XVI International Conference on Durability of Building Materials and Components
DBMC 2023, China
K.F. Li and D.P. Fang (Eds)

Intelligent Construction via Digital Twin Approach

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Abstract. *The paper presents the results of an ongoing research activity dealing with Digital Twin (DT) approaches for Intelligent Construction, optimizing Operation and Maintenance of buildings and urban areas. DT is an essential technological node of Industry 5.0, which leads to the growth of a Collaborative Industry based on the cooperation between machines and human beings to give added value to processes that meet the needs of users. DT realizes the synchronization between two realities: physical objects in real space, virtual objects in virtual space, remaining connected through the mutual exchange of data throughout the entire life cycle of the object. The construction sector is also adopting the new DT perspective to enforce innovative, responsible, and sustainable governance of the life cycle of buildings improving their durability and reducing environmental impacts. Due to IoT, AI, and virtualization, DT approaches permit prediction of future performance in-use, prevent anomalies, downtime, and inefficiencies, to experiment improvements or changes without having to test them on the construction itself or on special mock-ups.*
The research assumes the aforesaid considerations and states as its principal operational and experimental assets as-built virtual models in OpenBIM connected with Geographic Information Systems and an IoT infrastructure. They realize intelligent constructions integrated with an analytical data communication network for control and performance simulations.
Through the study cases analyzed, the paper also introduces arguments for a critical literature review on current statements and future challenges of the DT approach for Intelligent Construction.

Keywords: *Digital twin, Built Environment, Internet of Things, Intelligent Construction, Maintenance.*

1 Introduction

The EU report “Industry 5.0: Towards more sustainable, resilient and human-centric industry” (EC 2021a) introduces the characters of a new stage in the historical sequence of Industrial Revolutions. The Fourth, the current one, began in 2014 when Industry 4.0 took over. (Schwab 2016) The European Report affirms the need to speed up the transformation already underway - digital and ecological - to restore the environment and the economy, focusing on three principles: human centric - sustainability - resilience. These principles aim at the goal of a Collaborative Industry and Super Smart Society, characterized by intelligent cooperation between machines and human beings and capable of accompanying the “transition” from digital industry to digital society.

The current transition opens up essential opportunities linked to the aforementioned implementation policies of Industry 4.0 - now Industry 5.0 - and the related enabling technologies based on the principles of digitalisation, automation and interconnection of production processes. In this context, the innovative Digital Twin approaches emerge.

In 2002 Michael Grieves introduced the Digital Twin notion.

During the presentation of a virtual system - mirror of a real object - he called it “Mirrored Spaces Model”, first, and “Information Mirroring Model”, subsequently.

Grieves described its basic elements for the first time: physical products in real space, virtual products in virtual space as well as the connection of the data and information flow to be activated between the two dimensions during the life cycle of the system. (Grieves, 2006)

In 2011 Grieves himself thinned up the term Digital Twin, that is the virtual and digital corresponding of a physical product. (Grieves 2011)

Already several decades earlier, during the Apollo 13 mission in 1970, NASA planned and implemented a digital prototype simulation strategy for the first time. (Allen 2021)

An adaptive digital system was created as a virtual replica of the spacecraft’s behaviour.

It became possible to simulate its potential operating problems in a controlled context, conforming the prototype to realistic use conditions.

That intuition has been transformed into the current concept of the Digital Twin.

This technological evolution-revolution has determined the transition from atoms, whose dimension is material, to bits with informative, informational and immaterial character.

Digital Twins as virtual replicas of physical products allow simulating performance over time; experimenting enhancements without having to test them on material mock-ups of the product itself; changing its shapes and materials; evaluating alternative spatial articulations. (Boschert and Rosen 2016)

Considering their potential impact in all areas - from smart fabrics to smart agriculture, from smart health to smart cities, smart grids, smart buildings - the evolution of Digital Twins embodies the natural development path of the digital transformation launched with Industry 4.0. (Leng et al. 2021)

According to a survey conducted on the adoption of innovative technologies, digital twins are among the five emerging trends that will drive technological innovation for the next decades. (Gartner 2019, Grieves 2019)

Market trends also confirm their exponential growth and great potential. (Research and Market 2022)

Nowadays, the prospects of using the Digital Twin concern all complex production contexts, for which forecasting actions reduce unknown risk or malfunction, both in the design and operational phases.

Many sectors, from aerospace to aeronautics, from complex industrial scenarios to automotive and medicine, use them with ever greater pervasiveness. Albeit with atavistic slowness, this is also happening in the construction sector.

2 Digital Twin approach in Buildings

The Digital Twin for the construction sector is a digital entity that combines the graphic and information model with that of the smart object. It realizes intelligent construction: Smart Buildings, today Cognitive Buildings. “Phygital”, physical and digital constructions whose data and information dimensions as well as modelling operate in synergy throughout the building’s entire life cycle. (Brunone et al. 2021)

The experimental applications of the Digital Twin approaches aim at activating structured decision-making processes to: reduce the impact of buildings and infrastructures on the environment; plan management and maintenance strategies; improve the comfort and satisfaction of end users.

They allow synchronization between physical reality and virtual reality; the simultaneous management of the information available and that acquired through the survey of the operating conditions; real-time monitoring and updating of the data collected by the sensors connected to the physical asset; the detection of anomalies and potential risks; performance simulations using machine learning and artificial intelligence.

The data relating to the social context and the human component can also integrate those previous to ensure maximum optimization of the systems.

Current studies on DT approaches applied to the construction industry identify several themes for further implementation. Among these: widespread use of Building Information Modelling BIM (Parn et al. 2017, Aengenvoort and Kramer 2018, Sacks et al. 2018); its integration with Building Lifecycle Management (BLM) and Product Lifecycle Management (PLM) as part of the data generation process and information management for lifecycle planning (Stark et al. 2019, Qi et al. 2019, Sacks et al. 2020); technology and information-related issues specifically concerning O&M phase and the development of data-driven decision-making (Volk et al. 2014, Alvarez-Romero 2014, Aziz et al. 2016, Chen et al. 2018, Errandonea et al. 2020)

Some other themes focus on the implementation of data entities, types and parameters required for using IFC and Cobie (Hamledari et al. 2018); monitoring and availability of appropriately structured accessible data (Lu et al. 2020, Delgado et al. 2018, Wang et al. 2019); the integration of analytics, control and simulation functions to develop future performance models. (Motamedi et al. 2014, Evans et al. 2019, Delgado and Oyedele 2021, Zhao et al. 2022, Alanne and Sierla 2022).

Today the Digital Twin trials highlight the potential of advanced technologies, already available but not yet widely systemised and at the service of the construction sector.

- The "as built" BIM digital model is the graphic and informative model of the existing building, complete with information and technical specifications relating to the assets it contains. According to the ISO 19650 standard, the "as built" dimension corresponds to the digital representation of the construction systems to which the scheduling of maintenance and management operations during the building's service life cycle is associated. (Volk et al. 2014, Kassem et al. 2015)
- The Internet of Things is the network that allows connection between sensors, software and ICT technologies through Internet. It creates an information infrastructure that activates significant potential data flows relating to physical dimensions and performance of of buildings that become nodes of Smart Grids and Smart Cities, capable of communicating with other buildings, with mobility systems and end users. (Silva et al. 2018)
- The smart connection devices and systems installed in buildings allow the monitoring of performance in use as well as the real-time acquisition and recording of data obtained from Home Automation and Building Automation Control Systems, BACS. By integrating

viewers, virtual reality and augmented reality, allow the usage of the digital model for data visualization and for subsequent simulations and checks. (Pasini et al. 2016)

4 The ongoing experimentations

The as-built virtual model in OpenBIM connected with Geographic Information Systems and managed by Cloud or Edge Computing, the IoT, Internet of Things and the smart connection devices and systems for buildings, are the starting point for R&D actions developed by Academic Spin-off Building Innovative Governance, BIG srl.

BIG srl is a Spin-off of the *Mediterranean* University of Reggio Calabria the authors beings two of the six founders in partnership with ACCA Software Spa. (www.acca.it)

It operates in the field of technological innovation exploiting the potential of Information Communication Technology, ICT, in line with the operational trend of Industry 4.0.

To implement its mission, it assumes the interactions between technological capital (infrastructure and technology), human capital (researchers, companies, professionals, users, etc.), administration (institutions, universities, managers, etc.) and real estate (public and/or private heritage). The goal is to promote the introduction of smart processes for the experimentation, implementation and dissemination of an innovative system for the governance of real estate assets.

The outcomes here presented refer to the development of a Maintenance Management Model, MMM, based on Digital Twin approaches. (Lauria and Azzalin 2020a) MMM, is a response to the innovation and competitiveness needs of the construction sector, especially in regard to management and maintenance of real estate assets. It promotes an active dialogue between the subjects involved, innovative methods of configuration and data collection, in line with the European indications and requirements of the Digital Building Logbook, DBL. (EC 2021b)

The DBL is a repository of all the most relevant information relating to the building, configuring a preparatory action for the effective affirmation of Digital Twin approaches in the O&M phase.

The prototyping, patenting, experimentation and marketing tasks of the MMM, already financed in 2018 with POR Calabria Region funds, have recently obtained a two-year loan from the Smart&Start Italia subsidy program of Invitalia spa.

The Technology Readiness Level of the MMM is equivalent to a TRL6 (Technology demonstrated in relevant environment). The current actions in progress are aimed at the creation of a complete prototype system, equivalent to a TRL8 (System complete and qualified).

Closely connected to the MMM upgrade actions is also the PRESMA Infinity BIM research activity (PRogettazione, ESecuzione e MAnutenzione del modello digitale delle costruzioni per il digital twin della fabbrica “Infinita”) funded by the Italian Ministry of Economic Development, MISE.

The experimentation, currently underway, uses the same methodological approach with applications to two case studies. The buildings of the *Mediterranean* University of Reggio Calabria and the industrial plant of Mangiatorella spa, a mineral water bottling company, one of the most important in southern Italy.

Experimentation relating to the Digital Twin for maintenance is based on a preliminary deductive approach, aimed at verifying the possibility of identifying homogeneous families of properties - characteristics, performance, faults, anomalies, controls, etc. - used for the purposes of interoperable information management in the O&M phase. The quantity and degree of confidence in the information included in the “models” refers to an open process of continuous implementation.

From the initial step, the technologies used for the experimentation of the MMM refer to two distinct but interconnected systems:

- a cloud platform that allows you to take advantage of mass storage for archiving and contextual management of BIM models in a single Common Data Environment (CDE);
- an integrated monitoring system using customer-oriented Building Automation devices, interconnected via IoT to the platform to which the data is transmitted and where it can be viewed and archived in real time.

These devices, exploiting the potential of the Digital Twin in BIM format of the building, allow some general functions:

- coordination of management activities on an open and collaborative platform, Platform as a Service, accessible and usable online by browser;
- connection via desktop or mobile devices between operators and users, guaranteeing the isolation of data and applications;
- customizable visualization and real-time queries through viewers and Virtual and Augmented Reality of BIM models and data transmitted by Building Automation Control Systems;

The real-time monitoring function also configures a potential “observatory” of the phenomena that characterizes the transformations over time of building parts, components and products.

The MMM takes on a smart and digital approach which, in the subsequent upgrade phase of the experimentation, adopts the evolution of the concept from smart building to cognitive building, assuming its essential characteristics. Buildings can thus transform themselves into Intelligent constructions, accumulators and amplifiers of information, capable of detecting, processing, interpreting and communicating the data relating to the functioning of systems and equipment, the state of use, the behavior of users in real time to their Digital Twin, declining the general concept of Machine Learning into Building Behaviour Learning.

Two actions are underway, both strictly functional to the upgrade of the MMM.

- The definition of procedures and tools for the collection, structuring and management of a large amount of heterogeneous data - location, use, safety, accessibility, usability, environmental quality, etc - in an openBIM environment.
- The use of such data for the purpose of simulating and verifying the relative conditions of prevention of critical or risk events, through the system implementation of some specific tools. Information exchange language based on openBIM formats; digital model processing software, which exploits parametric logic; intelligent environmental monitoring systems, sensors and IoT; digital management software for real time monitoring data; cloud platform for the collection, control and processing of environmental parameters, the operation of sensors, systems, etc. related to the current Building Operating Systems.

The specific operations include:

- the connection between the Digital Twin loaded on the platform and IoT integrated in the building;
- the collection of data recorded by the sensors sent in real time to the application which acquires them, analyzes them and makes them directly visible on the BIM model in IFC

format.

- the possibility of controlling the operation of the various plant systems directly on the platform;
- monitoring of environmental parameters: temperature, humidity, ambient CO_2.

Current experimentation takes advantage of the opportunities offered by the growth of the digital sensor sector applied to buildings.

The digital models in openBIM format were created through the definition of specific parameters for the purpose of planning maintenance activities - a Digital Twin for Maintenance - with a first level of connection between interoperability systems and information capital.

Regarding the digital modeling phase, the possibility of using reverse engineering approaches - “scan to BIM” - allows the control and integration of information derived from the design documentation made available by the client.

The construction phase of the digital model of the buildings of *Mediterranean* University has also assumed importance in the context of a parallel experimentation, entitled Bim-basedforcovid19 Protocols, developed in concert with the academic governance. This experimentation welcomed the challenge of managing buildings in an emergency and post-emergency regime from Covid-19 from a Digital Twin perspective. It proposes Smart BIM-based Protocols to manage spaces, to control some environmental parameters and to monitor user behaviour. (Lauria and Azzalin 2020b)

Sensors connected via wireless technologies, smart metering, remote reading and remote management smart meters, etc. associated with Building Management System, BMS, today Building Operative System, BOS, allow both to centrally manage the monitored data, and to transmit them to centralized platforms. This makes it possible to connect not only the rooms of the same building but also several buildings at the same time.

The “phygital” association of the physical and digital world allows the monitoring of both systems, prevent problems, develop new opportunities and simulate future behaviours.

5 Discussion

The development of smart buildings is easier when concerned with a new design. The real challenge exists in being able to integrate current digital technologies into existing buildings.

Intelligent construction offers an overall opportunity to contribute to energy saving and decarbonisation both at the design stage and mainly in rethinking, redesigning and modernizing existing buildings. This is today an essential goal.

The challenges for the future concern the ability to activate integrated and synergistic processes capable of simultaneously understanding the adaptive capacity of both physical systems - territory, cities and buildings - and social and economic systems - communities and circular economies.

The centrality of a new machine-friendly and interconnected spatiality makes it possible to equip buildings - intelligent constructions - with systems and devices that carry out activities, provide services, collect and return data, exchange information between man and man, between machine and machine, between man and machine.

This framework shows the need to define the correct flow of information regarding each of the operators involved (the who); the time-table through which the aforementioned information must be entered and/or must be available (the when); the method in which it is entered (how and where). Requirement also confirmed by the recent indications that the European Commission has expressed defining DBLs, as tools to ensure shared methods of collection, structuring and subsequent processing of all information relating to buildings in their life cycle.

Today, technologies and various hardware, software and cloud applications are increasingly performing. They can manage and process an increasing amount of information, favouring its sharing.

The significant amount of data that is generated by the sensors (Big Data) and stored in cloud databases become the raw material for automatic regulation, predictive control and maintenance of building and its systems.

Widespread and pervasive use of Digital twins, enabled by IoT, AI, and virtualization can give impetus to promoting this new vision connected with the concept of smart and cognitive buildings, declining the general concept of Machine Learning into Building Behaviour Learning.

Some benefits arise: from technical to environmental and economic.

Several issues remain for further research: the punctual information framework to refer to, the interoperability of information, as well as the management of bidirectional interoperability between modeling and simulation software, and also of management.

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