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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.

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The cover image shows the building of Kharkiv National University of Civil Engineering and Architecture, destroyed as a result of a missile and bomb attack. March 2022 (Source: STRINGER/Reuters/Forum. https://www.pism.pl/publications/sweden-on-the-russian-aggression-against-ukraine)

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Contents

REVIEW NOTES

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The city challenges and the new frontiers of urban planning

Digital twins as tools of urban resilience: research and practices

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Abstract
The exponential growth of the world population must deal with the limitedness of the planet and its resources. The challenge is even more difficult as by 2050 two-thirds of the world's population will live in cities, urban ecosystems are becoming larger and more complex, and many other global challenges (climate, energy, health, ecological) require innovative answers in a very short time, with an integrated approach and in a medium-long and wide-ranging vision.
Within this complex framework: a multiple transition (digital, ecological, energy) is undelayable; the way of planning, designing, and managing cities is going through a phase of deep change; a new culture is emerging and spreading to improve informed and data-driven decision making.
Therefore, the article addresses the potential of new technologies, yet to be adequately explored in the fields of planning and design at different territorial scales, for better governance, sustainable development and quality habitats. It consists of three main sections, consistent with the methodology and the main steps of the ongoing research to which it refers. The first section focused on global challenges and on the potential of new technologies to make cities and territories more resilient and sustainable, in line with SDG 11 of UN 2030 Agenda. The second section addresses the theoretical aspects and implementation regarding the concept of urban resilience and the role of new digital technologies with reference to significant case studies in the EU panorama. The third and final section contains some concluding remarks on the limits and prospects of research for urban planning, territorial governance and management.

Keywords
Digital twin; Technological digital innovations for urban planning; Urban resilience to climate change.

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1. Introduction. Cultural background, critical framework of the scientific debate, methodological approach

Cities represent an unmissable opportunity for leveraging innovation and creative planning to combat global challenges and make meaningful improvements in the lives of billions of people, in an increasingly populated and interconnected world, as widely recognized, stated, and reaffirmed internationally (The Rockefeller Foundation, 2019; UN-Habitat, 2020 and 2022).

Given that the exponential growth of the world population has to deal with the limitedness of the planet and its resources, the challenge becomes even more difficult since by 2050 two thirds of the world population will live in cities and urban ecosystems will tend to become bigger and more complex, also due to unexpected and unpredictable (only at first glance) events like the COVID-19 pandemic and the conflict in Ukraine (EEA, 2020; UN-Habitat, 2022; United Nations Department of Economic and Social Affairs, Population Division, 2022). Therefore, the climatic, social, economic and health phenomena that have increasingly affected our cities in recent years require the identification and implementation of mitigations and adaptation actions aimed at improving the resilience of urban systems, both internally and in relation to the wider territorial systems (IPCC, 2022). Better and more effective governance, sustainable development and quality habitats, connected and efficient infrastructures are needed.

The ability to address this unprecedented *polychrysis* requires innovative approaches, more effective tools, and resilience strategies that can improve contemporary cities' capacities to address the multiple and often interconnected challenges to face[1] (Leone et al., 2020; UN-Habitat, 2020 and 2022), in line with SDG 11 of UN 2030 Agenda, "Make cities and human settlements inclusive, safe, resilient and sustainable" and with the other 16 Goals[2]. City sustainability is a multifaceted task entailing non-linear processes and system complexity on different spatial scales and with a long-term view (Pelorosso et al., 2018). In a nutshell, as important political centers, and major engines of innovation, cities stand at the forefront of the challenges, and opportunities of the 21st century, and the global pressures affecting both individuals and whole systems.

Within this framework, the climate, energy, health and ecological challenges make the multiple transitions (ecological, digital, energy) indispensable and the new technologies must be considered as enabling factors and tools capable of increasing resilience, intelligence and sustainability of cities and territories.

Increasingly over the last decade, cities worldwide have built digital infrastructure and embedded digital technologies into urban services and *smart cities* have become the dominant paradigm for innovative urban planning and governance strategies (Barresi & Pultrone, 2013; Campbell, 2012; Caragliu & Del Bo, 2019; Mills et al., 2021) (Fig.1).

Digital technologies such as Digital Twin (DT), artificial intelligence (AI), the Internet of Things (IoT), cloud computing, 5G connectivity, Big Data Analytics, Blockchain, Building Information Modeling (BIM), City Information Modeling (CIM) are all providing municipal authorities a powerful set of tools to make cities smarter, safer, cleaner and more inclusive[3] (Al Furjani et al., 2020; Birks et al., 2020; Charitonidou, 2022; Deng et al., 2021; Jones et al., 2020; Economist Impact, 2022; Elsheikh et al., 2021; Jiang et al., 2022; Lee et al., 2022; Leplat et al., 2022; Major, 2022; Yin & Cai, 2022; Zhao, 2022).

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1 With respect to any crisis advent, A. Leone, P. Balena and R. Pelorosso R. (2020) highlight it is necessary to pay attention to the resilience of the system, so the goal must be the robustness and even the anti-fragility of the socio-ecosystem, not the pursuit of the specific black swan in its different possible forms: from financial perfect storms to pandemics, to the unpredictable effects of climate change.

2 See: https://sdgs.un.org/goals/goal11; Striving for People, Plant and Peace. 2022 JOINT MEDIA PROJECT REPORT (2021). Berlin: The Non-Profit International Press Syndicate.

3 Inter alia, Deng, Zhang & Shen (2021) highlight the following different roles of technologies in DTCs: surveying and mapping technology, for collecting the static data of the buildings in cities; BIM technology, for the asset and infrastructure management of cities; IoT and 5G, for collecting dynamic data and feedback effectively; Blockchain technology, for the trust mechanism of transactions, logistics, and human behaviour; collaborative computing with 5G, for efficient real-time responses; simulation technology, for policy support, planning, and early warning mechanisms.

It is therefore more than ever essential to understand the technological transformations taking place in order to govern and manage them in the best way. About this, *The Digital Disruptions for Sustainability Agenda* (*The D^2S Agenda*), developed by Future Earth's Sustainability in the Digital Age (2020), explores the opportunities and challenges of leveraging the digital age to tackle the climate crisis.

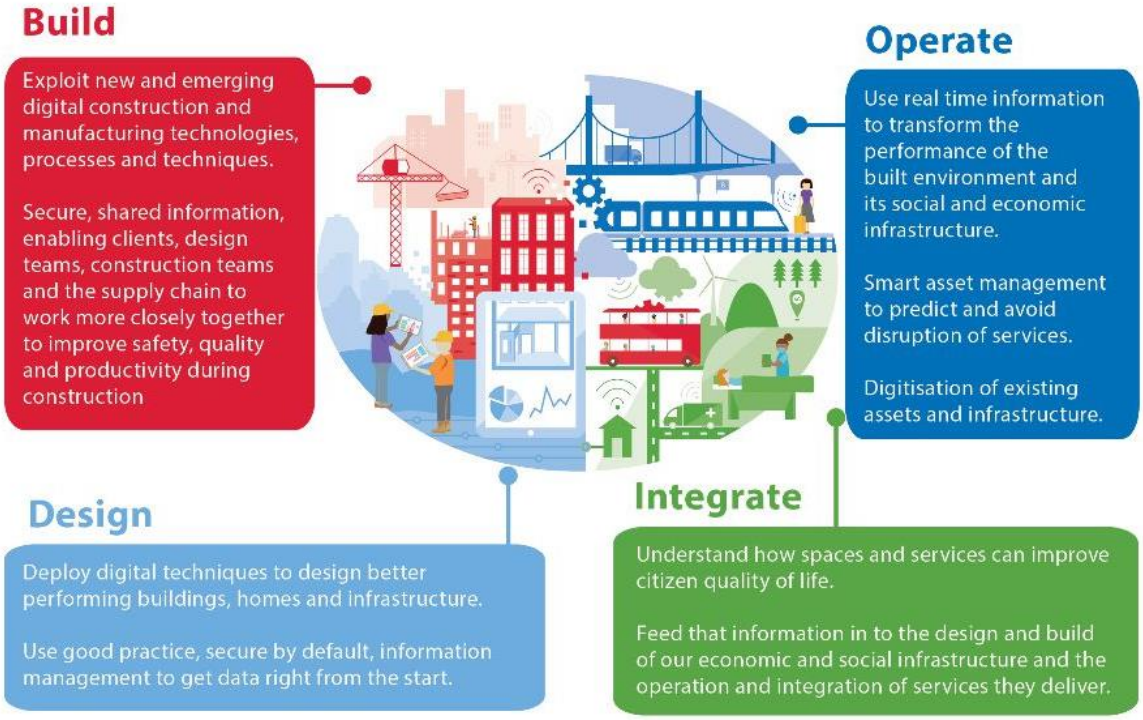

Fig.1 The potentials of digital Technologies for built environment as schematized by the Centre for Digital Built Britain

From analysis of the document, four key messages emerged, as below highlighted by A. Luers et al. (2020): 1) There are tremendous opportunities for leveraging the digital age to drive the transformative systems changes needed to address the climate crisis, but there are also major risks; 2) Tackling climate change and building a just and equitable digital world are one intertwined agenda, because humans are interconnected through and dependent on both the natural and digital worlds and our current trajectory poses global systemic risks that emerge from both worlds; 3) Seizing the opportunities of the digital age to drive transformative systems changes will require transdisciplinary research and innovation and collaborative actions; 4) Success will depend on overcoming the digital divide and developing inclusive strategies that consider differences among social and cultural contexts.

Specifically, in the field of planning and design at different territorial scales, DT and CIM have enormous potential yet to be explored, ranging from modeling, planning, forecasting through digital models made dynamic and interactive by real-time data. Through DT, in particular, the physical and digital worlds merge for interactive experiences, almost real-time information exchanges and better decisions

Taking into account the fact that the way of planning, designing and managing cities and territories is going through a phase of profound change, made even wider because it is linked to the way of understanding knowledge, a renewed cultural approach that enhances informed decision-making processes based on knowledge is indispensable in addition to the aforementioned procedures and tools.

These, in fact, tend to assume an increasingly central role also in urban and territorial planning and design processes as means and tools that, thanks to the convergence between 3D and 4D visualization, modelling of reality, mixed reality and engineering geotechnics allow you to create a complete and immersive view of infrastructural assets, on the surface and in the subsoil.

At the same time, as cities become more digital, a key question concerns the sustainability of the relationship between smart technologies and the need to overcome social problems, such as injustices and inequalities, in the age of the Big Data Revolution (Cavalli, 2023; Giovannini, 2016)[4]. In this regard, if on the one hand the new technologies can become a vital force of social evolution, many scholars highlight the possible sources of injustice seeping through a series of sociotechnical *assemblages* of the smart cities, and wonders whether working towards more just, sustainable, livable and just cities requires that we look beyond the limits of the "intelligence" of the whole (Mackinnon et al., 2022; Mergel et al., 2019; Papa et al., 2015; Peixoto & Steinberg, 2019; Rosol & Blue, 2022). In the light of above, the article has to be interpreted as a first stage of an innovative and recent wider research[5] addressed to explore and highlight the potentials provided by new technologies to have data and flows in real time (Ratti, 2013), and to give sustainable, immediate and effective responses to specific local problems in the coherent and integrated framework of a longer-term strategic planning that takes due account of the possible/different evolutions/developments of the ongoing urban dynamics. The following aspects are considered most relevant: 1) retrieval of information that improves the urban infrastructure; 2) improving collaboration and creating added value for cities and their inhabitants; 3) improvement of mobility and safety in public spaces; 4) involvement of citizens and investors, to whom to communicate, promote and share urban projects in an interactive way to obtain consensus; 5) creation of a resilient infrastructure, capable of predicting, responding and reacting to extreme events; 6) adoption of open data initiatives that allow others to design, develop and deliver services based on reliable information about cities and infrastructures. Furthermore, the DTs can also represent the strategic element to enhance the value of territorial assets (natural and anthropogenic) through the new projects and transitions underway favored by the National Recovery and Resilience Plans (NRRP) at EU level (thanks to *Next Generation EU* funding[6]), increasing the effectiveness of their governance, allowing processes of simulation and control of the complexity of socio-economic, environmental and landscape phenomena, positively feeding collective intelligence.
Anyhow, although the concepts of *resilience* and *smartness* applied to the cities, according to current scientific literature, seem to play a leading role in enhancing cities' capacities to cope with climate change (Papa et al., 2015; De Gregorio Hurtado et al., 2015; Galderisi & Ferrara 2012), as a matter of fact, urban innovation goes beyond the technological, encompassing essential social and institutional aspects, and requires a context specific, place-based and people-centred localized approach.

2. The new digital technologies (R)Evolution[7] for strenghtening urban resilience

2.1 The necessary *Resilience Thinking*

According to *The Global Risk Report 2022* (WEF, 2022), economic, geopolitical, public health and societal fractures, increased after Pandemics, risk leading to divergent and delayed approaches to the numerous critical challenges facing people and planet: accelerating the green transition in response to climate change, coordinating against heightened digital vulnerabilities, managing mobility and migration and safeguarding

4 As for Big Data, in August 2014 UN Secretary-General Ban Ki-moon asked an Independent Expert Advisory Group to make concrete recommendations on bringing about a data revolution in sustainable development. http://www.undatarevolution.org. L. Cavalli (2023) points out that, although none of the Sustainable Development Goals of the UN 2030 Agenda is directly dedicated to digital and technology, the world of politics and above all that of research are now unanimous in recognizing their role as a lever, an enabling factor for a faster achievement of sustainable development as, for example, also within the Italian National Recovery and Resilience Plan.

5 The article proposes a reflection on ongoing research by the Author concerning "Global Challenges, Technological Digital Innovations and the New Frontiers of Urban Planning Research", here declined more specifically on "urban resilience" in the face of the climate challenge.

6 See https://europa.eu/next-generation-eu/index_en

7 The term is taken from Khaled Diab (2022). The next (r)evolution: AI v human intelligence. Should we worry about chatbots becoming 'sentient'?. 18 Jun 2022, https://www.aljazeera.com/opinions/2022/6/18/artificial-intelligence-v-human-intelligence

space, defined as the next global commons. For governments, balancing costs, regulating for resilience, and adjusting data-sharing arrangements to ensure sharper crisis management are key to galvanizing stronger interaction between public and private sectors. Communities can help local governments to join up with national efforts, improve communication and support grassroots resilience efforts (WEF, 2022).

As highlighted in the first paragraph, in a world more densely populated and more interconnected than ever before, global challenges – such as extreme weather, refugee crises, disease pandemics, cyberattacks, war conflicts, problems of food and energy supply – become much more complex and new models of governance are required to mitigate risk and respond to challenges. *Business-as-usual* models will not generate the fundamental strength and flexibility, essential to thrive in the face of the aforementioned shocks and stresses. As a matter of fact, the harm caused by acute shocks is exacerbated by chronic stresses and pressures, as recurrent flooding, high unemployment, social inequalities, and overtaxed or inefficient public transportation systems, that affect especially the poor and the most vulnerable social groups. It is difficult for cities to tackle just one challenge at a time, considering the interdependent combinations of acute shocks and chronic stresses (The Rockefeller Foundation, 2019).

As for the EU context, around 75% of Europe's population live in urban areas and estimates predict that European urban population will rise to 80% in 2050. Furthermore, the European urban landscape is heterogenous and characterized by a diversity of mostly small and medium cities (EEA, 2021). The main challenge for the EU is to satisfy citizens' demand for cities while making them resilient to climate change, circular from the point of view of resource management, improving the quality of life that these environments offer and developing a green economy that allow an innovative economic development with limited environmental impact. This translates into the achievement of urban sustainability, conceived as efficient and intelligently planned cities in all their aspects: economy, personal services, mobility, water management, waste management, building management and regeneration, resilient to climate change. Cities can become the main driving forces for a green and just recovery. Infrastructure[8] investments, which can stimulate urban economic activity, above all, after the easing of pandemic measures, can be an opportunity to align the recovery with climate, environmental and social equity programs, but will need to be accompanied by better integration of policy sectors and by actions to maximize benefits, overcoming the still prevailing sectoral and silo approach (EEA, 2021). Adapting European cities and towns to inevitable climate change is crucial for the overall resilience of European society because of the population concentration — including vulnerable groups — assets and economic activities in urban areas (EEA, 2020).

In this context, the concept of *resilience* – born from the exigencies of the three converging trends of climate change, urbanization, and globalization – is defined as "the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation" (IPCC, 2022) and *urban resilience* as "the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what chronic stresses and acute shocks they experience".

Building urban resilience is a multisectoral, multidimensional, multi-stakeholder process that requires a clear change of trajectory from previous paths, a key principle to re-frame urban policies, paving the way to cross-

[8] As for the concept of "infrastructure", reference is made to IPCC Sixth Assessment Report (2022: 940) as specified below. Infrastructure includes the social systems, ecological systems and grey/ physical systems that underpin safe, satisfying and productive life in the city and beyond (Grimm et al., 2016). Social infrastructure includes housing, health, education, livelihoods and social safety nets, cultural heritage/institutions, disaster risk management and security and urban planning. Ecological infrastructure includes nature-based services: temperature regulation, flood protection and urban agriculture. Grey, or physical infrastructure, includes energy, transport, water and sanitation, communications (digital), built form and solid waste management. Framing infrastructure in this way enables an assessment of adaptation that is not constrained to the administrative boundaries of urban settlements, but also includes the flows of material, people and money between urban, peri-urban and more rural places, and can include adaptation actions deployed by government, individuals and the private sector.

sectoral urban strategies capable of better coping with contemporary challenges (Pultrone, 2018a and 2018b; Galderisi et al., 2020; UN-Habitat, 2022). Compound, cascading and transboundary impacts for humans and ecosystems result from the complex interaction of multiple climate hazards, exposures and vulnerabilities (IPCC, 2022: 82-83). So, the identification of urban fragilities could represent a fundamental first step in order to develop and to propose methodological and operative innovations for the planning and the management of the urban and territorial transformations as highlighted in recent European adaptation plans that provide for environmental actions aimed at ensuring sustainable use of the soil and also helping to contain the effects of climate change (Zucaro & Morosini, 2018).

Equally crucial, the next step of identifying approaches, methods, tools, and significant case studies on this highly innovative research topic, especially in the field of urban planning, and deserving of further developments and future insights.

2.2 The smart cities transformA(c)tion: continuous technological innovation as key opportunity for *Resilience Building*

According to the latest *The World City Report* (henceforth WCR, 2022), over the past two years, two important areas of socio-technical development have continued to accelerate and have taken an even more important phase in planning the urban future with attention to increasing urban resilience: the first area is the growing urgency for unprecedented, aggressive decarbonization; the second one relates to unparalleled advancements in the digital world (UN-Habitat, 2022).

Digitalization encompasses various smart technological innovations that enable ubiquitous computing, big data collection from widespread deployment of sensors and devices, large-scale data analytics, machine learning and autonomous decision-making. With reference to urban systems, these connected and digital technologies find expression in the *smart city*, which is a major paradigm of urban policy and have fundamental implications for the way in which cities are governed and planned, as complex systems involving a symbiotic linkage among people, institutions, technology, organizations, building environment, and physical infrastructure (Angelodu, 2017; Barresi & Pultrone, 2013; Caprari et al., 2022; Caragliu & Del Bo, 2019; Pultrone, 2014; Söderström, 2016; Zheng et al., 2020)[9].

In any case, the guiding question should be how to achieve inclusive urban development in the interest of citizens' wellbeing and environmental protection.

The same WCR (UN-Habitat, 2022) explores the role of cities as places of innovation, highlighting and deepening the following aspects: 1) the necessary interplay between technological, social and organizational innovation, and the four challenges for the smart city innovation; 2) the emergent frontier technologies centring upon the convergence of green and smart technology, and their adaptation to adapted to local contexts; 3) how combination of digitalization and automation forces are transforming the world and how will likely affect cities; 4) how cities can face both the digital divide and environmental divide arising from technological innovations, and related risk of creating new or exacerbating existing urban inequalities; 5) the opportunities of connected and digital technologies to enhance participatory governance through more open e-government, civic engagement and community technology making; 6) the benefits of responsible innovation as a tool for assessing both opportunities and risks of technology; 7) finally, seven policy lessons for inclusive sociotechnical innovations for urban futures. As known, the *smart city* has become a globally major policy

[9] For further information on the smart cities challenges see also: the articles published in the six issues of TeMA - Journal of Land Use, Mobility and Environment, vol. 6 (2013) and 7 (2014). http://www.serena.unina.it/index.php/tema/issue/archive; the specific section Smart cities Cities using technological solutions to improve the management and efficiency of the urban environment, on the website of European Commission, https://ec.europa.eu/info/es-regionu-ir-miestu-pletra/temos/miestai-ir-miestu-pletra/miestuiniciatyvos/smart-cities_en

paradigm for technology-driven urban innovation and development from the late 2000s onwards alongside other key urban conceptual paradigms, such as the *compact city*, *resilient city*, the most widespread *sustainable city* or even, more recently, the *circular city*, as documented by the extensive scientific production and experiments in many cities around the world.

However, many smart city initiatives have faced significant criticism, due to the risk of an overly technological approach to innovation without regard to different urban and social contexts. Specifically, the following four main challenges have been identified: 1) respect city-specific contexts; 2) adopt a people-centred perspective, to avoid the risk of an overly technocratic approach; 3) provincialize smart cities, developing more grounded approaches also in the global peripheries, in contrast to typically large-scale, capital-intensive interventions in the Global North; 4) ensure environmental sustainability, since the environmental costs of smart city projects are often overlooked, while there is growing evidence that technological Innovations can be carbon-intensive and harmful to the environment, a more explicit alignment of the smart city with the goals of city sustainability (UN-Habitat, 2022).

The application of frontier technologies, particularly related to green and smart technology sectors, has the potential to reconfigure urban development in radical and disruptive ways, not only in large global cities, but also in lower-tier cities and even in settlements informal.

This is because frontier technologies can be designed to be relatively low-cost and suitable for local adaptation. In this direction Digital Twins (DTs) can be considered an innovative tool to develop new patterns of urban governance, planning and design for sustainability and resilience, in order to deal with *polychrysis* and implement the right multiple transition, to which reference was made in the first paragraph[10].

2.3 Digital twins and new patterns of urban governance between theoretical approach, research activities and local implementation

City governments and other urban stakeholders have an active role to play in deciding how innovation and technology are adapted in ways that suite to specific urban contexts, foster sustainable development and enhance resilience.

According to the *Digital City Index* 2022 (Economist Impact, 2022), above all the involvement of citizens in the design of smart cities determines the projects' success. The last decade has marked great strides in digital infrastructure, providing municipalities with a range of features that are extremely important for developing safer, cleaner, smarter and more inclusive cities.

Some cities are making innovative use of data such as social media posts to track the progression and impact of floods and earthquakes, while micro sensors are pinpointing urban *heat islands* where temperatures are higher due to the presence of heat-trapping materials like glass and concrete.

Among the examples of frontier technologies in urban contexts[11], here it is argued that Digital Twins (DTs) are of particular interest for Urban Planning, in terms of the methodological approach and possible

[10] The concept of a virtual, digital equivalent to a physical product or the Digital Twin was introduced at first in 2003 at the University of Michigan Executive Course on Product Lifecycle Management (PLM), as specified in the Digital Twin White Paper by Michael W. Grieves titled Digital Twin: Manufacturing Excellence through Virtual Factory Replication (2014). Furthermore, to be precise, one of the first examples of a working DT was realized in 1996 during the construction of the Heathrow Express facilities at Heathrow Airport's Terminal 1. Consultant Mott MacDonald and BIM pioneer Jonathan Ingram connected the motion sensors in the cofferdam and wells to the digital model object to visualize the motions in the model. A digital grouting object was made to monitor the effects of pumping mortar into the ground to stabilize ground movements (Bolton et alii, 2018).

[11] Other examples of frontier technologies in urban contexts, in addition to Digital Twins (DT), as reported in WCR 2022 (UN-Habitat, 2022: 281):
- Artificial intelligence, or machine learning, increasingly deployed by municipal governments in the form of virtual agents like chatbots for issuing parking permits and in road traffic management;
- Blockchain, or distributed ledger technology, for secure, decentralized exchange of data among network partners. Used by transport operators to deliver shared mobility services, or by city governments to issue residents with digital identifiers for accessing local services;

implementations, since they are virtual representations of urban objects at various scales (building, neighborhood, district, etc.) used as planning tools, support diagnostic and prognostic analysis and model-making, dependent on completeness and accuracy of underlying data known as digital thread (Lv et al., 2022). Basically, DTs, as means to link digital models and simulations with real-world data, create new possibilities for improved creativity, competitive advantage and human-centred design. Moreover, DTs can help deliver on the grand challenges facing society, including achieving the United Nations' 17 Sustainable Development Goals and addressing rapid urbanization, population growth, and escalating infrastructure costs.

Definitely, they are becoming a critical tool for urban development in cities around the world, offering the following four new capabilities: 1) Planning; 2) Research; Virtual experimentation; 4) Virtual testing[12].

The undoubted importance of the wide innovative reach of the DTs is also highlighted in the *Action Plan for a Sustainable Planet in the Digital Age* (CODES, 2022), which places the following innovation at the top of the list: "Build Planetary Digital Twin: Prioritize innovations to measure, monitor and model the health of the planet's biosphere and interactions with economic and social systems". A key contributor to increasing resilience lies in the fact that DTs combined with AI can conduct automated risk and threat monitoring to key protected areas (natural or cultural areas as part of protection frameworks), global ecosystem services or endangered species[13].

The Report *Digital Twin. Towards a Meaningful Framework* (ARUP, 2019) examines the current state of DTs in the built environment and their potential value within five key markets – cities, energy, property, transport and water – providing an interesting review of the opportunities, challenges and exemplary case studies.

The aforementioned document notices that urban planners have long used data on places and people in their work, and that a traditional source of data for development proposals is census data, which is rather static, with respect to the periodicity of the update. Better data can, however, allow you to make better planning, design and management decisions, even considering the great potential in the volumes and speed with which the data itself is becoming available.

This is therefore an innovative topic in the field of Urban Planning worthy of further developments and insights since little has yet been done to explore the potential of using this data and new technology for planning and design processes. This is despite the 21st century has witnessed unprecedented technological advances and an explosion of available data on the built environment and the people who inhabit it, and city authorities are beginning to realize the potential to improve city management, to making it smarter. Intelligent use of data could help design places that effortlessly respond to public needs or reduce and reuse excess energy, better designed places and better design processes. Advances in Artificial Intelligence (AI) have enabled better understanding and analysis of physical assets, producing a wide and rich dataset of previously inaccessible information, and advanced DTs can be found more widely in the real estate and transportation markets. AI can also help to tackle broader policy goals, including sustainability and inclusion, as in the case of AI and

- 3D printing, allows for offsite fabrication of building components, thus potentially lowering construction costs of new buildings;
- Electric vehicle (EV) technology, a key technological challenge is the roll-out of electric charging networks. To date, 15 countries and 31 cities are committed to phasing out the sale of combustion-engine vehicles;
- Internet of Things (IoT), broad range of applications by embedding a multitude of sensors, smart meters and computer processors in urban infrastructure and objects, and connecting these to digital management systems via cloud computing (remote storage and analysis system over the internet);
- Renewable energy technologies, deployed for clean energy production, using various renewable energy sources (solar, wind, hydro, biomass, geothermal);
- Robotics, multiple urban applications, including drones for last-mile delivery and connected autonomous vehicles (CAVs). Dependent on 5G/6G technology to deliver high-speed broadband, ultra-reliable connectivity (for low latency) and ability to connect to a multitude of devices simultaneously.

12 https://www.asme.org/topics-resources/content/infographic-urban-digital-twins-reflect-smart-cities

13 For further information on the main research questions, innovative needs and critical issues concerning "Build Planetary Digital Twin" please refer to the cited Action Plan.

machine learning used to map the accessibility of sidewalks and pavements for people with disabilities including gauging width, gradient and surface composition[14].

Staying at the city scale, the *Smart City Digital Twin* (SCDT) paradigm has been introduced to increase the transparency of human-infrastructure technology interactions through the exchange of spatiotemporal information.

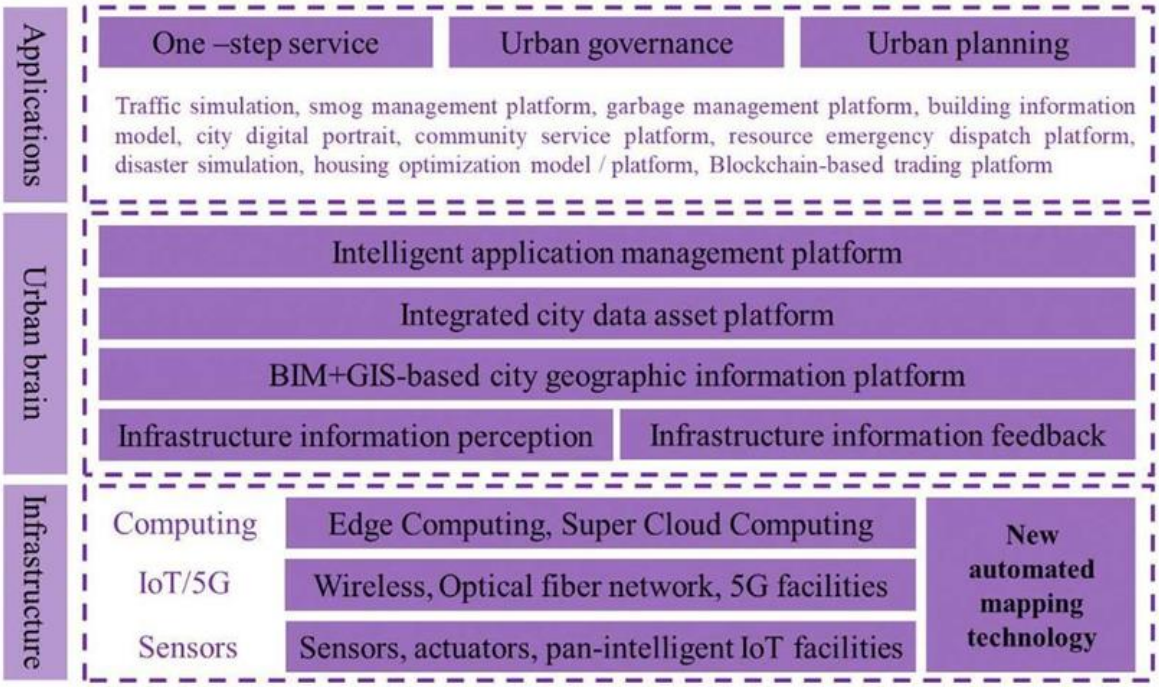

Fig.2 The composition of digital twin cities structure according to Deng et al.,2021

DTs may at first appear to be an exact replica, however, they are not necessarily realistic representations, but are rather relevant abstractions of the physical asset.

Ultimately, fit-for-purpose DTs need to be developed, and the level of fidelity will vary depending on the primary use cases. Of crucial importance is the connection between the physical and the digital system, which requires data exchange, as well as the inclusion of human beings in the role of designers or users. DTs must make better and better predictions about our physical infrastructure and, in their most advanced instances, they will continually increase in intelligence in an ongoing dynamic process.

Some issues are essential in the scientific debate on DTs, such as the steps required for planning, designing and implementing DTs in cities; how these can empower cities, even those of medium and small size, and increase urban resilience; the challenges and potential for their implementation.

DTs, virtual 3D replicas of a given system, place, or thing, allow cities and property owners to test changes before they implement them in the real world (Salomon, 2020).

Many North American or Asian cities, such as the well-known case studies in Boston, New York, Los Angeles, Orlando or Singapore (Fig.3), are increasingly using this technology to study the effects of development, traffic, climate change, and a host of other challenges that cities must face, so to increase also the resilience to these critical issues[15].

[14] See *Smart Cities for All. AI for Inclusive Urban Sidewalks* Project. https://www.smartcities4all.org/ai-for-inclusive-sidewalks/

[15] See also: https://www.esri.com/about/newsroom/blog/3d-gis-boston-digital-twin/; https://sig-digitaltwin-smartgeohub.hub.arcgis.com/; https://www.webuildvalue.com/it/megat rend/digital-twins-citta-usa.html; https://www.nrf.gov.sg/programmes/virtual-singapore; https://www.3ds.com/insights/customer-stories/virtual-singapore; https://www.smartnation.gov.sg/.

Fig.3 Representation of the digital space in Singapore

Local Digital Twins in the EU panorama

Focusing only on the European context, according to European Commission, Local Digital Twins (LDTs) will enable the next phase of smart and sustainable cities and communities. During the European Week of Regions and Cities 2021, the session *Local Digital Twins - Forging the cities of tomorrow* [16] explored the main challenges and potential are for the implementation of LDTs, defined as the virtual representation of a city's physical assets, processes and systems, using data, data analytics and machine learning to help simulation models that can be updated and modified (in real time) as their physical equivalents. They vary in terms of maturity and capacity, but this can actually allow even smaller cities to test their potential. When planning to create a LDT, cities need to consider a number of important aspects, the main challenges the city wishes to address, the scale and scope of the digital twin, its governance and expected functionalities. When designing the DT, it is important to consider the data base (availability, quality and interoperability) and the technical base (IoT, cloud computing, big data, AI, 5G). The Commission has indicated future funding for *an EU Local Digital Twin toolbox*, consisting of open standard solutions, reference architecture and reusable tools, through the DIGITAL program[17].

DUET Project: to break silos in urban management

In the case of European innovation project DUET[18], powerful analytics embedded within the digital twins integrate data silos and model the expected impacts of potential decisions across city systems, such as the

16 The session – organised in collaboration with DG CONNECT Technologies for smart communities, the LEAD and DUET H2020 projects working on Local Digital Twins, the Union of Municipalities of Turkey as well as ENoLL – took place on the 13th October, https://digital-strategy.ec.europa.eu/en/library/local-digital-twins-forging-cities-tomorrow

17 The Digital Europe Programme – the new EU funding programme focused on bringing digital technology to businesses, citizens and public administrations – provides strategic funding to answer these challenges, supporting projects in five key capacity areas: in supercomputing, artificial intelligence, cybersecurity, advanced digital skills, and ensuring a wide use of digital technologies across the economy and society, including through Digital Innovation Hubs. The Programme complements the funding available through other EU programmes, such as the Horizon Europe programme for research and innovation and the Connecting Europe Facility for digital infrastructure, the Recovery and Resilience Facility and the Structural funds. It is a part of the current long-term EU budget, the Multiannual Financial Framework 2021-2027. https://digital-strategy.ec.europa.eu/en/activities/digital-programme

18 Developed and tested in cities and Regions at different points in their digital transformation journeys – Flanders Region, Belgium, the City of Athens, Greece and City of Pilsen, Czech Republic – DUET has the aim to create the concept of Policy-Ready-Data-as-a-Service and ensure all cities across Europe will be able to create their own their

knock-on effects of road closures, new housing estates, and location of transport hubs, on roads, public transport, air quality and health. The evidence-based simulations support both city managers and policy makers in working together around common scenarios to make better, cross-domain, operational decisions and longer-term policy choices whilst enhancing transparency, citizen involvement and resource optimization. A pilot project by the City of Pilsen, Czech Republic, is using its 3D digital twin for urban planning to model and assess the predicted impact of new buildings on the local area. Improving citizen engagement in public decision making is the focus of the final pilot in the city of Athens, Greece[19] (Ruston McAleer et al., 2021).

URBANAGE Project to address extreme heat

Concerning the *resilience to extreme heat*, as part of the EU URBANAGE project[20], URBANAGE Digital Twin is an extensible platform that allows you to model the city and its processes through a virtual replica. The implementation of the DT involves the development of components to facilitate data modeling and mapping, geospatial analysis and data retrieval through web services (API and advanced visualization services). The modeling of the elements of the city is carried out through the City Information Model (CIM) which represents the four layers that allow to connect the different elements/levels that define the city and its processes: citizen, urban planning, both physical and technical infrastructure. The project is focused on improving, through smart city data, the life quality of senior citizens, the most vulnerable to the harmful effects of extreme heat during the summertime. In fact, one of the URBANAGE challenges, related to the aim of detecting comfortable, shadow rich places inside the city. In this case, the main challenge is to customise this information and make it relevant and easily understandable for the senior citizens community. Regarding the operating modes being tested in the city of Ghent (Belgium), based on soil data and the spread of trees and buildings, the impact of the shadow can be perfectly simulated at different time intervals during the day and for each day of the year using the specially designed map viewer. In this way, senior citizens of the city of Ghent can see where to find refreshing and shaded areas within the city on extremely hot summer days.

LISBON and the challenge of flood resilience

As for the challenge of climate change that is accelerating extreme weather events around the world, especially in coastal and lowland areas, the Lisbon case study is particularly significant[21]. As a matter of fact, in Portugal's capital, rapid urbanization has combined with climate-related problems such as rising sea levels and frequent and extreme rainfall, leading to increased flood risks and soil impermeability in the region. To improve the *city's flood resilience* with data-driven planning, development and operation, the city government decided to create a DT for urban flood simulation. Flood resilience models using DT help optimize the performance of existing drainage infrastructure resources and take preventative measures for superior flood resilience planning. The development of a flood resilience model involves the integration of urban-scale reality modeling, 3D mapping and flood modeling, which, when combined on a GIS platform, can be used for visualization, simulation and analyses. DT solutions help the city comprehensively model alternative scenarios to develop a comprehensive and foolproof master plan for multiple payback periods. Flood resilience models therefore allow you to better respond to extreme weather conditions. In Lisbon, the what-if scenario generates from the flood resilience models on the DT models is estimated to prevent 20 floods in the next 100 and save over EUR 100 million in damaged infrastructure and loss of livelihoods. The authorities also used the flood resilience model to define the best trajectory and size of the two tunnels to be built using the different simulations. The various simulations allowed the authorities to assess flood risks for the condition of existing drainage infrastructures

own Digital Twins that address ethical considerations around data use whilst also complying with Europe's stringent privacy and security regulations. https://cordis.europa.eu/project/id/870697/it

19 https://citytwin.eu/

20 https://www.urbanage.eu/

21 In general, the city of Lisbon is particularly attentive and active with regard to resilience strategies, see https://www.lisboaenova.org/images/stories/PontodeEncontro/2018/CML_PENCONTRO17ABRIL18.pdf

and also to assess and mitigation and resilience strategies for the new infrastructures. In addition, the city is now able to efficiently perform predictive analyzes of city supply, wastewater, stormwater and other water systems to predict flood risks and take necessary proactive actions and preventive measures before arrival of any wave of flood[22] (Fig.4).

Fig.4 The Digital Twin of Lisbon. Flood simulation in downtown: two different scenarios

ZURICH: the DT as an opportunity for desirable future urban scenarios

Also, Zurich, like many other European cities, will cope with a series of challenges in the coming years, as the increase in population and jobs will lead to densification and competing land uses. City administration faces increasingly complex tasks, while tools and methods are often based on traditional and static approaches while engaging a limited number of citizens and stakeholders in relevant decisions. The digital transformation of more and more parts of the planning process becomes indispensable and this is achieved through the creation of the DT of the city. Through the visualization and analysis of digital prototypes and the demonstration of interactions with the built environment, scenarios can be developed digitally and discussed in decision-making bodies. Urban climate questions can be simulated with the help of the digital twin and the results can be linked to existing 3D spatial data. This spatial and digital model of Zurich integrates the existing spatial data and metadata infrastructure (compliant with the European INSPIRE Directive and the GeoCat 2019 catalog) with 3D spatial data. Moreover, for the development of the city Master Plan (Municipal Structure Plan for Settlements, Landscape, Public Buildings and Facilities, 2018) the digital twin was used and different growth scenarios were developed and represented in 3D models, containing different levels of data: the state of the art of the building development, the maximum building capacity according to the rules of the Plan, the densification scenarios, information and impacts on the urban microclimate (heat islands), up to the 3D models of the proposals of competition notices for architects (Fig.5).

Through the visualization and analysis of digital prototypes and the demonstration of interactions with the built environment, the DT opens up new opportunities for discussion and dialogue on the future urban scenarios of the city between decision-makers and stakeholders, while the open model and collaborative

[22] https://www.geospatialworld.net/prime/lisbons-city-scale-digital-twins-for-flood-resilience-2/; https://www.gim-international.com/content/article/city-scale-digital-twins-for-flood-resilience

system allows the development of targeted applications and the development of diversified models according to the questions entered[23].

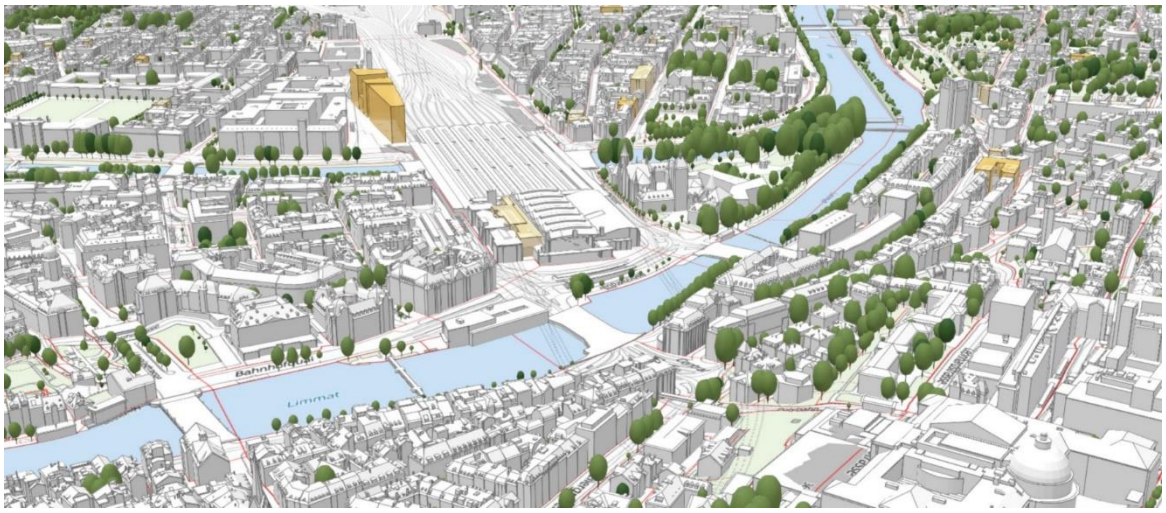

Fig.5 Representation of a 3D model of Zurich

Italian cities towards innovative resilient urban development

In Italy, cities do not yet appear adequately ready in the management of climatic emergencies, structured and efficient in the management of service networks (energy, transport, etc.), and need to design and introduce integrated operating and management systems, including protection, enhancement and enjoyment of the historical-cultural and natural heritage. In any case, here too, the first significant projects were launched: in addition to the city of Bologna which intends testing the first urban digital twin through the collaboration between the University and the city administration, the Department of Engineering, ICT and Technologies for Energy and Transport (DIITET) of the CNR is carrying out the strategic project *Urban Intelligence* (UI), based on an innovative paradigm consisting of an ecosystem of digital technologies aimed at supporting urban governance in achieving the sustainability goals defined by international documents such as the UN Agenda 2030, proposing to identify processes, tools and technologies for resilient urban development [24]. As part of this project, particularly relevant is a complex multidisciplinary work at the center of an experimentation of excellence, that is the DT of Matera, which also involves the House of Emerging Technologies of Matera. The main challenge is to transfer the DT to the urban environment where citizens are clearly the main actors. The goal is to put people at the center so that are both users and providers of information and content (Perna, 2022).

Preliminary concluding comments

This brief review of case studies is obviously not exhaustive but significant, and the next step of the ongoing research will take into consideration the systematization of the other collected, selected and in-depth case studies. Through synthetic tables and matrices, which will be specially elaborated starting from the data

[23] https://www.forumpa.it/citta-territori/il-digital-twin-per-la-pianificazione-urbana-il-caso-di-zurigo/; https://www.stadt-zuerich.ch/portal/de/index/politik_u_recht/stadtrat/weiterepolitikfelder/smartcity/english/ projects/zwilling.html

[24] The project is in line with the current approaches of MIT's "Senseable city" (https://senseable.mit.edu) https://senseableamsterdam.mit.edu/ and New York University's Urban Intelligent Lab (http://www.urbanintelligencelab.org) to think of an intelligence of the city that knows, models, builds scenarios and learns to then orient innovative policies. See also:
http://www.diitet.cnr.it/urban-intelligence/;
http://audis.cervelliinazione.net/dai-soci/il-progetto-strategico-urban-intelligence-del-cnr-diitet-8511/

available for each case study, the twofold objective is pursued, on the one hand, to relate the various challenges identified with the policies, strategies, actions and innovative projects thanks to the new digital technologies, of each city, on the other one, to make a comparison between the case studies to highlight the most relevant aspects of success and any critical issues, as well as emerging trends, and propose a useful virtuous process of mutual learning.

Anyway, at the conclusion of the current paragraph, it clearly emerges that DTs are an innovative tool to increase urban resilience, through a series of different functions, including in a broader sense: knowing the evidence of the territory and prevent emerging damage, with the solution of the modalities of these events, know the evidence of the territory and prevent damage deriving from emerging social, economic and environmental challenges; visualize streets that could become too crowded or busy, that could have significant problems in the event of a cyber-attack, such as a better response to buildings in danger of attack, establish the modalities of these events, direct maintenance interventions to the primary infrastructures and necessary networks for a strong containment of maintenance costs, last but not least, the integration in the Urban Planning practice, in the planning and management phase of plans and projects at different territorial scales.

3. Conclusion. Final remarks and future research directions

In the path undertaken so far, the article has focused and developed the role of New Digital Technologies, with particular reference to Digital Twins (DTs), in increasing urban resilience with respect to the global challenges arising from the exponential growth of the world population, the limitedness of the planet and its resources, and from other interrelated challenges (climate, energy, health, ecological). In this context, building urban resilience is a multisectoral, multidimensional, multi-stakeholder process that requires a clear change of trajectory from previous paths, and integrated urban planning is an essential component and prerequisite for resilient urban futures. In increasingly interconnected urban systems, the ability to predict the effects of perturbative events in real time, crucial for limiting human and economic losses, seems to become a concrete possibility. Big data for cities connects fundamentally different time scales of urban dynamics: the short-term scale of fast or real-time dynamics and the much slower long-term dynamics of urban structure and policies. The potential of urban digital twins for data-based decision making in urban planning therefore lies in our ability to jointly address these two different time scales and to develop conceptual and methodological tools that are able to do so. Another fundamental aspect in the use of big data for urban analysis concerns the social aspects involved in the formation strategies of urban policies,

Over the last decade, a growing number of cities have sought to take advantage of improving frontier technologies and the *smart city* is the most emblematic contemporary expression of the fusion of urbanism and digital technologies. As well as the improving quality and affordability profile of digital technologies, cities now also have a sizeable bank of experience to draw on when determining the best course of action to take and can improve their level of smartness/urban intelligence. As a matter of fact, cities are complex systems, not silos. Planning for more resilient cities and territories entails tackling challenges and creating solutions in an integrated, inclusive, risk-aware, and forward- looking manner. Solutions developed through resilience thinking can allow cities to enjoy multiple benefits, reducing and even helping to prevent the impact of shocks and stresses on the city's people, economy, and physical environment, and improving residents' quality of life. (The Rockefeller Foundation, 2019). This perspective requires the assumption of co-responsibility by politicians and administrators, research and education institutions, the various economic and financial sectors, all citizens. As also stated in the latest World City Report (UN-Habitat, 2022), municipal governments should: 1) align innovation policy and practice with major societal challenges, including climate change, pollution, poverty and inequalities; 2) support the urban agglomeration, and in particular the co-localization of complementary resources and organizations, through territorial and socio-economic planning and regulation; 3) create or support workshops and that involve stakeholders and communities in creating visions and creating scenarios;

4) conduct evaluations of innovation programs to assess impact and ensure feedback for continuous improvement, learning and capacity building. Above all, cultural change is needed in municipalities to show the relevance of digital skills and re-direct their investments and finances towards tailored capacity building programmes. Capacity building programmes can provide effective capacities and resources for improving urban planning, decision making, impact assessment, and change management.

Urban Digital Twins are really useful and effective when used to obtain new information and thus make better decisions, with a view to greater resilience and sustainability. This requires a culture that values informed and data-driven decision making, as well as business procedures that exploit infrastructural DTs. Agreeing with T. Elliot (2020), the advantages for cities thanks to the DTs can be summarized in seven points as follows: 1) Retrieval of information that improves urban infrastructure; 2) Improving collaboration across a broad ecosystem of stakeholders and creating added value for cities and their inhabitants; 3) Improvement of mobility and safety in public spaces, even during the organization of great events; 4) Improvement of urban planning and visualization of projects; 5) Improvement of urban planning and visualization of projects; 6) Involvement of citizenship and creation of a feedback sequence; 7) Adoption of open data initiatives that allow others to design, develop and deliver services based on reliable information about cities and infrastructures.

Though Digital twins are already used today for many purposes, there is still a lot to be experimented with. They can address a variety of spatial scales – territorial, environmental, landscape; building, urban or neighborhoods, regional, national – and a variety of time scales, as they can represent any point in the life cycle of resources, processes and systems, can be static or dynamic and face different time scales (reactive maintenance times, planned maintenance times, capital investment times). The discussions highlighted the need for both digital, i.e., data and ecosystem governance, data analysis, modeling, AI, DT, interoperability, and transversal skills, i.e., cultural change or new ways of working. On *Digital Twins and Digital Cities* held at GWF, 2022 in Amsterdam[25], industry leaders discussed how the latest developments in digitization will empower individuals, governments and citizens alike: a virtuous relationship between urban communities and urban planning and design. The new centrality of cognitive processes, Big Data and ICT, ex ante evaluation of decisions to compare alternative planning hypotheses, predict and anticipate the consequences of human actions changes the relationship with science and power, between technology, politics and the economy, if we consider digital technology as a means at the service of the quality of life and the environment in which we live, towards new knowledge-based urban futures (Campbell, 2012; Carta, 2017; Ratti, 2013).

The spread of DTs is taking on the character of an inevitable phenomenon, supported by the progress of the digital technologies used. Therefore, taking advantage of the experiences gained at the international level by pioneering cities, an increasing number of local public administrations, also in Italy, will look with increasing interest to the DT of their territory, as a valid tool to expand the possibility of creating innovative services to support of decision-making processes and to pursue the resolution of the problems of one's community in harmony with the objectives of sustainable development. Data is the *lifeblood* of decision making, but it is clear that data and the most innovative technologies alone are not enough, the ability to read them and predict future trends in the light of the changes expected from policies is also needed (Giovannini, 2016). Agreeing with Peixoto and Steinberg (2019) great attention must be paid to the fact that emerging new technologies are only as good as the institutions and processes in which they are embedded. What is needed are true institutional upgrades since the full benefits of emerging technologies are unlikely to be reaped under institutions that do not modernize their rules and cultural norms.

Ultimately, we must all probably understand and accept that significant changes are inevitable during periods of transition, such as the current one of the multiple transition (energy, ecological, digital) in the face of *polychrysis*. Flexible skills and capabilities are therefore required for the continuous evolution of digital

[25] https://geospatialworldforum.org/2022/aec.asp

technologies, which however only the human mind could execute and control, in order to increase the resilience of cities and territories to successfully face decisive global challenges, such as climate change.

References

Abdallat, A. for Forbes Technology Council (2022). *Forbes: Formidable Human-AI Relations Can Accelerate Sustainability Efforts*. Posted 13 May, 2022 Los Angeles, CA. Retrieved from: https://www.beyond.ai/news/forbes-formidable-human-ai-relations-can-accelerate-sustainability-efforts/

Al Furjani, A., Younsi, Z., Abdulalli, A., Elsaeh, M., Almahdi, A., Jouil, K., & Lashihar, S. B. (2020). Enabling the City Information Modeling CIM for Urban Planning with OpenStreetMap OSM. In *The Fourth International Conference for Geospatial Technologies–Libya GeoTec 4*.

Angelidou, M. (2017). The role of smart city characteristics in the plans of fifteen cities. *J. Urban Technol.*, 24(4), 3-28. https://doi.org/10.1080/10630732.2017.1348880

ARUP (2019). *Digital twin. Towards a Meaningful Framework*. London: ARUP. Retrieved from: https://www.arup.com/perspectives/publications/research/section/digital-twin-towards-a-meaningful-framework

Barresi, A., & Pultrone, G. (2013). European Strategies for Smarter Cities. *TeMA - Journal of Land Use, Mobility and Environment*, 6(1), 61-72. https://doi.org/10.6092/1970-9870/1455

Birks, D., Heppenstall, A. & Malleson, N. (2020). Towards the development of societal twins. *Frontiers in Artificial Intelligence and Applications. 24th European Conference on Artificial Intelligence* (ECAI 2020), 29 Aug - 08 Sep 2020, Santiago de Compostela, Spain. 2883-2884. https://doi.org/10.3233/FAIA200435

Bojanić Obad Šćitaroci, B., Pierantoni, I., Sargolini, M., & Sopina, A. (2021). Fostering holistic natural-risk resilience in spatial planning. *TeMA - Journal of Land Use, Mobility and Environment*, s.i. 1.2021, 155-179. https://doi.org/10.6093/1970-9870/7427

Bolton, A., Butler, L., Dabson, I., Enzer, M., Evans, M., Fenemore, T., ... & Makri, C. (2018). *The Gemini Principles: Guiding values for the national digital twin and information management framework.* Cambridge: Centre for Digital Built Britain and Digital Framework Task Group. https://doi.org/10.17863/CAM.32260

Campbell, T. (2012). *Beyond Smart Cities: How Cities Network, Learn and Innovate*. New York (NY): Earthscan. https://doi.org/10.4324/9780203137680

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, 6263. https://doi.org/10.3390/ su14106263

Caragliu, A., & Del Bo, C. F. (2019). Smart innovative cities: the impact of Smart City policies on urban innovation. *Technol. Forecast. Soc. Change*, 142, 373-383, https://doi.org/10.1016/j.techfore.2018.07.022

Carta M. (2017), *Augmented City. A Paradigm Shift*, Trento-Barcelona: List.

Cavalli, L. (2023). Le Città Digitali e la sfida della sostenibilità. *Equilibri Magazine. Rivista per sviluppo sostenibile*, 31 gennaio 2023. Retrieved from: https://equilibrimagazine.it/tecnologia/2023/01/31/le-citta-digitali-e-la-sfida-della-sostenibilita/

Charitonidou, M. (2022). Urban scale digital twins in data-driven society: Challenging digital universalism in urban planning decision-making. *International Journal of Architectural Computing*, 20 (2),238-253. Article first published online: January 10, https://doi.org/10.1177/14780771211070005

Coalition for Digital Environmental Sustainability - CODES (2022). *Action Plan for a Sustainable Planet in the Digital Age*. https://doi.org/10.5281/zenodo.6573509.

De Gregorio Hurtado, S., Olazabal, M., Salvia, M., Pietrapertosa, F., Olazabal, E., Geneletti, D., D'Alonzo, V., Di Leo, S., & Reckien. D. (2015). Understanding How and Why Cities Engage with Climate Policy: An Analysis of Local Climate Action in Spain and Italy. *TeMA - Journal of Land Use, Mobility and Environment*, s.i. ECCA 2015, 23-46. https://doi.org/10.6092/1970-9870/3649

Deng, T., Zhang, K., Shen, Z. (2021). A systematic review of a digital twin city: A new pattern of urban governance toward smart cities. *Journal of Management Science and Engineering*, Volume 6 (2), 125-134. https://doi.org/10.1016/j.jmse.2021.03.003

Economist Impact (2022). *Digital Cities Index. Making digital work for cities: A global benchmarking of urban technology*. The Economist Group. Retrieved from: https://impact.economist.com/projects/digital-cities/2022-executive-summary/

EEA (2020). *EEA Report No 12/2020. Urban adaptation in Europe: how cities and towns respond to climate change.* Luxembourg: Publications Office of the European Union. https://doi.org/10.2800/324620

EEA-European Environmental Agency (2021). *Urban Sustainability in Europe-Opportunities for Challenging Times*. Briefing no. 03/2021, https://doi.org/10.2800/870229

Elliot, T. (2020). Digital Twin, o Gemello Digitale: 7 modi in cui le città possono trarne vantaggio dal loro uso. *Ingenio, Informazione Tecnica e Progettuale*, 17/09/2020. Retrieved from: https://www.ingenio-web.it/28260-digital-twin-o-gemello-digitale-7-modi-in-cui-le-citta-possono-trarne-vantaggio-dal-loro-uso

Elsheikh A. et al. (2021). Integration of GIS and BIM in Urban Planning -A Review, IOP Conf. Ser.: Mater. Sci. Eng. 1090 012128, https://doi.org/10.1088/1757-899X/1090/1/012128

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

Galderisi, A., & Ferrara, F. (2012). Enhancing urban resilience in face of climate change: a methodological approach. *TeMA - Journal of Land Use, Mobility and Environment*, 5(2), 69-88. https://doi.org/10.6092/1970-9870/936

Galderisi, A., Limongi, G. & Salata, KD (2020). Strengths and weaknesses of the 100 Resilient Cities Initiative in Southern Europe: Rome and Athens' experiences. *City Territ Archit* 7, 16. https://doi.org/10.1186/s40410-020-00123-w

Giovannini, E. (2016). La rivoluzione dei big data a sostegno dell'Agenda 2030. *Equilibri, Rivista per lo sviluppo sostenibile* 1/2016, pp. 64-69. https://doi.org//10.1406/83553

Grieves M. W. (2014). *Digital Twin: Manufacturing Excellence through Virtual Factory Replication. Digital Twin White Paper.*

Grimm, N.B., Cook, E.M., Hale R.L. & Iwaniec, D.M. (2016). A broader framing of ecosystem services in cities: benefits and challenges of built, natural or hybrid system function. In Seto, K.C., W. Solecki and C.A. Griffith (eds.). *Routledge Handbook of Urbanization and Global Environmental Change*, 202-212, New York: Routledge.

Hollands, R. G. (2015). Critical Interventions into the Corporate Smart City. *Cambridge Journal of Regions, Economy and Society* 8 (1): 61–77. https://doi.org/10.1093/cjres/rsu011

Hudson-Smith, A., Batty, M. (2022). *Ubiquitous geographic information in the emergent Metaverse. Transactions in GIS*. https://doi.org/10.1111/tgis.12932.

IPCC (2022). *IPCC Sixth Assessment Report. Climate Change 2022: Impacts, Adaptation and Vulnerability*. Retrieved from: https://www.ipcc.ch/report/ar6/wg2/

Jiang, F., Ma, L., Broyd, T., Chen, W., Luo, H. (2022). Digital twin enabled sustainable urban road planning. *Sustainable Cities and Society*, 78, art. no. 103645. https://doi.org/10.1016/j.scs.2021.103645

Jones, D., Snider, C., Nassehi A., Yon J., Hicks B. (2020). Characterising the Digital Twin: A systematic literature review. *CIRP Journal of Manufacturing Science and Technology*, Vol. 29, Part A, 36-52, https://doi.org/10.1016/j.cirpj.2020.02.002

Kim, B., Lim, C.-G., Lee, S.-H., Jung, Y.-J. (2022). A Framework of Large-Scale Virtual City Simulation with Land-Use Model. *International Conference on Advanced Communication Technology*, ICACT, 2022-February, 58-61. https://doi.org/10.23919/ICACT53585.2022.9728864

Lee, A., Lee, K.-W., Kim, K.-H., Shin, S.-W. (2022). A Geospatial Platform to Manage Large-Scale Individual Mobility for an Urban Digital Twin Platform. *Remote Sensing*, 14 (3), art. no. 723. https://doi.org/10.3390/rs14030723

Leone, A., Balena, P. & Pelorosso R. (2020). Take advantage of the black swan to improve the urban environment. *TeMA - Journal of Land Use, Mobility and Environment*, 247-259. https://doi.org/10.6092/1970-9870/6851

Leplat, L., da Silva Torres, R., Aspen, D., Amundsen, A. (2022). GENOR: A Generic Platform for Indicator Assessment in City Planning. *Proceedings - European Council for Modelling and Simulation*, ECMS, 2022-May, pp. 245-253.

Luers, A., Garard, J., Clair, A.L.S., Gaffney, O., Hassenboehler, T., Langlois, L., Mougeot, M. & Luccioni, S. (2020). Leveraging Digital Disruptions for a Climate-Safe and Equitable World: The Dˆ2S Agenda. *IEEE Technology and Society Magazine*, 39(2), pp.18-31. https://doi.org/10.1109/MTS.2020.2991495

Lv, Z., Chen, D., and Lv, H. (2022). Smart City Construction and Management by Digital Twins and BIM Big Data in COVID-19 Scenario. *ACM Trans. Multimedia Comput. Commun*. Appl. 18, 2s, Article 117 (June 2022), 21 pages. https://doi.org/10.1145/3529395

Major, P., da Silva Torres, R., Amundsen, A., Stadsnes, P., Mikalsen, E.T. (2022). On the Use of Graphical Digital Twins for Urban Planning of Mobility Projects: a Case Study from a new District in Ålesund, Norway. *Proceedings - European Council for Modelling and Simulation*, ECMS, 2022-May, pp. 236-242.

Mackinnon, D., Burns, R. & Fast V. (2022). *Digital (In)justice in the Smart City*. Technoscience and Society Series. Toronto: University of Toronto Press.

Mergel, I., Edelmann, N., & Haug, N. (2019). Defining digital transformation: results from expert interviews. *Government Information Quarterly*, 36(4), https://doi.org/10.1016/j.giq.2019.06.002

Mills, D.E., Izadgoshasb I, Pudney S.G. (2021). Smart City Collaboration: A Review and an Agenda for Establishing Sustainable Collaboration. *Sustainability*, 13(16):9189. https://doi.org/10.3390/su13169189

Papa, R., Galderisi, A., Vigo Majello M.C., Saretta E. (2015). Smart and resilient cities. A systemic approach for developing cross-sectoral strategies in the face of climate change. *Tema. Journal of Land Use, Mobility and Environment*, *8* (1), 19-49. https://doi.org/10.6092/1970-9870/2883

Papa, R., Gargiulo, C., Cristiano, M., Di Francesco, I., & Tulisi, A. (2015). Less Smart More City. *TeMA - Journal of Land Use, Mobility and Environment, 8* (2), 159-182. https://doi.org/10.6092/1970-9870/3012

Pelorosso, R., Gobattoni, F., Ripa, M.N., Leone, A. (2018). Second law of thermodynamics and urban green infrastructure. A knowledge synthesis to address spatial planning strategies. *Tema. Journal of Land Use, Mobility and Environment, Issue Volume 11*(1), 27-50. http://dx.doi.org/10.6092/1970-9870/5326

Perna, M. (2022). *Matera sogna il suo avvenire tra gemello digitale e blockchain*. On line 04.07.2022. Retrieved from: https://www.wired.it/article/matera-digital-week-blockchain-gemello-digitale/

Peixoto, T. & Steinberg, T. (2019). Citizen Engagement: Emerging Digital Technologies Create New Risks and Value. Washington, DC.: World Bank. https://openknowledge.worldbank.org/handle/10986/32495 License: CC BY 3.0 IGO.

Pultrone. G. (2014). Participation and Governance for More Human Smart Cities. *TeMA - Journal of Land Use, Mobility and Environment*, 7(2), 159-172. https://doi.org/10.6092/1970-9870/2558

Pultrone, G. (2018a), Urban fragilities and resilience strategies. In L. Pignatti P. Rovigatti F. Angelucci M Villani (Eds.). *IFAU 2018. 2nd International Forum on Architecture and Urbanism. Territori Fragili/Fragile Territories. Paesaggi_Città_Architetture/Landscapes_Cities/Architecture*, 440-447, Roma: Gangemi Editore International Publisher.

Pultrone, G. (2018b). What Planning for Facing Global Challenges. In A. Leone & C. Gargiulo (Eds.), *Environmental and territorial modelling for planning and design*, 577-587, Napoli: fedOA Press. https://doi.org/10.6093/978-88-6887-048-5

Pultrone, G. (2020). La sfida del cambiamento climatico come opportunità per rafforzare la resilienza delle città in cammino verso la sostenibilità. Strategie, strumenti, sperimentazioni. In M. Talia (Ed.). *La città contemporanea*, 332-229, Roma-Milano: Planum Publisher. http://www.planum.net/planum-magazine/planum-publisher-publication/citta-contemporanea-atti-urbanpromo-2019

Ratti C. (2013). *Smart City, Smart Citizen*, M.G. Mattei (Ed.), Milano: Egea.

Rosol, M. & Blue, G. (2022) From the smart city to urban justice in a digital age*, City*, 26:4, 684-705. https://doi.org/10.1080/13604813.2022.2079881

Ruston McAleer, S., McAleer, M. and Kogut P. (2021). *Forging the Future of Responsive Cities Through Local Digital Twins*. Last update 30 Sept. 2021. Retrieved from: https://ercim-news.ercim.eu/en127/special/forging-the-future-of-responsive-cities-through-local-digital-twins

Salomon, A. (2021). *Are digital twins the future of urban planning? Digital 3D models can help city leaders plan for the future, but their value will depend on the data*. Published Nov. 1, 2021. Retrieved from: https://www.smartcitiesdive.com/news/are-digital-twins-the-future-of-urban-planning/609232/

Schrotter, G., Hürzeler, C. (2020). The Digital Twin of the City of Zurich for Urban Planning. *PFG 88*, 99–112. https://doi.org/10.1007/s41064-020-00092-2

Söderström, O. (2016). From a Technology Intensive to a Knowledge Intensive Smart Urbanism. In *Beware of Smart People!*, edited by J. Stollmann, K. Wolf, A. Bruck, S. Frank, A. Million, P. Misselwitz, J. Schlaack, and C. Schroder, 63–69. Berlin: Universitatsverlag TU Berlin.

Sustainability in the Digital Age-SDA (2020). *Digital Disruptions for Sustainability Agenda (D^2S Agenda): Research, Innovation, Action. Future Earth*. https://sustainabilitydigitalage.org/d2s-agenda/

Starr, P. (1994). Seductions of Sim: Policy as a Simulation Game. *The American Prospect* no. 17 (Spring 1994): 19-29. Retrieved from: https://www.princeton.edu/~starr/17star.html

Striving for People, Plant and Peace. 2022 JOINT MEDIA PROJECT REPORT (2021). Berlin: The Non-Profit International Press Syndicate. Retrieved from: https://www.sdgsforall.net/documents/Striving_for_People_Planet_and_Peace_2022.pdf

The Rockefeller Foundation (2019). *100 Resilient Cities. Learning from the 100RC Network*. Last access 2022, August 30. Retrieved from: https://resilientcitiesnetwork.org/downloadable_resources/UR/Resilient-Cities-Resilient-Lives-Learning-from-the-100RC-Network.pdf

Topping, D., Bannan, T.J., Coe, H., Evans, J., Jay, C., Murabito, E., Robinson, N. (2021). Digital Twins of Urban Air Quality: Opportunities and Challenges. *Frontiers in Sustainable Cities*, 3, art. no. 786563. https://doi.org/10.3389/frsc.2021.786563

UN-Habitat (2020). *World City Report 2020. The Value of Sustainable Urbanization*. United Nations Human Settlements Programme: Nairobi, https://unhabitat.org/sites/default/files/2020/10/wcr_2020_report.pdf

UN-Habitat (2022). *World City Report 2022. Envisaging the Future of Cities*. United Nations Human Settlements Programme: Nairobi, https://unhabitat.org/sites/default/files/2022/06/wcr_2022.pdf

United Nations Department of Economic and Social Affairs, Population Division (2022). *World Population Prospects 2022: Summary of Results*. UN DESA/POP/2022/TR/NO. 3.

van der Lans, R.F. (2019). *The Fusion of Distributed Data Lakes. Developing Modern Data Lakes. A Technical Whitepaper*. R20/Consultancy, https://www.tibco.com/sites/tibco/files/resources/Whitepaper%20TIBCO%20BigData%20V1.pdf

van Wynsberghe, A. (2021). Sustainable AI: AI for sustainability and the sustainability of AI. *AI Ethics 1*, 213-218. https://doi.org/10.1007/s43681-021-00043-6

Vander Meer, E. (2022). Green Infrastructure Mapping for Adaptation, Biodiversity, and Health and Wellbeing: A Tool Development Case Study in Edinburgh. *Palgrave Studies in Sustainable Business in Association with Future Earth*, 39-62. https://doi.org/10.1007/978-3-030-86803-1_3

WEF-World Economic Forum (2022). The Global Risk Report 2022. Edition 17th. Insight Report. Retrieved from: https://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2022.pdf?_gl=1*a93krw*_up*MQ..&gclid=CjwKCAjw9suYBhBIEiwA7iMhNJ_qkqK1frxmpL_r8ukkKjARJpKeG3iCocp39SjY6Nzs2jwNOG3mUBoCeVsQAvD_BwE

Yin, N., Cai, M. (2022). Urban Road Landscape Design and Digital Twin Simulation Modeling Analysis. *Discrete Dynamics in Nature and Society*, 2022, art. no. 8020549, https://doi.org/10.1155/2022/8020549

Zhao, D., Li, X., Wang, X., Shen, X., Gao, W. (2022). Applying Digital Twins to Research the Relationship Between Urban Expansion and Vegetation Coverage: A Case Study of Natural Preserve. *Frontiers in Plant Science*, 13, art. no. 840471. https://doi.org/10.3389/fpls.2022.840471

Zheng, C., Yuan, J., Zhu, L., Zhang, Y., & Shao, Q. (2020). From digital to sustainable: a scientometric review of smart city literature between 1990 and 2019. *Journal of Cleaner Production*, 258. https://doi.org/10.1016/j.jclepro.2020.120689

Zucaro, F., & Morosini, R. (2018). Sustainable land use and climate adaptation: a review of European local plans. *TeMA - Journal of Land Use, Mobility and Environment*, 11(1), 7-26. https://doi.org/10.6092/1970-9870/5343

Image Sources

Fig.1: Centre for Digital Built Britain website, https://www.cdbb.cam.ac.uk/AboutDBB/whatisdbB;

Fig.2: Deng et al., 2021, p.132;

Fig.3: https://codedesign.org/digital-space-singapore-everything-you-need-know-2022;

Fig.4: https://www.geospatialworld.net/prime/lisbons-city-scale-digital-twins-for-flood-resilience-2/;

Fig.5: https://www.stadt-zuerich.ch/ted/de/index/geoz/geodaten_u_plaene/3d_stadtmodell.html.

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