ISSN 2714-7533

A Review of Internet of Things (IoT) in Construction Industry: Building a Better Future

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ARTICLE INFO

Article history
Received June 4, 2021
Revised July 7, 2021
Accepted August 10, 2021

Keywords
Internet of Things
Construction
Sensors
Building information modeling

ABSTRACT

Construction companies today are aiming for the finest technologies to achieve their targets in minimum cost possible along with a high level of security and safety. Construction companies are focusing more on the benefits of internet in their projects in order to improve processes, reduce waste and optimally utilize their resources and Internet of Things (IoT) is making it possible in a much more efficient way than thought of. IoT has now become the newest of the technology that is being used in the construction industry. IoT is basically the network of physical objects—buildings, vehicles, devices and other objects fixed with sensors, software, electronics and internet connectivity which aids these objects to collect, store and exchange data. This paper aims to improve the understanding of the importance of IoT and its implementation in the construction industry. The paper presents the compiled study of the works done by various researchers in which IoT can be used in the construction industry. The findings of their work have been discussed in this paper and future scope of work regarding the usage of IoT in different fields have been identified.

1. Introduction

The first shelters must have been built with hands and simple tools in the paleolithic age. With the advent of the bronze age, cities began to grow and also came the usage of better tools. As the time passed the construction also became more complexed with the usage of mud to lime mortar to cement mortar and to steel structures and from conventional construction to prefabricated structures to 3D printing of the structures as the latest development. As the construction methods have changed from the very first shelters in the human history made up of mud to 3D printing of the houses, the construction industry has come a long way in adopting the changes. To cope up with the current needs of sustainability, safety and security, etc., construction industry has to adopt to newer technologies for better management of projects as the projects are becoming more complex than thought of.

With the increase in complexity of the construction projects, the construction industry is experiencing numerous challenges such as poor quality control, health and safety hazards for workers, low productivity and poor environmental performance. These problems are occurring because of the slow adoption of the advanced cutting-edge technologies such as IoT, robotics, automation, mechanization, etc. in the construction industry. The construction industry is a huge industry but it is very reserved in adopting new technologies[1].

The novel concept that is making round these days is the Internet of Things. With the advent of IoT each and every industry is striving to make effective use of this technology in order to increase their productivity and the construction industry will also have to adopt this technology in an efficient manner in order to avoid the challenges it is facing as discussed above. IoT is basically the network of physical objects—buildings, vehicles, devices and other objects fixed with sensors, software, electronics and internet connectivity which aids these objects to collect, store and exchange data without any human interaction.

With the use of IoT the decision-making process becomes quicker and more efficient. The way in which operations and decisions are taken has been revolutionized by the use of IoT in many industries such as robotics, healthcare, manufacturing, energy, etc. The adoption of IoT in these sectors is easy as it involves a repetitive process unlike the construction industry in which there are various complexities such as harsh work environments, remote construction sites, etc. The application of IoT in the construction industry can transform the way construction is happening but it will require a significant effort in changing the policies, technologies and managing the connectivity barriers.[2]

In developing countries, the infrastructure deficit poses a big challenge for further growth, especially for bringing about inclusive growth, from the waste disposal systems and roads to the modern bridges and world-class airports. Therefore, sustainable assets are the utmost need of the hour. This challenge in the wake of limited financial resources, necessitates the effective and efficient usage of Internet of Things in the construction industry. The various applications for which IoT can be used in different phases of construction is shown in Figure 1.

Figure 1. IoT applications in Construction phases of a project

2. Framework of IoT Application In Construction

Developed with input from a wide number of project management specialists, the project management body of knowledge (PMBOK) framework encompasses all of the core processes required for construction projects and is divided into six categories, as shown below:

1. Construction Planning and Control.
2. Quality Assurance in the Construction Industry.
3. Construction Safety Management.
4. Construction Equipment Management.
5. Construction Procurement Management.
6. Construction Execution.

In addition, each of these platforms has the capability of being integrated with a particular type of data collection equipment. For example: A construction progress monitoring platform can be integrated into bar codes, RFID tags, laser scanners, and other similar types of devices. A study conducted by Bernal et al. [3] at MIT on construction safety demonstrated the use of several sensors to keep a check on a worker's health, as well as the possibility of integrating several sensors into a construction worker's vest and jacket to monitor the working environment. In the same way, data can be acquired by placing the sensors in workers' helmets, shoes, and other accessories in order to track their movements. For the purpose of monitoring, all these data can be saved in the database of the company and made accessible to members of the safety team for the purpose of identifying potentially hazardous circumstances and warn the worker's team, the worker or site supervisor to the problem. In order to track and collect information about various pieces of equipment, GPS-based sensors can be utilised.

2.1 The Architecture of an Internet of Things System

During the course of a building project, a huge number of processes or activities may be taking place at different locations at the same time. A joint embedded system of IoT devices, actuators and numerous sensors needs to be placed in order for the integrated IoT system to collect data from all departments. Each of these IoT items should be configured to work specifically in its relevant processing environment. To this end, it is the obligation of the individual departments to gather the information needed, and this information can be made available to the management staff in the project office or to those in the relevant department to make decision-making in that department easier. Using the Internet of Things (IoT) in projects can be accomplished through the use of five layers that link with one another gradually to construct IoT platforms, as explained below.

2.1.1 The Physical Layer (also known as the Sensing Layer)

This is the bottom-most layer and various devices that capture or sense data are present on this layer. Although not officially known as the perception layer, it is responsible for perceiving information from the environment and is therefore commonly referred to as such [4]. A network of things is comprised of a collection of sensors, actuators, RFIDs, mobile devices, and other devices that work together to form a network.

In this category, there are two types of network of things: static and mobile. These can be positioned anywhere on the construction site, including desks of the staff, integrated with the machinery, entry and exit gates of the site, inside offices, in the hands of site engineers, and any other location from where critical data can be gathered and stored. These devices are either directly or indirectly connected to the Internet of Things network. These are the devices that make up the network's nodes. There are numerous limits placed on the nodes in the sensing layer, including energy limitations, wireless medium reliability, security and privacy concerns [5].

2.1.2 Network Layer

One of the two sublayers in the connectivity layer is the network layer which is made up of routers, hubs, servers, local area network controllers, and other network forming devices. As this layer forms a connection between the nodes and the internet, this layer is essential. The gateways provided in this layer are responsible for connecting the nodes or items in the network. Typically, in a local area network, the VPN gateway serves as a jurisdiction for the nodes under its control, assigning them a local IP address in the process. IPv6 is a protocol that is commonly used for addressing Internet of Things nodes. The data is then routed through a proxy server before reaching a web socket in the next layer if internet connectivity is necessary. They send data to target nodes whenever they need to communicate with one another or give data to another node. If the intended destination is located beyond the local network, the data must first be transmitted to the local network and then delivered through internet gateways to reach the intended destination [7].

2.1.3 Transmission Layer

The second sublayer of the connectivity layer is the transmission layer. When data is saved and processed, this layer works as a bridge between the network and cloud platforms. It focuses on end-to-end communication and includes aspects such as reliability, congestion avoidance, and ensuring packet delivery in the same sequence as they were sent [6].

2.1.4 Cloud Layer or Processing Layer

Backend services such as analytics and cloud computing are included at this layer. The analog data from the devices is transformed into an easy-to-read format here. Machine learning, artificial intelligence, or neural networks can all be used to power these analysis techniques. It is possible that integrating cloud computing and service-oriented architecture (SOA) will result in a high-performance middleware for the Internet of Things that is very heterogeneous and flexible[5].

It also provides information on the utilisation of Internet of Things products and helps to resolve service quality issues within operations by identifying the device that is causing the problem and providing reports and anomaly analysis [5].

2.1.5 The Business Management Layer (also known as the Application Layer)

It is necessary to integrate people and businesses in the application layer in order to collaborate and make decisions based on data collected through Internet of Things system. It can be integrated with the company's enterprise resource planning (ERP) system and made available to different departments through internet and mobile apps, allowing them to access data, set configurable standards for specific operations, and make appropriate revisions as required. It may be possible to choose between auto-actuation and manual-actuation for critical machinery in some cases.

3. Literature Review

This section contains the previous studies done by researchers regarding IoT and its applications in the Construction Industry. To accomplish this, the databases were searched and relevant documents were extracted and are presented here after the analysis in a brief literature.

Reja and Varghese [7] identified the potential of IoT technology and its usage in various construction projects. They also discussed the hinderance caused in implementing this technique due to poor connectivity issues and focused on how the adoption of 5G technology will benefit the usage of IoT in various processes of a construction project. They did a study for masonry activity of a construction project and compared the time taken to upload the video to the cloud server using 4G and 5G connection and they inferred that using 5G for data transmission will save a considerable amount of time. They concluded that it will not be an easy task to effectively adopt and implement IoT in the construction industry and there is a need for continuous improvement of IoT and faster network for better application in the construction industry.

Taffese et al. [8] proposed a conceptual framework for monitoring and assessment of Reinforced Concrete (RC) structures in which sensors will be embedded into the concrete and the sensors will provide the necessary data which can be analyzed to get the up-to-date information about the status of the structure. They concluded that the usage of sensors in assessing the RC structures is beneficial over the conventional methods of durability assessment as it can help in continuous monitoring of the structure without the need of taking the samples destructively and testing in the laboratories. Also, the data from the sensors can be analyzed by the material scientists to develop a concrete mix which is deterioration resistant.

Xu et al. [9] proposed an IoT platform based on cloud for prefabricated construction works which will be beneficial for small and medium enterprises (SMEs) as it will be economical and flexible. They explained the principle on which their platform works and then they implemented their platform in an actual prefabricated construction project in Hong Kong. They also used various lab-based LEGO construction models to support the effectiveness of their proposed platform. They concluded that the adoption of their proposed platform will benefit the prefabricated construction industry in automating their process.

Kanan et al. [10] presented a unique solution for averting the accidents in construction sites. An autonomous system is developed which warns the labourers when they are within a danger zone with the help of a wearable device. The device gets activated whenever it is in close proximity of the sensing unit which is located at the rear end of the vehicle and alerts the worker that he is in a danger zone. They concluded that the proposed solution reduces the risk of accidents and is also economical. Xu and Lu [11] proposed a framework inspired by IoT and smart construction technologies. It facilitates the usage of web-based applications, mobile digital devices, robotics, Wireless Sensor Networks (WSN), Global Positioning System (GPS), Auto-ID, Augmented Reality (AR), Building Information Modeling (BIM), 3D laser scanner and drones to gather the data from different stages of a project's lifecycle. After the data is collected it is processed and shared in a single platform for its fficient use by all the stakeholders involved in the project in order to take better decisions throughout the lifecycle of the project. They concluded that their proposed framework can be adopted for smart construction throughout the lifecycle of the project as it captures and shares the data to all the stakeholders in real-time.

Jeevana and Kulkarni [12] proposed a framework based on real-time monitoring of the sensors to minimize the delay caused at the construction sites which is majorly due to the poor site management. The major cause of delay was found by the researchers by a detailed questionnaire done in 30 construction industries. The sensors are monitored in real-time and once the problem is identified, the site manager is immediately alerted so that he can take action on the issue.

Kumar and Shoghli [13] reviewed various possibilities of using Supply Chain Management (SCM) of construction materials. They stated that efficient use of various sensors could be helpful in material tracking with high accuracy and the various errors caused due to human behavior and environmental factors can be avoided. They also concluded that the real-time data obtained from the IoT devices will help the supervisors and the project managers to manage the inventory in a better way and have a good control on the overall construction process.

Zhou et.al. [14] proposed a theoretical framework for smart construction in mega construction projects. They used a case-study on "Hong-Kong-Zhuhai-Macao-Bridge" to support the feasibility of their proposed framework. They used various IoT technology to demonstrate their framework which included usage of BIM in the offsite manufacturing stage for prefabrication production to GPS, Sonar and weather systems in the transportation and assembly stage. They reached to a conclusion that the implementation of IoT in the construction industry is still in a nascent phase. The advancement of IoT will help in the construction industry, but more work is required by the researchers in order to effectively implement the IoT technology amongst different participants in the construction project process.

Teizer et al. [15] introduced a concept of integrating IoT and BIM. They conducted two case studies to demonstrate their concept. In the first case study they traced the location of the workers and in the second case study the environmental data such as the brightness level at the workstations, time spent in high or low temperatures, etc. The authors also developed a Dynamo script to visualize all the sensor data in real-time in Autodesk Revit. They concluded that their concept has the potential for implementing it in facility management and construction operation processes.

Zhong et al. [16] presented a "multi-dimensional Internet of Things enabled BIM platform (MITBIMP)" for achieving real-time traceability and visibility in the process of prefabricated construction. The significant contributions by them are:

(i) Various Smart Construction Objects (SCO) are created which can work collaboratively with IoT and the three phases of prefabrication which are manufacturing, logistics and on-site assembly.

(ii) A multi-dimensional BIM platform is created which is helpful to all stakeholders involved in various construction activities as it provides real-time data captured from the SCOs to the stakeholders and they can make better decisions by enhanced information sharing amongst themselves.

(iii) The platform can be used for monitoring the status of the project, its progress and its real-time cost and it can be used by different end users.

(iv) The platform is an improvement over the traditional 3D BIM as it is converted to nD BIM by the integration of time and cost into the BIM

Praba [17] designed an assembly of piezo sensors and called it as "Piezomat" to monitor the deflection in a beam by using Raspberry Pi 2 and Piezoelectric sensors. They stated that the impact energy which is produced by the movement of vehicles on the bridge can be converted to electrical energy. They finally concluded that the use of Piezo sensors and Piezo generators can be useful in analyzing the strength and serviceability of the bridge and the electricity generated can solve the problem of demand of electric energy for better living.

Riaz et al. [18] proposed a framework to measure the environmental conditions for the worker safety in confined spaces using wireless sensors. The sensors measure the oxygen level and temperature and if the sensor data crosses the threshold as decided, the area is highlighted in the virtual model, thus alerting the supervisor to take necessary actions. They concluded that by using this framework the health and safety of a worker at a construction site can be improved and the remote monitoring of the confined spaces will help the facility managers to ensure the health and safety of the occupants of the building.

Marks and Teizer [19] used Radio Frequency technology as real-time proximity warning device for worker safety at construction sites. They concluded that their technology is helpful in detecting the presence of heavy construction equipment and once anything is detected, the system alerts the workers and equipment operators about the proximity issue which can be hazardous.

The different types of IoT technologies used and the construction field in which the studies have been done by the researchers in the above reviewed literature are summarized in Table 1 for the better understanding of this paper.

Table 1. Literature Summary of IoT In Construction Industry

Author	**Technology used**	**Application Field**
Reja and Varghese	5G Construction	Construction Project Management
Taffese et al.	Wireless Sensor Network (WSN)	Structural Health Monitoring
Xu et al.	RFID and NFC tags	Prefabricated Construction
Kanan et al.	RFID	Worker safety in Construction
Xu and Lu	RFID, Barcodes, WSN, GPS	Construction Automation
Jeevana and Kulkarni	Wireless Sensor Network	Site Management
Kumar and Shoghli	RFID, GPS	Construction material supply chain
Zhou et.al.	GPS, SONAR	Smart Construction
Teizer et al.	Wireless Sensor Network	Facility Management
Zhong et al.	RFID, BIM	Prefabricated Construction
A. Praba	Sensor Network	Structural Health Monitoring
Riaz et al.	Wireless Sensor Network	Health and Safety
Marks and Teizer	RFID	Worker safety in Construction

4. Result and Discussion

As reviewed in the literature, most of the studies propose a conceptual framework which can be used in different projects in order to validate their feasibility. The construction industry is a huge industry but it is very reserved in adopting new technologies. As mentioned in the various literatures there are many fields in which the use of IoT can be done for bringing a change in the construction industry which in turn will make life easier for the different participants involved in the project and the construction industry can also be automated.

There is plethora of fields in which IoT technology can be used. One such field is site facilities and materials management. In this field the use of RFID technology is the most popular which can be used for positioning and tracing of the materials and machines. RFID tags can be combined with BIM and by obtaining the structural geometry information from BIM, the position of materials and other facilities equipped with RFID tags can be known and it becomes an easy task for the managers to make deployment schedules which in turn saves time and effort. The other field in which RFID sensors can be of a great use is the prefabrication industry. The real-time visibility and traceability of different components of the prefabricated construction can be visualised directly in the BIM model by integrating the BIM and IoT technology. This can be used in progress monitoring of the project without relying on phone calls and e-mails to get the status of the project.

With the advent of IoT, accidents on the construction sites, which are the major cause of fatalities, can be avoided. The workers can be alerted if they are in close proximity of any heavy machinery or vehicles and the accidents can be avoided thus developing a safe environment for workers. The use of IoT can also be done to monitor the activities of the workers at sites and they can be alerted if the environment around them deteriorates and pose some health risk to the workers.

The IoT technology has opened up gates for the construction firms to enhance their performance by implementing the technology in smart objects and smart homes and with the availability of the 5G technology in the near future the application opportunities of this technology in all over the surroundings including the construction industry will increase many folds thus helping the construction firms to build a better future for the mankind.

5. Conclusion

The use of IoT in construction industry is still in its premature stage. There is a need of extensive research to be done in order to explore the various possibilities in which it can be used to make the construction industry adopt this technology in a positive manner. IoT is a new concept and its use in construction industry may be beneficial to all the stakeholders involved in the project. Its integration with the applications already in use in the industry will me more beneficial as the problems which are currently being faced by the professionals can be highlighted and researchers can work upon in addressing those issues. For future studies researchers may focus on structural health monitoring, supply chain management, aspects of security and privacy issues in adopting this technology, quality control, progress monitoring, air quality monitoring, etc.

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