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Impacts of Industrial Cyber-Physical Systems on the Building Trades

William DERIGENT[1] **and Laurent JOBLOT**[2]
[1] *CRAN CNRS UMR 7039, University of Lorraine, Nancy, France*
[2] *Arts et Metiers Institute of Technology, LISPEN, HESAM University, UBFC, Chalon-Sur-Saône, France*

14.1. General introduction

The construction industry plays a decisive role in the world economy. Despite its importance (1,502,500 workers in France for 148 billion euros (excluding VAT) of work per year[1]), it is still described as less productive and innovative than other sectors. A 2020 study even revealed that the added value of a worker on a building site in France has fallen by about 20% over the last 20 years (Beddiar 2020). In response, many actors recognize the need to innovate in order to reverse this trend. New forms of work are emerging thanks to the introduction of technologies or principles such as building information modeling (BIM), virtual and augmented reality, prefabrication, the Internet of Things (IoT), additive manufacturing and robotization. All over the world, large companies are already experimenting with some of these technologies, but their implementation is still in its infancy, especially

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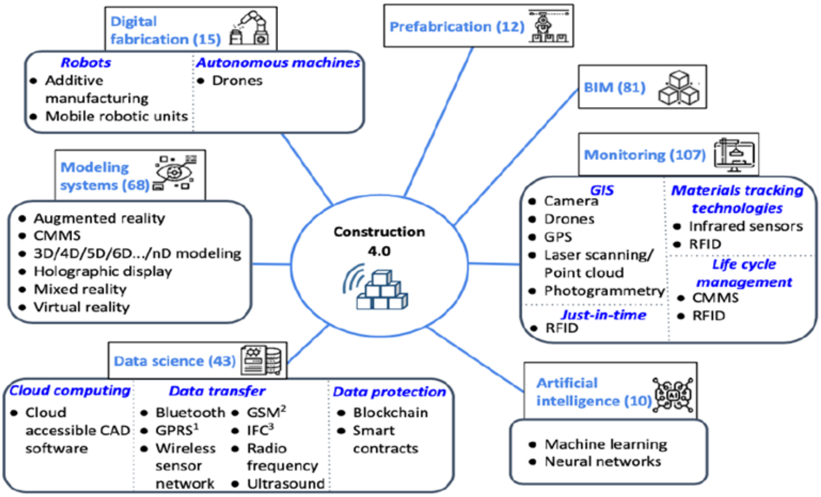
For a color version of all figures in this book, see www.iste.co.uk/cardin/digitalization.zip.

[1] https://www.ffbatiment.fr/federation-francaise-du-batiment/le-batiment-et-vous/en_chiffres/les-chiffres-en-france.html.

in small companies. This is indeed the major difficulty of this sector of activity. In 2020, small companies (fewer than 20 employees) represent about 99% of French construction companies and 59% of the sector's salaried employees. On a European scale, the situation is the same, with 92% of companies having fewer than 10 employees[2]. It is also an extremely diversified and fragmented sector with, for example, 24% of companies specializing in general masonry and 11% in electricity or painting. A total of 650,000 companies (+45% in 10 years) in the sector are ultimately spread over more than 20 different trades in France[3].



[1]GPRS: General Packet Radio System
[2]GSM: Global System for Mobile communication
[3]IFC: Industry Foundation Classes

Figure 14.1. *Distribution of 4.0 technologies used in construction according to seven technology groups from Perrier* et al. *(2020)*

This overview, though very brief, may at first glance seem rather bleak. The definition proposed in this book for industrial cyber-physical systems (ICPS) seems to be rather far from the construction activities and the picture presented here. The means and size of the companies involved are more reminiscent of craftsmanship than of systems that operate autonomously and interact. However, the situation is not fixed, and we see it as a unique opportunity for cooperation between researchers and industrialists to work on numerous projects with significant scope and impact. The significant margins of progress that remain make construction a very stimulating and worthy sector. This chapter therefore provides a non-exhaustive

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2. https://www.capeb.fr/les-chiffres-de-lartisanat [accessed November 2021].

3. https://dataviz.metiers-btp.fr/entreprises [accessed November 2021].

picture of the opportunities, experiences and transformations that have taken place over the last 10 years. Many of these have been, and increasingly will be, supported by the emergence of "new" technologies originally developed for the manufacturing sector.

A study aimed at providing a comprehensive classification of the 4.0 technologies currently studied and applied in the construction industry (Perrier *et al.* 2020) reveals, indeed, that these technologies are finally managing to spread within this sector. This literature review, based on 2,041 documents from the Scopus database, clarifies in particular the main actions and the most common applications in construction. As summarized in Figure 14.1 by the authors, it turns out that seven technological "bricks" are under consideration and are very regularly cited and applied by different authors, namely: digital manufacturing, prefabrication, BIM, artificial intelligence (AI), modeling (AR/VR, nD modeling), dimensional or geographic survey technologies (laser scanning, drones, unmanned aerial vehicles (UAVs), photogrammetry, GPS) and material tracking (RFID tags, wireless sensor networks). Some of the most promising advances are presented in the following sections.

Thus, through these numerous studies and with regard to Figure 1.5 in Chapter 1, we can see that technologies already exist in the building sector to complete the various functionalities of ICPS. Some solutions allow for the **capture and distribution** of information to report more precisely and more quickly the situations encountered on site by the interveners. Some blocks of technology will contribute perfectly to the activity of **digitalization of the building sites** then facilitating the activities of piloting and decision-making. As we will emphasize later on, routines and autonomous solutions are currently being studied, in particular to enrich and accelerate this digitalization phase. Finally, just like the manufacturing sector's infatuation with digital twins, data science or AI reinforces the potential of BIM models during the construction and operation phases through increased **learning and interaction** capacities. In this sense, Construction 4.0 systems are ICPS (or parts of ICPS). Even if there is not yet a widely-used ICPS in construction that includes all of these functions, initiatives are appearing in the form of proofs of concept (POC). An example of an ICPS prototype under construction is presented in section 14.4.

14.2. The place of BIM in Construction 4.0

Following in the footsteps of the major groups, and in order to finally change the paradigm, the construction sector is stepping up its efforts and attempting to embark on the digital path. The best example of this is the digital mock-up (DM) and more specifically BIM. In agreement with the French-speaking association buildingSMART France[4] and a large majority of the actors in the construction industry, BIM is commonly the acronym for "building information model" and corresponds to the digital representation of the physical and functional characteristics of a building. The BIM is then used as a shared database to capitalize on the information related to the building, and to exchange it. This exchange process (interoperability) is facilitated by the industry foundation classes (IFC) exchange standard[5] (International Organization for Standardization 2016). BIM can also be "building information modeling" as a business process of generating and using building data during its entire lifecycle. It is then a process of exchange around the DM for collaborative work between professionals. With these different functionalities, BIM is thus seen as a decision-making tool during the lifecycle of a project. We can even mention 4D or 5D if the modeling takes into account time and cost, respectively. To be more precise, 4D BIM, for example, is a process that makes it possible to associate a 3D digital model with information relating to the planning of a project, which provides precise visual planning for all phases of the project and can go as far as the simulation of the movements of materials (movements of cranes, for example, to check the accessibility on site). 4D can be implemented through tools such as Synchro 4D[6] or Navisworks[7]. Many therefore see BIM as "the cornerstone of Construction 4.0" (Bourgault *et al.* 2021). These authors rely on studies conducted by the construction industry in Quebec which have highlighted more than 30 opportunities made possible by the use of BIM[8]. In addition to the improvement of the quality of the works and the information exchanged, the five elements most often mentioned by the experts are the importance of efficiency gains (35% of the experts), the reduction of risks on the construction site (33%), the possibility of prefabrication and integration of manufacturers (25%), the reduction of waste (23%), as well as the improvement of the transfer of construction data to the management of the assets (20%). Many of these gains seem to be tenfold if BIM is accompanied by a lean approach and digitalization of the company[9]. It would thus be possible to move from a plan completion rate (in the sense of planned activities) of 50 to over 70%. The use of BIM thus acts as a catalyst for improvements and

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[4] https://www.buildingsmartfrance-mediaconstruct.fr/.

[5] ISO 16739:2013.

[6] https://www.bentley.com/fr/products/product-line/construction-software/synchro-modeler [accessed November 2021].

[7] https://www.autodesk.fr/products/navisworks/overview [accessed November 2021].

[8] https://espace2.etsmtl.ca/id/eprint/20928/2/Poirier%20E%202018%2020928.pdf [accessed November 2021].

[9] https://www.bcg.com/publications/2018/boosting-productivity-construction-digital-lean [accessed November 2021].

changes that go far beyond the functions of modeling, sharing and information exchange.

It is still difficult to propose a consensus definition of the term “Construction 4.0”. We have just mentioned the fact that many 4.0 technologies are already benefiting a few precursors in the sector. The question could then be raised as to whether these “new” technologies are in some way “**redundancies**” or **complements** to BIM alone. By looking at the intentions of different studies on the subject, some answers can be proposed. The analysis of articles published since 2011 and the appearance of the notion of Industry 4.0 confirms that not only are the *raisons d’être* of BIM reinforced, but that they are, in fact, enriched (Joblot *et al.* 2020). By “*raison d’être*”, the authors mean, for example, improving productivity, collaboration, data quality and dissemination, or reducing costs or environmental impacts in construction projects. Beyond that, other improvements have been noted, generally driven by technologies such as the IoT, the use of drones, 3D printing (used, for example, in prefabrication), AI and cloud computing (to improve feedback or to enable the automation of choices). The synthesis proposed by the authors makes it possible, in fact, to highlight the appearance of new functionalities that allow, *in fine*, new industrial perspectives. Indeed, it is regularly about real-time monitoring of objects and/or stakeholders, now making possible simulations and real-time optimization (e.g. to optimize flows, time or resources; Laurini *et al.* (2019), Favier *et al.* (2019)). The monitoring of planning and the creation of knowledge and experience databases are also being tested and could then become widespread and again facilitate planning, risk or cost management (Tibaut and Zazula 2018).

All of these elements and this rapprochement to the ICPS bring new sources of interest or questions for industrialists, as we detail in the following sections, yet BIM was still only occasionally exploited by less than 1/3 of French companies in 2018[10].

14.3. Examples of transformations in the construction sector

ICPS can be the source of important transformations in the construction sector. In the following section, several examples of the use of technologies and principles are detailed, according to the four functions of an ICPS, i.e. control, learn and interact, sense and distribute information, and digitalize.

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[10] https://axeobim.fr/observatoire-du-bim/.

14.3.1. *Control: real-time site management*

ICPS, given their ability to control complex systems, could be applied to the control of construction sites. Indeed, academics and construction professionals agree on the fact that construction projects are becoming increasingly difficult to manage due to the increasing complexity of the projects. To understand this complexity, several works have recommended and demonstrated the usefulness of tools such as BIM 4D. Tserng *et al.* (2014) suggest, for example, that BIM 4D could be used for construction site monitoring, with adaptations. Indeed, if this approach makes it possible to have a visualization of the theoretical progress of the construction site, it remains, in practice, not very suited to monitoring of construction sites and to the control (in the sense of the management of the construction site) of possible deviations from the initial plans. To remedy this, it is therefore necessary to couple BIM 4D with data collected on the construction site in order to compare the planned state ("as-planned") with the actual state ("as-built") of the building. The information collected for the monitoring can be either directly related to the tasks (i.e. percentage of task completed) or to the products or resources of these same tasks (i.e. product status, product location). In the latter case, measurement of the planned/actual variance is not direct and it is then necessary to define metrics, making it possible to calculate it from the collected information. The collection method can vary: it can be manual, semi-automatic or even automatic. This process can be illustrated by the work of Matthews *et al.* (2015) who present an architecture based on BIM 4D, where the percentage of completion of each planned task is updated daily either by the contractors or by the site manager, via mobile applications.

In order to automate this update, Han *et al.* (2015) propose a 4D object recognition system that combines 3D object recognition, based on site surveys, with planning information. By determining the geometric differences between the actual 4D model and the planned 4D model, it becomes possible to identify deviations. The Internet of Things can also be used to capture information from the construction site where 4D BIM models are updated with product information collected by RFID readers. In terms of performance improvements, some studies suggest a reduction in the overall construction time of approximately 17% following the adoption of a system that combines RFID and BIM 4D. However, these systems require implementation efforts, including careful management of resistance to change and training of site personnel. The information collection method chosen can create time-consuming steps in the construction process, due to the manual reading of information, for example.

This quick overview of the objectives and constraints related to real-time site management actually reveals that the barriers between the academic and industrial sectors must be as porous as possible. It is in this way, and by constantly integrating or experimenting with new technologies and organizational models, that the obstacles resulting from increased productivity or expectations can be overcome. It is possible to go even further by bringing more immersive experiences to the construction actors to visualize in real time this well-known information coming from the field or more simply to better define the contours of a project, to anticipate or prepare more upstream evolutions or certain interventions.

14.3.2. *Learning and interacting: virtual reality and machine learning*

The concepts of virtual (VR), augmented (AR) or mixed reality (MR) are not new and are gradually being introduced in the manufacturing industry. Their use in construction, however, is more limited. VR is, for example, a set of technologies that allows a user to be immersed in a virtual environment in real time and with “realistic” interactions, involving sensory receptors such as sight, hearing and touch. It is an experience, if visual, that can be exercised on computers, tablets, VR headsets, or through much weightier solutions such as CAVE (Cave Automatic Virtual Environment). The study by Perrier *et al.* (2020) specifies that there are many scientific or industrial experiments in VR or AR in the construction sector to date. This article on the construction trades made it possible for the authors to classify the 4.0 technologies present according to:

– their ability to meet 10 target actions (automate, communicate, distribute, localize, model, optimize, reconstruct, simulate, normalize and visualize);

– the phase of the construction project lifecycle during which the experiment took place (the columns);

– the project management process that the technology impacts (communication management, costs, health and safety, human resources, procurement, quality, risks, project scope or duration).

The prospects for VR/AR techniques in a construction project are summarized in Table 14.1.

The chosen angle of analysis, however, did not allow any particular advances to be identified in “Operation and Maintenance” activities. For many years, however, VR/AR applications have been aimed at investigating how to improve facility management, another important issue related to building operating costs. Indeed, it has been noted that “80% of the costs of operating, maintaining, and replacing a building are determined in the first 20% of the design process”[11]. In other words, the maintenance and renovation of a building is four times its initial cost over its lifecycle. The monitoring of equipment and the facilitation of these stages via VR-type applications has therefore become a priority for companies and start-ups in recent years, such as the HORUS solution[12] proposed by the IARA team of developers. The functionalities proposed via these applications are thus multiple and AR/VR support can improve guidance on the intervention site, the visualization of hidden elements, interaction and quick access to information (technical data sheets, plans, etc.).

	Design and engineering	Construction
Communications	***Visualizing*** – 3D visualization of digital models and texture – (AR/VR/nD modeling) – 3D visualization of building information (VR) – Communicate Improvement of customer understanding in the design phase (VR)	***Visualizing*** – 3D visualization of digital models and texture (AR/VR/nD modeling)
Health and safety	***Simulating*** – Safety training (VR)	***Locating*** – Capture of hand movements (VR/camera) ***Communicating*** – Safety training (VR)
Risk	***Simulating*** – Safety training (VR)	

Table 14.1. *Prospects for VR/AR technologies. Based on the review by Perrier* et al. *(2020)*

Bridges are also tending to develop between VR/AR and other solutions such as building management systems (BMS), CMMS and IoT. The ultimate challenge is to enable and generalize the use of the BIM as-built documentation. These prospects justify the current enthusiasm of publishers such as BENTLEY[13] and Unity (world leader in free game engines) who seek to orient their products to make them “BIM compatible”. For example, the latter offers “Unity Reflect”[14] to facilitate VR

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[11] ISO 15686-5:2008.

[12] https://www.horus-bim.com/ [accessed November 2021].

[13] https://www.bentley.com/fr/about-us/news/2017/october/09/pna-06-microstation-lumenrt [accessed November 2021].

[14] https://unity.com/products/unity-reflect [accessed November 2021].

experimentation and development while maintaining real-time updates and project imports from Revit, BIM 360, Navisworks, SketchUp or Rhino. Interoperability and compatibility with these leading vendors is likely to be the primary requirement for widespread use of these new features.

14.3.3. *Capturing and distributing: use of wireless technologies (RFID and WSN)*

The Internet of Things has developed significantly since the early 2000s leading to a number of initiatives in the construction field. Two main types of microelectronic technologies are used: passive, semi-active or active chips (RFID and NFC) and wireless sensor networks (WSNs) using various types of communications (LORA, SigFox, BLE, etc.), powered by energy or autonomous. The major application remains to capture and send back information coming from construction products (i.e. prefabricated beams) or from resources used during construction (i.e. cranes, trucks, etc.) for management or maintenance needs. For example, in the field of lifting, the Potain company monitors crane activities based on different data and conditions of use, obtained through sensors placed on the structure. The data collected in this way can be used to supplement a maintenance logbook and is used by rental companies to optimize their maintenance and repairs (see Chapter 3). They are also offered in the field of operator training to personalize the educational content proposed[15].

On a completely different note, many research works have highlighted the benefits of integrating Internet of Things technologies in prefabricated construction products, which are increasingly used for cost and time reasons. As proof, Li and Becerik-Gerber (2011) already presented an extensive review of research works or industrial initiatives in the construction field, using RFID technologies. These have thus been tested and can generate significant economic gains in all phases of the precast concrete lifecycle, for example, in the quality management of precast products or for the construction supply chain, by providing product information to stakeholders. WSN are used when active monitoring of the structure is required, such as for early inspection of concrete or for structural health monitoring (Jiang and Georgakopoulos 2012). There are also some industrial initiatives. For example, the Lafarge company embedded RFID tags directly into the concrete of the D2 tower for a traceability application. Companies such as 360 SmartConnect (www.360sc.io) are using these NFC technologies to offer innovative services related to the universal and intelligent traceability of products, materials and construction sites. These

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[15] http://www.chantiersdefrance.fr/reseaux/constructeurs-potain-digital-transforme-lentretien-grues-a-tour/ [accessed November 2021].

long-lasting devices can be integrated directly into the material. However, this can be accompanied by problems of accessibility of the chip and storage memory. To solve these problems, research work has focused on "communicating materials" (Kubler *et al.* 2010), materials capable of communicating with their environment, processing, exchanging information and storing data in their own structure.

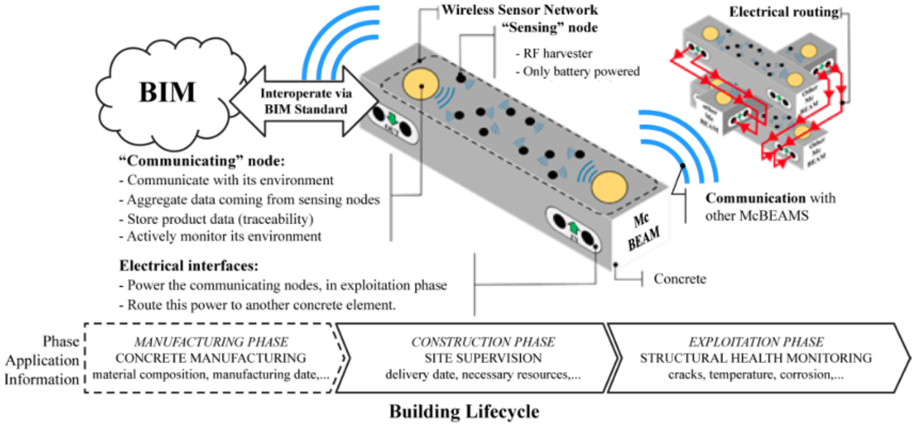

Figure 14.2. *Description of the ANR McBIM project*

In addition, these materials also have the ability to measure the state of their environment and to measure their own internal physical parameters. Mekki *et al.* (2016) propose to apply this principle to construction by integrating wireless sensor networks into concrete. However, while the application seems interesting, it needs to overcome technological and scientific limitations currently studied in the framework of the McBIM project (communicating materials for BIM) labeled by the ANR (French National Research Agency) in 2018, ongoing until 2022 (http://mcbim.cran.univ-lorraine.fr), as presented in Figure 14.2.

14.3.4. *Digitalizing: digitalizing technologies for BIM*

For an old or existing building, the concept of a digital mock-up is too recent to be available. For a renovation project in BIM, it will therefore be necessary to make this model in the image of the building as built. Hence, it is called an "As-Built" model. This is a complex task due to the imperfections of the real building, and this often time-consuming rendering implements various digitalization solutions (Landrieu *et al.* 2013; Volk *et al.* 2015). To improve the accuracy and speed of this acquisition, many solutions have been developed over several years, allowing for object recognition and automatic insertion/prediction of invisible objects (Tang *et al.* 2010). With the help of 4.0 technologies, professionals are also proposing increasingly innovative means of surveying, which they praise for their performance, ergonomics and accuracy. In addition to digitalizing buildings using drones, Geoslam is now offering the original Zeb Go[16] acquisition process, which can obtain 43,200 points per second. The announced accuracy is +/- 0.1% or 1 cm, and this product only requires a simple movement, camera in hand, inside the building to transcribe the existing into a point cloud. The growing use of tablets is pushing developers to innovate and solutions such as ARtoBuild[17] can now generate 2D plans in PDF format and 3D plans in IFC format from tablets of 10 inches or more.

Figure 14.3. *Spot®, Bostondynamic's robot dog*

Steps are therefore gradually being taken and many construction companies throughout the world (Bouygues Construction in France, Pomerleau in Canada, etc.) are also experimenting with "robot dog" type solutions (Spot®[18]) from Bostondynamics (Figure 14.3) to inspect the progress of worksites autonomously or to carry out scanning or surveillance of potentially dangerous sites. Equipped with a camera or laser scanner (compatible with FARO and Trimble), Spot® helps to identify deviations and rework more quickly and is capable of routinely and safely scanning a workspace in the event of coactivity (cobotics). It then contributes, as recently for the FORD plant in Van Dyke, to the creation of digital twins of construction sites or production sites.

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[16] https://geoslam.com/solutions/zeb-go/ [accessed November 2021].

[17] https://www.bimeo.fr/artobuild [accessed November 2021].

[18] https://www.bostondynamics.com/spot [accessed November 2021].

14.4. Example of ICPS in construction

Once again, it is necessary to distinguish between the construction phase and the building operation phase. Future constructions and the emergence of smart cities suggest “over” exploitation of 4.0 technology to make buildings more intelligent, comfortable, economical and secure (Beddiar *et al.* 2019). It is, however, still rare to combine all or part of the digital developments presented in this chapter for construction purposes to thus develop and exploit an ICPS in construction. Some experiments are, however, undertaken in this direction and are the subject of publications or POCs (Furet *et al.* 2019; You and Feng 2020). The solutions implemented in this last publication to “**print**” a 95 m^2 social housing and named Yhnova are, for example, based on a technology named Batiprint3D[19] and developed by teams from the University of Nantes (LS2N, GeM). This work, which was launched in 2017, required the development of a set of processes centered around a specific “autonomous” robotic machine rolling directly on a concrete slab, the base of the future building. This ICPS consisted of a poly-articulated arm (PAA) to print the walls (“standard” robot, branded Staübli[20]) and the automatic guided vehicle (AGV) came from the company BA Systèmes[21].

Figure 14.4. *Implementation of the Yhnova project*

Thus constituted, the PAA allows for, initially and by successive layers, the realization of the polyurethane foam formworks (two “parallel” boards forming a complete wall, as presented in Figure 14.4). The AGV ensures the positioning/movement of the arm between different positions according to trajectories defined from the BIM model. Positioning errors caused by slab flatness defects are corrected in real time by measuring the spatial position of the AGV via a set of 11 fixed targets/laser beams. The information transmitted by two on-board inclinometers further improves the knowledge and digital representation of the

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[19] https://www.batiprint3d.com/en [accessed November 2021].

[20] https://www.staubli.com/en-us/ [accessed November 2021].

[21] https://alstefgroup.com/ [accessed November 2021].

“physical” assembly. Thus, by successive processing of the data and reconfiguration of the models, the position of the 3D printing nozzle is corrected in real time, allowing for positioning to within +/ – 0.5 mm of the future installations. Thanks to BIM, all the reservations of the pre-equipment (fluid inlets and outlets, energy and network inlets, windows and doors, etc.) and the reinforcement steels of the construction are, in the same way, positioned with precision. These foam structures are then used as formwork in which the concrete is poured by the same robotic 3D printer for a house built in less than 54 hours.

14.5. Achieving the digital transformation of businesses

The previous points have highlighted how the four functions of an ICPS (control, learn and interact, sense and distribute, and digitalize) can be used, step by step, to make up for the delay in the construction sector. If properly mastered, these functions will help to erase the image of a craft sector that has become obsolete or uninteresting for the new generations. The building and public works sectors are in turn caught up in the wave of digitalization which they must learn to overcome. This digitalization and the major changes that accompany it will be all the more accepted and rapid if companies know how to be critical and organized during the deployment of new digital solutions and technologies. It will also be necessary to reduce the compartmentalization of activities, companies between them and solutions implemented. The scientific literature reveals that these last challenges can be overcome thanks to the deployment of indicators making it possible to quantify the maturity of companies relative to these technologies. It will also be necessary for publishers and solution providers to make these new technologies simple, adaptable and interoperable, and thus to facilitate links between the multitude of players and businesses involved in projects.

Faced with the process of adopting these new technologies, and in particular BIM, many argue that without internal (individuals, teams, organizations, projects) or sometimes external (subcontractors or stakeholders) measurements and evaluations, different partners are unable to regularly quantify their successes, failures, strengths and weaknesses. It would even be impossible for them to be effective and critical of their investments (Proença and Borbinha 2016). However, to remedy this, they could rely on the use of maturity models (MM). The latter are described as tools that help characterize, throughout the process of implementing an information system, fragilities and/or progress. In the scientific literature, the underlying concepts are defined as follows: capacity (BIM or not) is the ability to perform a task, deliver a service or generate a product; maturity is the degree of excellence or mastery in the execution of this task. MM thus make it possible from matrices of situations or from successions of questions to restore in the form of visuals and indicators the levels of mastery of the entity facing, for example, the imperatives of BIM – but not only this (Azzouz *et al.* 2016). These MM represent an essential basis for the continuous improvement process. They may focus on risk management during a construction project, the involvement of stakeholders, the safety culture and so on (Eadie *et al.* 2012) counted 10 years ago about 53 MMs for the construction sector to "characterize" its maturity with regard to information and communication technology (ICT). Even today, such solid and well-constructed sets of BIM-oriented metrics can really help companies to optimize the performance of their workforce and can alleviate some of the reluctance related to the implementation of BIM (by including aspects such as training and education). They are also important supports when stakeholders develop roadmaps or identify future business goals and projects. Even though they are still not widely used by industry, more and more targeted models are being developed to best meet the needs and specificities of companies. Without being exhaustive, let us note, for example, the recent appearance of the "IDEAL" maturity model aimed to evaluate and analyze the performance of projects that implement both BIM and Lean (Mollasalehi *et al.* 2018). This integrated BIM and lean MM thus aim to evaluate and monitor the performance of projects that implement these two organizational supports. The authors proposed a maturity evolution according to five main levels, from *Initial* to *Optimized in the long run*.

In another way, the BIM maturity model for renovation (BiM²FR) supports the evolution of small companies involved more particularly in renovation. This MM is based on good practices and principles that should be addressed during the implementation of BIM (Joblot *et al.* 2019). The structure of BiM²FR and its use make it possible, among other things, to question and focus on key success factors, organizational and managerial approaches such as Lean Construction, project management, the Integrated Project Delivery Approach[22] (The American Institute of Architects 2007) or the contents of BIM Agreements[23], all elements that facilitate the implementation of BIM. This MM is available via a free web platform (www.BiM2FR.eu), making it possible for each company to obtain in a few minutes objective feedback on the situation in which it finds itself on the path of BIM. Finally, other studies have recently focused on the correlation between the maturity of a BIM model and the ability to collaborate to develop a low environmental impact construction (Mohammed 2020). Based on already existing governmental[24] and

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[22] http://www.aia.org/contractdocs/AIAS077630 [accessed November 2021].

[23] https://buildingsmartfrance-mediaconstruct.fr/memos-pratiques-BIM/#sample-convention [accessed November 2021].

[24] http://www.aia.org/contractdocs/AIAS077630 [accessed November 2021].

scientific models (BIS 2011; Succar *et al.* 2012) and through a validation by the Delphi survey technique, the author proposes an organizational framework to regulate and optimize the collaboration and maturity level of a BIM model and thus facilitate the execution and final characteristics of the developed green buildings.

Beyond the consulting companies, many supports are available to accompany companies in these important digital and organizational changes. This "4.0 migration" is to be expected in the years to come within the construction sector and its multitude of players. This migration is integrated or can be articulated around the digital model and BIM. The main challenge that remains to be overcome is that of interoperability and the ability of all the players and solutions mentioned to communicate and interact. As recognized by industrialists and scientists, the generalization of BIM practices alone, although irremediable and irreversible, is still slow and hampered by the lack of interoperability between solutions (Sattler *et al.* 2020). Fortunately, this point is evolving, step by step, thanks to numerous works based on the neutral IFC exchange format. However, the task has become even more complex with the appearance of all the new technologies and functionalities mentioned in this chapter. In addition to the problems of interoperability "of the" digital models, there are also those resulting from the desire to enrich and interact with a multitude of "means" with very different languages and temporalities. However, it is through this last integration effort that the systems resulting from Construction 4.0 will become fully-fledged ICPS.

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