Industry 4.0 in Construction Site Logistics: A Comparative Analysis of Research and Practice

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Abstract: The fourth industrial revolution, also known as Industry 4.0, has underpinned the digital transformation of the manufacturing industry for several years. Earlier studies show that Industry 4.0 is now impacting the construction industry and one of its specific features: supply chain management and particularly on-site logistics. Although many technologies have been associated with what can be called Construction 4.0, little attention has been paid to the applications resulting from these technologies. Thus, the utilization of technologies remains largely unknown. The aim of this article is to explore the technological applications associated with Industry 4.0 and used in on-site logistics. The study is based on a comparative analysis of the technological applications found in the scientific literature and those identified in practice.

Keywords: Construction industry; Industry 4.0; Construction 4.0; Supply chain; Logistics.

1 Introduction

The fourth industrial revolution, also known as Industry 4.0, is transforming business models and decision-making through a set of digital technologies and the general connectivity of processes, products, and services (Danjou, Rivest, & Pellerin, 2017; Santos, Costa, & Grilo, 2017; Santos, Loures, Piechnicki, & Canciglieri, 2017). Although Industry 4.0 is expanding rapidly in the manufacturing industry, its transformations are gradually impacting other industries, such as construction.

In this article, we investigate the integration of concepts related to this phenomenon, in the specific context of on-site logistics at construction jobsites. In simple terms, we can define two components of on-site logistics: procurement for the jobsite and site logistics. Our study focuses on the latter aspect, which concerns the management of physical flows on the construction site, and differs from procurement logistics, which covers the delivery of materials to the site (Sundquist, Gadde, & Hulthén, 2018).

In this article, we propose to examine the topic of *Construction 4.0* in more depth by conducting a comparative analysis of technological applications mentioned in the scientific literature and in professional practice. In Section 2, state of the art on *Construction 4.0* is outlined, while the analysis methodology to achieve the comparison is described in Section 3. In Section 4, the analysis between scientific literature and professional practice is presented, followed by a discussion of the results in Section 5. We conclude the article in Section 6.

2 Research background

Even though the construction industry has long been considered slow at adopting digital technologies, the sector has recently made important steps towards adapting Industry 4.0

technologies. Industry 4.0 applications will most likely build on recent efforts made with other structuring technologies such as Building Information Modeling (BIM). This section offers a brief discussion of these two major trends after defining on-site logistics.

2.1 On-site logistics

According to studies carried out as part of the research project conducted with major players in the construction industry, on-site logistics appears to be a crucial point in the supply chain for the construction industry. Therefore our study is more specifically focusing on on-site logistics. On-site logistics, defined by Sundquist et al. (2018), is the management of physical flows on a construction site. We will consider three categories of physical flows; human flows, material flows, and equipment flows (Sundquist et al., 2018):

- Human flows concern all movements of people (workers, non-workers, passersby, etc.) on or to the jobsite;
- Material flows concern movements of materials used directly in construction (floors, beams, etc.), as well as their storage; And
- Equipment flows concern movements and storage of machinery and tools used, among other things, to move materials.

Although on-site logistics accounts for physical flows, Industry 4.0 also captures data flow in real-time. However, real-time is relative to the progression of a task. “Real-time” should not be confused with continuous data collection, which does not actually exist as. A digital system collects data at regular intervals, which may be short but are nonetheless discrete. Thus, the interval can change as a function of the task. For example, it is not necessary to collect data every second when it takes an hour for changes to appear.

On-site logistics relies on data valorization in the value chain to enable real-time decision-making, one of the key concepts of industry 4.0. Therefore the following section proposes a study of Industry 4.0 in the field of construction in order to see the related issues in this sector, although initially thought for the manufacturing industry.

2.2 Industry 4.0: The state of the art in construction

Industry 4.0 is often considered to be the revolution associated with the digitalization of processes (Danjou et al., 2017). Some articles have reviewed the literature on Industry 4.0 in the construction industry - also called *Construction 4.0*. *Construction 4.0* is related to data science, digital fabrication, artificial intelligence, modeling systems (augmented reality, building information models with various numbers of dimensions, computerized maintenance management systems) and technologies related to surveillance such as geographic information systems (laser scanning, drones, photogrammetry, global positioning systems) and materials tracking (radio frequency identification - RFID tags).

Several authors have examined the impact of Industry 4.0 on the construction industry, including Oesterreich and Teuteberg (2016), who present the state of the art of Industry 4.0 in this sector. They carried out a systematic literature review with a triangulation method to gather the data, as well as a case study, in order to enhance understanding and define what Industry 4.0 represents in the construction industry. Numerous technologies related to Industry 4.0 and situated at different levels of development emerged in their study (Oesterreich & Teuteberg, 2016). At another level, Dallasega, Rauch, & Linder (2018) concentrate on the impact of Industry 4.0 concepts on the construction supply chain. Their article addresses the concept of proximity between subcontractors and the construction site, and specifically the impact of Industry 4.0 on this proximity. To do so, they used a systematic literature review and case studies (Dallasega et al., 2018).

These authors counted existing technologies in the research field and analyzed their applicability through case studies. Nevertheless, it is clear that there is a lack of information concerning the applications of these technologies. It remains difficult to understand what really lies beneath the name of technology. The major difference between the application of technology and the technology itself resides in the fact that technology does not respond to a need, whereas an application of that technology does. In other words, technology is merely a tool that is intended for a particular use. On the one hand, a given technology can have several applications. For example, drones can be used for photogrammetry to map batches of materials (Tezel & Aziz, 2017) or to guide equipment on a jobsite (Oesterreich & Teuteberg, 2016).

On the other hand, the so-called, “Industry 4.0 technologies,” often existed long before the concept of Industry 4.0 arose. It is reasonable to think that 4.0 relies on the applications of these technologies. Therefore, this article focuses on the applications of technologies, going beyond their names, and examining how they are actually used in industry or as reported in the scientific literature. Throughout this article, Industry 4.0, as applied to the construction industry, will be referred to as *Construction 4.0*.

In recent years, digital transformation has been initiated in the construction sector under the umbrella of "Building Information Modeling," both out of necessity and motivated by regulation. The following section provides a quick overview of the contribution of this model in *Construction 4.0*.

2.3 Building Information Modeling

Building information modeling (BIM) is part of the digital transformation of construction processes. First, it is a technology in its capacity to generate multiple dimension digital models (n-D). BIM can also be a process and a working method, a method for sharing information. It allows sharing data with all stakeholders involved during the lifecycle of the building. From design to destruction, through the construction and utilization, BIM allows a constant evolution of the model during each construction step. Using a common model provides access to relevant data as soon as the data is up to date by stakeholders. BIM creates a direct and real-time collaboration between architecture, engineering, construction and operation industries that are involved in construction projects. The scientific literature reflects the interest that different communities, including industry, have shown an interest in this change. As suggested in **Figure 1**, there was a sharp increase in the number of documents using BIM beginning in 2009.

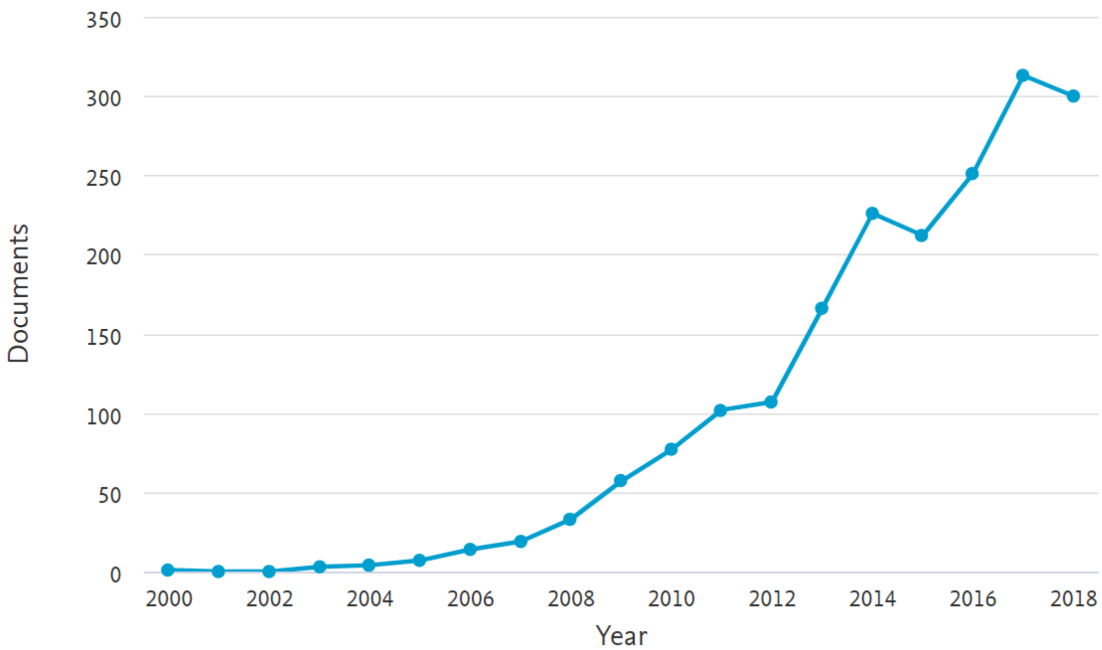

Figure 1: Number of relevant articles found per year

For the purpose of this paper, BIM has been considered as the central element, a baseline if you will, (Li & Yang, 2017) because BIM precedes the technologies we chose to analyze. Therefore, it will not be viewed as the technology itself. As described in the literature, BIM constitutes an essential element for proper operation-specific technologies described. However, BIM augmented by several dimensions (or n-D BIM) will be considered as a separate technology in Industry 4.0. Among other things, certain technologies are based on BIM for real-time applications, as Castro-Lacouture, Quan, & Yang (2014) show in their examination of the interaction between BIM and GIS.

In our literature search, we found several literature reviews and articles concerning technologies and digitalization in the construction field. Our literature review has revealed that the application of those technologies, digitalization in the construction field, are not discussed and do not provide significant content for a company that would like to jump into *Construction 4.0*. The remainder of this article proposes a methodology and a comparison between scientific works and professional practice. The next section describes the methodology used to carry out a comparative analysis of the applications of technologies described in the literature and applied cases implemented by companies in the construction industry.

3 Methodology

This comparative analysis resulted from an in-depth review of the literature on *Construction 4.0.* This proposed name is based on the concepts of Industry 4.0 and digitalization related to this industrial revolution in the construction industry.

This bibliographical analysis investigated subsets of articles in the field of construction-related to topics concerning Industry 4.0, Technology 4.0, and digitalization. It was done using the Scopus database, which covers several Elsevier databases, which in turn reference numerous high-impact journals. The analysis was limited to articles published after 2009 since that year marked a turnaround in the attention paid to Building Information Models in scientific articles. Indeed, the number of articles published that contained keywords associated with BIM grew strongly starting in 2009, as **Figure 1** shows.

The results of this search were mainly English-language journals and reviews articles and conference papers published between 2009 and 2017. As a result of this analysis, we found 188 relevant articles. Among the 188 articles initially identified, we sought to find those related to on-site logistics. On this topic, there were only 94 articles remaining. We then eliminated the theoretical and empirical articles (22) (Wacker, 1998). Finally, we were left with those dealing with the underlying technologies and technological applications (72). **Figure 2** shows the process of narrowing down the base of articles.

To do this comparative analysis of research and practice, we needed to seek out real, practical applications in the construction industry. We considered only practical applications that had to have been tested in a laboratory or in real conditions.

To find companies using the applications of *Construction 4.0* technologies, the following methodology was applied. We searched for practical applications of technologies first in the Derwent Innovations Index, a database of industrial patents, then in articles on media and corporate websites. All these search tools represent a way of making as comprehensive a search as possible. However, it is probable that companies do not reveal information about applications of specific technologies since these comprise their intellectual property.

Figure 2: Article selection process

The results of the comparative analysis consist of a series of technological applications related to on-site logistics. Considering the various applications identified in the scientific literature, a framework was developed within which these applications could be classified. This framework is based on two dimensions:

1. Three action verbs that serve as the basis for the comparative analysis. With these three action verbs, one can categorize all the scientific and professional applications related to logistics that emerged in the field of *Construction 4.0*. Therefore, **locate, allocate, and secure** characterize three major aspects of the management of physical flows associated with on-site logistics through the lens of Industry 4.0. These three verbs emerged from the association of technologies.

2. Three types of physical flows exist in the construction industry, as mentioned in section 2.3: human, material, and equipment flow.

Using these two dimensions, every application identified has an associated flow and can be characterized by an action verb.

Now that the framework and methodology have been explained, the next section presents the comparative analysis, including the results of the search of the literature and of applied cases in companies.

4 Comparative analysis of research and practice

In this section, our comparative analysis of the applications of technologies identified in the literature and their 'real-world' applications within companies is organized according to the framework described in section 3 with the three action verbs and three kinds of physical flows. At the end of the section, **Table 1** summarizes the classification within the proposed framework.

4.1 Locate

In this article, "Locate" means the action of identifying the location of a person or object. This action is a prerequisite for on-site logistics. In order to be able to control physical flows, the first step is often to find out where they are in space. The management of flows of material resources depends on various technologies, which are often combined to produce different applications.

The literature review highlighted several tools used to track items in real-time in the supply chain, particularly RFID tags, which make it possible to track and enhance the allocation of jobsite resources (Li & Yang, 2017). These tags are often combined with sensors or read by mobile devices (Watson, 2011). When associated with smartphones, RFID tags enable users to identify and locate items on site (Laine & Ikonen, 2011). This application of mobile devices also exists in practice.

Applied case: For example, *busybusy* (Busybusy^{TM}, 2019) provides a real-time jobsite tracking solution based on mobile devices. All companies that provide this kind of service are based on the same principle of an application connected to project management software. Thus, it is possible to monitor the supply chain on the jobsite in real-time and know the position, movements, uses, and quantities of resources. These applications are not limited to the supply chain; they allow for more general tracking on the jobsite and automated report creation.

Imaging technologies such as photogrammetry make it possible to capture the position of all logistical elements on a jobsite. For instance, by analyzing data, for example, photos of the site, it is possible to detect equipment and materials. All this can be done in real-time if the images are captured in real-time. For example, photogrammetric sensors can be combined with a drone to map a group of items on a site (Tezel & Aziz, 2017).

Applied case: *SiteAware* (SiteAware Systems Ltd., 2018) uses drones to do site exploration and calculate volumes on construction sites. The drone automatically follows a flight plan, and the images are collected and then analyzed by a human. Software is used to measure area and volume, making it possible to track the volumes being moved on a jobsite, whether the operation involves the extraction or backfilling. It is easy to see how this technology could be applied in earth-moving operations.

Drones are also deployed to generate 3-D models that will be used by autonomous machines to position themselves on site. In a sense, the drone becomes the automated machine's eyes (Oesterreich & Teuteberg, 2016).

Applied case: *Skycatch* (Skycatch, 2018) provides a drone guidance solution for construction machinery, particularly excavators and bulldozers. Japanese company *Komatsu* (Krewell, 2017) is already using Skycatch's technology to control its construction machinery. This technology is mainly used in earth-moving operations.

Waste monitoring and management have become an issue that must be taken into consideration on a jobsite. The use of new GIS technologies such as RFID makes it possible to determine the characteristics of items and materials on a site. These materials can be sorted correctly, and a control system can be set up to ensure that different kinds of waste are not mixed together and to process each kind appropriately. Moreover, integrating an environmental feature into the BIM will allow a building to receive certification. In the case of building renovation or demolition, materials can be processed correctly (Castro-Lacouture et al., 2014).

The literature also presents robotic applications that can sort waste autonomously. Robots can search for recyclable materials and also remove asbestos (Oesterreich & Teuteberg, 2016).

Applied cases: In view of the growing need for waste reclamation, the management of construction waste represents a real opportunity to be seized. A true treatment line or autonomous robot associated with construction or demolition sites does not yet exist. Businesses are only starting to move in this direction. For example, *Paprec Group* (PaprecGroup, 2019) is developing procedures in sorting construction waste with automated treatment lines. Since these lines are not mobile, it is still necessary to move the waste to the sorting line.

4.2 Allocate

Logistics 4.0 in the form of real-time flow management is necessarily concerned with resource allocation. This is a crucial aspect of jobsite management that *Construction 4.0* can improve.

Neural network approaches arising from AI concepts are also recommended in scientific publications for use in optimization issues. In association with multidimensional modeling, they enable flows to be optimized (Nguyen, Shehab, & Gao, 2010). For Example, the software now exists that can predict whether a tractor-trailer is able to access a specific area of a jobsite by simulating its possible movements (Lin, Yang, Hung, & Kang, 2013). Real-time may be a possibility with this application, but it should be recalled that jobsite configuration is not mobile in the same sense as jobsite advancement, since the data remains the same over a significant period of time. For the logistics of crane positioning, GIS tools can be integrated into BIM to predict possible conflicts or collisions (Irizarry & Karan, 2012).

BIM, and specifically 4-D modeling (including the dimension of time), make it possible to improve the allocation not only of material resources on the jobsite but also of work teams. Indeed, the temporal dimension makes it possible to determine the needs for materials in different areas of the jobsite. It is, therefore, possible to allocate the necessary quantities to all locations, as well as the human teams and equipment needed (Wang, 2013).

Applied cases: *Equipon* (Invento, 2018) provides solutions to control equipment on jobsites through the Internet of Things (IoT), with the specific purpose of allocating equipment in such a way as to save fuel. *Uptake* (Uptake Technologies Inc., 2019) also supplies solutions driven by data on asset management, including material and human resources. According to these companies' websites, these solutions represent the uses of AI, including machine learning and IoT.

4.3 Secure

Security is an important factor on a construction jobsite. The introduction of new technologies represents an opportunity to reduce jobsite accidents and prevent them in real-time.

RFID tags allowing for the location of items are a very widespread application mentioned in the literature. But they are also used for controlling the access of resources to the site, whether this access relates to equipment or the arrival of trucks on the jobsite (Dallasega et al., 2016). Management of arrivals on a construction site makes it possible for traffic to move more smoothly and thus reduces the risk of collision with workers (Lin et al., 2013). The same technology can also be used to monitor and control employees' access to the jobsite. RFID can serve to prevent access by unauthorized persons and to track the number of workers who are on-site and their identification codes (Oesterreich & Teuteberg, 2016).

Applied case: *Biosite* (Biosite Systems Ltd, 2019) provides a biometric system for controlling jobsite access. It also supplies a closed-circuit television service to detect intrusions. These technologies make it possible to monitor and secure a jobsite in real-time. In addition, in the case of problems on the site, this kind of surveillance system allows companies to protect themselves as they can prove that the site was monitored.

Real-time flow management also allows companies to prevent collision risks. With new 3D modeling technologies, it is now possible to view trucks in their environment and thus model the least dangerous routes (Lin et al., 2013). A combination of RFID and ultra-high-frequency (UHF) radio technology makes it possible to create a system for keeping track of workers and machinery. In association with a 3D environment, this technology prevents human-machine or machine-machine collisions (Woodhead, Stephenson, & Morrey, 2018).

Applied case: In the business world, *HC Safety* (Ho Cheng Safety Enterprise Co., 2018) provides a worker protection system, which can warn users of dangerous situations on the jobsite, such as alerting workers to the fact that a piece of machinery is close by so they can avoid collisions. Real-time data collection allows work conditions to be tracked and improved. Workers are located with GPS and LTE (long-term evolution) technology.

The neural networks and machine learning approach can be very powerful in jobsite security. They will allow for improved analysis of the movement of cranes or other construction machinery to detect a future collision. These data can be captured by drones then analyzed efficiently online thanks to systems that rely on machine learning. In that way, it is possible to warn the relevant people of imminent danger as soon as possible (Irizarry & Karan, 2012). In addition, the analysis of jobsite images due to certain kinds of AI will make it possible to compare them to dangerous situations that led to accidents on other jobsites (Ding et al., 2013).

Applied cases: *Komatsu*, in partnership with *Nvidia* (Krewell, 2017), uses cameras on its construction machinery to obtain a 360° view of possible collisions between machines or with employees. The information is used in real-time, sorted and then transmitted to drivers. Eventually, when the technology allows this, the machinery itself will be able to make decisions in order to react more effectively to dangerous situations. *Smartvid.io* (Volvo, 2019) is a platform that processes photos and videos from jobsites to identify situations that are dangerous for workers. AI is used to analyze the huge amount of data coming from a jobsite. The aim is to analyze dangerous situations in real-time and be able to warn the people involved.

Many applications from the scientific and professional worlds have the purpose of managing human flows. Some of them specifically concerns the management of human flows in emergencies, whether for the purpose of prevention or during an emergency. The use of 4-D modeling with BIM makes it possible to simulate jobsite evacuations in case of problems. Technologies combined with GIS make outside interventions easier in case of emergencies (Isikdag & Underwood, 2011).

Applied case: The mobile application marketed by the startup *SignOnSite* (SignOnSite, 2019) provides, among other things, an option for an evacuation order at any time. In case of immediate danger, the alarm can be triggered instantly, and workers told what to do by means of their smartphones. In that way, workers can be tracked in real-time during an evacuation.

Thanks to this technology, safety training can now be done remotely but immersively. Virtual reality makes it possible to create an environment that has no real risks for participants but allows them to experience a variety of scenarios in hazardous environments (Oesterreich & Teuteberg, 2016).

Applied cases: *Bechtel* (Bechtel Corporation, 2019) has set up a safety training program that uses virtual reality and augmented reality. With this fully immersive teaching method, employees can be placed in really dangerous situations. *NextWave Safety Solutions* (NextWave Safety Solutions Inc., 2018) provides virtual reality solutions where workers can make progress on a virtual jobsite. These solutions are much more engaging for workers than a video about jobsite safety. It is also possible to use virtual construction machinery in the same environment in which the employees will be working.

4.4 Summary of comparative analysis

Based on the two dimensions of the framework described in Section 3, the various applications identified in the scientific literature and professional practice have been set out in **Table 1**, which summarizes the comparative analysis.

Table 1 highlights two cells without any application: to locate human flows and to secure material flows. Several hypotheses might be considered. On the one hand, manufacturers may not be interested in such an application. On the other hand, they might not disclose any information in order to protect their intellectual property.

As regards the human flows, to locate construction site workers is a key issue because of the work control generated by such application.

The lack of applications on securing material flows is likely explained by the material itself will not cause any risky situation. It is rather its use or transportation that could lead to a dangerous situation. Therefore, action on material flows would not be useful to improve the safety of construction jobsite.

All the other cells contain applications that improve on-site logistics. Even if there are differences in maturity levels, most applications are common to both the scientific and professional world.

Table 1: Summary of comparative analysis

	Locate	**Allocate**	**Secure**
Human flows		- Resource allocation on the jobsite by 4D modeling integrated into BIM (Wang, 2013)	- Access control and tracking of the number and identification of human resources on the jobsite using RFID tags (Oesterreich & Teuteberg, 2016) - Location of workers to prevent risks of collision with machinery using RFID combined with UHF waves (Lin et al., 2013) - Protection of workers by locating them with GPS and LTE (Ho Cheng Safety Enterprise Co., 2018) - Simulation of jobsite evacuations using 4D modeling integrated with BIM (Isikdag & Underwood, 2011) - Tracking of worker evacuation in real-time with their smartphones (SignOnSite, 2019) - Simulated evacuation for safety training using virtual reality (Bechtel Corporation, 2019)
Equipment flows	- Mapping of groups of items on-site using photogrammetry associated with drones (Tezel & Aziz, 2017) - Generation of 3D model with a drone for autonomous machine guidance (Oesterreich & Teuteberg, 2016) - Drone guidance of construction machinery (Skycatch, 2018)	- Prevention of crane collisions by using GIS tools integrated into BIM (Irizarry & Karan, 2012) - Control of equipment on the jobsite using IoT (Invento, 2018)	- Control of access to equipment such as trucks on-site using RFID tags (Dallasega et al., 2016) - Simulation of truck routes to assess the least dangerous using 3D modeling (Lin et al., 2013) - Real-time analysis of crane movements using drones (Irizarry & Karan, 2012) - Real-time comparison of situations with past hazardous situations by AI to prevent accidents (Ding et al., 2013) - Detection of potential collisions by 360° cameras on machinery (Krewell, 2017)
Material flows	- Identification of items on-site and location using RFID tags (Li & Yang, 2017; Laine & Ikonen, 2011) sometimes associated with mobile devices (Watson, 2011) - Real-time resource tracking by mobile devices (Busybusy™, 2019) - Tracking of volumes moved (SiteAware Systems Ltd., 2018) - Waste management and sorting assistance with GIS and RFID tags (Oesterreich & Teuteberg, 2016)	- Flow optimization using neural networks and multidimensional modeling (Nguyen et al., 2010)	

5 Discussion

5.1 Industry 4.0 technologies and concepts applied to optimize on-site logistics

Industry 4.0 technologies allow for much easier, more effective and more reliable data collection than was previously possible. In addition, data quality is easier to control since data collection is (at least partially) automated.

The *Locate* function is fairly new in on-site logistics. Actually, it is very dependent on the Industry 4.0 technologies associated with it. Before the introduction of these technologies, a human being had to locate resources on the jobsite or monitor the progress of jobsite tasks; this task took time but did not represent sufficient added value to be worthwhile. In addition, human beings are unable to monitor work advancement in real-time. Today, new technologies such as drones combined with digital imaging sensors make it possible to execute this task almost instantaneously. It should be recalled that the applications associated with this fourth industrial revolution are often described as new technologies even when they make use of existing technologies. It is their use and the exploitation of the data they generate in real-time for decision-making that makes them new, particularly in the construction industry.

We mentioned that the *Secure* function already existed before the introduction and use of these technologies. Nevertheless, security is facilitated by this 4th industrial revolution. Unlike location, security has long been taken into consideration on construction jobsites as health and safety are major concerns for companies in this industry.

This component has been revolutionized by new technologies. Improved prevention and control are possible with intelligent sensors such as RFID. Better tracking of workers is possible to prevent accidents. All these new technologies and the real-time use of the data they provide allow for enhanced working conditions and safety on jobsites and the prevention of dangerous situations.

The actions associated with the *Allocate* function are also assisted by these technologies, which provide faster, more accurate results. The allocation was done by hand before these technologies were introduced in the market. In addition, for all these actions, the amount of data used was reduced to what a human was able to process. Today, the limits on the amounts of data that can be exploited digitally have increased. It is easier to control the quality of data collected when the process is automated, and the human factor does not come into consideration. All these automatically processed data make it possible to obtain more reliable, relevant and accurate results. For example, in the *Allocate* function, it is now possible to take account of all the necessary tasks and resources to allocate machinery, cranes and materials.

The technologies to collect data exist today. In the future, the processing of these data will be improved because the core concept of Industry 4.0 is to enhance real-time decision-making. Indeed, the processing of such “big data” often requires very complex, demanding algorithms. Solutions based on AI are starting to be mentioned in the scientific literature. Some major industrial groups have begun to work on this topic. However, Industry 4.0 is still far from being used at its full capacity, particularly in industrial fields, and even more so in construction. In addition, the methods for viewing processed and applied data should be improved. Virtual reality will likely cease to be used, giving way to augmented reality, which can link the real and virtual worlds.

5.2 The difference in maturity between business and academia

A few rare applications posited in the scientific literature do not yet have real-world counterparts. There are several possible explanations for this finding. From the practitioners’ point of view, the stage of development of the application may still be too early for a startup, or a market analysis may not reveal sufficient potential for such development. Sometimes the business world lags and the applications require prerequisites that have not yet been introduced. This is often due to the conservativeness of the construction industry compared to other industries, especially manufacturing.

5.3 The common features of business and academia

From a more general perspective, the business world is at the same level as academia in the development and implementation of solutions related to Logistics 4.0 in the construction industry. Whereas academics examine certain topics and applications theoretically, the industrial world is already developing and applying them in practical cases. Therefore, we see a correlation among ideas but a gap in the development and application of these technologies and ideas. Startups and innovative young companies are already combining their various tools and technologies to create new ones. One example involves drone technologies with laser sensors. The scientific literature has often addressed this topic but without providing any practical applications or connections. The business world, however, is already proposing a solution for the construction industry. Real-world practice often goes a bit farther in practical applications and technology development. Even when ideas have been presented in the scientific literature, the industry goes farther. In the case of drones, businesses are producing fully autonomous robots that can move around jobsites and collect information; Doxel is one such company (Doxel Inc., 2019). The scientific literature stops at the possibility of doing so and often mentions drones, which are able to traverse obstacles and are much easier to control.

Together, these scientific applications, whether they arise in the business world or the scientific literature, constitute a cluster of solutions for the construction industry, where there is no one integrated solution that can incorporate all of these technologies. This is a considerable difference from the manufacturing industry, which has witnessed the development of numerous integrated enterprise management software applications. Although the BIM integrated model was a key driver of the emergence of Industry 4.0 in the construction industry, the current trend is for the introduction of technological solutions that are not correlated with each other and may or may not be related to BIM.

The future challenges for the industry and scientific research will be an arrangement of these technologies' applications in their own contexts. It would imply to correlate real usages with research and development in order to achieve real-time and facilitate decisions. Furthermore, the question will be to know whether BIM will remain the central element of which technologies will refer to, or many solutions will emerge in the same way it is already seen in industry 4.0.

6 Conclusion

Further to a comparative analysis of technological applications that have emerged from the scientific literature and the world of practice, this article shows that the concepts of Industry 4.0 have a direct impact on on-site logistics. Although the construction industry is lagging the manufacturing sector, the adoption of Industry 4.0 technological applications is now underway and is changing management practices on construction sites. The introduction of real-time management of physical flows is disrupting the processes used to track work advancement on the jobsite and make informed decisions.

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