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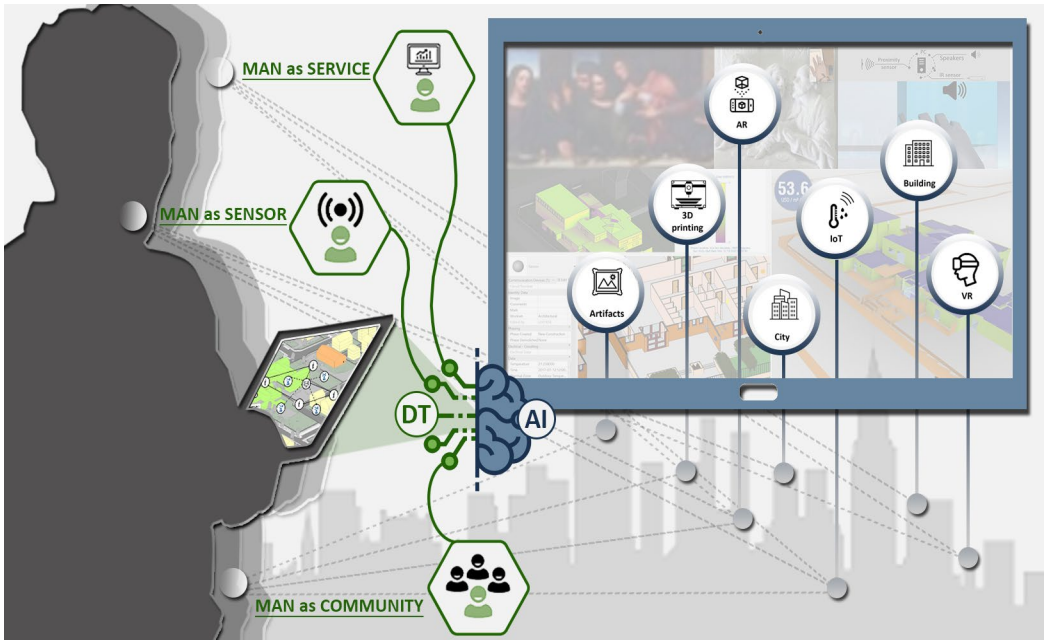
Multi-Level Information Processing Systems in the Digital Twin Era

Daniela De Luca
Matteo Del Giudice
Anna Osello
Francesca Maria Ugliotti

Abstract

The most challenging aspect of the scientific panorama linked to technological innovation is the search for possible connections between Representation, Man and Artificial Intelligence (AI) in the complex ecosystem that defines a Digital Twin. Man plays a crucial role in facilitating communication processes both for the dissemination of knowledge and the accessibility and usability of content and for his ability to become a "sensor" and communicate information, feelings, emotions. The contribution proposes a cross-section of applications that link and decline Augmented Reality and AI differently according to a gradual scale shift from the artefact contained in a building overlooking an urban context of interest. The result is a multi-level information processing system derived from the three-dimensional matrix that links data collection, representation and visualisation techniques and tools with the cultural heritage – city, building, artefact – according to specific use cases.

Keywords
digital twin, BIM, drawing, society 5.0, multi-level information processing systems.



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Introduction

The social and economic changes of recent years have highlighted a new vision of a human-centred society in which people can better manage their quality of life. In this way, users' needs determine the fusion of physical and virtual space to optimise their information and create a new ecosystem of values and high-tech solutions [Atkins 2021]. Thanks to introducing new technologies that improve the control of everyday actions carried out by the digital user, the human-system interaction of Information and Communication Technologies (ICT) provides sustainable and interoperable services.

Social innovation extends services into policies and regulations capable of shaping the decision-making choices of future generations through improved quality of life. In fact, establishing an ecosystem through global and dynamic technological platforms makes it possible to determine new balances between society-technology-human behaviour. The logic that manages societal change is the use of efficient tools that are easily accessible to each individual and the identification of smart platforms [Baheti, Helen 2011]. Enormous advantages can be deduced from this new vision of society: (i) ease of cataloguing information and availability in consulting it; (ii) different contents according to the services required; (iii) dynamic learning modes; (iv) means of communication and visualisation integrated with sensors and real-time monitoring [Deguchi et al. 2020].

The transformation of citizens' lifestyles, cities and artefacts intensify the dynamic properties of their configuration by overcoming static relational barriers. New technologies are best able to govern the intelligent society during the digital process [Del Giudice et al. 2020]. The challenges and paradigms posed by Society 5.0 are overtaken by new tools that must be applied within smart and interconnected cities where a dynamic and social Digital Twin can manage new technological frontiers [Fuller et al. 2020]. The combination of Artificial Intelligence (AI), Internet of Things (IoT), Machine Learning (ML), Deep Learning (DL), cognitive computing and big data analytics allows humans to delineate the real-world boundaries within the virtual model and improve their behaviour in the real world [Fukuyama 2018]. This new development of a digital twin has underlined the need for precise, stable and multi-layer cataloguing and data transmission techniques. Therefore, we can describe the Digital Twin as a virtual model that analyzes real processes to simulate and interpret performance at different scales, generating optimized information flows.

The deployment of the virtual model is closely linked to the integration of platforms capable of automating the flow of information in every social sphere. Therefore, the domains of relevance range from industry and construction to the entire city. It is precisely in the last domain that the diffusion of virtual models has led to effective solutions. The growth of smart cities, develop societies connected with the integration of wearable and non-wearable devices that collect data and determine human choices. The ability to adopt web services that communicate with sensors makes it possible to plan future choices through AI algorithms that monitor and analyse the duality between real and virtual behaviour [Gartner Inc. 202; Gladden 2019].

The main challenges faced by the Digital Twin are related to technological progress, as ICT infrastructures must be able to collect data and analyse them in real time, eliminating data without content. Improving data quality is important for the efficient use of DT. Finally, information security and trust in the reliability of tools guarantee the sharing and implementation of experiences [Grivies 2014]. Thanks to Virtual Augmented Reality (VAR) and AI tools, the integration between different simulated environments and existence is facilitated by innovative methods to calculate and manage process flows [Nair Meghna et al. 2021].

These tools have seen a strong increase in their adoption over the years. According to technology reports, digitisation has changed the traditional systems the user interfaces with by increasingly putting people and their independence at the centre with resilient models. The centrality of humans is linked to digital behaviour in the use of the web, the experience of virtual actions and finally the storage of data [Madani 2020; Marr 2020].

The combination of different technologies not only facilitates information flows, but also

connects the individual to associated behavioural events, changing the society and services of the smart city. There is so much information being generated that precise techniques for managing Big Data are required. In this sense, the IOT evolves into IoB (Internet of Behaviors) where continuous monitoring of the user may or may not encourage choices in a range of well-structured possibilities. The spin-offs are related to the strategy of creating shared experiences that connect to multi-experiential and personalised activities [Mohammadi, Taylor 2017]. Virtual environments that follow these characteristics allow three-dimensional objects and the database to be visualised, modified and reloaded at different scales. The platforms that underpin this utilise reliable web protocols where information is collected, with a decentralisation of machine learning systems. The new technologies of AR and VR are able to improve the perception of places, promote the well-being of society and increase the efficiency of everyday life.
The implementation of these systems with AI algorithms makes it possible to innovate in many areas such as the public sector, industry, education and training, healthcare, and the construction sector.
The adoption of digital technologies can also make the interaction between humans and society more collaborative for the various stakeholders who manage and optimise the decision-making processes of the city of the future.
The contribution analyses the need to investigate concrete actions to be transferred within virtual environments, i.e. a Digital Twin that brings together different scales and objectives. It is possible to define the main actions that Human 5.0 can carry out about cultural heritage, starting from analysing the needs of an artefact. Even at the building level, if connected to a network of sensors, it is possible to self-generate the services humans require, optimising the continuous changes with AI. Similarly, if we investigate the city, each user can communicate data and modify it over time through Deep Learning and Machine Learning techniques. In this way, it is no longer possible to speak of a single type of digital model but of tools that communicate through new systems of visualisation and representation (Fig.1). So drawing, understood as a two-dimensional representation, evolves into advanced three-dimensional information techniques where AI manages its change. Methodologies such as Building Information Modelling (BIM) and District Information Modelling (DIM) allow citizens to manipulate Big Data optimised by AI. Digital components, asset twins, twin units and process twins thus become helpful tools for improving communication, monitoring, simulation and management of knowledge and behaviour in the digital society [Mohammadi, Taylor 2017]. The main challenge of a socie-

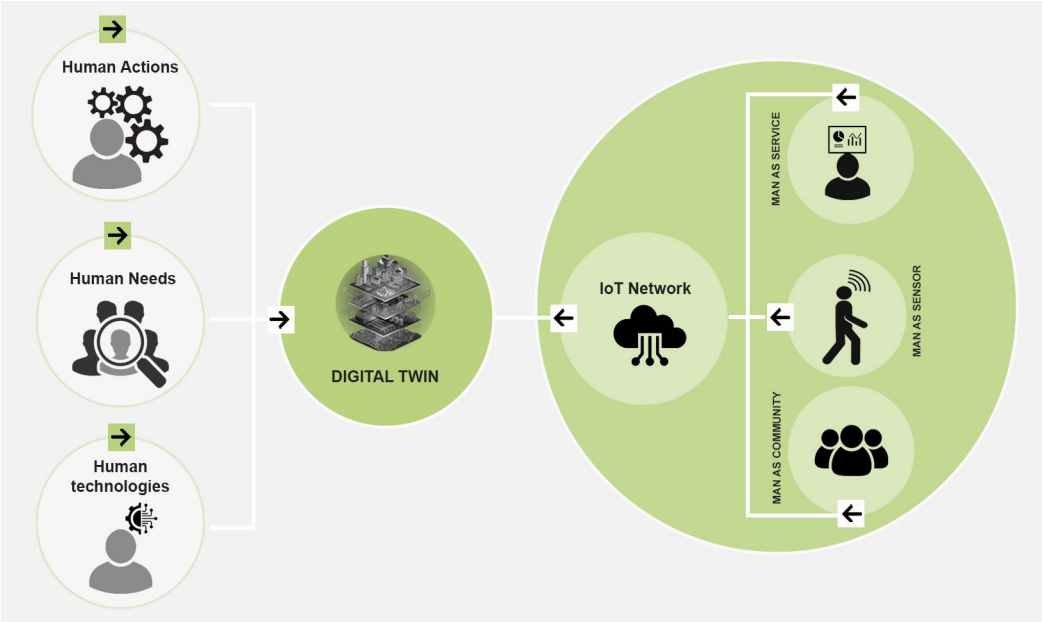

Fig. 1. Workflow.

ty rich in information stimuli is adopting a digital twin that can use sensors to control the effects of the virtual world on reality [Srivastava et al. 2012]. At the same time, the digital model is the means whereby man, understood as a set of social actions and behaviours, becomes a receiver and communicator of information in real-time, like a real sensor. For this reason, a Man-Sensor is defined as a person who can transfer virtual actions to a network of users that improve various domains such as health, mobility, energy, and social relations.

Methodology

The growing need to monitor and manage existing tangible and intangible cultural assets throughout the life cycle provides an opportunity to turn the focus on the challenges launched by ICT for the development of a Digital Twin. It is usually based on three main components:i) the physical world, ii) the virtual world; iii) the data connections that tie them together [Trauer et al. 2020]. The main aspect the paper focuses on is how people can interact with it to extract specific information related to the social and cultural and environmental aspect, from the scale of the individual to the surrounding urban context. Therefore the focus is directed on sharing information between people and their surroundings.
The duality of human-computer interaction is summarized in the methodological framework to define the fundamental characteristics (Fig. 2). The physical world is composed of objects useful to humans, places in which humans live, and cities in which society interacts on a daily basis. The resulting image of reality highlights aspects related to knowledge, cultural identity, behaviour, and policies put in place by the city policy makers. The digital world has the task of collecting data from the physical world to implement monitoring of specific features, to develop simulations of different types and to propose improvement scenarios of wellness. It is composed of i) Sensors; ii) Computing capability; iii) Visualization. Clearly, the feasibility of virtual physical duality must include the creation of an IoT network capable of connecting physical and digital entities. In this case, the approach is that the proposed digital twin is characterized by a multilevel system in which users can connect with different entities including artefacts, the surrounding environment and the people who constitute the community of a district/city. For this reason, three case studies (Fig. 3) were selected to evaluate the usability of data at the social level, the communication of data at the environmental/building level, and the dynamic interaction of data for greater awareness as an active part of a community.

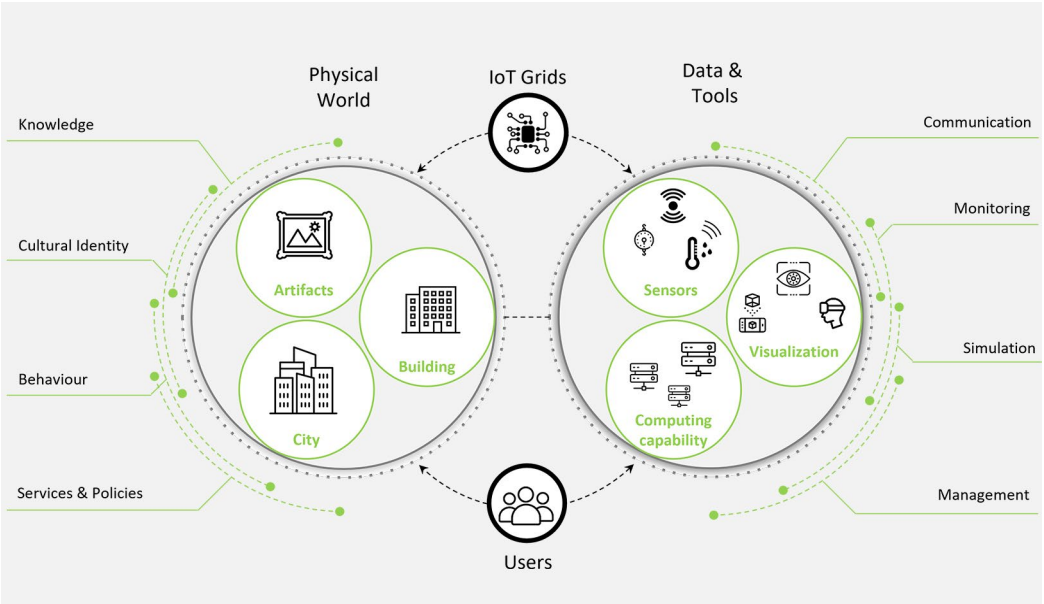

Fig. 2. Methodological framework.

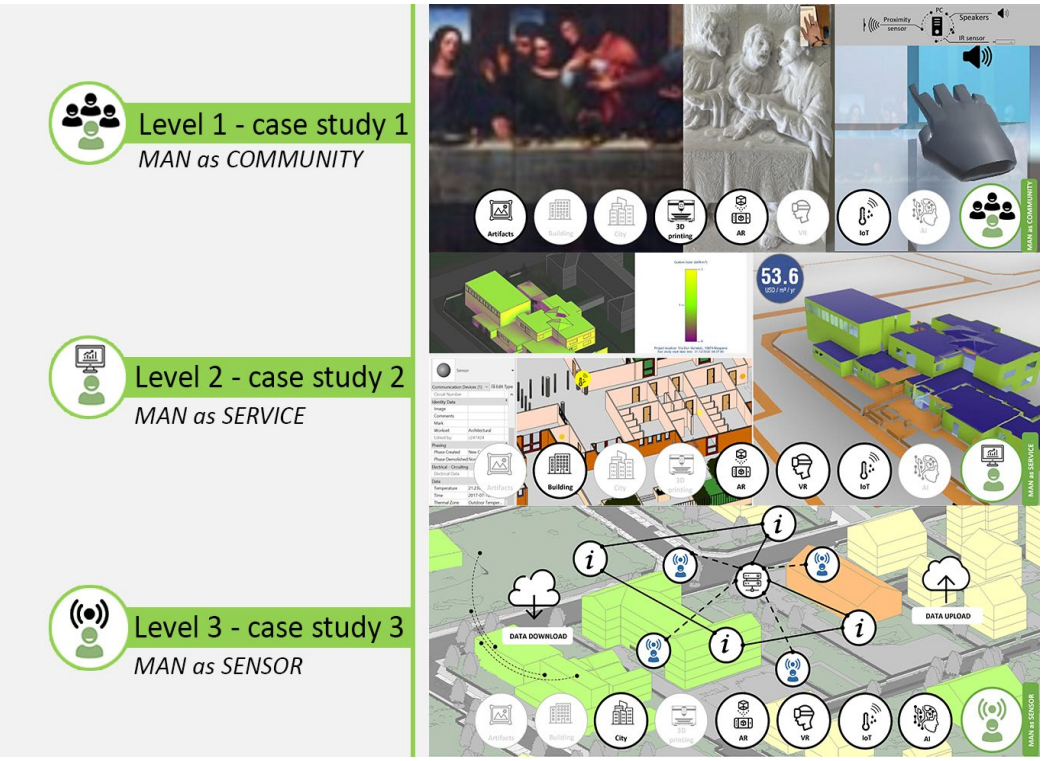

Fig. 3. Case studies.

Level 1 – Man as Community

A first use case relates to user awareness, which becomes social inclusivity beyond disability. The designed tactile experience of a painting is triggered by a proximity sensor that detects the presence of a guest. The artwork, digitally reproduced from point clouds and 3D printed, is divided into parts to which diversified audio content is associated through a mapping system developed with Leap Motion technology. An infrared (IR) sensor tracks the actual position of the hand on the physical replica and transfers the spatial coordinates into the virtual model. In this way, the interaction between the real experience and the activation of the virtual content is managed by an algorithm that activates audio sequences selectively and automatically. 3D printing makes it possible to maintain contact with the artwork, even when it is being restored and inaccessible. In this case, man can make his feelings available with the community.

Level 2 – Man as Service

The second case enables the possibility of creating virtual tours of a building, making information available thanks to the direct interaction of the user with special markers placed in the field. Starting from the development of a BIM model, an informative model is created describing the artificial environment in which humans live. Different sensors (e.g. temperature, humidity) installed in the indoor environment collect information dynamically and are subsequently interrogated by users during virtual tours for the management of indoor thermal comfort. In this case, the digital twin of the building has no relationship with other buildings in the context and no relationship with other people with whom they share the same environments. Therefore, the benefit obtained is only local and is linked to the individual citizen, not producing direct effects for society from a smart city perspective. Buildings incorporate the needs of citizens that become a service to achieve a smart building.

Level 3 – Man as Sensor

The third use case is linked to the possibility of acquiring information from the user immersed in an urban context. Man becomes a receptor of information that he can transmit through questionnaires/platforms that can be retrieved through a QR Code. The data collected will thus feed a cloud database that, once synchronized with the digital models, allows the monitoring of certain parameters and conditions (quality of the environment, maintenance problems, perception, etc.). Through the sharing of various information for the management of the physical world it will then be possible to set up an experiential database in which each user characterises their own way of communicating specific information. This creates the premises for the definition of a smart city that adopts Recommender Systems(RS) [Van Dinh et al. 2020] that employ AI techniques in order to increase user engagement and to guide citizens in the process of finding services that match with their preferences.
Through the three levels described above, it is possible to state how the proposed digital twin is still in an initial study phase. Through the proposed multiscale approach, in the near future it will be possible to activate a multi-scale system in which people are at the center of the virtual physical duality.

Results

This contribution recognizes and affirms the constant need to evaluate the intersections between the real and virtual worlds. The increasing diffusion of Augmented and Virtual Reality technologies has allowed starting more and more challenging research and experimentations that try to go further, widening the boundaries, crossing the domains, and including an ever more vast pool of users. In this context, the discipline of drawing is facing a reflection oriented to meet a significant challenge to improve the quality of human life. The graphic representation of artefacts, buildings and the city can be the starting point to meet the increasingly demanding humans needs. It is essential to elaborate on the different forms of expression through the new visualization, processing, and data collection opportunities. Through this step, the foundations are laid to set up a Digital Twin that is increasingly useful to solve the problems of everyday life.
As described in this paper, the multi-level information processing system enables ever greater accessibility and governance of data. The proposed use cases show a growing potential arising from this framework that places humans at the centre of a super-smart society.
The immediacy of communication reaches the individual but contextually creates an information-based community (Fig.4). While the first use case makes available primarily static and divulgation information, the second expands opportunities through the collection and sharing of dynamic data. In this way, the synergy between human sensor and representation enables a service model covering activities from monitoring to mainte-

Fig. 4. Multi-level information process system for a Digital Twin.

nance and management. In the third case, man is no longer a simple reader of data but becomes himself an interceptor of information, situations, strategies.
The ability to report is enhanced by the intervention of the individual and finds strength in the community. The simpler and more immediate the reporting tool, the more it will be used. In this way, the data collected becomes real big data that can be processed for a variety of purposes.
Unlike the second case, where the data is objective, it is also possible to collect intangible information, which can be evaluated with a different sensibility by the user. For example, let's imagine the interesting scenarios that can be opened up by going to collect the emotions that places inspire.
These can be exploited as elements of investigation to improve the urban texture of the city and adopt solutions shared by citizens towards a city that is not only smart but also resilient.
The objective or subjective evaluation derived from the various sensors, human and non-human, with which the city may be equipped, generates ranking or rating that are best managed through machine learning systems that are returned to the user in the form of recommendation engines.

Conclusions

The adoption of artificial intelligence within the evolution process of society has made services that regulate the relationships between users accessible and sustainable and defines the best strategies to optimise the information and behavioural flows. Indeed, in this way, people can communicate their feelings within virtual experiences where specific algorithms process heterogeneous information defining a dynamic and interconnected database.
The use cases analysed have made it possible to evaluate a multilevel system of processable information in which users and tools relate between the virtual world and real environments. Therefore, the interaction between digital models and the 5.0 society today presents a labile process in which the duality between Human, Artefact and Artificial Intelligence requires interoperable tools adapted to the future society.
The advantage of developing capacitive models expresses a high response to the innovative representation of digital environments at different scales.
Thanks to developing a Digital Twin, linked to Artificial Intelligence through a recommendation system, it will return different information. The user will process this information in the form of alerts that, depending on the location, suggest personalised tours to a generic user and convey information on what defines Society 5.0.
Technological progress linked to Artificial Intelligence, Big Data, Robotics, Deep Learning and Machine Learning tools is opening up new scenarios that on the one hand improve man's way of life, and on the other require automation with high cognitive capabilities. Therefore, the establishment of an effective and efficient ecosystem will have to ensure sustainability in economic, environmental, social and political terms where humans determine new social values.
The sensory capacity acquired thanks to the digital infrastructure constitutes a new vision of the smart city capable of developing a digital version of the real world that enables dynamic environments. Augmented reality overlays the real world with virtual data, making the city and its ecosystem observable and tangible by humans in its various forms.
New technologies such as Augmented and Virtual Reality connected to AI will not only become tools for knowledge, behaviour and social and economic policies of the 5.0 community. Still, they will bring about a real revolution in meeting the needs of human beings within a smart city.

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Authors
Daniela De Luca, Dept. of Structural, Geotechnical and Building Engineering, Politecnico di Torino, daniela.deluca@polito.it
Matteo Del Giudice, Dept. of Structural, Geotechnical and Building Engineering, Politecnico di Torino, matteo.delgiudice@polito.it
Anna Osello, Dept. of Structural, Geotechnical and Building Engineering, Politecnico di Torino, anna.osello@polito.it
Francesca Maria Ugliotti, Dept. of Structural, Geotechnical and Building Engineering, Politecnico di Torino, francesca.ugliotti@polito.it

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