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Use of the Internet of Things in the Construction Industry and Facility Management: Usage Examples Overview

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Abstract

Internet of Things (IoT) represents an important area that is evolving rapidly in the context of digitalization efforts related to the Construction 4.0 era. This paper deals with the Internet of Things applications within the construction industry in selected phases of the facility's life cycle, namely the construction and operational phases. In particular, relevant examples of its use were collected, discussed and supplemented with several review papers on a given topic. Results of the analysis show that the potential of the Internet of Things usage is wide and varied in connection with the complexity of the construction projects and the long-term service life of the facilities. The concepts of the Internet of Things usage in the above-mentioned life cycle phases are mostly different focusing e.g., on quality, health and safety issues within the case of construction phase or smart concepts and energy management during the operational phase. Furthermore, one common theme was identified for both investigated phases of the life cycle, namely the interconnection of Building Information Modelling and the Internet of Things. It can be expected that the importance of such interconnection will continue to rise as construction projects implemented with the support of the Building Information Modelling become more and more common in the future.

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1. Introduction

The development of smart construction requires the deployment of innovative methods, tools and approaches. Internet of Things (hereinafter referred to as IoT) represents functional (objects worldwide can exchange information through the internet) as well as technical (identification, data collection and processing capabilities) perspectives and can be applied variably e.g., for monitoring and intelligent management processes [1]. In this way, IoT contributes to Industry 4.0/Construction 4.0 efforts by providing technologies for effective data sharing and management beneficial to smarter, cheaper, faster and more sustainable production and operation.

Available scientific literature provides several definitions of IoT. For example, International Telecommunication Union understands IoT as "A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies" [1, 2].

IoT is beginning to be widely used within the construction industry which is highly specific for a large resource consumption of material, energy and labour. Furthermore, an important aspect is the long service life of the built structures as well as the high level of complexity of the entire construction project. Therefore, the IoT has a high potential for use within the construction sector from various points of view.

When speaking about the long service life of buildings, it is important to study them in their particular phases. The general life cycle of every construction consists of the product stage, construction process stage, use stage and demolition stage. Lesniak [3] has identified the following stages of the building life cycle as the conceptual analysis and design phase, execution (construction) phase, operational phase and decommissioning phase. It is worth mentioning that each life cycle of a particular facility is specific from various perspectives, such as the set of activities realized or outputs expected.

The main aim of the conceptual analysis and design phase is to make the project as efficient as possible. An efficient and smart decision-making process creates less cost in earlier design phases. At this stage, it is easier to make changes to the project. The results of the product stage are the basis for making a decision on the implementation of the investment project, adjusting the investment plan or refusing to implement the project.

The following construction stage begins by obtaining a building permit and ends with the commissioning of the facility. An important part of this stage is to ensure that the contractor completes the project according to plan and to carry out the quality control inspections. The total environmental impact of the construction phase is about 11%. [4]

During the operation phase of the building life cycle, it is being used and related to significant operation and maintenance costs. The operation stage is the longest and most expensive part of the building life cycle [3]. The operational phase has the highest percentage (80–85%) of energy consumption in the building life cycle [4]. At this stage, it is important to plan the building maintenance and timely repairs to prevent the premature end of its life cycle.

Finally, the liquidation phase is carried out in case of deterioration of the physical condition of the building when reconstruction is no longer possible. If a demolition decision is made, the life cycle of the building ends. An important point in demolition works is the management of construction waste [5].

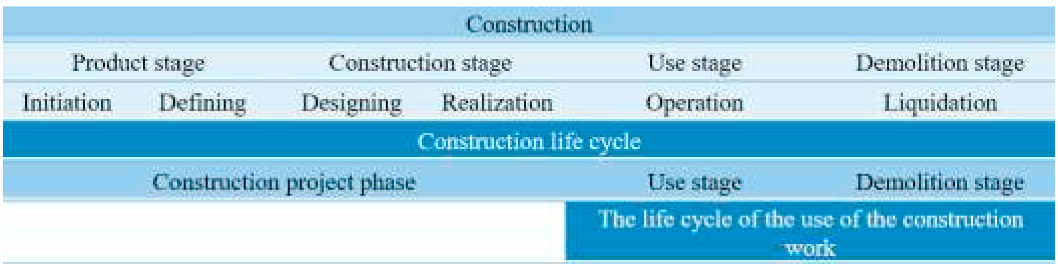

Fig. 1. Main building life-cycle phases, based on [3, 6].

The above-mentioned description of individual building life-cycle phases (see Figure 1) indicates that the deployment of IoT might be different for individual phases. This work builds on the existing research on the topic of the possibilities of IoT use within the construction industry from the life-cycle perspective. Emphasis is placed on the analysis of the IoT use in two major phases of the construction facilities' life cycle, i.e., construction and operational phases. The aim of this study is to provide an actual overview, key terminology and possible ways of the IoT usage based on reliable sources with emphasis on the application examples.

2. Methodology

Search for sources was carried out within the Web of Science, Scopus and ScienceDirect databases. The keywords used in the search contained expressions such as: "Internet of Things", "Construction", and "Building Information Modelling". The search was carried out in the "Engineering", and "Energy" subject areas. During the initial screening of titles and abstracts, the list of publications was shortened with a focus on practical case studies (topical focus), a number of citations (scientific significance) and date of publication, i.e., recent publications were preferred (timeliness of resources). Based on these three approaches, it was possible to identify relevant publications for further analysis. Following the reading of the full-text papers, the final list of publications resulted in 21 sources published mostly in scholarly journals and supplemented with a conference paper and a book. The analysis also included review papers in order to be aware of the state-of-art published so far.

Thereafter, the final list of publications was analysed with the aim to reveal practical areas, i.e., examples of its usage relevant to the construction industry with emphasis on the construction and operational phases of the building life-cycle. Based on these steps, it was possible to compile an overview table containing areas of the usage divided into these two phases of the life cycle.

3. Identification and the usage examples overview

3.1 Examples of usage in the construction phase

As construction projects are typically characterized by a high level of complexity and a high number of different activities to be carried out, it could be expected that the potential of IoT deployment during the execution of construction works is relatively high and varied. The following paragraphs present selected examples of usage that demonstrate the possibilities of using IoT during the construction phase.

IoT is used in the construction industry to monitor quality. For example, Chen (2020) [1] provides the analysis of the usage of IoT for the real-time monitoring of the construction quality of gravel piles. Traditional manual methods of quality control have limitations which might cause imprecisions. The paper develops a digital control system based on IoT which was verified at the construction site of Chengdu Tianfu International Airport. Results of the study proved the reliability of real-time data transmission and helped to optimize the inspection process. More specifically, the safety of the foundation was increased and construction time was reduced. Another study carried out in the field of construction quality was presented by Yao (2021) [7]. The main goal of the experiment was aimed at improving the quality and bearing capacity of the underground facilities, more specifically quality control of cement mixing pile construction.

The issue of health and safety is one of the most important issues on construction sites. Research by Kanan (2018) suggests using IoT to improve workers' safety. An autonomous system that monitors, localizes, and warns workers has been created. The system consists of sensors located on vehicles and wearable devices for workers. The nodes use energy management and storage circuitry to continuously operate indoors and outdoors. Based on test results, back over accident prevention and the smart alerting system for potential hazard avoidance were successfully created [8].

Cheun's work (2018) considers the possibility of the integrated usage of IoT and BIM, which can develop construction safety management. The case study involves combining environmental condition data obtained from IoT and their visual display for analysis and control based on the BIM model. The created sensor system was placed on an underground construction site to collect data on the level of dangerous gas and the state of the environment (temperature and humidity). When an abnormal condition is detected, the BIM model starts an alarm, which automatically starts an alert at the construction site [9].

Another research made in the field of safety on the construction site was made by Zhou (2017). The safety barrier warning system has been applied in Yangzte river-crossing metro tunnel underground construction site. The system enables data collection to monitor workers and equipment on the site in real time and generate alerts with a high response speed. IoT technologies such as positioning, ultrasonic detection at the centimetre level and infrared access technology were used. This can help workers avoid accidents, as well as improve safety management through work organization and safety planning [10].

The problem of the IoT implementation was also considered by Woodhead (2018). In this paper, the authors argue that considering the Internet of Things (IoT) in certain narrow areas limits the prospects for possible development. It is proposed to consider IoT in a complex, taking into account the achievement of a fundamentally new level of development for the Smart cities in the field of information technologies, for example, BIM modelling. Due to the complex approach and the possibility of processing a large amount of data, it is possible to increase the efficiency of the decision-making process and project management workflow [11].

3.2 Examples of usage in the operational phase

Taking into consideration, that the operational phase typically represents the longest phase of the building's life cycle, just like in the case of the construction phase, it can be assumed that IoT has the potential to play a significant role in the context of evolving digitization. In the next paragraphs, knowledge coming from selected review papers and particular usage examples is presented.

In Wong's review (2018) [12] results of a study of existing sources on the possibility of using digital technologies in the field of Facility Management (FM) are presented. Based on the study, it was found that digitalized FM could be developed by Building Information Modelling (BIM), GIS, IoT and Realty Capture Technologies (Point Cloud, Laser Scan). The combination of these systems allows for the processing of the information, which is necessary for object management in the use phase of the construction. Such a combination has a high potential to bring additional benefits resulting from synergic effects related to the interconnection of various systems or technologies.

The review about the integration of Building Information Modelling (BIM) with real-time data from the Internet of Things (IoT) (Tang, 2019) provides information about possible developments in the subject. The BIM model, as a resource of information about the object, can be supplemented with information from IoT sensors. This complementarity expands the possibilities of processing and perception of information necessary for building management. Nowadays processing a large amount of information has limits and restrictions. Despite this fact, the potential for further development of the interaction between BIM and IoT has been highlighted for the communication, construction and progress monitoring, health and safety, logistics and management, automation, prefabrication, lean construction, FM, energy management and emergency response. [13]

A case study carried out in Hong Kong by Zhai (2019) [14] concerns the development of modular integrated constructions by using an IoT-enabled BIM platform during the operational phase. The combination of IoT and BIM allows for expanding the possibilities of object management. According to the achieved results, the platform supports autonomous decision-making by collecting real-time information, helps to control the construction and procurement process and processes emergency signals. Such an approach addresses the matters related to inconvenient data collection, incomplete information and non-automated decision support.

According to a study made by Kang (2021) [15], the use of wireless IoT technologies in combination with geographic information systems (hereinafter referred to as GIS) opens opportunities for the landscape design of street architecture. For example, comprehensive consideration of the physiological parameters of the soil, climate and plant community helps to speed up the process of creating a sketch for a future design due to the information available in one source. It also helps to solve the problem of using monitoring tools to plan and execute irrigation programs. This approach aims to create an automated smart system and therefore reduce the need for specialized staff training.

The IoT is also considered an opportunity for further development of Smart cities. Jiang (2020) reveals that the problem of the inconvenient processing of a large amount of information in traditional urban management can be solved through the combination of IoT and cloud computing. Experimental technology introduced in his research is designed to solve the problem of data transmission. The case fields were Intelligent Environment Monitoring, Intelligent Security and Intelligent Transportation [16]. Improved technology helps to avoid failures in the process of data transmission, which raises the efficiency and opportunities of Smart cities.

A smart urban environment monitoring system based on wireless IoT technology (Zhihan, 2020) shows how the comfort and intelligence of modern cities can be improved. During the experiment, a wireless system for collecting information was proposed. The network of sensors was connected with the help of street lamps and taxi cars. These elements were chosen as frequently encountered in modern cities, and the installation of sensors in such places was not a problem for implementation in the already existing urban environment. Real-time traffic information and real-time weather monitoring information have been collected [17]. The creation of the system opens up prospects for the further development of modern Smart cities and their operation.

The field of Smart housing is also mentioned in the bibliometric analysis carried out by Choi (2021). The study includes an analysis of existing scientific publications in the Scopus database limited by selected conditions such as the time of publication from 2015 to 2019. From selected sources, the frequency of mentioning IoT and smart housing was investigated. Results indicate that the smart home Internet of Things become a significant emerging area of research since 2016 and relies on state-of-the-art technology [18].

The impact of IoT is mentioned in the field of renewable energy sources by Wu (2022). The paper presents the implementation of IoT into solar photovoltaic panels. The complete integrated design of building systems and photovoltaic units can be achieved due to the IoT benefits. It is said that the improved system helps to increase the level of integration, energy efficiency, reliability, energy consumption level and effective monitoring measures. As the result was presented the solar cell system based on an IoT with such advantages as reduced cost and high efficiency [19].

Using IoT with fuzzy framework technology for smart home and sustainable energy monitoring systems infrastructure was proposed by Alowaidi (2022). The suggested system, which focuses on wind and solar power, was tested using experimental calculated data about insulation, wind speed and energy prices. Thanks to the created device, an increased level of optimization was achieved. the operator could work in real time, and part of the input data was used to predict the possible behaviour of the device, so it is possible to analyse and plan the stable operation of the devices based on it [20].

Another review in the field of smart energy systems, made by Ahmad (2021), shows the possibilities of IoT for energy consumption and infrastructure improvement. Moreover, it claims that the energy business models based on IoT technology are more profitable for businesses. The positive effect can be achieved due to big data handling, the ability to identify critical and potentially critical issues and automatization of the processes. Reducing energy storage demand and costs can be achieved by the comprehensive implementation of IoT [21].

More practical research was carried out by Muralidhara (2020) to control consumed energy resources. The usual reports on the amount of energy are often expressed by general indicators. For better control was created an Internet of Things based energy meter to measure power consumption at the device level. A smart energy meter is a device that does not require special installation, due to this it can be installed both in households and in industrial buildings. The obtained data was compared with the already available information about the studied devices. Thanks to data on consumer behaviour, consumers can consciously reduce energy consumption and therefore minimize energy costs [22].

The ability of IoT to cooperate with FM on the BIM platform is mentioned by Cheng (2020). The data from the BIM model and machine learning algorithms was applied along with the FM system for MEP elements (mechanical, electrical and plumbing) maintenance. The research was directed to the development of a condition monitoring and fault alarm module, a condition assessment module, a condition prediction module, and a maintenance planning module. Based on the results, due to the developed system, the state of the MEP components was effectively predicted and the efficiency of facility maintenance management was improved [23].

In the reviews of Gosh [24, 25], possible areas of application of IoT are studied in detail. It is stated that, due to the evolving interdisciplinary nature of the building field, it can be applied in different phases of the building life cycle. The main highlighted topics are quality control, construction safety, optimization and simulation, data visualization, prefabricated construction and construction waste management.

3.3 Discussion summary

After introducing various examples of usage, a comparison table was provided to point out the similarities and differences identified among examined life-cycle phases, i.e., construction and operational phases. Topics identified within the set of use cases as well as selected review papers indicate that the application of IoT has mostly different features in individual phases (see Table 1).

More specifically, when looking at the construction phase, it is possible to say that recent applications of IoT are preferably related to quality and health and safety issues. These are important aspects influencing the success of the construction project, in addition, the quality issue belongs to the "iron triangle" [26], representing major project constraints together with costs and time. When focusing on the operational phase, we can see that most of the IoT concepts are connected with a smart approach in various conceptions, starting from the general smart cities level, followed by smart housing, detailed energy management or more complex facility management and related environmental issues.

During the review of usage examples, one joint topic has been identified for both examined phases: collaboration or connection between the BIM model and IoT. As BIM models are developed both to facilitate the planning of the construction projects and facilitate construction activities as well as the management of the facility under operation/use, it is therefore logical that efforts to establish or strengthen this connection are visible in both phases of the facility's life cycle.

In addition, it is also worth mentioning the major effects of IoT in the construction industry and related key drivers. According to a scientometric review [25], the major effects of IoT adoption were "high-speed reporting, complete process control, data explosion leading to deep data analytics, strict ethical and legal expectations" while key drivers for IoT adoption represented "interoperability; data privacy and security; flexible governance structures; proper business planning and models".

Table 1. Usage examples of the Internet of Things in the construction and operational phases of the construction process

Construction phase	**Operational phase**
Monitoring of construction quality [1, 7, 24]	Facility management [13, 22, 23]
Health and Safety monitoring [8, 9, 10, 13, 14, 25]	Energy management [13]
Strength test of jointer material [14]	Safety [14, 17]
Prefabricated construction [25]	Smart cities [11, 16, 17]
Cooperation with BIM [9, 11]	Smart housing [18, 20]
Decision making, project management [11, 25]	Smart energy systems [21, 22]
Optimization and simulation [24]	Renewable energy sources [19]
	Street architecture landscape design [15]
	Construction waste management [25]
	Cooperation with BIM [12, 13, 14, 23]
	Data visualization [25]

4. Conclusion

This paper focused on the deployment of IoT within selected phases of the building's life cycle, namely the construction and operational phases. In the preceding sections, several examples of usage as well as outputs rising from a few selected review papers were presented and discussed. The analysis shows that the specific IoT concepts applied in construction and operational phases are varied (e.g., quality and health and safety monitoring; smart concept and energy management respectively), however, one major joint issue was identified as well, namely the interconnection of the BIM model and IoT.

This paper has its limitations. The aim of this paper was not to provide a systematic review of the topic, however, we aimed to focus in more detail on specifics of IoT usage during the construction and operational phases of the facility's life cycle and discuss them from the construction management perspective. Future research should continue to monitor the development of this area in order to reveal new/anticipated managerial benefits of IoT usage in construction practice.

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