data from any sources are then fed into distributed real-time processing service buses (for example Kafka clusters) that can perform filtering, routing, shaping and processing of data before writing to the Storage layer.

The Storage layer handles all non-volatile storage needs and usually consists of specialized database management systems that cover different needs:

- Relational storage - SQL
- Raw time-series storage for sensor data
- Document storage
- BLOB (Binary Large Objects) storage

The Service layer is a series of microservices, closely (via IPC) or loosely (via Cloud APIs) interconnected between them. Those services carry the overall system intelligence, Digital Twin infrastructure, AI/ML and rule execution subsystems, and implement the decision-making outcome by issuing API requests towards the Edge Computing layers' advertised API endpoints.

This layer allows the system to use data processing and analytics services in order to derive insights and patterns from the data ingested previously via the acquisition layers. These services can include various algorithms, machine learning models, statistical analysis, and other data processing techniques to extract valuable information.

Additionally, the Digital Twin architecture incorporates models and simulations that replicate the behavior of the physical and logical objects of the "real world". These models allow the Digital Twin to predict future states, analyze what-if scenarios, provide recommendations, make decisions and actuate directly towards devices and 3rd party services and create alerts.

Finally, the Application layers are the User-facing applications (Web, Mobile, etc) that enable consumption of analytics, guided what-if scenario execution, and all user interaction in general.

At the moment the high-level flow that is shown in the figure depicts the acquisition of data, the analysis the use in applications, training, what if scenario execution and actuation of functions and activities that the edge that will enable the applications.

8.2 Network Technologies

The Network architecture suitable for METACITIES comprises the heart of the digital infrastructure as a necessary interconnection element for the data to be scouted, collected, processed and analysed. The network will also allow actuation of specific interconnected elements and all user interaction with the digital infrastructure along with visualization of data. In the figure below (Figure 86), a generic overview of all METACITIES network elements and technologies are depicted and the way that the

digital infrastructure is orchestrated together with the data platforms described in the previous paragraph will be entailed in next deliverables and reports. It is noted that in order to illustrate exactly the network architecture that is required for the execution of the METACITIES Proof of Concepts and design of pilots, we need to define in detail the overall use case descriptions with respect to METACITIES priorities and also the business models that are available for service the development of such infrastructure.

In the figure below, starting from the lowest perception level of the METACITIES network technologies grid, a list of Smart City related data producers and the way these may be interconnected between them or through a higher level gateway is depicted. The sensors comprising this layer are grouped into technologies according to their power consumption, mobility characteristics and bandwidth requirements, in order to highlight the variety of characteristics that the METACITIES devices (sensors etc) may impose on the network and the overall system and the requirements that they may serve for the various applications. The general understanding is that the devices and data producers will be owned by the City, however this may not be always the case. In the right corner of the lower sensing layer, a set of citizens owned devices are depicted.

As it was described, Use Cases and applications that may be deployed in METACITIES, may require access to the data received from various mobile devices, for example cameras. Evidently, all the above sensing and IoT technologies will be interconnected to the edge and cloud with various network technologies and protocols some of which are specifically described in the figure below. The list may contain other technologies as well, together with a list of corresponding gateways.

Nevertheless the following high level specifications for the network technologies are stemming from the requirements:

- Provide ultra-fast speeds – a minimum of 10Gb download speeds and in some cases matching speeds for upload may be required
- Reduce network delays (low latency) – 1ms delays is some cases for safety related applications
- Increase transfer capabilities & capacity (ultra-high bandwidth) – more things connected simultaneously
- Increase reliability – improved coverage (eventually), less network dropout / low signal
- Increase security – a more secure network

All the above are met by 5G and 6G networks however this may not always be necessary or feasible in the smart city environments where other technologies may be suffice when the specifications are different:

- Low cost
- Small size and footprint
- Can operate on batteries for years , with great autonomy
- Optimized to communicate for very small data rates

Depending on the ranges and assuming that wireless technologies offer the advantage fo scalabilty, the short raneg options include WIFI (which has large power consumption, Bluetooth, ZigBee, Z-Wave [[104]. For large range counter parts, the two most used technology players today are SigFox and LoRa. SigFox and LoRaWAN operate on a free ISM (Industrial, Scientific and Medical) frequency band, so there is no need for a license. If this frequency band is free,but can be used only fo small data rates.

NB-IOT, for “Narrow Band IOT”, is an evolution of 4G (LTE) that offers a low power consumption solution, with limited throughput, based on an update of the current 4G network.

The requirement for at least two levels of processing with respect to the proximity to the access network stems from the use cases and the low latency requirements. Depending on the business model that will be adapted by each City combined with the priorities that will be sought in the City R&I strategy, the network architecture will be defined in detail.

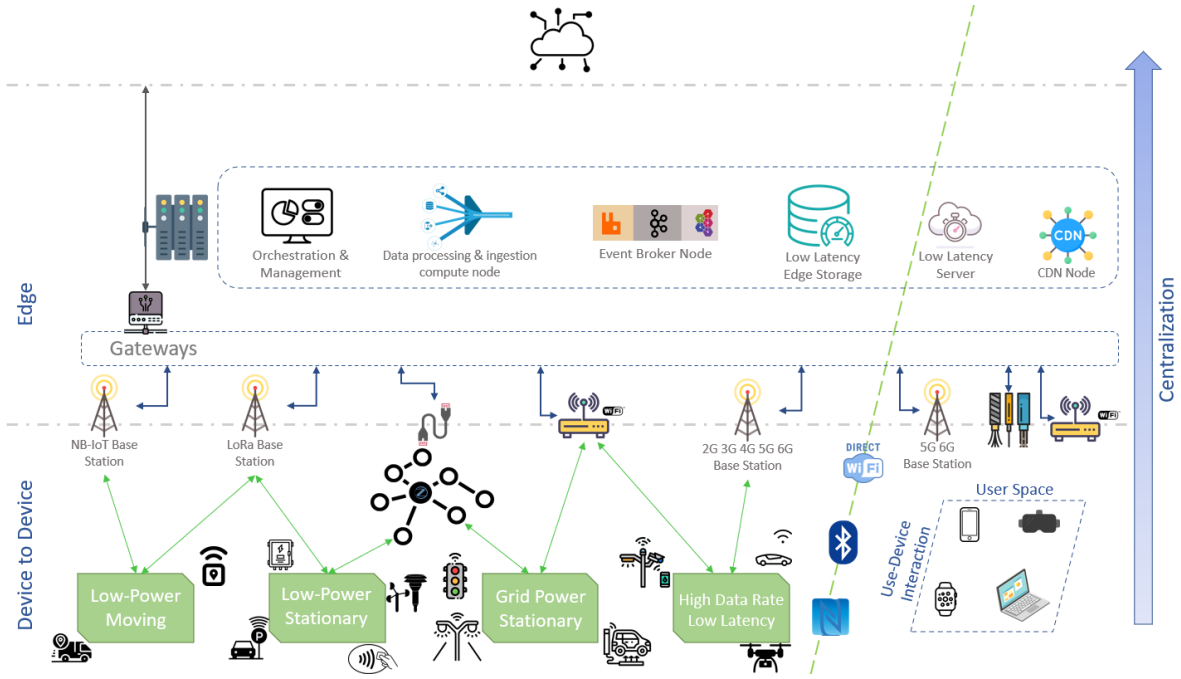

FIGURE 86: NETWORK TECHNOLOGIES FOR METACITIES DIGITAL INFRASTRUCTURE

9 Conclusions

This deliverable presents the functional requirements and end-user needs, following a user-centric social and economic dimension as well as the technical specifications of the ODTF. Additionally, a first version of the proposed architecture of METACITIES Digital Twin is provided.

The work presented in this deliverable was carried out in four main steps; starting from an extensive literature review, selecting three use cases of all innovation ecosystems, Smart Mobility, Green City and Urban Planning, conducting a socio-techno-economic requirements analysis through questionnaires in the quadruple helix, identifying functional and non-functional requirements and finally proposing a high-level architecture of METACITIES Digital Twin.

The main conclusions can be depicted in the identified functional and non-functional requirements. Regarding the Smart Mobility, users wish real-time information and notifications on parking availability, ability to pay using different payment methods, automatically identify valid people with disabilities, identify and track emergency incidents, monitor traffic volume, etc. Regarding the Urban Planning, users wish real-time data such as traffic, weather, and air quality, access to historical data and future projections about the city's infrastructure and energy performance, virtual and/or augmented reality view of the city. Regarding the Energy and Green City, users also wish real-time data for energy consumption, CO2 levels in interior spaces, consumption of electricity, water and heat, level of lighting, access to data for both public and residential buildings and compatibility with other planning tools. Similar non-functional requirements emerged for all use cases, like privacy-preserving mechanisms to protect user's personal and financial data, AI algorithms for prediction, user-friendly interfaces and mobile applications, utilization of IoT sensors for data collection and accessible and inclusive platforms for all.

Finally, the main outcome is the proposal of the first version of the generic Digital Twin architecture. The proposal is a high-level architecture and depicts the initial blocks and requirements for the METACITIES digital architecture that can support the specific DTs and Metaverses that can lie at the core of the R&I Strategies. Layers are cleanly separated with each serving clear purposes: Device layer, Edge Computing layer, Data Acquisition layer, Storage layer, Service layer and Application layer. Additionally, a generic overview of all METACITIES network elements and technologies that will be exploited, is presented.

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