Chapter 12
Digital Information Management in the Built Environment: Data-Driven Approaches for Building Process Optimization

Francesco Muzi, Riccardo Marzo, and Francesco Nardi

Abstract In Italy, the traditional management of construction works, throughout life cycle, still dominates the market compared to a digital approach. This research aims at bringing out the potential and benefits of a digital management by developing strategies and methodologies able to optimize processes related to three different use cases. The proposed use cases have been developed by applying digital methodologies to different building contexts, aiming at both site management and management of the built environment. The first case deals with an important public building of 35,000 m^2 located in a residential context in the center of Rome. The use of digital methodology made it possible to optimize and prevent problems related to large-scale works and construction sites located in central residential areas. The second case concerns a residential complex of 16 buildings located in Rome, where the BIM model supplies a constant flow of information for predictive maintenance system. The last one refers to port infrastructures located on the coast of Lazio region in Italy. The digital information model was developed to set up a risk management system capable of safely managing the port's main assets. In conclusion, the results achieved through the implementation of a digital approach generated by a structured information flow integrated with the BIM model, allowed an optimized management of time and economic resources in the three case studies mentioned, although the diversity of objectives and types of construction works. This improvement is made possible by a shared and connected digital model, characterized by a high level of geometric and informative detail and cloud computing strategies to enhance process efficiency, supporting decision-making and information management.

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E. Arbizzani et al. (eds.), *Technological Imagination in the Green and Digital Transition*, The Urban Book Series, https://doi.org/10.1007/978-3-031-29515-7_12

Keywords Digital construction management · Building Information Modeling · Construction management · BIM

12.1 Introduction

The traditional management of building infrastructures has been overturned by the processes of building automation (Quinn et al. 2020), thanks to technological development that allowed considerable progress toward a digital (Dahanayake et al. 2021) and environmentally sustainable (Rosa et al. 2022) management. This evolution coined the concept of intelligent building, able to manage different systems on a single digital and interoperable asset, exchange information flows, and perform actions in relation to the derived parameters. Part of the management process is the use of IoT devices and the connection of each device to the network (Dave et al. 2018).

In this way, connected objects (e.g., light bulbs or cameras) create an information database that provides more specific and adaptable services. This revolutionary process leads to the development of cloud-based platforms that move big data into virtual memories (Tomazzoli et al. 2021). In the era of building digitization and the renewal of the construction industry, it is important to capitalize on the advantages of BIM to optimize workflows and improve the management of the life cycle. The Building Information Modeling methodology implemented with IoT devices and Artificial Intelligence algorithms, in fact, allows the creation of a digital twin that replicates the real building and contains all the information needed to control the building process, from concept to maintenance (Agostinelli 2021). The digital management achieved through Building Information Modeling (BIM) enables the construction industry to improve all phases, from better planning of resources to improving collaboration between various disciplines, helping to keep the project on time and on budget (Ruperto et al. 2019). BIM is a digital methodology that represents a method of managing construction and infrastructure projects, suitable for digitizing the representation of assets to build and as-built, optimizing entire processes (Cinquepalmi et al. 2019).

12.2 State of the Art

The BIM model under study is created and prepared to follow the regulatory evolution in the field of construction, in order to generate a virtual environment able to provide information about the status and the building systems that compose it. Combining BIM model with IoT devices and ML systems is set up the concept of digital twin (DT) as a digital object into which information can be input and output (Guidi et al. 2020). The DT enables the collaboration between artificial intelligence and data analytics to create dynamic and predictive models that can learn and update the state of its physical opponent. The aim of developing these technologies is the creation and setting of intelligent buildings that transcend the areas of comfort, optimizing performance and reducing energy waste.

This is made possible by the creation of digital twins of infrastructures capable of generating predictive models that enable the establishment of smart cities. The development of new technologies makes the innovation process possible and aims to improve it through digital management (Piras et al. 2022). One of the main aspects dealt with in the case studies is related to data management. In fact, the use of cloud-based solutions for collecting, sharing, and using information is planned. In addition, for management, maintenance activities include the use of digital solutions for automated building maintenance such as cable robots for facade cleaning, integration of IoT devices for security, and building monitoring at the users' service. It can therefore be claimed that the methodology proposed in the three case studies is aligned with the digital transformation process and directs in its application the activities toward aspects of optimization and mitigation of delays.

12.3 Methodological Approach Strategy

In this work, the digital BIM methodology (Matarneh et al. 2019) plays the role of common denominator in the three case studies described. The system devised is illustrated in Fig. 12.1, where the project placed at the center of the process plays both the role of objective and protagonist.

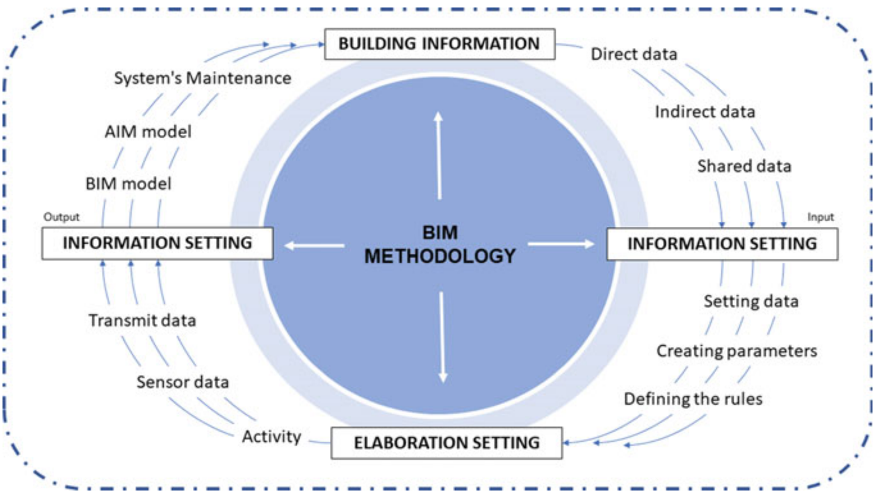

Fig. 12.1 BIM methodology workflow for the digital twin—R. Marzo (Next City Lab)

The implementation of a digital model with a high level of information requirements (LoIN) builds a digital twin capable of transferring data from the building to the virtual reproduction (Liu et al. 2021). This information, obtained from IoT devices, makes it possible to structure an information database. Through the processing of this data, it is possible to set up energy analyses for consumption management and maintenance analyses for building asset management (Heaton et al. 2020). In the first case study, the time and cost management of a 4D and 5D BIM model based allow stakeholders to prepare simulations and forecast scenarios aimed at optimizing resources (Agostinelli et al. 2019). Moreover, this digital model can play a decisive part in the definition of predictive maintenance and energy management strategies as analyzed in the second case study (Gonzalez et al. 2021).

Finally, in the case concerning port areas, the process led to the management of strategic assets for Risk and Safety Management activities (Rodrigues et al. 2022). The assets are digitized to pursue Facility Management strategies aimed at providing very high-performance standards in each case study. The big data are then used by information models in CDE's shared environments (Abbasenejad et al. 2021) (Fig. 12.2).

The approach is therefore guided by the thread of parametric modeling with informative objects. The assets are described, modeled, and computerized in order to pursue the strategies of the facility, intended to ensure very high standards of performance in each case study. The attainment of the objectives passes therefore from the predisposition of the geometric, spatial, functional, and technological information, and the successive step is defined from the use of the informative models in environments of sharing CDE (Abbasenejad et al. 2021).

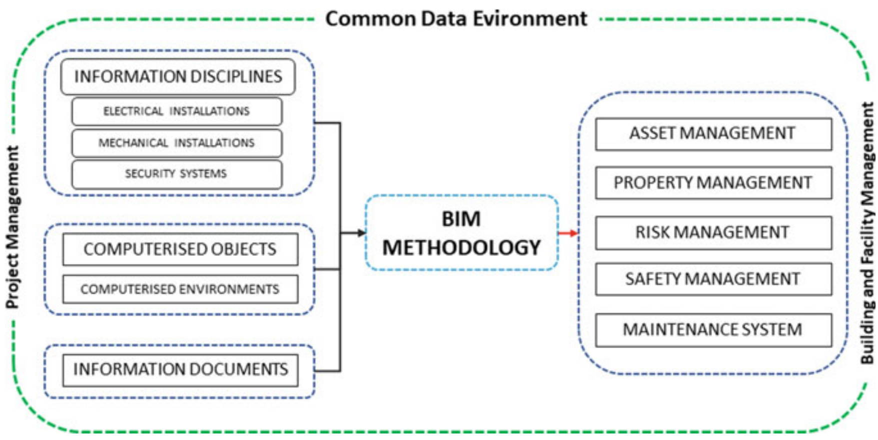

Fig. 12.2 Key point in Common Data Environment—R. Marzo (Next City Lab)

12.3.1 *First Case Study: Public Building in a Residential Area*

The application case (Fig. 12.3) discusses a 35,000 m^2 building owned by a public institution (CDP), located in Rome in a central urban context. The building was built starting in 1914 and officially opened in 1928, became the headquarters of the Istituto Poligrafico dello Stato and later the site of an industrial activity until 2010, when it was abandoned. Requalification work began in 2021 thanks to the intervention of a large Italian company (ENEL) that decided to transform part of the building into their offices. The project is driven by environmental sustainability and from the conceptualization phases of the program and construction design based on two cornerstones, respect for historical memory, with high-quality restoration, and a new modern architecture for the volumes on the rooftop. The benefits of the requalification are not only limited to the building proper but extend to the urban context. In fact, the upgrading process is aimed at following high international standards to pursue a positive impact in the construction and operation process. The construction site is monitored by IoT sensors that transmit data to a CDE to track and provide a measure of the estimated 8% reduction in CO_2 emissions in the neighborhood area. The project (Home page Piazza Verdi project, https://www.poligraficopiazzaverdi.it/il-progetto/) has an investment of €160 mln in public funding, and the project phases include the preparation of a renewal of the exterior facades, a new distribution of interior spaces, and the construction of a four-floor underground parking garage. The digital approach of the implemented process is oriented to the management of the future real estate asset by furthering FM strategies, such as energy management, asset management, property management connected to Business Intelligent services. Facility strategies are supported by the presence of a digital model, defined Asset Information Model (AIM), which by geometric and informational structuring is able to empower operators and management of operational phases with the knowledge and technical instruments to be able to manage and maintain the asset.

In this case, the preparation of a parametric digital model with high information content, obtained by applying a Building Information Modeling (BIM) methodology, allows the actors in the construction process to communicate precise information and to forward it at the end of the process, associated with a 3D model which can be consulted and is updateable. This peculiarity of BIM is made possible with the structuring of a Common Data Environment (CDE), a common data storage useful for the transmission, optimization of the worksite phases, and the subsequent management phase of the work. The creation and use of a DT for the maintenance and management phases of the asset, as a step subsequent to the architectural regeneration, allow the asset's owner and future manager to equip their selves with an FM model even from the realization phases, predicting critical issues and problems before the work is put into operation.

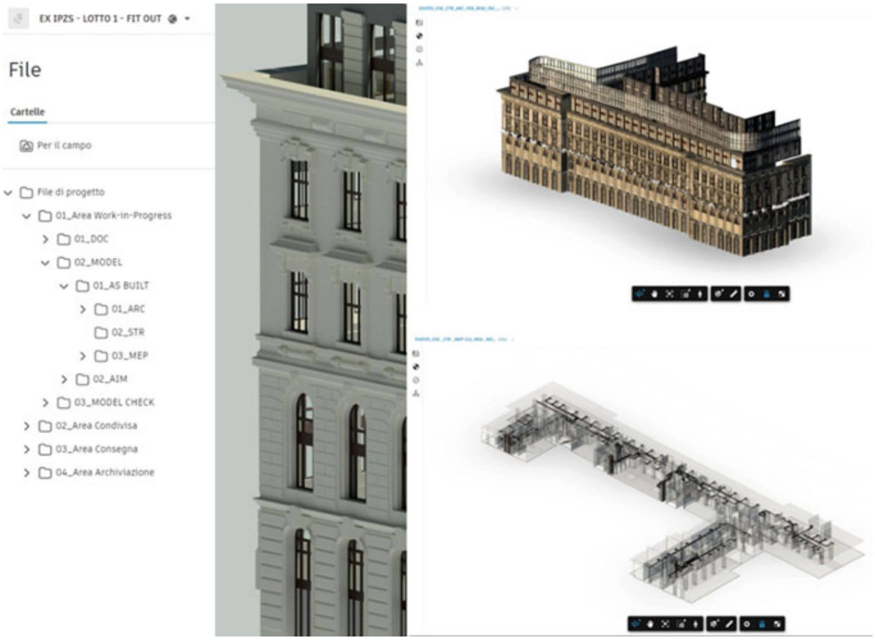

Fig. 12.3 Common Data Environment of the project, example of queryable information on facade restoration and installation of mechanical system

12.3.2 Second Case Study: Residential Compound

The case study (Fig. 12.4) concerns a residential complex composed of 900 flats located in Rome.

The complex represents a state-of-the-art building system for the use of materials and for the use of energy systems powered by renewable sources. Through a detailed quantitative and qualitative analysis of the entire compound, the realization of the as-built BIM digital model began, which was implemented with a high amount of information related to the project. This connection made it possible to design a

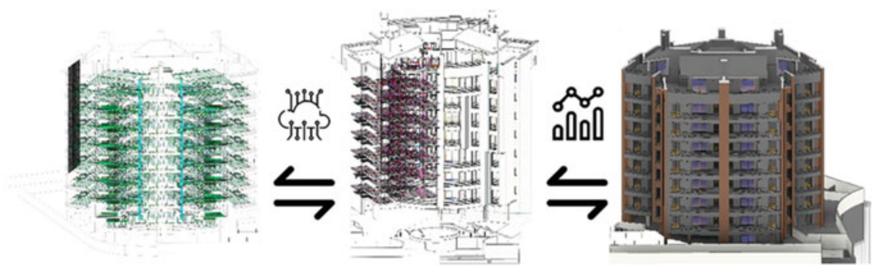

Fig. 12.4 Digital twin representation of the residential complex

digital twin capable of providing economic-temporal simulations for the production of innovative and functional solutions to support decision-making. This virtual duplicate therefore allows the physical part to be optimized to make it more efficient and adaptable to technological-energetic developments in the building industry.

Predictive maintenance methodology. The process developed and applied to the building complex concerns a predictive maintenance strategy to improve the performance of mechanical and electrical systems.

The strategy can provide a customized maintenance service based on machine learning systems to reduce malfunctions and failures. The amount of data needed to support decision-making activities is obtained after a certain period of time (maximum three years). This period depends on the duration of the maintenance loops: for example, an item with weekly maintenance operations reaches the target necessary for its full operation much earlier than items with monthly maintenance periods. This methodology determines an acceptable failure rate of components on the basis of statistical data derived from specific maintenance reports drawn up by the operator. If the failure rate is exceeded, the maintenance period is reduced by the difference between the real failure rate and the target failure rate. In this way, that item should remain functional in the next maintenance operation. In addition, labor costs can be combined with the duration of each operation to analyze costs. In this case study, the analysis concerns the mechanical, electrical, and lighting systems that supply the outdoor and communal areas, without considering the flats for private use. Predictive maintenance through big data analysis has been shown to substantially improve the overall operation of the residential installations investigated through the optimization of maintenance cycles. The aim is to enable the entire production chain to reduce maintenance time and increase productivity, thereby reducing costs and responding flexibly and effectively to consumer needs.

12.3.3 Third Case Study: Port Infrastructures

The use of this digital approach can also be seen in the third and last case studies analyzed in this section (Fig. 12.5), a set of parallel projects involving the port areas of Anzio, Terracina, Formia, and Ventotene, located along the mid-Tyrrhenian coast. The common objective of all these projects was to implement and improve the traditional real estate, in other words the complex of services for the management of buildings and real estate in general, declined according to its five main management activities, specifically those of Asset Management, Project Management, Property Management, Building Management, and Facility Management, through the adoption of a digital approach and, specifically, the use of BIM processes with the potential to improve communication between all actors involved, safety; optimize maintenance and in general the management of the life cycle; increase the energy, space, and economic awareness of the asset. The core of these objectives is the creation of

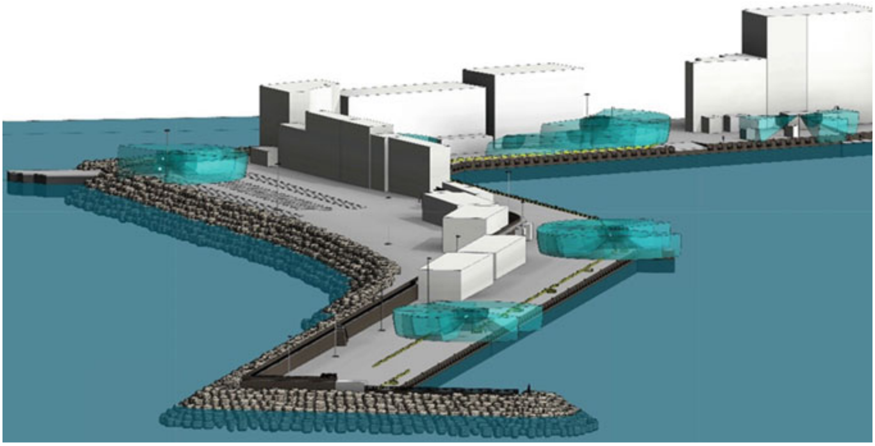

Fig. 12.5 Digital twin representation of security system

detailed parametric models in which the large amount of data describing a vast asset such as a port area, meant as a complex of buildings, infrastructures, and equipment, can be collected and stored.

Focusing on the port area of the city of Anzio, the digital revolution mainly involved the areas of Risk Management, Security Management, and in addition, Energy Management. The use of the BIM model for the assessment and consequent energy efficiency of the port area, with regard to urban lighting, highlighted the presence of isolated areas with poor lighting and lack of video surveillance cameras, consequently, focused attention on the problem of security. The first phase involved the identification of the risk, which means the areas considered critical from the point of view of safety, taking into consideration a series of factors, which can be summarized as follows: location of the area in relation to the built-up area, level of occupancy, public lighting, and coverage of the video surveillance system. The second phase examined the risk assessment and can be summarized in the creation of an automatic area classification system, obtained by translating the above-mentioned qualifying factors into precise rules, combined and merged within an algorithm capable of returning, according to a pre-established coding system, the result of the analysis for each sub-area, into which the entire port area was automatically subdivided, obtaining a decision support tool. The identification of the areas with the highest risk consequently made it possible to circumscribe and focus the design and economic effort for the implementation of security in the port area. The main area of intervention concerned the implementation of the existing video surveillance system, supported by the introduction of an advanced computer vision system to identify specific critical circumstances, such as intrusion attempts, assaults, and similar.

12.4 Conclusions

The objective is to provide a predictive system for maintenance and safety, an intelligent management capability, and at the same time, a data sharing environment accessible over time and upgradeable. The idea of the digital twin as a model for managing and controlling physical systems based on Big Data has emerged over the last decade in industrial sectors. BIM platforms were developed in response to the need for more effective tools for management, allowing processes to evolve to meet the requirement for digital prototyping in construction. In fact, the proposed projects made it possible to create, on a rich database, a digital reproduction of the work, able to accurately simulate and estimate activities and possible interferences, providing a better and faster execution. In the three case studies described above, the efficiency of a dynamic digital approach is highlighted by the inefficiency of traditional systems. Looking forward future developments, this methodology can be set to make it usable and replicable in different projects for managing the built environment by exploiting business intelligent systems powered by big data.

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