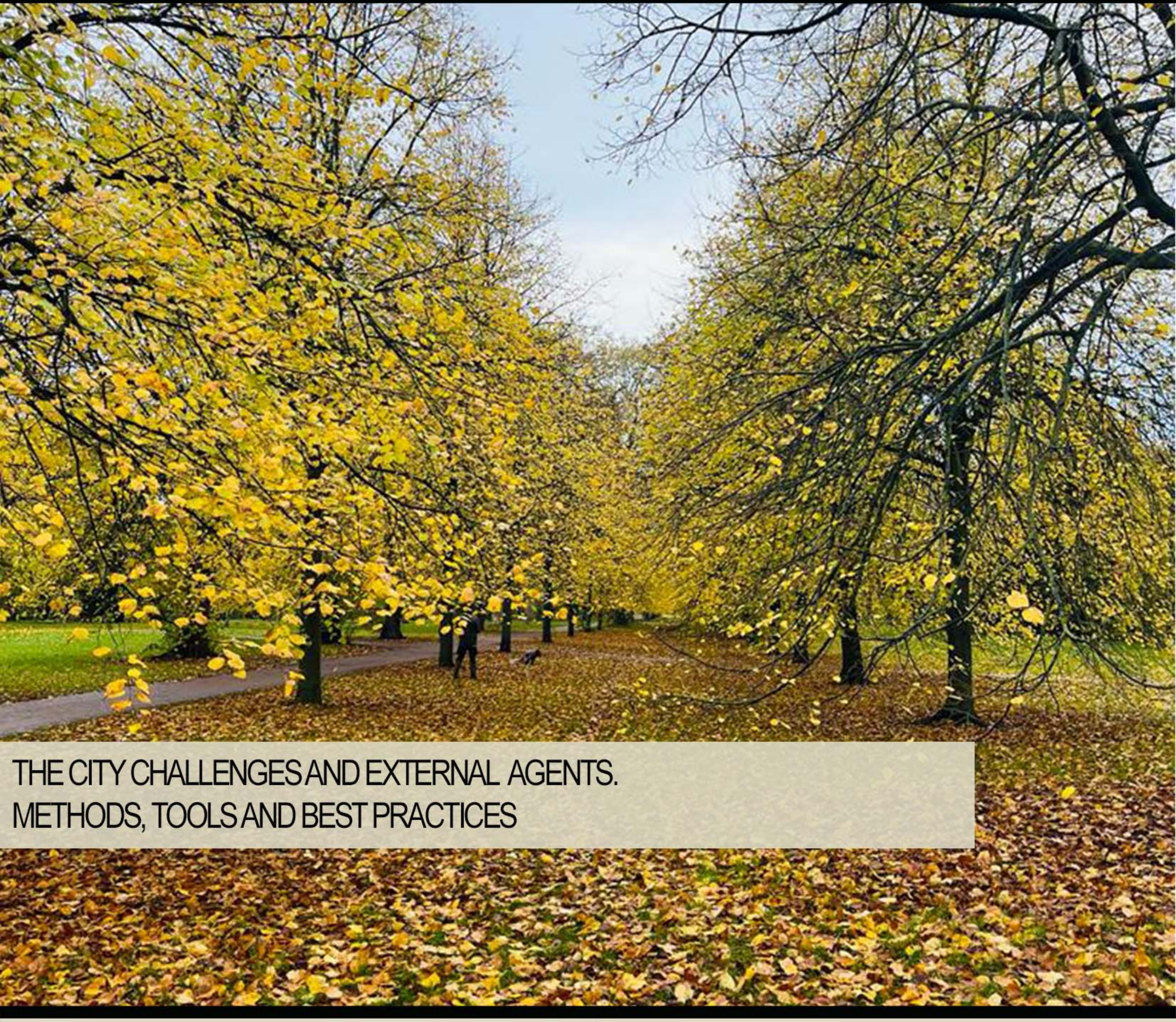
TeMA

Journal of
Land Use, Mobility and Environment

The climatic, social, economic and health phenomena that have increasingly affected our cities in recent years require the identification and implementation of adaptation actions to improve the resilience of urban systems. The three issues of the 16th volume will collect articles concerning the challenges that the complexity of the phenomena in progress imposes on cities through the adoption of mitigation measures and the commitment to transforming cities into resilient and competitive urban systems.

TeMA is the Journal of Land Use, Mobility and Environment and offers papers with a unified approach to planning, mobility and environmental sustainability. With ANVUR resolution of April 2020, TeMA journal and the articles published from 2016 are included in the A category of scientific journals. From 2015, the articles published on TeMA are included in the Core Collection of Web of Science. It is included in Sparc Europe Seal of Open Access Journals, and the Directory of Open Access Journals.



THE CITY CHALLENGES AND EXTERNAL AGENTS.
METHODS, TOOLS AND BEST PRACTICES

Vol.16 n.3 December 2023

print ISSN 1970-9889 e-ISSN 1970-9870
University of Naples Federico II

TeMA

Journal of
Land Use, Mobility and Environment

THE CITY CHALLENGES AND EXTERNAL AGENTS. METHODS, TOOLS AND BEST PRACTICES

3 (2023)

Published by
Laboratory of Land Use Mobility and Environment
DICEA - Department of Civil, Architectural and Environmental Engineering
University of Naples "Federico II"

TeMA is realized by CAB - Center for Libraries at “Federico II” University of Naples using Open Journal System

Editor-in-chief: Rocco Papa
print ISSN 1970-9889 | online ISSN 1970-9870
Licence: Cancelleria del Tribunale di Napoli, n° 6 of 29/01/2008

Editorial correspondence
Laboratory of Land Use Mobility and Environment
DICEA - Department of Civil, Architectural and Environmental Engineering
University of Naples "Federico II"
Piazzale Tecchio, 80
80125 Naples
web: www.serena.unina.it/index.php/tema
e-mail: redazione.tema@unina.it

The cover image shows a view of Hyde Park in London (United Kingdom) during the autumn season.
The photo was taken by Enrica Papa in November 2023.

TeMA. Journal of Land Use, Mobility and Environment offers researches, applications and contributions with a unified approach to planning and mobility and publishes original inter-disciplinary papers on the interaction of transport, land use and environment. Domains include: engineering, planning, modeling, behavior, economics, geography, regional science, sociology, architecture and design, network science and complex systems.

With ANVUR resolution of April 2020, TeMA Journal and the articles published from 2016 are included in A category of scientific journals. From 2015, the articles published on TeMA are included in the Core Collection of Web of Science. TeMA Journal has also received the *Sparc Europe Seal* for Open Access Journals released by *Scholarly Publishing and Academic Resources Coalition* (SPARC Europe) and the *Directory of Open Access Journals* (DOAJ). TeMA is published under a Creative Commons Attribution 4.0 License and is blind peer reviewed at least by two referees selected among high-profile scientists. TeMA has been published since 2007 and is indexed in the main bibliographical databases and it is present in the catalogues of hundreds of academic and research libraries worldwide.

TeMA Journal of
Land Use, Mobility and Environment

THE CITY CHALLENGES AND EXTERNAL AGENTS. METHODS, TOOLS AND BEST PRACTICES

3 (2023)

Contents

475 EDITORIAL PREFACE
Rocco Papa

FOCUS

479 **The evolving regional transport planning: the case of Piemonte region**
Sylvie Occelli

499 **Duration-based or time-based congestion toll pricing?**
Amir Reza Mamdoohi, Elnaz Irannezhad, Hamid Rezaei, Hamid Mirzahossein, Xia Jin

523 **The impact of land taken by logistics in two Italian regions**
Silvia Ronchi, Stefano Salata, Andrea Arcidiacono, Elisabetta Peccol

LUME (Land Use, Mobility and Environment)

545 **The investment of NextGeneration EU vs urban competitiveness of Italian metropolitan areas**
Carmela Gargiulo, Sabrina Sgambati

565 **Digitalisation process and sustainable development of vulnerable territories. Assessment of equity potentials of major Mediterranean Islands**
Chiara Garau, Giulia Desogus, Anastasia Stratigea

595 **Digital data to support urban planning processes to develop women safety cities: an application to the city of Naples**
Gerardo Carpentieri, Carmen Guida, Andrea Gorrini, Federico Messa, Lamia Abdelfattah, Benjamin Büttner

609 **Spatial regional electricity intensity and equitable well-being to support just transition**
Ginevra Balletto, Martina Sinatra, Alessandra Milesi, Emilio Ghiani, Giuseppe Borruso, Francesco Zullo

REVIEW NOTES

625 **City vs Energy consumptions: Community-led Energy Planning (CLEP) practices from the world**
Carmen Guida

631 **Urban planning and GeoAI in smart city policies**
Federica Gaglione

639 **Urban spaces and pedestrian mobility: the role of urban design for enhancing walkability**
Annunziata D'Amico

645 **The interventions of the Italian Recovery and Resilience Plan: cities adaptation to climate change**
Sabrina Sgambati

653 **Energy transition: digital (t)win?**
Valerio Martinelli

TeMA

Journal of
Land Use, Mobility and Environment

TeMA 3 (2023) 653-659
print ISSN 1970-9889, e-ISSN 1970-9870
HTTPS://DOI.ORG/10.6093/1970-9870/10321
Received 10th October 2023, Available online 30th December 2023

REVIEW NOTES – Methods, tools and data for the city energy governance

Energy transition: digital (t)win?

Valerio Martinelli

Department of Civil, Architectural and Environmental Engineering
University of Naples Federico II, Naples, Italy
e-mail: valerio.martinelli@unina.it
ORCID: https://orcid.org/0009-0007-8703-6573

Abstract

Starting from the relationship between urban planning and mobility management, TeMA has gradually expanded the view of the covered topics, always remaining in the groove of rigorous scientific in-depth analysis. This section of the Journal, Review Notes, is the expression of continuously updating emerging topics concerning relationships between urban planning, mobility and environment, through a collection of short scientific papers written by young researchers. The Review Notes are made of four parts. Each section examines a specific aspect of the broader information storage within the main interests of TeMA Journal. The section Methods, tools and data for city energy governance focuses on challenges that urban energy planning commonly addresses, providing food for thought to readers and fellow researchers.
Specifically, this contribution aims to examine these challenges and the solutions proposed in the scientific literature, focusing on the issue of digitalisation and how this can help urban energy planning.
In particular, this section is dedicated to in-depth analysis of digital twin technology and how this can be useful for the energy transition, taking into account the gaps between theoretical scientific progress and their actual practical implementation.

Keywords

Energy transition; Digital twin; Urban energy planning.

How to cite an item in APA format

Martinelli, V. (2023). Energy transition: digital (t) win? *TeMA - Journal of Land Use, Mobility and Environment*, *16* (3), 653-659. http://dx.doi.org/10.6093/1970-9870/10321

1. Introduction

In recent years, the world has faced numerous challenges of unprecedented magnitude, from rapid urbanisation to devastating natural disasters, pollution and global warming. Significant transformations to cope with the new situation have occurred in all aspects of society, from work routines to energy use and production methods. Therefore, sustainability, digitisation and the use of renewable energy are the focus of the energy transition in terms of production, distribution and application. In particular, the city, where more than half of the population currently resides, plays a key role in achieving this goal (Carpentieri & Favo, 2017). Approximately 55% of total energy consumption is for space heating, private homes, retail, trade and services. In cities, major challenges such as urbanisation and increasing greenhouse gas emissions have stimulated efforts to make them smarter and more sustainable (Papa et al., 2014). As outlined by the 2015 Paris Agreement, emissions must be reduced by 45% by 2030, and to achieve the UN's set sustainable development goals there is a need for energy-saving-oriented digital innovation (Guida, 2022). The intersection between smart cities and energy transition lies in the opportunity for real-time smart planning and digital energy management. Digital city twins are a recent attempt to create a digital replica of urban infrastructure linked in real time to city data, envisaged to improve city monitoring, control and decision-making (Mohammadi & Taylor, 2017). Given the increasing availability of city-scale energy performance data, DTs can be a promising platform for urban energy assessment and management (Francisco et al., 2020). The urban management sector has recently shown interest in implementing DTs in cities to improve urban planning, optimise resource management and create safe and sustainable cities (Ferré-Bigorra et al., 2022). Recently, with the development of emerging energy technologies such as Internet of Things (IoT), Machine Learning (ML), Artificial Intelligence (AI) and cloud computing, global energy development is gradually shifting towards digitisation and interconnection that significantly increase the overall efficiency of thegui urban system. At the same time, policies to transform cities into more sustainable and energy-efficient urban areas are increasing. According to Action Plan 3.2 of the European Strategic Energy Technology (SET) Plan, Positive Energy Districts (PEDs) are an essential part of the overall approaches towards sustainable urbanisation to accelerate the transition to clean energy and further achieve the EU's energy and climate goals (Zhang et al., 2021). Huge advances in technology have heralded the emergence of digital twins (DTs), creating ways for real-time synchronisation and monitoring of the energy system through computerised and virtual modelling of services, derived from consumer data, information and behaviour. The growing popularity of the digital twin demonstrates that the physical and virtual worlds are becoming increasingly connected and integrated as a whole (Ghenai et al., 2022).

2. Digitalisation and digital twin in urban areas

In 2014, Grieves coined the term digital twin (DT) to describe a system that contains: a real physical part, a digital (or virtual) replica and a data connection linking the real and virtual components (Grieves). This communication link enables the control, monitoring and optimisation of the physical entity through the continuous exchange of information. This concept was first introduced in the aerospace industry and then developed in other fields, until it was ranked by Gartner as one of the top 10 technology developments in 2019. Given the multifaceted nature of the energy transition involving various sectors and levels, the implementation of DT at different scales has become essential, even involving urban planning. The city, understood as a system, encompasses a wide and varied range of subsystems such as road infrastructure, water supply, electricity and public transport, among others.

Therefore, an urban digital twin models many subsystems to which as many models correspond: physical, meteorological, mobility, electricity grid infrastructure models, electricity supply models, natural gas models, etc. (Agostinelli et al., 2022). A digital twin of the smart city facilitates energy efficiency through near real-time prioritisation and decision-making, resulting in better urban management and a more sustainable city.

(Francisco et al., 2020). Furthermore, digital twins can model multiple systems and process information from a wide range of datasets simultaneously, enabling city planning and control in a single tool. This would be a continuously evolving tool that would allow for a holistic and integrated approach to spatial governance and that has the capacity to continuously adapt to the becoming of the urban system, transforming with it in real time (Mazzeo, 2013). Smarting the city is a complicated process because of the complexity of a city, which is not an automated system that can be easily understood and predicted, but rather a living system that evolves through variations and developments in its physical constructions, economic and political activities, social and cultural contexts, and ecological systems (Shahat et al., 2021).

However, despite the challenges mentioned above, Digital Twin has been shown to achieve important benefits and advantages in various energy sector applications by providing a unique way to connect the digital platform to real systems and simulate its energy performance (Yu et al., 2022). The 'twin city' concept goes beyond the 'smart city' sectoral approach by integrating the two components (virtual/digital and human) within a multi-purpose infrastructure that aims to produce new knowledge from data and vice versa. The smart city concept is inextricably linked to a process of optimisation and technologisation of the urban environment, this process of digitisation of urban and administrative dynamics is closely interconnected with the issue of DTs (Caprari et al, 2022). The urban application of this tool, which has been tested mainly in other disciplines, is motivated by the need to analyse urban dynamics and assess them in advance in order to optimise the efficiency and impact of new projects in cities.

Digitisation in the energy sector is recently gaining more attention, with the use of multiple digital technologies to manage energy systems worldwide, such as the use of smart meters, the development of advanced control systems, artificial intelligence and deep learning algorithms, cloud and Digital Twin (Ghenai et al., 2022).

2.1 Digital twin application for the city energy governance

The energy system is an important infrastructure closely linked to production and urban life (Fistola & La Rocca, 2014). It is also one of the key links in the construction of a smart city, going so far as to speak of Energy Digital Twin (EDT) (Yu et al., 2022). From the perspective of urban development, a clean, efficient and customisable energy supply is an important measure to meet the diverse needs of production and social life, improve resource use efficiency and optimise the urban environment.

Through technologies that collect and analyse data, digitisation has led to a greater integration of modern energy systems, resulting in increasing connectivity between the latter and the physical environment, contributing to improved safety, efficiency and durability of energy systems (Borowski, 2021). These mentioned benefits could be summarised in two words: decarbonisation and digitisation, which underpin the energy transition for both energy demand and supply. Both concepts lead to the importance of using the digital twin in all energy-related sectors (Ghenai et al., 2022).

Digital twin technology can be implemented along the entire energy chain: in the energy generation phase from fossil and renewable resources (Zhang et al., 2021); in the energy storage phase (batteries, mechanical and thermal storage, hydrogen, hydropower, etc.); up to the end-user consumption phase (residential and commercial buildings, transport and industrial applications).

The availability of smart meter data has stimulated a range of research assessing how this data, combined with statistical data and machine learning algorithms, can support a wide range of applications crucial to the energy transition (Jafari et al., 2023):

- energy consumption analysis and electricity load forecasting: the connection between the virtual and physical worlds enables the projection of energy consumption at various scales by improving grid management and distribution, using simulation models based on real-time data to understand users' energy behaviour and to optimise energy pricing in real time. Thanks to the possibility of running simulations on the virtual model, it is possible to make future predictions and optimise the performance of the physical counterpart (Hämäläinen, 2020). Instead of just developing virtual models, DTs allow cities to run simulations of new policies or infrastructure projects and predict their possible impacts before making real-world decisions;

- energy storage: digital twin technology will help create an optimal daily or hourly operational strategy based on weather conditions, cost, carbon emissions, system status, resident behaviour, mobility, energy demand, local energy supply and social structure information (Khajavi et al., 2019);
- operation and preventive monitoring based on the use of the Digital Twin can lead to the reduction of maintenance expenditure thanks to a constant flow of data from sensors, cameras and smart networks installed within cities, always returning a virtual mirror of reality in real time (Agostinelli et al., 2022). This interaction enables real-time analysis and informed decision-making, resource efficiency and improved comfort;
- fault detection and maintenance: the objective of fault modelling is to predict and avoid hardware problems, avoiding inconveniences and slowdowns when problems occur (Ghenai et al., 2022). Real-time monitoring of residential energy consumption and its maintenance can contribute to the efficiency of approximately 40% of the energy consumed in buildings (Bortolini et al., 2022);
- Better management of renewable energy flows: the digital twin of renewable energy systems will help to build and manage smart grids, optimise production and costs using renewable resources and meet growing energy needs. An urban digital twin can be instrumental in managing the energy flows of microgrids, autonomous power grids that produce energy from renewable energy resources, allowing electricity to be generated in an independent and localised manner and used when it is most needed (Jafari et al., 2023). Localised power generation and reduced transmission losses also improve the overall efficiency of the energy system (Papa et al., 2016).

The application of digital twins for the energy sector is still new but offers several opportunities to stimulate the energy transition and achieve future sustainable energy development goals. The energy system is, in fact, the basis for the functioning of the urban system in all its components and directly and indirectly affects the quality of life of its users.

The expected challenges make it necessary to bring together energy planning, digitisation and urban development in a single instrument. A digital twin can accelerate innovation, create consensus and save time and money by simulating and analysing the performance of energy components and systems and diagnosing problems at low cost in the virtual world. Digital twins have numerous other benefits that help promote sustainability, circularity and decarbonisation within cities. In the transport sector, for example, companies are motivated to maximise travel and fuel efficiency to optimise expenditure. Controlling traffic systems, informed by real-time updated data in the digital twin and the use of machine learning and artificial intelligence analytical tools, can lead to accurate traffic forecasts and thus save time and money, reduce energy consumption, improve drivers' psychological health and enhance performance (Jafari et al., 2023).

Another implication is the possibility of controlling energy consumption operations on a city scale, e.g., in public spaces and with street lighting.

However, further research is needed to explore the possible implications of the city's digital twin in various sectors of the city, such as construction, healthcare, and education to provide a richer and more accurate decision-making basis for urban planning.

However, due to the complexity of the city, several challenges still need to be explored and at present, DTs are mainly implemented in industry or in limited areas (Yu et al., 2022). For example, a large city model would impose challenges regarding data management and processing. In addition, the divergent activities and relationships in the city, as opposed to manufacturing facilities, would impose other types of challenges regarding data acquisition and interpretation (Shahat et al., 2021).

3. Limitations in urban digital twin implementation

The energy sector will benefit greatly from the use of DT technology, including better asset performance, higher revenues and reduced negative environmental impacts, but for better performing urban digital twins to develop, digitisation of the city is necessary. In other words, urban DT cannot succeed without a powerful and interconnected IT infrastructure (Jafari et al., 2023). Data collection and acquisition is one of the most important procedures for data-driven energy savings. The quality of the DT implementation in relation to energy savings is only as good as the quality of the available data. Although the implementation of digital twins in the urban environment is considered beneficial for the city, its citizens and its administrators, it is not without drawbacks.

First, a major limitation contributing to the current gap in the scientific research of DTs and their actual application in the urban environment lies in the difficulty of collecting energy data which, being recorded as personal data by energy suppliers, are generally not available (Guida, 2023). A further limitation is the reliability of the data. Due to the lack of available real data, research efforts towards urban DT are largely based on modelled data, e.g., consumption data, age and building type. Such data are based on assumptions, abstractions and are not totally reliable, therefore, at present, urban DT is associated with uncertainty. One of the main challenges of digital twin technology is to ensure the accuracy of the models despite changes in the system. Therefore, to accurately reflect system behaviour, the digital twin needs to be updated as often as possible (Qi et al., 2018). The continuous updating of the model is another related challenge, as real-time data is continuously collected through control and monitoring applications and processed through data analysis techniques. Cloud computing and IoT are driving this change. In addition, data analysis, such as machine learning, enables the creation of algorithms to produce energy prediction models. Future research should also focus on improving these algorithms to make decision-making processes more efficient, accurate and flexible (Bortolini et al., 2022). Furthermore, the development and implementation of digital twins has a higher cost than simpler control and monitoring systems. Finally, due to due to the technical complexity of a digital twin, skilled workers and sophisticated technologies are required to design, install and maintain it. This is a great challenge as servers with high computing capacity are needed to process these large datasets in real time, and yet, computational resources are expensive and limited (Shahat et al., 2021).

Smart City Zurich – The Digital Twin of the city of Zurich for urban planning

In the case of Zurich, the construction of the Urban Digital Twin, started in 2019, is primarily aimed at improving the level of sustainability of the city, becoming a tool to address a series of urban challenges due to the expected increase in the number of inhabitants in the coming years, the resulting employment, urban densification and competition in land uses. The DT of the city of Zurich enriches a previous 3D model of the city (realized in 2011) resulting in a substantial increase of the 3D spatial data inventory and adds the life cycle management of individual components as well as the entire data inventory to the modelling and data description. In the construction and real estate sector, new construction and maintenance processes are digitally mapped using 3D spatial data and a model as a digital replica showing the structure and its behavior with interactive connections conveying real-time information on its structural and operational status. Electricity, water supply, public transport and waste disposal services have also been digitized. This was possible because since 2012, the city of Zurich has been making public administration data available openly and free of charge. The main 3D spatial data in the DT in Zurich are related to public space, the cadastre of utilities (energy, waste, water, transport), façade modelling, bridges, high-voltage lines and historical elements of the city. In particular, the DT formed the basis for the development of the municipal land-use plan, as the visualisation of the 3D model and the linking of these with various urban planning and building parameters enabled town planners to make predictions on the most appropriate design choices based on the data (Schrotter & Hürzeler, 2020).

Furthermore, it was possible to integrate the climate issue into urban planning, with the aim of maintaining functional urban areas that constitute characteristic cold-air corridors for which the orientation, extension and height differentiation of buildings are decisive for good ventilation of the city. The analysis showed that, depending on spatial characteristics (length, width, height, location), new buildings have a demonstrable influence on climatic factors such as temperature, wind and cold air flow.

References

Agostinelli, S., Cumo, F., Nezhad, M. M., Orsini, G. & Piras, G. (2022). Renewable Energy System Controlled by Open-Source Tools and Digital Twin Model: Zero Energy Port Area in Italy. *Energies*, *15* (5), 1817. https://doi.org/10.3390/en15051817

Borowski, P. F. (2021). Digitization, digital twins, blockchain, and industry 4.0 as elements of management process in enterprises in the energy sector. *Energies, 14* (7), 1885. https://doi.org/10.3390/en14071885

Bortolini, R., Rodrigues, R., Alavi, H., Vecchia, L. F. D. & Forcada, N. (2022). Digital twins' applications for building energy efficiency: A review. *Energies*, *15* (19), 7002. https://doi.org/10.3390/en15197002

Caprari, G., Castelli, G., Montuori, M., Camardelli, M. & Malvezzi, R. (2022). Digital twin for urban planning in the green deal era: A state of the art and future perspectives. *Sustainability*, *14* (10), 6263. https://doi.org/10.3390/su14106263

Carpentieri, G. & Favo, F. (2017). The End-use Electric Energy Consumption in Urban Areas: A GIS-based methodology. An application in the city of Naples. *TeMA - Journal of Land Use, Mobility and Environment, 10* (2), 139-156. https://doi.org/10.6092/1970-9870/5173

Ferré-Bigorra, J., Casals, M. & Gangolells, M. (2022). The adoption of urban digital twins. *Cities, 131,* 103905. https://doi.org/10.1016/j.cities.2022.103905

Fistola, R. & La Rocca, R. A. (2014). New Technologies for Sustainable Energy in the Smart City: the WET Theory. *TeMA - Journal of Land Use, Mobility and Environment*, *7* (1), 29-42. https://doi.org/10.6092/1970-9870/2267

Francisco, A., Mohammadi, N. & Taylor, J. E. (2020). Smart city digital twin–enabled energy management: Toward real-time urban building energy benchmarking. *Journal of Management in Engineering*, *36* (2), 04019045. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000741

Gargiulo, C. & Papa, R. (2021). Chaos and chaos: the city as a complex phenomenon. *TeMA - Journal of Land Use, Mobility and Environment*, *14* (2), 261-270. https://doi.org/10.6093/1970-9870/8273

Ghenai, C., Husein, L. A., Al Nahlawi, M., Hamid, A. K. & Bettayeb, M. (2022). Recent trends of digital twin technologies in the energy sector: A comprehensive review. *Sustainable Energy Technologies and Assessments*, 54, 102837. https://doi.org/10.1016/j.seta.2022.102837

Grieves, M. (2014). Digital twin: manufacturing excellence through virtual factory replication. *White paper*, 1(2014), 1-7.

Guida, C. (2022). Energy saving and efficiency in urban environments: integration strategies and best practices. *TeMA- Journal of Land Use, Mobility and Environment, 15* (3), 517-531. https://doi.org/10.6093/1970-9870/9549

Guida, N. (2023). Energy transition: pinning down the gaps between theory and practice. *TeMA - Journal of Land Use, Mobility and Environment, 16 (*2), 469-472. https://doi.org/10.6093/1970-9870/10041

Hämäläinen, M. (2020). Smart city development with digital twin technology. *In 33rd Bled eConference-Enabling Technology for a Sustainable Society*: June 28–29, 2020, Online Conference Proceedings. University of Maribor. https://doi.org/10.18690/978-961-286-362-3.20

Jafari, M., Kavousi-Fard, A., Chen, T. & Karimi, M. (2023). A review on digital twin technology in smart grid, transportation system and smart city: Challenges and future. *IEEE Access*. https://doi.org/10.1109/ACCESS.2023.3241588

Khajavi, S. H., Motlagh, N. H., Jaribion, A., Werner, L. C. & Holmström, J. (2019). Digital twin: vision, benefits, boundaries, and creation for buildings. *IEEE access*, *7,* 147406-147419. https://doi.org/10.1109/ACCESS.2019.2946515

La Greca, P. (2023). Il divenire della disciplina urbanistica: il contributo di Paolo La Greca. *TeMA - Journal of Land Use, Mobility and Environment,* (1), 107-117. https://doi.org/10.6093/1970-9870/9748

Las Casas, G. (2023). Il divenire della disciplina urbanistica: il contributo di Giuseppe Las Casas. *TeMA - Journal of Land Use, Mobility and Environment,* (1), 119-123. https://doi.org/10.6093/1970-9870/9749

Mazzeo, G. (2013). City and Energy Infrastructures between Economic Processes and Urban Planning. *TeMA - Journal of Land Use, Mobility and Environment*, *6* (3), 311-324. https://doi.org/10.6092/1970-9870/1929

Mohammadi, N. & Taylor, J. E. (2017). Urban energy flux: Spatiotemporal fluctuations of building energy consumption and human mobility-driven prediction. *Applied energy*, 195, 810-818. https://doi.org/10.1016/j.apenergy.2017.03.044

Papa R., Gargiulo C. & Zucaro F. (2014). Urban Systems and Energy Consumptions: A Critical Approach. *TeMA - Journal of Land Use, Mobility and Environment.* https://doi.org/10.6092/1970-9870/2552https://doi.org/10.1016/j.rser.2022.112479

Papa, R., Gargiulo, C., Zucaro, F. (2016). Towards the Definition of the Urban Saving Energy Model (UrbanSEM). In: Papa, R., Fistola, R. (eds) *Smart Energy in the Smart City. Green Energy and Technology*. Springer, Cham. https://doi.org/10.1007/978-3-319-31157-9_9

Qi, Q., Tao, F., Zuo, Y. & Zhao, D. (2018). Digital twin service towards smart manufacturing. *Procedia Cirp, 72*, 237-242. https://doi.org/10.1016/j.procir.2018.03.103

Schrotter, G. & Hürzeler, C. (2020). The digital twin of the city of Zurich for urban planning. PFG–Journal of Photogrammetry, *Remote Sensing and Geoinformation Science, 88* (1), 99-112. https://doi.org/10.1007/s41064-020-00092-2

Shahat, E., Hyun, C. T. & Yeom, C. (2021). City digital twin potentials: A review and research agenda. *Sustainability, 13 (6), 3386. https://doi.org/10.3390/su13063386*

Yu, W., Patros, P., Young, B., Klinac, E. & Walmsley, T. G. (2022). Energy digital twin technology for industrial energy management: Classification, challenges and future. *Renewable and Sustainable Energy Reviews*, *161,* 112407. https://doi.org/10.1016/j.rser.2022.112407

Zhang, X., Shen, J., Saini, P. K., Lovati, M., Han, M., Huang, P. & Huang, Z. (2021). Digital twin for accelerating sustainability in positive energy district: A review of simulation tools and applications. *Frontiers in Sustainable Cities, 3,* 663269. https://doi.org/10.3389/frsc.2021.663269

Author's profile

Valerio Martinelli

He is an engineer, with a master's degree in Building Engineering-Architecture at the Department of Civil, Architectural and Environmental Engineering of the University of Naples Federico II. He is currently a first year Ph.D. student in Civil Systems Engineering at the same department. His research activity focuses on the study of Renewable Energy Communities.