# Towards Sustainable Urban Development: Matera's Urban Digital Twin and Challenges in Data Integration

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**Abstract.** This work is part of the project CTEMT "House of Emerging Technologies of Matera" aims to develop an ICT platform, i.e., "Alpha model", connecting sensor networks with advanced simulation and monitoring services for the creation of the urban digital twin of the city of Matera. The ambition is to build a set of digital models for city systems to analyze the complex dynamics of the urban environment. The first phase required a detailed context analysis to explain the role and function of the "model Alpha" in the city of Matera, identifying the main thematic structures territorial of the city and their connections and effects on the area. For this purpose, the urban context is analyzed by splitting it into three different spatial information layers: Point Of Interest, road graph and public space. The implementation of an operational urban digital twin was found to be a complex process involving several technical and logistical challenges even before the mapping phase began. Beyond data collection and integration to provide accurate representations of the urban environment to the model, another challenge was the engagement of analysts from multiple disciplines throughout the deployment process. Indeed, different semantic interpretations of information and purposes of the urban digital twin have emerged. This work aims to give an overview of the CTEMT experience and analyze the critical issues related to the development of urban digital twin.

**Keywords:** Urban Digital Twin · Urban management · Smart city · Urban planning

## 1 Introduction

The journey of Matera as the European Capital of Culture in 2019 highlighted how a cultural program can act as a catalyst for implicit processes of urban regeneration, transforming public spaces into areas for experimentation and the development of creative and innovative processes. Through the implementation of the European Capital program, the city positioned itself at the center of a critical reflection on the potential of technology for maintenance, governance and future development of the urban context. The focus extended beyond the well-known tourist sites and cultural heritage, such as


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the Sassi, and encompass the modern neighborhoods and suburbs of the city. This focus also included the adoption of the city's Urban Digital Twin, presenting an opportunity for Matera to re-discover its urban space and dynamics, and effectively manage future urban regeneration projects [1].

The project "The House of Emerging Technologies in Matera" (CTEMT) aims to transform Matera into an international reference center for the application of emerging technologies in the urban domain, specifically Artificial Intelligence (AI), Blockchain, Internet of Things (IoT), and 5G. Technologies to serve city government in a broader sense, for example an optimizer and simulator of scenarios related to ongoing forms of urban system management, i.e. pedestrianize a street, traffic management, maintenance of urban greenery, waste management, and strategic planning i.e. the projects and strategies for the city and assessment of future trends.

Firstly, hardware interventions will establish a technological infrastructure for gathering data from various aspects of the city. Secondly, software interventions will enable the analysis, management, and processing of this data, resulting in the development of innovative models, systems, and services. The resulting data, applications, and services will be accessible, with a particular emphasis on providing opportunities for startups involved in the project's innovation domains to develop their products and services.

The concept of digital twin entails the creation of a virtual replica or simulation that mirrors physical objects, systems, or processes [2]. It serves as a dynamic model, emulating its real-world counterpart, and finds application in various domains. This discourse presents a series of ambitious yet concrete scenarios that underscore the utilization of digital twins in urban contexts [3]. Several frameworks have been released for the description and development of Digital Twins in industrial sectors [4]. Each framework is accompanied by a delineation of the context, requisite data, the most suitable technologies and addressed needs, offering comprehensive insight into the concept's essence.

Within the domain of urban development and planning, the creation of a digital twin of a city holds significant potential. Integrating diverse data sources, this twin encapsulates the entire urban environment, allowing simulations of infrastructure development, transportation optimization, and energy consumption. Urban planners can leverage this model to assess the impact of new construction projects, predict traffic patterns, and evaluate environmental factors, thereby facilitating the design of sustainable and efficient cities.

However, implementing urban digital twins poses several challenges and hurdles that cities should investigate if they want to reach the levels of industrial ones. These challenges can include personal data privacy and security concerns, data integration and interoperability issues, high costs of implementation due to the technical complexities, and comprehension and use of such technologies by the institutional stakeholders.

## 2 Digital Twins: Lessons from Matera's CTEMT

Relevant experiences concerning the identification of specificities arising from recent research in this field can be found in the literature [5]. On one hand, authors rely on the technological response that the Digital Twin can offer as an innovative solution for

specific urban challenges [6, 7]. On the other hand, it opens up a broader reflection based on disciplinary contributions and integrated expert knowledge to assist in defining urban development strategies. In line with [1]:

> "*generally, a computerized model of a physical system can never be the basis for a digital twin since many elements of the real system are ignored in such an abstraction. However, there is no doubt that some models are closer to reality than others...*"

The reference to the complexity of the city as a system finds unique elements in the case study of Matera, not only related to the physical configuration of urban spaces characterized by the uniqueness of the "Sassi" [8], but also to the recent valorization experience associated with the process of being the European Capital of Culture. The legacy of 2019 necessitates the association of the physical dimension with the social dimension of the context through a renewed interpretive structure. This process begins with the evaluation of past experiences and projects towards new forms of modeling, simulation, and optimization of the relationship between citizens and the city, with a focus on quality of life, safety and resilience, and socio-cultural-economic opportunities [9, 10]. In addition, another strategic dimension should be considered, which regards "tourists" as temporary users of urban space and services, sometimes seen as antagonistic to residents, but at other times supporting converging instances that contribute to defining "opportunities" for development from a new perspective of the city and the territory [11].

Regarding the Matera case study, issues related to the scale and size of the urban system emerge in relation to defining optimality criteria. The demographic threshold significantly influences the search for a balance between the demand and supply of services, allowing the utilization of technological and organizational solutions developed in contexts with a high concentration of demand. This requires the consideration of intervention areas and performance improvement objectives within the urban system as a set of elements conditioned by a hierarchy of priorities, where certain components must be preferred to concentrate resources and investments at the expense of others [12]. This depends on a future vision that can be better defined through the project's experience.

In a broader representation of the disciplinary debate, it is crucial not to forget that innovation experiences referred to as "smart cities" [13–15] offer a rich heritage of experiences and models worth considering. This can enable the activation of adaptation and transfer of urban practices to the components that the project will develop, both in terms of the strictly technological and digital aspects, as well as the wider perspective of urban development sustainability.

## 3 Data Model

A further level of insight is related to defining a representative data model of urban components essential to producing useful digital replicas useful for urban analysis. A key factor in defining the data model is that such model should maintain a close connection to the objectives of the project, should be functional for modeling within the Twin, and aimed at optimization processes consistent with the instances that at the urban scale may characterize useful application domains of the Urban Digital Twin [16].

In the virtual space of an urban digital twin, many of city physical infrastructure elements come together to form a comprehensive and dynamic simulation. Buildings and structures populate the virtual landscape, encompassing the residential, commercial, and industrial buildings.

The mobility system and transportation networks weave throughout the digital twin, mirroring the real-world roads, highways, railways, etc. Street graph could be accurately recreated, capturing the details of intersections, traffic flows, and public transportation routes [17]. Moreover, parking lots and private garages could be mapped providing insight into the availability and utilization or saturation of parking spaces. All of this information results in a massive amount of data from a variety of sources that can be defined as big-data and as such is affected by 5V's [18].

Within the context of the "model Alpha" in the city of Matera, a diverse range of geometric spatial data serves as the foundation for mapping the city's physical infrastructure and identifying the main urban thematic structures. Each type of data brings different spatial information and contributes to simulate the digital replica:

- Point data plays a crucial role in pinpointing specific locations or Points Of Interest (POI) within the urban shape. By precisely capturing the coordinates of buildings, commercial properties, transportation facility, and utility poles, point data enables the digital twin to simulate the exact location and distribution of these elements. This simplifies visualization, analysis, and monitoring of individual infrastructure components, enhancing the overall fidelity of the virtual city and facilitating topological associations with other type of data [19];
- Line data offers a means to represent linear features that traverse the urban environment. The detailed mapping of roads, railways and utility networks provides useful insights into the connectivity and layout of transportation or utility infrastructure through road graph mapping. By incorporating line data, the urban digital twin can simulate the flow of traffic, utilities, and resources, supporting planning and decision-making related to infrastructure optimization, route planning, and network design [17].
- Polygon data introduces the concept of enclosed areas or public spaces within the digital twin. By delineating administrative zones, parks, green spaces, and specific districts using polygons, the virtual representation can accurately depict the boundaries and extents of these areas. Polygon data is instrumental in simulating land use patterns and spatial relationships, empowering planners to assess urban density, analyze green spaces usage, and design urban interventions more precisely.

However, a city is more than its physical elements, it is a dynamic entity shaped by its inhabitants. The pursuit of understanding social infrastructure within the urban digital twin is driven by the objective of fostering more inclusive, sustainable, and resilient cities and participative citizens [20–22]. Through unraveling the social implications of urban interventions, promoting citizen engagement, and facilitating evidence-based decision-making, the groundwork is laid for the development of cities that thrive and cater to the diverse resident and tourists needs [23].

The social infrastructure focuses on capturing and modeling the intricate web of human interactions and behaviors within the urban context. This encompasses factors such as social interaction, community dynamics, events, and cultural practices that constitute the social fabric of the city [9].

To get the insights embedded within this interplay, a diverse array of data sources has to be employed. These sources encompass data derived from social media platforms, mobile phone records, surveys, and municipal authorities' statistics, especially for analyze tourist dynamics [24, 25]. This type of data needs advanced analytical techniques such as network analysis, agent-based modeling, and data visualization to unravel the intricate relationships, patterns, and dynamics that shape the social fabric of the city within the virtual environment.

## 4 Conclusion

In conclusion, the "Alpha model" to be developed in the Matera House of Emerging Technologies (CTEMT) project is a useful laboratory for testing and implementing IoT technologies and AI models for understanding and managing the complex dynamics of the urban environment. In general terms, the spatial data upon which the Urban Digital Twin's functionalities are built should be made and organized according to a logic that aims to generate information to address specific urban questions. This involves defining synthetic indices and attributes based on a predefined classification of the territorial components to be modeled within the digital infrastructure. While some applications such as optimization for pedestrian routes may go as far as considering point disconnections and/or dynamic criticalities on the path such as a construction site, on the other hand, understanding the most frequently used areas of a green space does not require too much detailed representation. Such a process would streamline the mapping phase and simplify the development of IT models.

By integrating social infrastructure into the urban digital twin, a deeper understanding of the multifaceted interplay between the physical and social systems emerges. This enables exploration and analysis of various aspects, including the impact of transportation on social equity, the influence of public spaces on social cohesion, and the relationship between urban form and community well-being [26].

The rationality of this process depends on the integration of two disciplinary languages: urban planning and computer science. The feasibility of defining functionalities that effectively address urban challenges depends largely on how well this integration is conducted, considering the project's high technological potential in terms of digital infrastructure, sensor networks, and computational capabilities.

Thus, it is necessary to work with the available data for the city of Matera, harmonizing the information requirements of the modelers, the availability of open data or data provided by project partners, and the functional requirements for urban governance. This complex methodological action will be carried out in the coming months as a short-term activity aimed at realizing the "model Alpha" according to the project specifications and additional features defined in collaboration with the Municipal Administration and the project partnership.

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