Chapter

Digital Transformation in the Construction Sector: From BIM to Digital Twin

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Abstract

In the next years, perhaps more than ever before, a technological revolution will transform the construction sector in all its aspects, greatly affecting services, production, and supplies. With BIM, and even more considering the Digital Twin topic, the innovation of tools has entailed a methodological innovation for the whole sector, owing to virtual reality simulations and actual dynamic real-time monitoring. This research, starting from an integrated analysis between the current research trends and some relevant national and European projects about the digitalization of construction sector, aims at providing a systematic analysis of some of the pillars that are guiding this phenomenon. In detail, the state of the art, activities, and trends of standardization and platform development in construction sector are considered and intersected to provide a clear background towards the future trends in the sector.

Keywords: BIM, digital twin, digital platforms, standardization, process management, construction

1. Introduction

In the next years, perhaps more than ever before, a technological revolution will transform the construction sector in all its single aspects, greatly affecting services, production, and supplies. Freehand drawing, drafting machines or CAD have represented innovative tools in graphic representations. In such cases, the evolution of tools for the productivity of the sector has improved and quickened the design, but not more than that. With Building Information Modeling (BIM), and even more considering the Digital Twin (DT) topic, the innovation of tools has entailed a methodological innovation for the whole sector. Around BIM and DT several technologies and topics needs to be analyzed including virtual reality simulations, dynamic real-time monitoring and controlling, data driven decisions, etc. Nowadays, several drivers can be identified in the evolution of both the research and the industrial applications. Hence the need to provide a systematic analysis that can provide a clear background useful for future research works. Among these drivers the standardization activities and the development of digital platforms for the construction sector represent key points for the understanding of the ongoing research and development in the digitalization of the construction sector. The work here presented has been developed starting from an integrated analysis between the current research trends and some relevant national and European projects about the digitalization of construction sector and considering a perspective view that comprehend the history and evolution of the BIM topic and its implications.

This research aims at providing a systematic analysis of these two pillars considering the intersection of both the research trends and the results obtained from the development of some key national and European projects. The results here proposed can inform future research paving the way for the development of new works around these two key drivers of the digital transformation in the construction sector.

Following these directions, this chapter is organized as follows. Section 2 reports a brief analysis of the main evolution points that shaped the change from CAD to BIM. Section 3 proposes an analysis of the standardization framework analyzing the existing works and the ongoing and future activities. Section 4 reports a presentation of some of the main projects that have been developed in the context of the development of digital platforms for the construction sector. Finally, Section 5 reports the conclusions of the chapter.

2. BIM: from CAD to BIM

2.1 The first steps

In the last two decades the work of designers has radically changed not only in relation to conceptual differences in the representation of the project [1], more and more oriented to 3D development as a model from which to derive two-dimensional drawings of plans, sections and elevations, but also in relation to the technical instrumentation offered by the software and hardware capabilities related to the representation and simulation of the project, with inevitable repercussions on the professionalism and responsibility of individual actors [2].

On the one hand, the ability to represent the project as classically occurred in the past has remained the same for centuries, delegating to the designer the realization skills of his own project, with responsibility for all parts of its development and the obligation to represent and describe every single piece of information destined to its best realization; on the other hand, the step change that occurred with the digital design processes was first slight with the introduction of the first two-dimensional CAD, then more and more involving with the transition to BIM [3].

The transition from manual drawing to CAD [4] takes place as for BIM starting from the mechanical and precisely automotive industries; the need for absolute precision in the design for production is required by the simulations related to the efficiency of vehicles as well as the hypothesis of making the house a machine for living is becoming more and more possible.

In a traditional design workflow, the designer generally worked on his single area of expertise and from a preliminary architectural content descended the structural and plant choices unless required by a state of necessity. The subordination of actions in the development of the project was very clear and the roles as well. With the advent of CAD and the use of different layers this position of absolute dominance over the project begins to waver, if only for the possibility of greater flexibility in the construction of variants compared to previous workflows. Coordination becomes part of the design routine, at least above a certain size, and a process of modernization of the workflows takes place. Coordination has very specific goals: smoothing out conflicts, introducing compatible variants, correcting layers. There remains a vast waste of forces and time to correct different layers, sections, up to a better coordination between the windows of the model space but still in two-dimensional and limited scope. The discordances between those who work in architecture and those who work in engineering remain also when we try to visualize the project: for an architect it's about evaluating the space and the perspective views or anyway the 3D sketches are the most used means; for an engineer the most adequate representation concerns plans and construction details.

In the early days of the BIM revolution [5], the first calculation applications linked to CAD tools, some first library of materials and objects, offered as blocks, mainly linked to price lists, came forward.

When BIM arrives, the revolution is disruptive; the designer's point of view changes from the setting, working primarily from the 3D model. The sub-units of the model are objects, parametric, informed, and offer rapid possibilities in their transformation, in the modeling of the whole [6]. The preliminary phase of the project already brings in itself more information than necessary, having the single objects parameters defined; some argue that this definition from the first phases of the project of the objects risks binding the less experienced to the design. Nevertheless, the obtained model results the only true DB of all the information on the project, through which we can build the base documentation and not only.

In addition, the parametric model combines the expectations of two worlds: the expectations of architects, who want to visualize the project at 1 m from the ground, and of engineers, who want to visualize what is in the project, such as in the walls or floors, finds a point of contact [7].

2.2 BIM model definition and introduction of a disruptive process

Once the backroom battles that accused BIM of deadening the creative process of designers have died down, process integration comes into its own. Geometric information alone does not allow the representation of the project necessary for the BIM process in its entirety, and therefore BIM proposes an object-based representation. In the case of construction, this translates into a representative schema modeled around the project entities and their mutual relationships.

In the definition of the floor object, for example, the geometry constitutes only one of the different properties of this building element; a room consisting of floors and walls, in addition to the geometric data will contain information such as connected walls and adjacent spaces. We speak not only of model set-up but of "building representation", considering the specific domain of information integrated in the objects.

As the structural principles of object modeling are reshaped, metrics are introduced to measure the actual application of BIM within production facilities; as the level of maturity of BIM adoption increases, so do the levels. Level 0 represents the initial form of the introduction process; generally, people still work in two-dimensional mode, with 2D drawings enriched by data without shared standards. We are in traditional procedures, prodromes of a real BIM and far from an object-based structure. In level 1 standardized structures and formats are introduced, certainly in the design phase there is a 3D phase enriched by 2D documents with design information; however the collaborative phase is still remote and federated models are not yet in progress so the strengths of BIM are not yet used. At Level 2, we are already thinking in a fully collaborative environment: all parties are using 3D CAD models, and collaboration comes in the form of how information is exchanged between the various parties through common file formats that allow anyone to create a investigable federated model. So, we are in a 3D environment with attachments where the starting disciplines are still on separate models that can be assembled. At level 3, sharing and collaboration between disciplines is total. There is a single design model allocated in an IFC-compliant repository referred to in the following lines. At Level 3, the design team has overall control over design and construction, and design optimization is achieved. In Level 3, we talk about a fully open process and data integration enabled for standards-compliant "web services." (**Figure 1**)

2.3 Federated models and shared environments

The need to deal with a common language, to share procedures and basic documents, to use interoperable and sharable software, a choice reinforced using BIM within the Public Administrations, together with the need to have reference figures for certain categories of work in the design flow, to be able to build environments of data sharing determine at first a disruption in the organization of work [8]. In BIM the information flows related to the project are integrated; there is a shift from a "document-centric" approach, to an innovative "data-centric" approach, with attention paid to the entire life cycle of the work; the BIM model therefore immediately guarantees the complex management of the building and distributed over time starting from the design, planning for the realization, estimation, up to the realization and management of the work.

The big step forward is about the ability to work synchronously on the same model as the key element; each project is modeled in relation to a number of models focused on specific disciplines. The models are associated with a federated model, a centralized repository of information for the entire project. In a typical construction project, the federated model may consist of the architectural model, the structural model, and other specialized models containing all the relevant information provided by the building owner, architect, structural engineer, mechanical engineer, plumbing

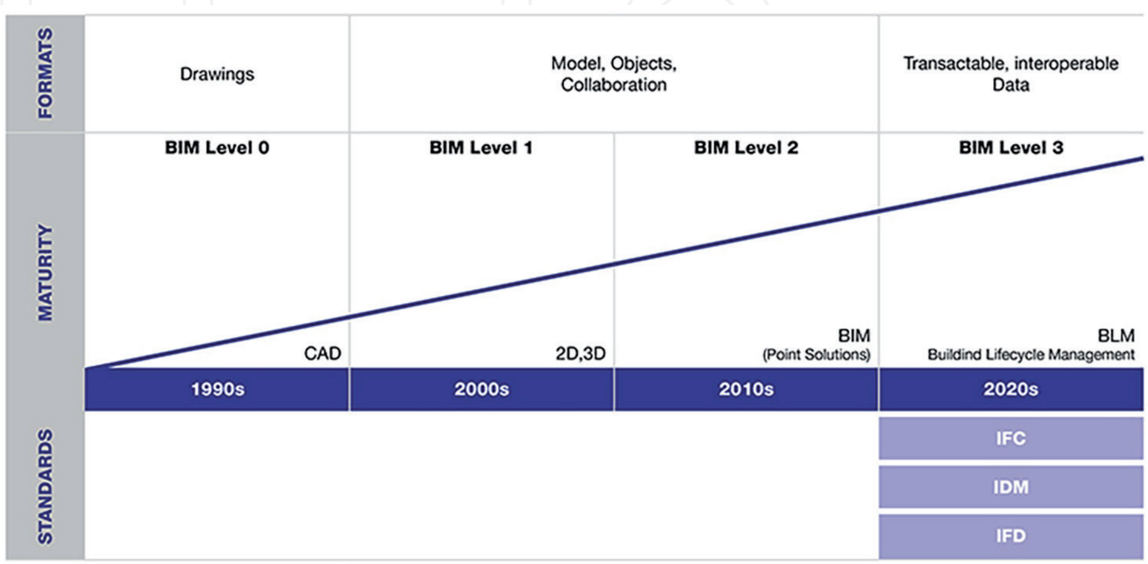

Figure 1.
Levels of insight into the use of BIM, from level 0 to level 3 objective, BSI PAS 1192–2.

engineer, and contractors. It is easy to understand how the possibility of cooperation between the different types of design and the consequent management of conflicts can be resolved through platforms, but not only; shared work imposes the sharing of procedures and requires a shared environment, favoring the construction of digital environments where information can be transmitted.

The sharing environment is CDE, in Italy, better known as Common Data Environment [9] abroad: it is an environment of organized collection and sharing of data related to models and digital works, referring to a single work or a single complex of works. The professional figure who deals with the management of the Data Sharing Environment and the information dynamics based on the introduction, exchange, management and storage of data is the CDE Manager. The Data Sharing Environment Manager is a figure who is in charge of the data sharing environment implemented by the organization to which they belong.

2.4 BIM dimension and new professionalisms

For the intrinsic properties of the models in BIM environment they lend themselves to simulation processes even complex enough; we can consider them as prodromal to the development of Digital Twins. To explain their natural inclination to the complex management of the built environment, a scale of dimensional values, from one to seven, has been coined to describe the intrinsic characteristics within the workflow; after the second and third dimensions of BIM, graphic representation of the work in 2D, function of the plan, or 3D, function of space, the fourth dimension 4D is introduced to simulate the work or its elements as a function of time, as well as space; the fifth dimension 5D [10] as a function of economic value; the sixth 6D as a function of simulating the work for management, maintenance and eventual disposal; the seventh 7D as a simulation of the work as a function of economic, environmental and energy sustainability of the intervention (**Figure 2**).

For the management of the whole process new roles are needed and different degrees of specialization are introduced, keeping the focus of the activity linked to the management of the model even if informed; also the UNI 11337–7 [11] standard

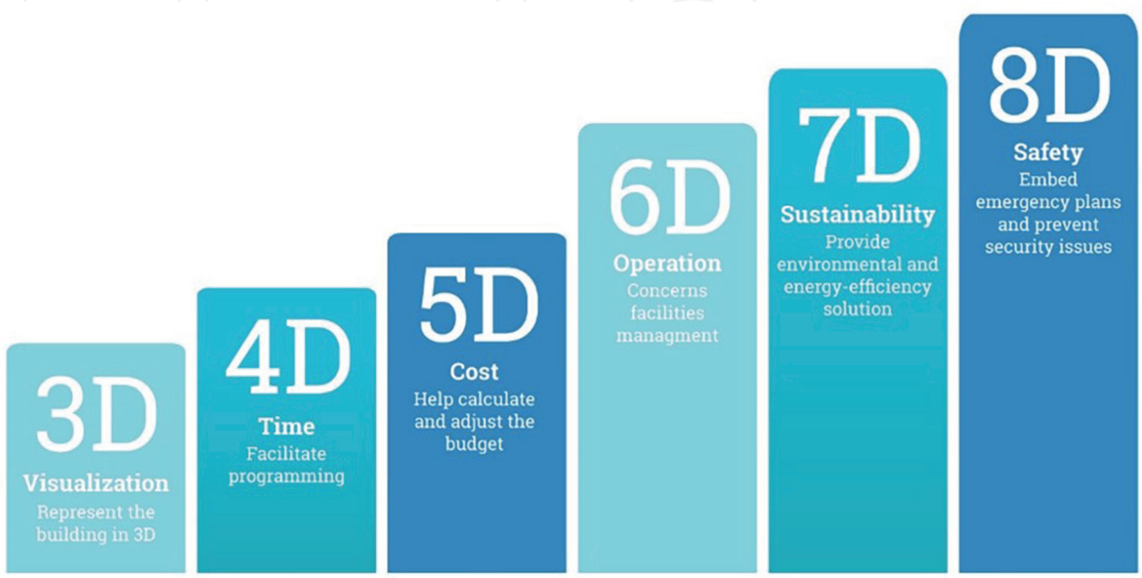

Figure 2.
BIM "3D-7D" graph [10].

identifies roles, knowledge and skills associated to the professional activities involved in the BIM information flow, aggregating the roles foreseen by previous British standards in the following four roles. The BIM manager is considered for the general supervision and coordination of the projects from the information point of view. This is the person who defines the BIM instructions and the way in which the digitization process impacts the organization and the work tools. The BIM Coordinator operates at the level of the single order, in agreement with the top management of the organization and on the indication of the BIM Manager. The BIM Specialist is the advanced operator of management and information modeling and usually acts within the single orders for authoring activities through digitization procedures and object modeling and management.

Generally, he follows the elaboration of the model and also interfaces with the CDE Manager. The BIM specialist must know the software for the realization of a BIM project, according to his own disciplinary competence (architectural, structural, plant engineering, road, hydraulic). He must understand and use the technical and operational documentation for the production of drawings and models (standards and procedures); he/she must "model the information" for the graphic and non-graphic models, interfacing with the supervision and coordination of the BIM Coordinator or the BIM Manager of the company or of the design group in order to elaborate the graphic models and the related objects and their libraries; he/she must extract data from the models, from the drawings and from the objects; he/she must modify the models and the objects derived from the coordination between models and from the project revisions. Its intervention is part of the digital workflow enhanced by the ability to analyze the contents of the information specification and the information management plan having full capacity to verify the information model, and to validate its consistency.

2.5 Interoperability standards and ongoing evolutions

The progressive transition to BIM has created an inevitable proliferation of software products related to information modeling [12] in which the model can find full expression of its geometry and related information. However, the coordinated work between different teams, as well as forcing the sharing of data in a common environment, imposes the solution of problems related to communication between software. The software is proprietary, with problems of communication between each other such as to require an open format whose purpose lies in neutrality towards commercial brands of software to share sets of projects and assets through standards of communication and data exchange. The attempt to standardize data transmission through the use of an open format has decades of history (**Figure 3**).

Over the years, the evolution of the data schema has added multiple degrees of complexity to its hierarchical structure based on the entity-relationship model, to provide a data transposition that preserves more and more information and the consequent relationships. Currently the IFC standard can standardize and codify different components of the BIM model: the recognition of the object in an automatic way, the information on characteristics and attributes, the relationships with other objects, all this to transmit the information model keeping the logic and the geometric-documental information connected to it. However, the IFC attempts to enclose in a predefined logical scheme a context, such as the construction sector, which is represented by a greater degree of complexity than is currently possible to unravel by computer and this particular points it is that one that renders still more important the geometric definition of the model like first interface with the consumer destined to the understanding of the model.

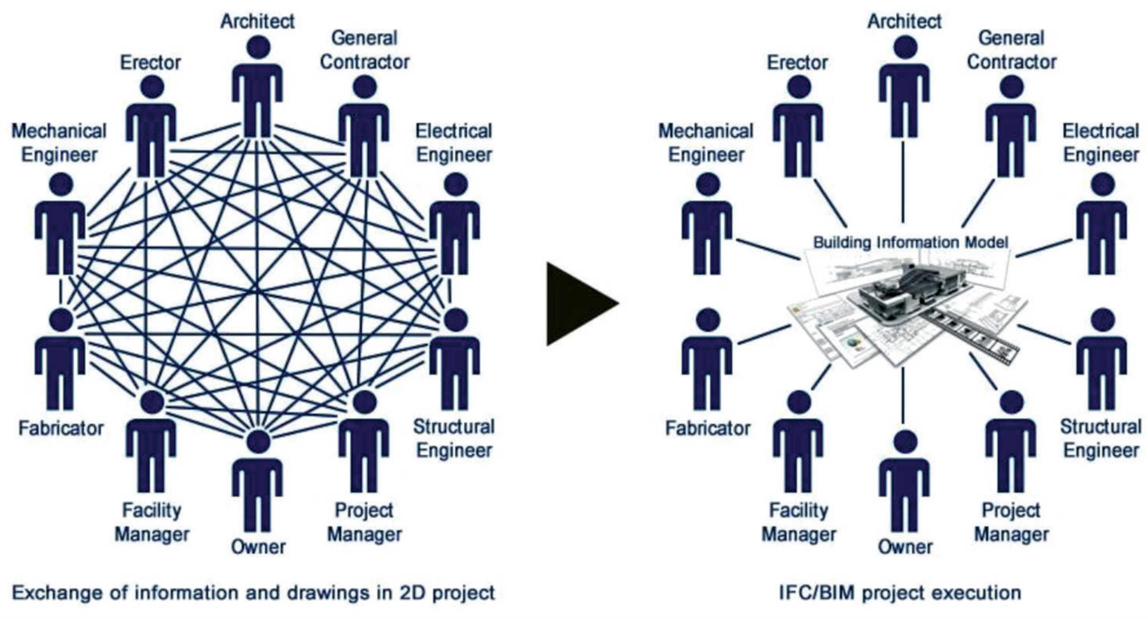

Figure 3.
Interoperability [12].

3. BIM standardization: UNI, CEN TC442, ISO TC59 SC17, buildingSMART

The evolution over time of Building Information Modeling can be traced back to three fundamental aspects:

- technological evolution;
- legislative developments;
- evolution of technical regulations.

The technological evolution can be traced back to the transition from CAD (Computer Aided Design) software systems also dedicated to the construction sector (from the early 80s) to Object-Oriented programming systems of the AEC (Architecture Engineering Construction) domain, also known as BIM Authoring software (starting from the late 80s and with considerable development since the late 90s—**Figure 4**).

The legislative evolution (laws, mandatory rules), especially in the European panorama, can be traced back to the strategy of relaunching the construction sector of the British government after the systemic crisis of 2007/2008 and the related PAS (2011–2013) which they achieved (**Figure 5**): the obligation of government BIM public procurement above 5 million pounds in 2016 in the UK; the introduction of BIM in voluntary form in the European Procurement Directive of 2014: the consequent transposition of BIM in the contract codes of the EU member states (by 2016) and, for example in Italy, the introduction of mandatory BIM from 2019 to 2025 (complex works greater than or equal to 100 million–2019; each works over 1 million euros–2025).

The regulatory evolution at the level of the practices and standards presents three fundamental moments, corresponding to the production of three reference documents (**Figure 6**): the PAS 1192–2 UK (2013), the BIMForum LOD Specifications USA (2013) the BIM Project Execution Planning–of the Pennsylvania University, USA (2010).

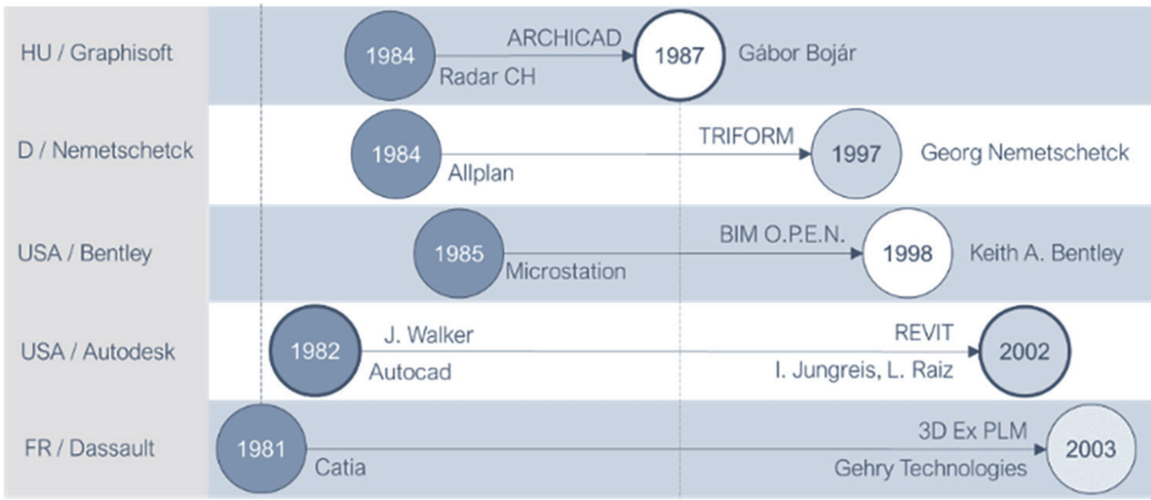

Figure 4.
Tools evolution to BIM (example).

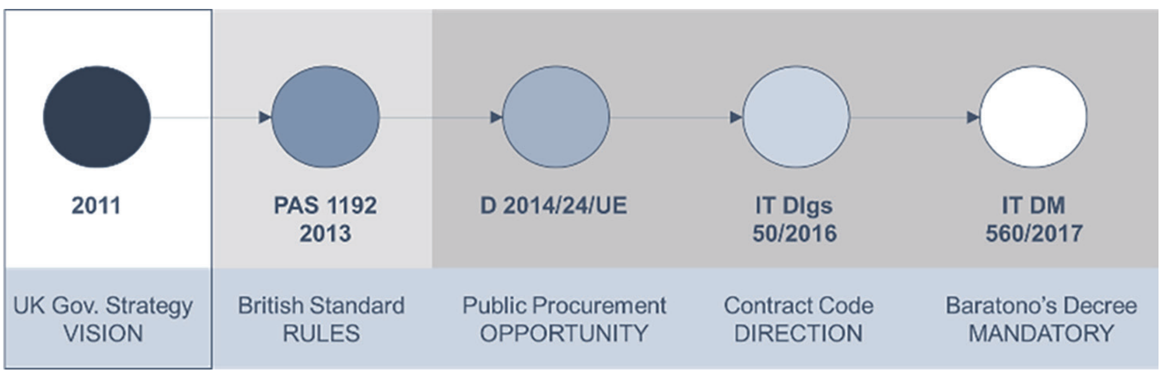

Figure 5.
Laws evolutions to BIM (EU).

Figure 6.
Main technical specifications and reference practices for BIM.

These constitute, on the one hand, the arrival points of the first works and standards on BIM (ISO STEP 10303; ISO 16739—IFC), on the other hand, the principle of all voluntary technical regulations now in use (**Figure 7**): worldwide at ISO level, in Europe at CEN level and in each individual state (e.g., Italy, Great Britain and United States of America) at UNI, BSI, ANSI levels among others.

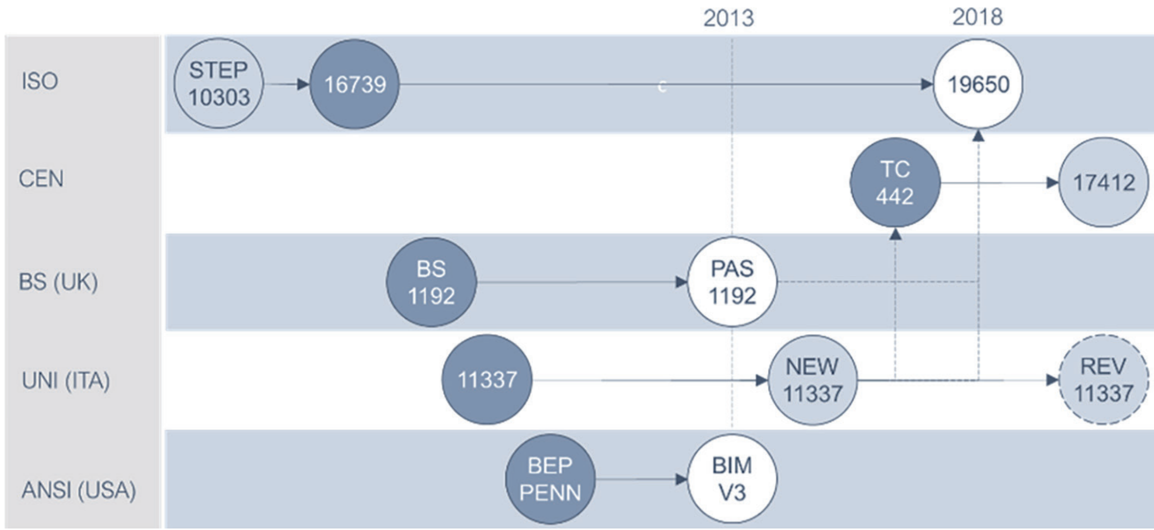

Figure 7.
BIM standard evolution in the world.

The voluntary technical standards are non-mandatory regulatory references that the market adopts to define a workspace–market–within whose boundaries all the actors concerned recognize common principles, shared, with which to operate to protect everyone and the market itself. The standardization body that operates internationally is the International Organization for Standardization (ISO), and its standards take the acronym: ISO. The standardization body that operates at European level (and some added states including Great Britain) is CEN, and its standards take the acronym: EN. CEN is part of ISO. For BIM there is an agreement called "Vienna Agreement" for which (from 2017) each ISO standard automatically becomes a CEN standard (without specific further adoptions). The ISO standards on BIM, after 2017, are therefore ISO EN standards. Finally, each state has its own national standardization body (for Italy the UNI, for Great Britain the BSI, for the USA the ANSI, etc.). They draw up the national rules valid in the specific territory in the national language. For the EU countries the EN standards are automatically adopted even at national level, therefore, in the BIM panorama, the ISO and CEN standards are for example: in Italy UNI EN ISO, and in Great Britain BS EN ISO (**Figure 8**).

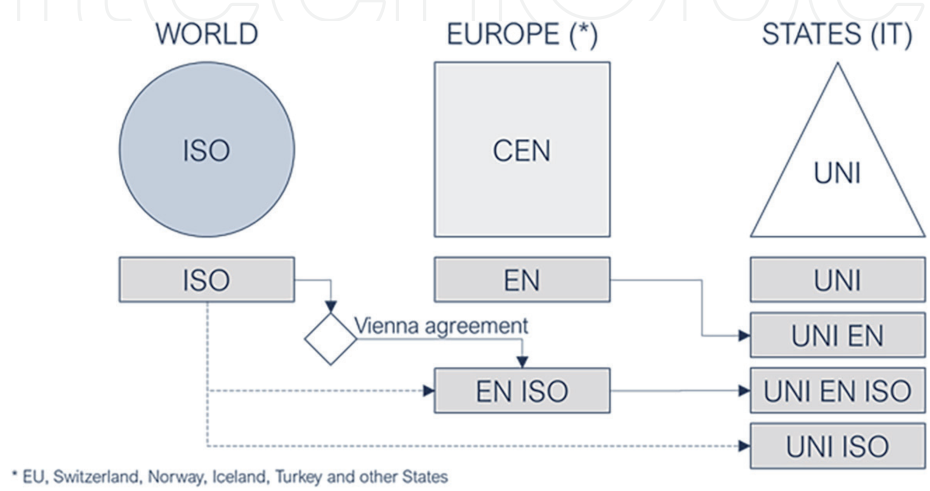

Figure 8.
Standard body structure in the world.

Analyzing the three normative levels (national, CEN and ISO) we see that BIM, although not yet so widespread and prevalent in the construction sector (compared for example to CAD), enjoys a large panorama of reference standards that actually allow a conscious and regulated use in every market, as illustrated in the following **Figure 9**.

With the publication of the first part of the package of standard ISO 19650: 2018 (Information Management—IM) the basic regulatory framework of BIM assume a picture like the one presented in **Figure 10**. Although the last born, ISO 19650 (in its various parts) becomes the reference standard, applicable in all markets. In Europe, it applies together with the subsequent CEN standards (of which, the first, is on the definition of the Level of Information Need: EN 17412:2021).

Nowadays, only Italy and Great Britain have decided to apply the faculty, provided for in ISO 19650, to insert national annexes to facilitate local markets in its application. Other states are considering adopting their own annexes (Spain, France, Germany, Morocco, etc.).

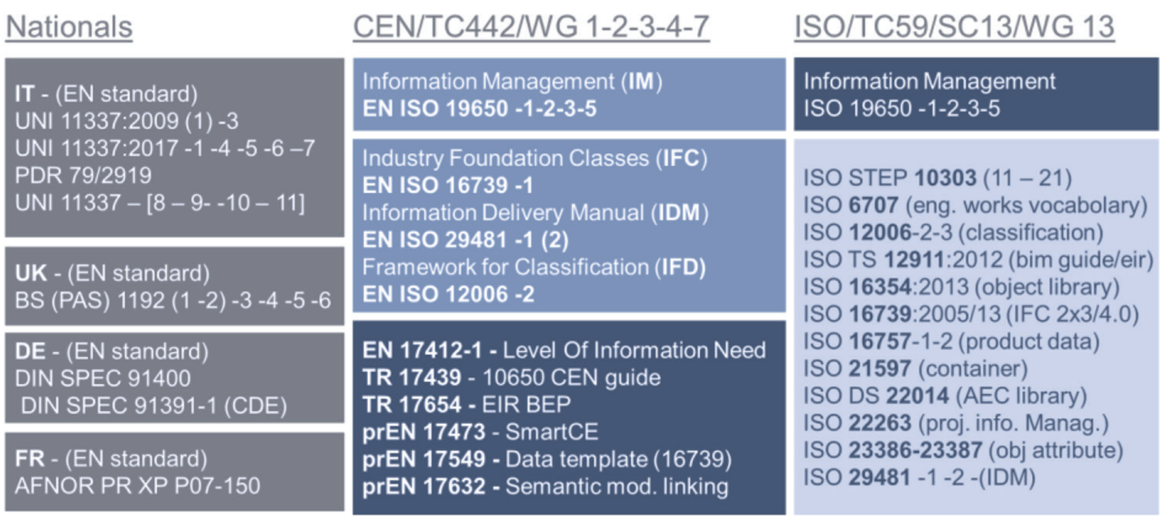

Figure 9.
Map of BIM standards in the world.

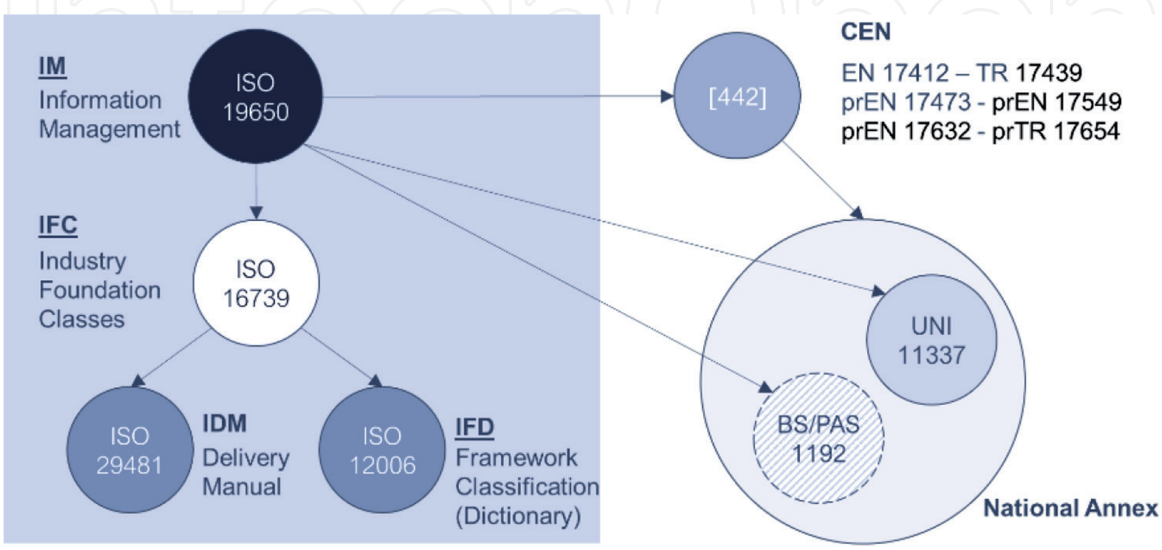

Figure 10.
BIM standard basic relationship.

In particular, while Italy has adopted the path of attaching the entire international package to national standards UNI11337, as a separate package, Great Britain has chosen to withdraw its standards and practices of group 1192 as the fundamental principles of these are assumed in ISO 19650 and insert the remaining parts not transposed at the bottom of the UK national version of ISO 19650 part 2 (in these regulatory annexes). For this reason, it should always be remembered that BS EN ISO 19650-2 (**Figure 11**) has a different conformation from the original version, which does not include annexes.

The Italian decision to keep in force the entire package of UNI 11337 standards is justified by the need to verticalize on the Italian market not only the ISO 19650 but all the most important ISO and CEN standards. In addition to stimulating the writing of other parts or standards necessary not only in the Italian market but also in the international or European scene (**Figure 12**).

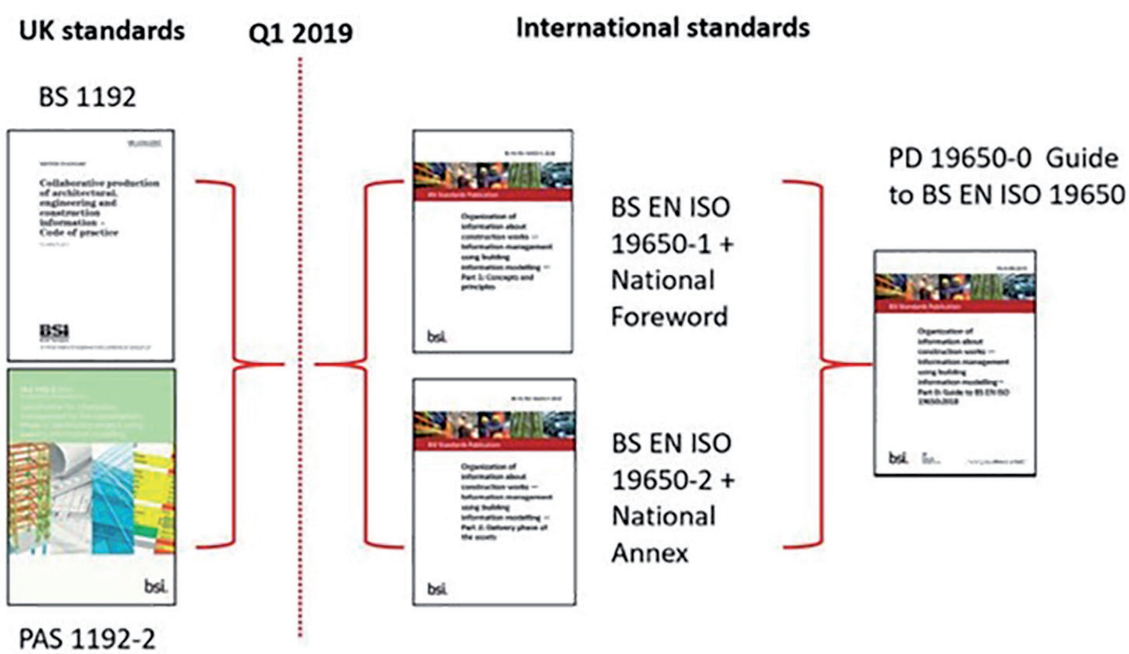

Figure 11.
ISO 19650 vs. BS EN ISO 19650.

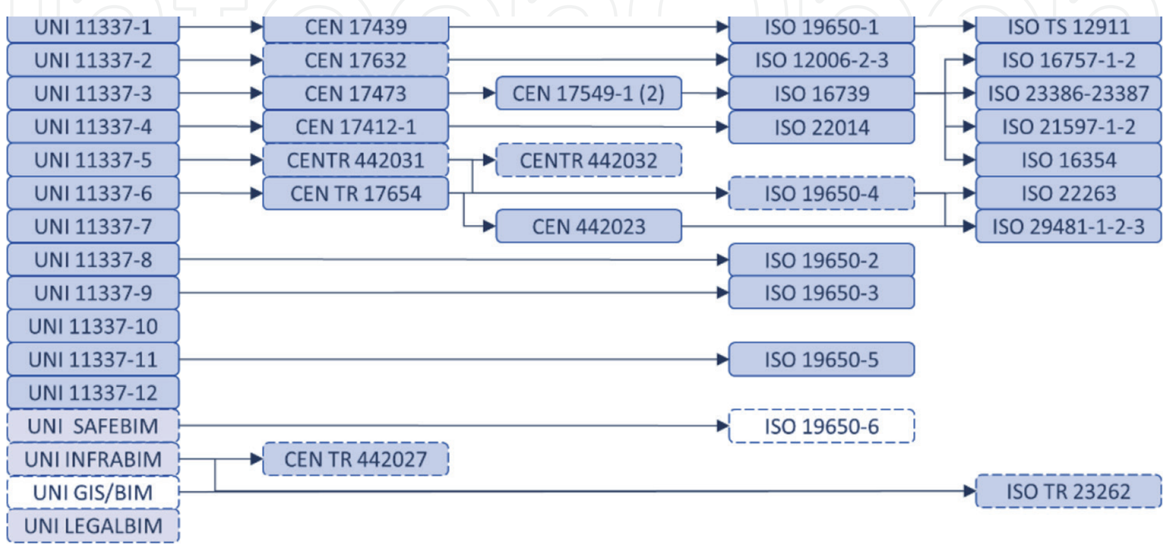

Figure 12.
Standard BIM map relationship.

For example, part 7 of the UNI 11337 (2017) is currently being studied at CEN 442 for the definition of BIM roles and figures at European level, in order to clarify the confusion currently present between BIM professionals, such as between these and those of Project Management (BIM Manager vs. Project Manager; **Figure 13**).

The BIM figures of UNI 11337–7:2017, are:

- **Common data environment manager (CDE manager):** the common data environment manager (CDE manager) is a figure who deals with the data sharing environment implemented by the organization to which it belongs or contractually provided for a specific order by another entity.

- **Manager of digitized processes (BIM manager):** The manager of digitized processes (BIM manager) is a figure that relates mainly to the level of the organization, as regards the digitization of the processes put in place by the same, possibly having the supervision or general coordination of the portfolio of orders in progress. Delegated by the top management of the organization, he defines the BIM instructions and the way in which the digitization process impacts on the organization and on the work tools.

- **Coordinator of the order information flows (BIM coordinator):** The coordinator of the order information flows (BIM coordinator) operates at the level of the individual order, in agreement with the top management of the organization and on the recommendation of the manager of the digitized processes.

- **Advanced operator of management and information modeling (BIM specialist):** The advanced operator of management and information modeling (BIM specialist) usually acts within the individual orders, collaborating in a stable or occasional manner with a specific organization.

An outline of BIM standards cannot fail to end without a quick mention of the IFC (Industry Foundation Classes) standard for open language and OpenBIM. IFC is curated and implemented worldwide by BuildingSmart International and is regulated by the ISO 16739 standard. IFC is both a data model (with definition of standard classes and relationships) and an open schema for generating exchange files in non-proprietary format (**Figure 14**). Non-proprietary formats guarantee the integrity and readability of data over time, which is extremely important, for example, in public procurement.

LEVEL	PM	BIM Management		
	ISO 21500	USA	UK	UNI
Organization	Proposal Manager	Information Manager	//	BIM Manager
Job order	Project Manager	BIM Manager	Information Manager	//
			Task Inform. Manager	
	PM Staff (Communication)	BIM Coordinator	Interface Manager	BIM Coordinator
		BIM Specialist	Information originator	BIM Specialist
		//	//	CDE Manager

Figure 13.
BIM figure and roles.

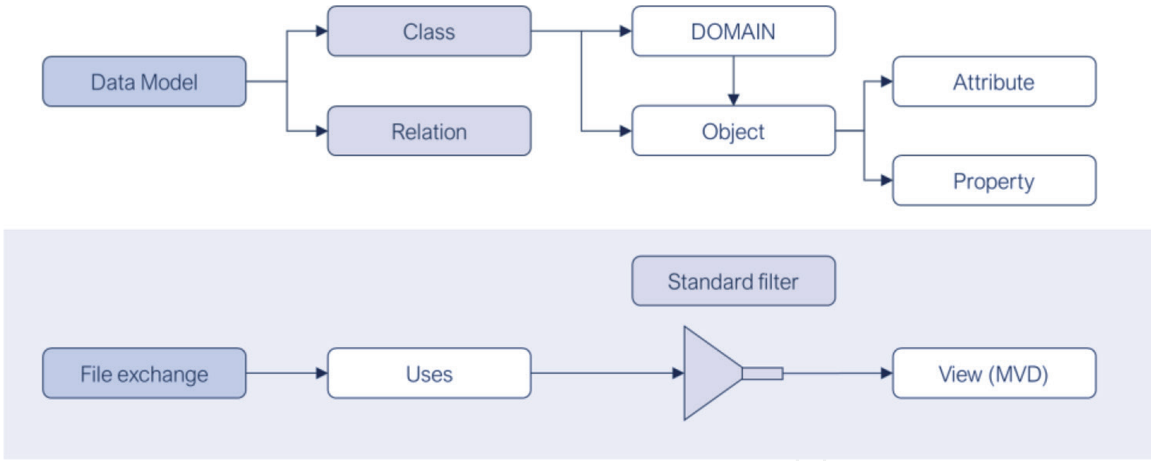

Figure 14.
BuildingSmart ISO 16739–IFC.

4. BIM-based platforms for building process management and research developments towards digital twin

The entire building process must deal with an ineffective information exchange between actors due to a data exchange still mainly based on paper-based transmission system, a variety of classification systems as well as on a use of disparate criteria and practices and a consistent number of stakeholders involved such as architects, engineers, services, and contractors from the design to operation phase. Each stakeholder possesses different set of skills, standards and tools, and thus the communication and the information exchange are characterized by a high level of complexity, as well as the knowledge and process management are often time-consuming [13].

The relevance of BIM in the Architecture, Engineering, Construction, and Operation (AECO) sector is worldwide recognized. Its implementation benefits the construction project reducing and avoiding errors, speeding up the process, improving the communication among the involved actors [14]. It integrates multidisciplinary data to create a digital representation of an asset throughout its life cycle from planning and design to construction and commissioning. BIM-based platforms such as INNOVance and BIMReL help in this direction enhancing data and information exchange along the building lifecycle.

The first BIM-based platform for the construction sector in the Italian context is INNOVance. It aims at collecting, processing and sharing data and supporting involved stakeholders by creating a unique code for the products, services, activities and resources used, a standardized datasheet and a web portal that allows users to use the information at every stage of construction [15].

BIMReL is an interoperable open-source BIM library for construction products that allows to associate all the technical information of the products to the BIM objects present in it. It supports the management of information throughout the entire life cycle of a building, based on the definition of information and technological needs. The added value lies in providing standardized datasheets conforming to UNI 11337–3 [13].

With the need to monitor and control assets all through their lifecycle and with IoT introduction and Artificial Intelligence (AI) diffusion, the birth and the growing affirmation of the Digital Twin has become more and more important [16].

The DT can be defined as "a realistic digital representation of assets, processes, or systems in the built or natural environment" [17] where data are synchronized from the physical to the digital [18], therefore it is seen as a technology that enables the physical and virtual space to communicate [19].

DT presents a new approach in the AEC sector: it is not only a building visual representation, but the latter can be enhanced with real-time data to diagnose the asset state and with the integration of statistic, probabilistic or AI models to allow predictive skills [20–22]. DT can be used for the following applications: real time monitoring, simulation, diagnosis, and performance prediction [16, 23–25].

BIM and DT are still mainly applied on new buildings, even though a growing consideration for the renovation requires their use and advantages.

In fact, since AECO sector and especially buildings are the cause of serious issues to the environment such as high level of energy consumption and CO_2 emissions, in recent times more attention is being paid to renovation phase [26–28].

Hence, the practice of renovating and re-using buildings needs to be stimulated. Nevertheless, improving the quality of renovations, reducing the time of building construction phase, minimizing the impact on tenants, and guaranteeing that cost/benefits targets are accomplished are typical barriers that need to be faced and overcome [29, 30].

Digitalisation becomes an instrument towards the construction sector to enhance the renovation process. Digital solutions can be adopted to manage information and data in a more ordered structure, with a consequent reduction of time and building waste and, an increased productivity and performance [31].

4.1 BIM in renovation context: The BIM4EEB project

To improve the building process efficiency towards the main renovation barriers, Europe is responsible for various initiatives for the promotion and dissemination of digital tools through policies (e.g., 'Renovation Wave' [28], funding (e.g., InvestEU [27]) and regulations (e.g., EU-level regulatory framework for the creation of the Single Market for Data for better data quality and data management [31]).

Also, it is responsible for several research projects aiming at exploiting digitals tools to make the renovation process more efficient and improve the performance of the building with attention to the sustainability aspect. The waste of time and the consequent waste of money caused by inefficiency is limited and reduced with the digitalisation that results in using resources more efficiently and responsibly.

In this respect, regarding technologies such as BIM and DT aiming at improving the building information management and communication there are different H2020 projects. Among these projects aimed at developing BIM-based tools for an efficient retrofitting [32], BIM4EEB can be mentioned.

The ongoing European project BIM4EEB, namely BIM based fast toolkit for Efficient rEnovation of residential Buildings, has the main goal to develop a BIM-based toolkit for improving renovation of existing residential buildings. The research activity developed within the project involves the use of IoT in residential buildings, the development of a platform for the share of information among the involved stakeholders and different kind of BIM-based tools implemented.

The BIM-based toolkit has been developed for different areas of renovation, such as: fast mapping of existing buildings, building information management, energy simulation of renovation scenarios, fast-track construction management, etc.

BIM-based tools are connected and can be accessed by the BIM management system (BIMMS), a platform where all the activities of the building process can be managed and the interested parties can exchange data from different sources.

BIM4EEB toolkit is characterized by the following tools, as showed in **Figure 15**:

- BIM Management System
- BIMplanner is a fast-tracking tool for renovation operations
- BIMeaser is a BIM assisted Energy refurbishment assessment tool
- AUTERAS and BIMcpd are tools to support decision-making and energy refurbishment assessment
- BIM4Occupants is a human machine interface tool
- Fast mapping toolkit is a tool for reducing the survey time

As part of the project, testing and validation of the developed toolkit are planned at three demonstration sites identified in existing residential buildings and located in different environmental contexts: Mediterranean (Italy), continental climate (Poland) and northern countries (Finland).

A social housing building owned by ALER has been selected for the Italian demonstration site and it is located in Monza (Lombardy). The building, dating back to

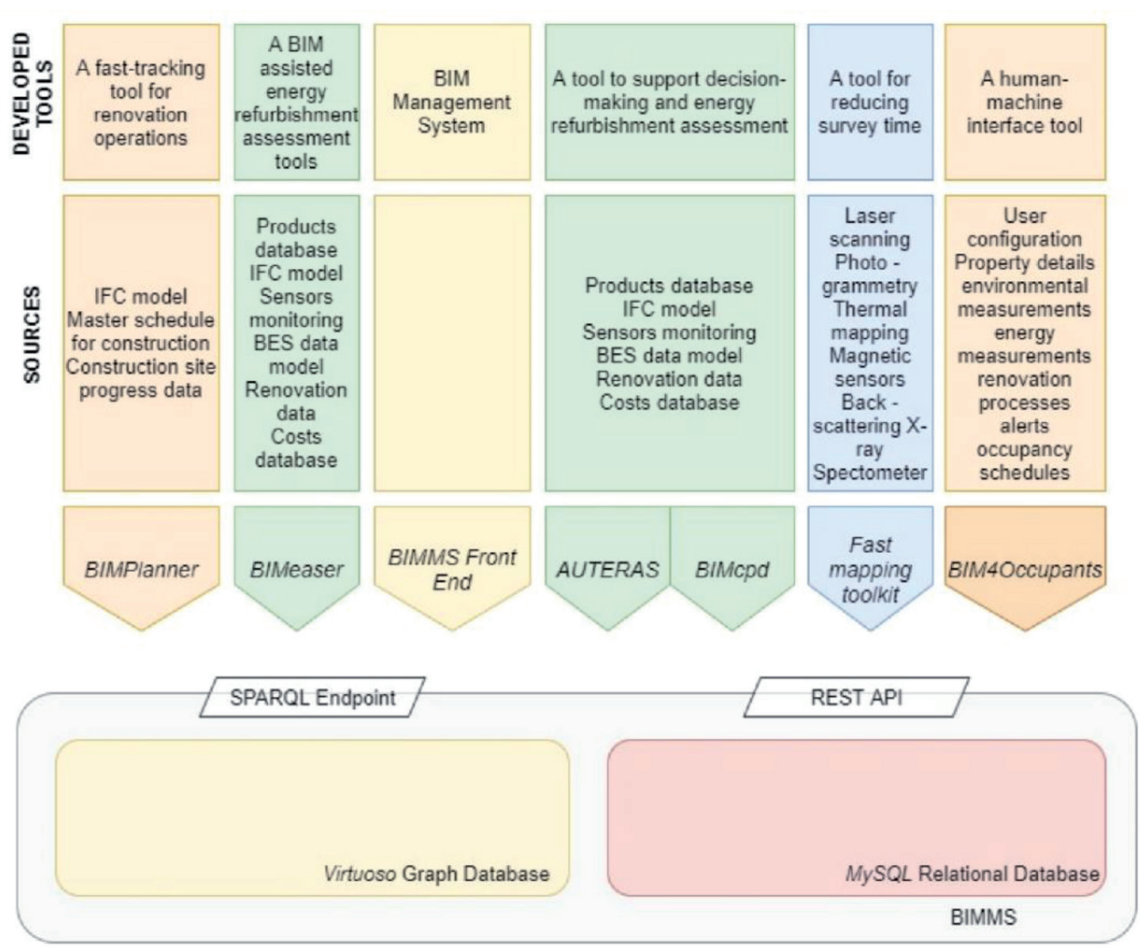

Figure 15.
BIM4EEB toolkit Daniotti et al. [33].

the 60s, presented a significant need for renovation measures. Hence, it has been subjected to two main renovation interventions such as the replacement of windows and the application of external thermal insulation.

The Poland demonstration site is placed in Chorzow, a town in the southern Poland, and it was built at the beginning of 1900.

The Finnish demonstration site instead is located in the city of Tampere.

The expected results of the project are the following:

- a time reduction by at least 20% compared to traditional methods,
- a cost reduction by 15%,
- a net primary energy use reduction by 10% for a residential apartment,
- working days reduction from 3 to 1.5 required for a deep energy audit.

The project, lasting 3 years, is now at its conclusion. The last part of the project consists in the demonstration of the BIM-toolkit feasibility to the previously mentioned case studies. In this regard, the achievement of the project is assessed by using Key Performance Indicators (KPIs) such as Renovation Process KPIs, Energy Performance KPIs, Human Comfort KPIs, Economic Performance KPIs, Social Related KPIs, Environmental and Safety KPIs evaluating objectives and stakeholders' requirements fulfillment.

4.2 Building information modeling adapted to efficient renovation: H2020 projects

Belonging to the topic "Building information modelling adapted to efficient renovation", in addition to BIM4EEB project, there are other Horizon 2020 projects: BIM4REN (BIM-Based Tools for Fast & Efficient Renovation) [34], BIM-SPEED (Harmonized Building Information Speedway for Energy-Efficient Renovation) [35], BIMERR (BIM-based holistic tools for Energy- driven Renovation of existing Residences) [36], ENCORE (ENergy Aware BIM Cloud Platform in a COst-Effective Building REnovation Context) [37]. Also SPHERE project (Service Platform to Host and SharE REsidential Data) [38], part of "ICT enabled, sustainable and affordable residential building construction, design to end of life" topic, is considered among BIM4EEB sister projects (**Table 1**).

All these projects have in common the study and development of solutions for a more efficient building renovation by using BIM. The main objectives are reduction of renovation working time of at least 15–20% compared to current practices; acceleration of the market uptake across Europe, by speeding-up industrial exploitation, among constructing/renovations companies with a target of 50% of their renovation business based on BIM; creation of best practice examples for the construction retrofitting sector with benefits for the operators and associated stakeholders.

If on the one hand BIM4EEB, BIM4REN, BIM-SPEED, BIMERR and ENCORE are all characterized by the development of BIM tools, on the other hand SPHERE project aims at improving the energy design, construction, performance, and management of building with the development of a BIM-based Digital Twin platform based on Platform as a Service (PaaS) approaching the concept of Digital Twin.

Programme	Topic	Project
Technologies enabling energy-efficient systems and energy-efficient buildings with a low environmental impact	LC-EEB-02-2018 Building information modeling adapted to efficient renovation (European Commission, Building information modeling adapted to efficient renovation (RIA), 2018)	BIM4EEB
		BIM4REN
		BIM-SPEED
		BIMERR
		ENCORE
	LC-EEB-06-2018-2020 ICT enabled, sustainable and affordable residential building construction, design to end of life	SPHERE

Table 1.
EU projects promoting digitalization in the built environment.

SPHERE is a Horizon2020 project that has developed a Digital twin environment based on Platform as a Service. The project aims at enhancing the performance and management of buildings, reducing construction costs and the environmental impact, starting from the design and construction phase but including also manufacturing and operational phase. It enables the integration of large-scale data, information and knowledge, and it facilitates decision making and the collaboration among involved users. SPHERE exploits the concept of Digital Twin for predictive and interrogative purposes. For the first the Digital Twin will be used for the prediction of future performance of the building, for the latter the Digital Twin will be investigated to get information about the current and past status [39].

5. Discussion and conclusions

This chapter proposes an overview of the main drivers that are guiding the digital revolution in the construction sector. The intrinsic changes that the entire construction value chain is experiencing are generating and will generate important impacts not only on construction but on the entire society and the people that will live in buildings and use infrastructure. Nowadays, the Digital Twin topic represents a key element of both research and practice innovation with enormous potential impacts considering the possibility to continuous monitoring buildings and infrastructure and the integration of controlling systems. This evolution will produce impacts on several scales, from the practical development of assets with a better quality up to the operation and maintenance with the possibility of creating data driven decision systems.

To provide a comprehensive overview on this area three main points are reported in the chapter. First, the movement from CAD to BIM is clarified to highlight the main key points that are driving the creation of digital simulation (information models) of buildings and infrastructures. Then a detailed description of the standardization context is provided. To clarify how standards are shaping the BIM context and will impact on its integration at the different levels (international, European, national) the standardization principles are presented and linked to the evolution that the standards have experienced in the last years shaping the BIM panorama. Finally, the so called "platformization" concept is proposed with the presentation of some key national (considering Italy) and European projects that have been developed or are under development and will shape the creation of the future platforms for the construction sector (DigiPLACE, BIM4EEB, INNOVance, BIMRel, Sister projects, SPHERE).

Platforms and standards represent two main axes of the digital transformation of the construction sector and are strictly intersected providing the backbone to enable the future of the digital constructions. Nevertheless, platform development is still an open research and industry topic that needs to be clarified and disseminate in the construction sectors considering the different levels that characterize it (European, national, regional, etc.). This dimension should be considering according to the standardization works that needs to be distributed in these different levels to guarantee, on the one hand a sufficient generalization for common topics, and on the other hand detailed focal points integrated in the national/local context to guarantee a practical applicability from the interested stakeholders. Researchers and industry stakeholders can start from the results here presented to have a clear picture of the standardization and platform development driver. Future research should work to integrate other trends and key topics in this picture to create a shared map of the drivers for a digital evolution of the construction sector.

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