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The Role of Internet of Things in Delivering Smart Construction

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Abstract

The construction industry is the least digitised sector in the world and it contributes significantly less, in terms of productivity, to the global economy than its average potential. Current trends in the construction industry are aimed at leveraging cutting-edge technologies to improve productivity and decision making, this approach is commonly referred to as smart construction. Smart construction involves the augmentation of construction resources such as machinery, devices, components and people with digital technologies for transforming the construction industry. Many aspects of construction have witnessed transformation through automation, cyber-physical systems, cloud-computing, cognitive computing, immersive technologies and so on. An emerging concept in digital technology known as internet of things (IoT) is gradually advancing the possibilities of smart construction in various areas of application. This study aims to assess the role of internet of things (IoT) in enhancing the delivery of smart construction. From the perspectives of modern construction methods such as offsite construction, lean construction, smart assembly and so on, this study presents a mixed methods systematic review of the various areas of application of IoT in modern construction methods and identifies the emerging themes of IoT application in smart construction. The methods and current challenges of using IoT in application areas such as; cyber-physical modelling; offsite manufacturing; onsite assembly; handling and logistics; real-time monitoring and control; health and safety; information management and communication; energy management; waste minimisation; remote inspection; and lean construction management, is presented in the paper. This study substantially contributes to existing knowledge of using digital technologies for transforming construction operations and lays a solid foundation for further research in the application of IoT for smart construction. The challenges identified from the various areas of IoT application are opportunities for the development of cutting-edge solutions in construction.

Keywords: Internet of Things, Offsite Construction, Smart Construction, Assembly, Efficiency

1. Introduction

The need for improving construction productivity is necessitated by the importance of construction or infrastructural development to economic growth and the notorious inefficiency of converting resources to products in the industry (Gbadamosi et al., 2018). Although many other industries rely on the construction industry for their operations, the construction industry has the worst records in terms of efficiency, reliability and safety (IPA, 2018). Current trends in the construction industry are targeted at mitigating the inefficiencies of construction operation through cutting-edge digital technologies. Traditional methods of designing and implementing construction projects are being revolutionised by innovative technologies such as internet of things (IoT), big data and cyber-physical systems (Woodhead et al., 2018). In a bid to improve the overall productivity and business value in the construction industry, principles of Design for Manufacture and Assembly and Industry 4.0 have transformed construction to be viewed as a manufacturing process with huge opportunities of using Big Data for improving operations and making informed decisions at various stages (Bilal et al., 2016).

With the growing market of low cost sensors and advancement in artificial intelligence, the IoT ecosystem is capable of generating and transforming data through its integrated layer of hardware, software and internet connectivity to enhance various stages of construction (Cheng et al., 2018). Current transformation in the construction industry has described the capability of using data and digital technologies to augment construction operations for improved efficiency as a smart construction (Bragatto et al., 2018; Li et al., 2018). The concept of smart construction offers a transition from the traditional methods of construction to manufacturing through the increased usage of standardised components and offsite fabrication (Gbadamosi et al., 2018). The dyad transformation of the construction industry through the use of Modern Methods of Construction (MMC) and increased use of big data presents great application opportunities for IoT in smart construction. This study reviews the current application areas and challenges of IoT in smart construction.

2. Background

The construction industry is transforming from traditional methods of construction to manufacturing and this transformation comes with new challenges (Kochovski and Stankovski., 2018). Although the modern methods of construction have tremendous benefits for increasing business value such as improved accuracy and quality, faster delivery time and lower cost of construction projects (Woodhead et al., 2018). Construction businesses now seek improved value from IT investments, digital skills acquisition and advanced digital infrastructure. Innovative technologies now dictate how buildings are designed, constructed and managed (IPA, 2018). With the current trend of increased use of data and availability of low cost sensors, this paper will examine the application of IoT in smart construction. From the perspectives of innovative technologies in construction, the current and potential challenges will also be explored.

2.1 Innovative technology and construction

The three major phases of construction which is usually described as the CDM (construction, design and management) process has been improved using various innovative technologies (Abanda et al., 2017). The design phase of construction has evolved from 2D CAD designs to 5D BIM designs which includes detailed virtual 3D visualisations and time and cost projections and the other two dimensions (Eastman et al, 2011). Even more, construction companies are now using more data for decision making in design phases through improved organisational learning, active client’s involvement and artificial intelligence (Bilal et al., 2016). The construction phase has also witnessed massive transformation from traditional onsite construction to increased use of offsite prefabricated and preassembled components (Li et al., 2018). The Modern Method of Construction (MMC) is sometimes referred to as smart construction because it involves streamlining construction processes through increased use of big data, adoption of lean principles, digital collaboration and remote monitoring (Woodhead et al., 2018). Also, facility managers now leverage innovative technology for automatic fault detection, assets monitoring and predictive maintenance. The need for increased data capturing and processing has put IoT the best position to drive smart construction to the next level.

2.2 IoT and Smart Construction

Internet of Things (IoT) is described a network of things or objects that have unique identification (UID) or internet protocol (IP) address and sends data (e.g. temperature, humidity, vibration) about its state and its environment, and can receive data connected to actions in actuators (Rai and Jagadeesh, 2017). The major advantage of using IoT applications for the CDM process is the availability of real-time data which enables the efficient performance monitoring, informed decision making, smarter designs and results in higher productivity, lesser emissions, lesser labour and faster project delivery (Bragatto et al., 2018; Woodhead et al., 2018).

Adopting manufacturing in the construction industry has the potential to increase productivity by up to 40% (IPA, 2018). However, due to the current culture of fragmentation and resistance to change presents huge challenges in the construction industry (Gbadamosi et al., 2018). Aside from the common challenges of cybersecurity and data security, the construction industry is faced with challenges of data formats, data ownership and so on (Park et al., 2017; Lilis and Kayal, 2018; Shah et al., 2018). The challenges within the construction industry are unique and the implementation of IT solutions to tackle the challenges in the construction industry require peculiar efforts to yield the appropriate investment value therefrom (Li et al., 2016). Based on this premise, the aim of this paper is to review extant literature to identify the application areas of IoT in smart construction and the current challenges of implementing IoT on various stages of the CDM process in relation MMC.

3. Methodology

The methodological approach adopted for this paper is the mixed-methods systematic review. This was adopted to enable the exploration of the relevant findings from extant literature. According to Booth et al. (2012), a systematic review is used for identifying, selecting and appraising all the literature that is relevant to a research question. The database source used for this review is Scopus. Only literature published between 2011 and 2019 were included in this study, this because the application of IoT in smart construction is an emerging subject area. The database search was carried out using the "Title/Abstract/Keyword" field for *Internet of Things in Smart Construction*.

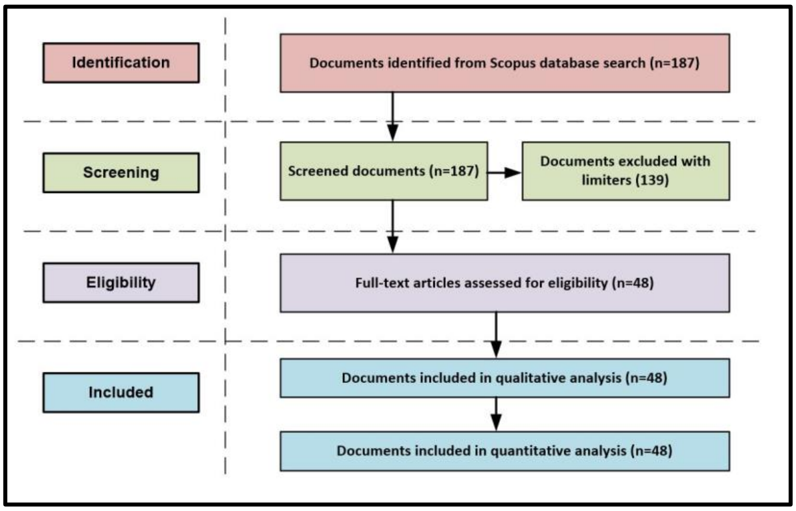

Figure 1: Flowchart for Systematic Review Process

A total number of 187 documents were identified through the database search. However, after limiting the document language to "English" and the document type to "Article", this number was reduced to a total of 48 documents. The systematic review focused on documents with source types of journal to ensure accessibility of review documents.

Figure 1 shows the flowchart for this systematic review which was adopted from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The final number of documents after applying the inclusion criteria is 48. The 48 documents were reviewed and analysed two steps. The first step includes the following procedure (1) title; (2) year of publication; (3) source of publication; (4) country/territory; (5) subject area. The second step involved the identification of application areas and challenges of implementing IoT in smart construction. The information at each stage of the process was gathered from Scopus database to obtain the result.

4. Results and Discussion

The result obtained from the systematic review is presented following the steps explained earlier in the methodology. The first step is presented in section 4.1 and it entails the procedure (1) to (5). The identified application areas and challenges of IoT in smart construction is presented and discussed in section 4.2.

4.1 Publishing Framework

All articles obtained from this review of the application of IoT for smart construction were published between 2012 and 2018 with about 80% of the articled published within the last three years. This indicates that there is an increase Table 1 shows the annual distribution of the published articles.

Table 1: Annual Distribution of Articles on IoT for Smart Construction

Year	**Documents**
2018	17
2017	10
2016	9
2015	3
2014	3
2013	1
2012	4
2011	1

Table 2 shows the journals where at least two articles have been published on IoT for smart construction. "*Automation in construction"* has the highest number of published documents and has the highest SJR impact factor. Other journals with relatively high impact factors include "*future generation computer systems*" and "*IEEE access*".

Table 2: Number of Documents by Source and Impact Factor (only includes journals where two articles or more are published)

Source	**Documents**	**SJR Impact Factor 2017**
Automation in Construction	5	1.613
Technical Bulletin	3	0.101
Future Generation Computer Systems	2	0.844
IEEE Access	2	0.548
International Journal of Distributed Sensor Networks	2	0.255
International Journal of Embedded and Real-Time Communication Systems	2	0.176

At least ten countries/territories have the minimum of two journal publications on IoT for smart construction with the United Kingdom and Italy having the highest among European counterparts. Current trends of IT investment in the construction sector will put the UK at the fore-front of the global construction market. 37.5% of the published articles were in China, this reflects the output of investments in research, development and innovations. Figure 2 shows the number of documents according to country/territory.

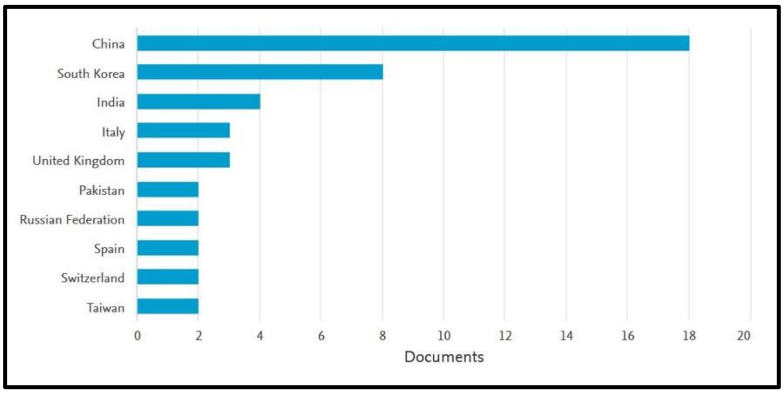

Figure 2: Number of articles by region/territory (only include countries where two articles or more were published)

Figure 3 shows the subject areas where articles relating to IoT for smart construction have been published. The most significant subject areas in which studies were conducted are engineering (34.4%) and computer science (26.7%).

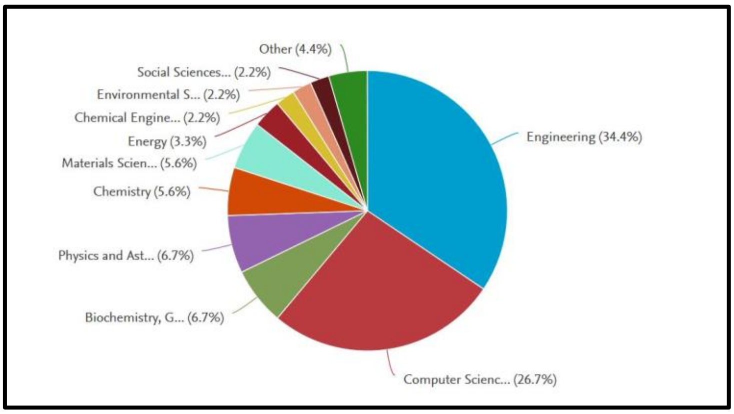

Figure 3: Number of articles by region/territory (only include countries where two articles or more were published)

4.2 Areas of Application of IoT in Smart Construction

As mentioned earlier, this section includes the result for the comparative review of literature of the areas of application of IoT in smart construction. As shown in Table 3, eight key areas of application were identified for this study, these include: (i) Offsite Manufacturing (OM); (ii) Handling and Logistics (HL); (iii) Onsite Assembly (OA); (iv) Real-Time Monitoring (RM); (v) Cyber-Physical Systems (CP); (vi) Design and Analyses (DA); (vii) Energy Consumption (EC), (viii) Facility Management (FM).

Woodhead et al., (2018) discussed the application of IoT in various phases of construction including design, construction and facility management. It can be seen that the application of IoT for on-site operation (10.41%), off site manufacturing (16.67%) and cyber-physical systems (16.67%) in smart construction are the least researched areas. The application of IoT in design and analysis (25%), handling and logistics (25%), and energy consumption (29.17%) have relatively my research interest to the authors. Most of the authors (62.5%) discussed the application of IoT for real-time monitoring in the aspects of data sensing, video streaming and image captioning.

Some application real-time IoT data usage were discussed relative to facility management for predictive maintenance, automatic fault detection, reliability analysis and emergency response (Korzun et al., 2015; Zavyalova et al., 2017; Zhang et al., 2018). Some researches were done on the application of real-time data for energy balancing and energy consumption optimisation (Junbin et al., 2012; Sung et al., 2013; Jeong et al., 2016; Zheng et al., 2016; Salamone et al., 2016; Lilis et al., 2017; Inga et al., 2018;). Other studies were conducted including tunnel management against fire accidents (Kim et al., 2018), smart hospital management system (Korzun et al., 2015; Zavyalova et al., 2017; Shah et al., 2018), and emergency monitoring (Yang et al., 2013; Vijayalakshmi et al., 2016). The application of IoT for smart construction was found to be more in the aspect of post-construction as compared to design and construction phases.

Table 3: Application Areas of IoT in Smart Construction

S/N	Documents	OM	HL	OA	RM	CP	DA	EC	FM
1	Sosa et al. (2018)		✓						
2	Woodhead et al., (2018)	✓	✓	✓	✓	✓	✓		✓
3	Tian et al., (2018)				✓				
4	Zheng et al., (2018)	✓			✓		✓		
5	Inga et al., (2018)							✓	
6	Kim et al., (2018)				✓				✓
7	Zhang et al., (2018)				✓				✓
8	Hendaoui et al., (2018)		✓		✓		✓		✓
9	Li et al., (2018)	✓		✓	✓	✓			
10	Shah et al., (2018)							✓	
11	Bermudez et al., (2018)		✓		✓		✓	✓	
12	Bian et al., (2018)		✓				✓		
13	Lilis and Kayal., (2018)				✓	✓	✓		
14	Al Sibahee et al., (2018)				✓	✓			
15	Kochovski et al., (2018)	✓	✓	✓	✓				✓
16	Mohan et al., (2018)		✓		✓			✓	
17	Bragatto et al., (2018)	✓		✓	✓				
18	Lai (2017)						✓	✓	✓
19	Cheng et al., (2017)				✓				
20	Park et al., (2017)	✓		✓					✓
21	Wanchun et al., (2017)				✓		✓		
22	Rai and Jagadeesh, (2017)		✓		✓		✓		
23	Lilis et al., (2017)							✓	✓
24	Zhang et al., (2017)		✓		✓				
25	Lee et al., (2017)	✓			✓	✓			
26	Zavyalova et al., (2017)				✓	✓			✓
27	Kim et al., (2017)				✓			✓	✓
28	Kang et al., (2016)	✓	✓						
29	Calvo et al., (2016)							✓	✓
30	Fok, (2016)					✓			
31	Salamone et al., (2016)							✓	✓
32	Li et al., (2016)							✓	
33	Zheng et al., (2016)				✓			✓	✓
34	Huang et al., (2016)				✓		✓		
35	Jeong et al., (2016)						✓	✓	
36	Vijayalakshmi et al., (2016)		✓		✓		✓		✓
37	Fu et al., (2015)				✓				
38	Kim and Kim (2015)								✓
39	Korzun et al., (2015)				✓				✓
40	Li et al., (2014)								✓
41	Wang, (2014)				✓				✓
42	Kumar et al., (2014)				✓				
43	Sung et al., (2013)				✓			✓	
44	Yang (2013)		✓		✓				✓
45	Junbin et al., (2012)				✓			✓	✓
46	Yu et al., (2012)								✓
47	De et al., (2012)					✓			
48	Jiang et al., (2011)								✓

Evidences of IoT application for during the design and implementation stages of smart construction in this study includes process documentation through edge computing (Kochovski and Stankoski) and decision-making and planning (Kang et al., 2016). Zheng et al., (2018) also leveraged on data-driven IoT applications for performance analyses and efficient prediction for manufacturing enterprises. Also, in a concept referred to as "digital twin", Li et al., (2018) captured the application of a combination of BIM, RFID and IoT sensors data for real-time modelling and decision support system for site managers to visualise the physical environment in a digital world.

Advances in the field of IoT is enhancing the application of cyber-physical systems (CPS) which use computer-based algorithms to monitor and control physical things and the environment. CPSs have been deployed in a concept described as cyber-medicine system (CMS) in the digitalised management of healthcare information through the integration of medical facilities (Zavyalova et al., 2017). With rapid development in IoT technology and the current transformation in construction technology, it is important to understand the current trends, future opportunities and common challenges to the implementation of IoT for smart construction.

Many of the reviewed literature identified challenges of implementing IoT for smart construction. Some common challenges include the privacy, security and power consumption requirements of operating IoT hardware and software applications (Lilis and Kayal, 2018; Shah et al., 2018). Woodhead et al., (2018) argued that a major limitation of using IoT applications in environments such construction sites is the safety and quality of service (QoS) requirements because of the temporality of construction operations and the constantly changing environment. Authors such as Part et al., (2017), Shah et al., (2018) also identified many other challenges including service availability scalability, adaptability, connectivity, resiliency, portability, maintainability and compatibility of IoT devices and applications.

5. Conclusion

This study aimed to identify areas of application and challenges of implementing IoT in smart construction. A mixed-method systematic review approach was adopted and 48 journal articles were reviewed in this study. IoT is an emerging technology in smart construction and its current applicability for construction has been criticised by some authors. However, this study identified some areas of application including off site construction, on-site assembly, real-time monitoring, energy consumption management, facility management, design and analysis and so on. This review is an important basis for identifying the future opportunities for IoT application in smart construction. With the growing need for increased big data processing and current availability of useful data, the use of IoT applications in smart construction is unavoidable.

This study also identified some factors that could act as barriers to the implementation of IoT in modern construction methods. Some of these challenges include security, privacy, safety, maintainability, scalability and portability. A major challenge that is peculiar to the construction industry is the constantly changing environment and fragmentation among industry stakeholders, which gives rise to problems such as data ownership, and reluctance to long-term IT investments in projects-based organisations. Based on these challenges, this study highlighted the willingness of research and business owners to invest more on implementing IoT facility management and rather than in design and construction phases of smart construction.

However, there are evidences of implementing IoT for planning and design, construction monitoring, decision making in factories, safety and emergency response planning. Through the gradual transformation of the construction industry, construction products and processes will gradually evolve to be standard and stable. This will give rise to easier implementation of IoT technologies at the design and construction phases of smart construction. Furthermore, IoT implementation strategist could integrate these challenges into the risk management plan within the IoT implementation plan.

Relying on a single database for literature is one of the limitations of this study. Also, other keywords relating to the application of IoT in smart construction were later developed in this study. Further studies should integrate more keywords and search through more databases to expand the sources and amount of available literature. This study is an important bedrock for further review of extant review of literature and technical review of IoT application for smart construction.

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