Use cases for the Internet of Things (IoT) in the construction sector: Lessons from leading industries

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Abstract

This study conducts a cross-sectoral comparative analysis of academic and industry literature to determine the use cases of the internet of things (IoT). Specifically, the research seeks to explore digital applications (e.g., building information modeling (BIM), radio frequency identification (RFID)) within the construction supply chain – a sector berated for its lack of innovation. An interpretivist epistemological lens provides the overarching methodological approach adopted in which the literature constitutes units of analysis. Ensuing discussion defines the architecture of proposed real-life scenarios and provides a description of an IoT layout for these scenarios. In practical terms, the study contributes to the field by raising awareness of potential use cases of IoT for construction practitioners as 'proof of concepts'. For researchers, the findings provide a blueprint template layout of suggested use cases to be tested in future research studies hence, offering a sound basis and a fertile ground for advancing the body of knowledge on this topic area.

Keywords: IoT, Industry 4.0, Industrial Internet, BIM, RFID

1. Introduction

Customers have heightened, new, and customized expectations today by learning from other industries and demand that the construction industry brings similar innovations. A case in point being hybrid renewable energy solutions linked to a building's daily carbon footprint (Woodhead *et al.* 2018). Device-agnostic mobile applications are the need of the hour that shall identify crucial and critical information and cater to the needs of consultants, contractors, and clients in an integrated manner. Researchers conclude that apart from design intent and clarification, there are slight differences in the information demands of consultants and contractors; however, client's needs deviate significantly from them (Nourbakhsh *et al.* 2012).

The ease of accessing data on sites is of primary concern while developing smart tools and data visualization platforms. Strategies like developing BIM-enabled tools to allow site workers using portable devices to access design information and to capture work quality and progress data on-site are the need of the hour (Davies and Harty, 2013). Knowing that the various sectors where wearable technologies have been greatly applied are not a high-risk industrial sector like construction, there is an urgent need to change the status quo in terms of the application of wearable technologies in construction. (Awolusi *et al.* 2018). Today there is an urgent need to raise awareness and communicate the success of innovative digital technologies and solutions to revolutionize the construction industry.

The Construction Industry has often been seen as laggards when it comes to adapting to emerging technologies. The Internet of Things (IoT) provides exciting opportunities for the Construction Industry to shed this unwanted tag and be on the forefront of utilizing IoT to solve its time and resource constraints and frequent defaults. Construction operations are typically spread across large areas and require remote collaboration between multiple contrasting departments and resources that create the need for ubiquitous, rapid, and automated decision-making on the worksite (Louis & Dunston 2018). The Internet of Things (IoT) utilizes systems such as sensors and connected devices to monitor real-time parameters and harness the information gleaned through techniques like data analytics and data mining to provide visually informative end-results. For the construction industry to address the current technological challenges in this Industry 4.0 age, it needs to adapt and transform itself from its traditional primitive methods to digitalised automated systems which will act as a major step forward towards improving its productivity, efficiency, and sustainability and lead to dynamic planning and management (Dallasega 2018).

2. Research Methodology

This paper follows an open-ended research literature review of scientific publications obtained from Scopus and Web of Science databases. The search query included "internet of things" OR "industry 4.0" OR "digital engineering" OR "big data" OR "operational technology" OR "digital" OR "cyber-physical systems" OR "digitalisation" OR "industrial internet" OR "industrial internet of things" AND "construction industry". Publications are selected with a focus on relevant practical used cases in the construction sector and provides relevant "proof of concepts" of practical implementation of Internet-of-Things to facilitate its uptake in the construction industry. Review papers and conceptual frameworks were avoided, and only real-life case studies were included, which resulted in 21 publications included in the scope of this study.

3. Use Cases

Publications are selected with a focus on relevant practical used cases in the construction sector and provides relevant "proof of concepts" of practical implementation of Internet-of-Things to facilitate its uptake in the construction industry. Fig.1 shows the plethora of opportunities and use cases that have been focused upon in this study and provide a description of relevant used cases in these categories from literature.

Figure 1: Sub-domains of IoT adoption in the construction industry

3.1 Raising awareness and communicating the success RFID

Despite its enormous potential, RFID is adopted at a leisurely pace in the construction industry. There are two possible ways to achieve its broader applications. One is to inform the industry of the potential in an effective way. The scenarios identified in this work, animated later using Google Sketch Up, can serve as a vehicle for better communicating the potential of RFID to construction practitioners (Lu, Huang, and Li, 2011). Wang (2014) fused RFID in prefabricated construction to improve construction productivity. Kereri and Adamtey (2019) investigated key drivers and success factors for RFID adoption in the residential or commercial construction industry. Lanko *et al.* (2018) considered the application feasibility of blockchain in logistics of construction materials through the usage of RFID technology. Xue *et al.* (2018) provided practitioners with guidelines for linking RFID to BIM for various construction engineering and management needs.

3.2 Safety monitoring

Construction worker safety is of paramount importance towards attaining a successful zero-casualty objective targeted by most project managers. There is a need to develop a holistic and collaborative information integration framework for safety monitoring that collects, analyzes, and disseminates safety information (Xu, Chong and Liao, 2019). In response to this need, researchers have developed innovative strategies to improve, enhance, and integrate worker safety, especially in the construction of tall buildings. Fang (2019) developed an automated inspection method to check PPEs' usage by steeplejacks who are ready for aerial work beside exterior walls. RFID-based location and tracking technology, centimeter-level of ultrasonic detection technology, and infrared access technology were developed in three-tier network architecture to help workers change their risky behaviors and avoid accidents on the changing construction site (Zhou and Ding, 2017). The adoption of wearable technology has the potential for a result-oriented data collection and analysis approach providing real-time information to construction personnel taking valuable lessons from other industrial sectors (like mining and manufacturing) to measure and monitor a wide variety of safety performance metrics in construction (Awolusi, Marks and Hallowell, 2018). Edirisinghe (2018) envisaged that the future construction worker who is part of the digital skin of the context-aware future construction site would wear smart wearables. These include e-textiles, such as smart safety vests (Edirisinghe and Blismas, 2015), smart hardhats (SmartCap, 2017).

3.3 Data Visualization

The success of incorporated IoT techniques will significantly depend on the ease with which critical data is displayed, and key performance indicators and metrics captured and reported in-time. Real-time representation dashboards such as Google Data Studio will allow the graphical presentation of the data to be improved and offer a more user-friendly tool (Martín-Garín *et al.* 2018). Wireless sensor technology can be used by engineers to monitor conditions in and around buildings. An interface to review the data and a web-based system was developed that allows a user to mine the database using parameters such as the type of data, location of the sensor, and the time of data acquisition (Jang, Healy and Skibniewski, 2008). Edmondson (2018) harnessed the capacity to visualise and predict flood performance to anticipate surcharging of manholes and inlets as well as discharge events from combined sewer overflows (CSO) to develop a Smart Sewer Asset Information Model (SSAIM) for an existing sewerage network opportunity within the wastewater sector to harness and report in real-time sewer condition data for operation management.

3.4 Structural Engineering Applications

The Internet of Things has essential applications in the field of structural engineering. Naser (2019) developed foldable structural components (called Autonomous Structural Reconfiguration (ASR)) and incorporated them with artificial intelligence and Internet of Things (IoT) technologies. Integrated into structural engineering applications, this institutes the first step towards realizing autonomous and resilient infrastructures. These components act as secondary, and independent structural systems, that allow civil construction to autonomously reconfigure their internal structure to adapt to severe loading conditions in real-time. Zhang *et al.* (2018) analyzed the practical application value of the IoT technology in the crack identification of bridge structures and established a bridge structural health monitoring system based on IoT technology.

3.5 Prefabricated Construction

The Internet-of-Things can act provide a much-needed boost to prefabricated and modular construction. Zhong (2017) provides evidence how the Hong Kong Housing Authority (HKHA) sped up housing delivery by employing advanced technologies, including Building Information Modelling (BIM) and Radio Frequency Identification (RFID), in some of their pilot prefabrication-based construction projects. Tao *et al.* (2018) developed an IoT-based framework to monitor the greenhouse gas (GHG) emissions in real-time for manufacturing prefabricated components.

3.6 Cloud-based platform

Data stored as cloud asset could sense its real-time status, adapt to different working scenarios, be controlled remotely, and shared among agencies. It enables accurate real-time control of every asset, and thus improves the management efficiency and effectiveness (Xu, *et al.* 2015; Xu, *et al.* 2018). Núñez *et al.* (2018) developed a mobile computing based knowledge management platform to manage lessons learned in different Chilean construction projects of small and medium enterprises through an iterative and user-centric methodology.

3.7 Construction waste management

The Internet-of-Things can act as an effective means to monitor and reduce construction waste. Chen (2002) developed a group-based incentive reward program (IRP) to encourage workers to minimize avoidable wastes of construction materials by rewarding them according to the amounts and values of materials they saved. The bar-code technique is used to facilitate effective management of construction materials. An IRP-integrated construction management system is also introduced to avoid jerrybuilding and solve the rescheduling problem due to rework of quality failure.

3.7 Educational opportunity

The growing emergence of IoT provides excellent opportunities for active participation of researchers and students to develop innovative solutions and use cases for applicability in real-life scenarios in the construction sector (Dave *et al.* 2018). Nati *et al.* (2013) demonstrated that university campuses were the perfect testbed for experimenting with the Internet of Things incorporating the involvement of real users and satisfying the need for emerging realism in research work.

4. Barriers to IoT Adoption in the construction industry

Some of the possible barriers identified and measures to mitigate them regarding IoT adoption in the construction industry are as follows:

a.) **Incompatibility and unclear value propositions:** Consistent coordination between various departments regarding the collection, monitoring and regulation of data along with their processing and analysis at an integrated level to enhance decision-making and definite value addition is a challenge and significant hindrance for smooth IoT adoption. This obscurity can only be resolved through proper integrated planning before employing IoT devices or techniques on the field. Clear guidelines, policies, and benchmarking regarding the use of IoT devices and procedures would greatly assist in defining clear procedures and policies.

b.) **Data privacy and security**: The explosion of enormous data generated by IoT devices lead to concerns over its legality, privacy, and governance. Misuse could prove to be immensely counterproductive to the main aims of employing IoT. Unscrupulous hackers and data thieves may maliciously corrupt stored data or use historically compiled data to further their nefarious purposes. The security protocols and access have to be carefully developed and monitored to prevent this occurrence.

c.) **Bureaucratic governance structures:** Construction industry has traditionally been governed by rigid and bureaucratic hierarchies which are resistant to change and evolution. This provides a significant hindrance to the gradual and smooth uptake of IoT techniques and processes. The only solution is to convince the important decision-makers of the numerous benefits of IoT especially in a financial context so that change is effected from a top-down flow making it more effective and integrated, rather than a bottom-up approach which results typically in point-solutions as observed from the literature review.

d.) **Business planning and models:** Effective business plans are to be formulated incorporating the IoT techniques. A practical benefit-cost analysis proves necessary evidence before the uptake of any new technique in a project. Failure to plan the absorption in a systematic process would provide to be a significant hindrance for the successful adoption of IoT in construction projects.

5. Limitations and Future Scope

This study provides a preliminary exploration of the various possibilities and potential of the applicability of Internet-of-Things in the construction sector to satisfy the heightened demands of customers in the present technological age. Since the Internet of Things is a nascent field of study concerning the construction industry, only 21 publications referring to real-life case studies were included in this study. With growing interest in this field of research, it is highly possible to have additional case studies highlighting applicability and effectiveness of Internet-of-Things in the construction sector which would increase the body of knowledge that we currently hold in digital construction techniques and tools. The findings provide a blueprint template layout of suggested use cases to be tested in future research studies; hence, offering a sound basis and a fertile ground for advancing the body of knowledge on this topic area.

6. Conclusion

Internet-of-things can significantly enhance and automate the decision-making process in construction projects. While it can be argued that the practice of daily meetings for a project comprises monitoring and control for decision-making, its low temporal frequency is detrimental to project performance in terms of taking timely actions based on up-to-date information from the field (Louis and Dunston, 2018). Project delivery times and quality can be upgraded by utilizing the principles and techniques of IoT.

It was observed from the preliminary literature review that most of the solutions were point solutions that aimed to satisfy short-term localized goals instead of developing an integrative system for providing "umbrella solutions" targeting any significant aspect of the construction industry as a whole. Although many review papers tried to highlight the possible future impact of growing digitization and IoT in the construction sector, a bibliographic approach without relevant human or industry perception through questionnaires was observed. Various techniques like big data management, data mining, cyber-physical systems, and proposed conceptual frameworks were discussed without sufficient successful examples from real-life case-study implementation. There is an urgent need to translate the theory of IoT into practice in the construction industry with an integrated ecosystem changing with a view towards possible hindrances and measures to mitigate them chalked out in advance.

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