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Smart Buildings Construction and Maintenance by Means of Internet of Things (IoT): A Review

Ali Moazzeni Khorasgani [1], Ghazal Asadi Eskandar [2], Mousa Maleki [3] *

[1] Visiting scholar, Department of Architectural Engineering, Illinois Institute of Technology, Chicago, United States

[2] PhD student, Department of Architecture and Urban Planning, Islamic Azad University Isfahan (Khorasgan) Branch, Isfahan, Iran

[3] PhD student, Department of Civil, Architectural, and Environmental Engineering, Illinois Institute of Technology, Chicago, United States

Abstract

Smart building with internet of things (IoT) is one of the technologies that is developing rapidly. Digital devices are not only in our pockets, but also increasingly present at buildings. For example, we can refer to a temperature control sensors that continuously measure the temperature of a room. After measuring the temperature of the area, these sensors send the data to the hub, and the hub regulates the valves to be opened or closed, which causes the least energy loss along with the corresponding air in the room. There are many ways to fix problems in buildings, but with the IoT, this can be done easily. In a smart building, by installing different sensors and connecting different equipment such as water and energy meters, lighting, security, heating and cooling systems, etc., if they are all equipped with the relevant sensors, easily with data analysis. The obtained information from the equipment can be put in a good condition with the application software, and it can be done easily to solve the problems. Previous experiences and papers about IoT-based maintenance systems for buildings are evaluated in this study and some practical approaches for optimization of smart buildings are suggested.

Keywords: *Internet of Things, maintenance, buildings, sensors*

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I. Introduction

In simple terms, we can introduce the Internet of Things as, IoT means: different devices are connected to each other through the Internet and interact and talk with each other and with people on the Internet. Any device you have that has this capability, such as a smartphone, headphones, and such devices, or devices such as a coffee maker, washing machine, etc., can be included in the Internet of Things circle. In fact, the Internet of Things is a network of objects and people that are connected by the Internet and have a large number of connections. The communication between the members of this network is in 3 general forms: human to device, device to device, human to human (Bellavista 2013).

Among the most important applications of the Internet of Things that have been registered and are available so far, we can mention the smart house, smart city, smart car, smart agriculture and smart agriculture, smart production cycle. With the advancement of this type of technology, we should expect more interesting events in the near future. In the following, we want to tell the application of Internet of Things in building smartness. Smart building is one of the most important applications of Internet of Things. We must say that IoT has caused a complete revolution in the intelligent industry. This home smart technology is provided with the purpose of controlling devices and providing comfort and security. The connection of mechanical, electrical and electromechanical platforms and systems with each other leads to the construction of smart networks. Systems

* Corresponding Author's Email: mmaleki1@hawk.iit.edu

communicate and interact with each other and by monitoring themselves and each other, perform operations automatically whenever needed. It can also be said that the data collected from the devices connected to the smart network helps the managers in the buildings to put the efficiency at a high level by analyzing the information and data and take measures to create smarter buildings (Bellavista 2013).

With regards to the recent trends, IoT has started to penetrate in the building industry in the past years. Specialists are exploring the benefits and drawbacks of IoT through actual implementation. For example, several companies including IBM and Intel are already launching their products of smart buildings to the world (Conti et al. 2018), demonstrating the competitive edge and future tendency of IoT. As a result, it is vital to understand how to integrate IoT into this industry to benefit the development of smart buildings. However, to the best of the authors' knowledge, although surveys for IoT-based smart buildings exist (Stojkoska and Trivodaliev 2017; Alaa et al. 2017), current literatures lack a comprehensive review and assessment of IoT applications to the overall fields for future building development. In addition, as the interest for interdisciplinary research continues to increase, an analytical review may be a new starting point for researchers in the fields of civil, construction, and architectural engineering. Therefore, although the whole IoT sector is technology driven and suffers from a top-down approach while the users are not the core that drives the change, a thorough understanding of the technical needs and potential application areas to the building industry is significant to help supplement improvement dimensions of IoT and expedite the development of smart buildings.

In the recent decades, a majority of research focused on smart buildings, communities, cities, and infrastructures (Schaffers et al. 2011; Minoli, Sohraby, and Occhiogrosso 2017). One of the goals of these research activities is to develop an approach to provide reliable and energy efficient services without compromising the comfort and satisfaction level of people in the targeted contexts. However, until now, this topic is still being explored though researchers have studied related issues from different aspects (Shaikh et al. 2014; Wang et al. 2012; Nguyen and Aiello, 2013; Siano, 2014), as the practical implementation plan is under investigation, and the topic involves an adaptation of technologies and knowledge from multi-disciplines. From the viewpoint of operational aspects, the current progress towards the development of smart buildings, communities, and cities may be described as isolated and segmented in terms of integration of technology and application development, mainly owing to the current IoT applications' limitations and sensor networks in buildings, cities, and infrastructures that are not seamlessly unified (Gyrard and Serrano 2015).

Buildings are the basic and crucial units for human's living environment. The idea of smart buildings originates with the increase in integration of advanced technology to buildings and their systems such that the buildings' whole life cycle can be remotely controlled for comfort, convenience, and in a cost- energy- efficient manner. It is strongly accepted that the use of new technologies is a basic prerequisite to achieve the realization of smart buildings (also known as intelligent buildings), which includes, but not limited to, sensor deployment, big data engineering and analytics, cloud and fog computing, software engineering development, and human-computer interaction algorithms, etc. Among these supporting technologies, one of the trending areas is the development of IoT, as one of the challenges of smart buildings is to deal with a complex web of integrated functional entities in different aspects of a building.

II. Background

Smart Buildings are designed to be more efficient, sustainable, and comfortable for occupants. According to Al-Ma'aitah and Al-Saraireh (2021), smart buildings integrate various advanced technologies to provide intelligent services, energy efficiency, comfort, safety, and security to occupants and building managers. The concept of Smart Buildings dates back to the 1970s when the first building automation systems were introduced to control and monitor building systems such as lighting, heating, and air conditioning. However, with the advent of the Internet of Things (IoT) technology, Smart Buildings have become more advanced and integrated.

IoT refers to a network of physical objects, devices, and sensors that are connected to the internet and can communicate with each other. This technology has enabled the development of smart sensors that can collect data and provide real-time information about building systems. As Khan et al. (2021) note, the integration of IoT technology in smart buildings has opened up new possibilities for energy efficiency, security, and intelligent maintenance.

Advancements in IoT technology have made it possible to collect and analyze data from various building systems, providing valuable insights into the performance and efficiency of these systems. As Zhang and Wang (2020) point out, IoT-based intelligent building management systems enable the integration of various subsystems, including heating, ventilation, and air conditioning (HVAC), lighting, and security systems, and provide a holistic approach to building management.

The application of IoT in smart buildings maintenance has been an area of research in recent years. IoT can be used to monitor and diagnose building systems, perform automated maintenance tasks, and predict potential problems before they occur. As Lee et al. (2021) note, the integration of IoT technology with smart buildings maintenance can improve the performance, efficiency, and safety of building systems while reducing maintenance costs.

However, there are also challenges that need to be addressed when utilizing IoT in Smart Buildings maintenance. Data privacy and security are major concerns, as building systems collect sensitive information about occupants and their activities. Integration of IoT devices into existing building systems can also be complex and require significant planning and investment.

In the following sections of this paper, we will examine the role of IoT as a central operation system for smart buildings maintenance, the benefits and challenges of this technology, and the future directions for research in this area.

2.1 IoT as a Central Operation System for Smart Buildings Maintenance

If we can connect any device to the Internet, then it is natural to be able to control it remotely. This means that we do not need to be in the environment for many construction issues. The future of mankind is safe from environmental, chemical and many environmental hazards. While sitting in a safe environment, he instructs the machines with a few clicks on how to place one brick on top of another. In the near future, there will be a smart system like handsfree in the ears of construction workers. This means that workers are aware of all the conditions before the newly constructed roof falls, before reaching the dangerous edge of the building and even stepping into the restricted area.

2.2 Low cost construction with the help of Internet of Things

If the Internet of Things is actively involved in your construction and project, no building materials will be lost. How many excavators are there in this building? Where are each located? To answer these questions, just look at the map on your mobile phone. This means that the time lost in the search for lost items as well as the cost of purchasing replacement items is greatly reduced. How much this part should be dug? Where is the diameter of this column or its exact location? Is everything done right? A virtual drilling map answers these questions precisely. You use the map to determine the exact location of everything. Then just a few clicks are enough for smart machines to make cuts, drills or other changes.

2.3 Reducing the cost of construction repairs

The machines will be equipped with sensors and sensors in the near future. This means that you are aware of their status at all times. Just a small warning from the sensors is enough to service the device or solve the problem before it breaks down and costs a lot of money. Naturally, repairing and servicing machinery before it breaks down is much less expensive than repairing a broken tool.

2.4 Building Information Modeling (BIM)

In today's world, with the help of software, everything is modeled before it is made, and if everything is correct, then it will be actually made. This is what the Internet of Things does in the construction industry. All built houses can be equipped with sensors. This means that during the life of a structure, you update this information every day and have it according to a real model: (1) Impacts of climate change on buildings; (2) Impact of time; (3) Energy wasted due to the age of the structure; (4) How the structure behaves during an earthquake; (5) How a bridge bends or buckles a structure due to traffic and pressure

2.5 The Internet of Things estimates exact time, quality and cost

The building market is a highly competitive and saturated market. As a result, construction project managers must beat their competitors in this market in terms of both delivery time and quality of final work. Trying to complete the project on time and with the budget set is one of the constant challenges of the construction industry. This challenge has become even more relevant today as the complexity of construction plans grows, making it more difficult to anticipate and schedule projects and complete costs.

One of the effects of the Internet of Things on the future of the construction industry is that it can improve the accuracy of project estimates and thus contribute to proper planning in the industry. To ensure that all resources allocated to the design process are properly spent, business owners need new ways to monitor the performance of their teams. Intelligent monitoring methods and resource cost estimation can be another aspect of the IoT impact on the future of the construction industry.

2.6 Safe construction, the magic of the Internet of Things in the future of the construction industry

The construction industry is one of the industries in which many casualties occur. Some of the main injuries that workers face in this industry are: falling from a height, defective protective device; injury from repetitive movements, electrocution, and falling debris and materials. Although there are safety protocols and checklists that can help workers, most people are unfamiliar with them. The Internet of Things can reduce casualties by simultaneously training the workforce and increase the security of construction projects with the help of construction robots designed to monitor work instantly. For example, by connecting construction machines to the Internet, the quality and service life of all their parts can be checked online, and in case of technical weakness in any part, it warns managers before an accident occurs.

2.7 Waste management with IoT

According to the law, the owners of construction projects are obliged to dispose of the waste and rubbish of these projects. Fuel costs for logistics operations, the need to document waste disposal, and determine the most effective ways of recycling are among the important tasks of industry managers. When it comes to waste management, the following tasks are among the most important concerns of a project manager: create an effective waste disposal plan; apply a waste-free and sustainable production policy; Workforce training in waste management, disposal of various types of construction waste and rubbish. One of the effects of the Internet of Things on the future of the construction industry is waste management. Using the intelligent mechanism, it is possible to closely monitor the tasks mentioned above.

2.8 Replacement of digital systems in construction

The use of old technologies slows down the growth of the construction industry. Older hardware and software systems are expensive to maintain and lead to a loss of financial opportunities. In the construction industry, systems transformation using digital technologies is slow. This is partly because the decision makers in the industry are generations who are not comfortable with digital technology and are reluctant to use it. However, to have the upper hand in the industry, building managers can not use outdated systems. The Internet of Things is a breakthrough in this field and can help modernize the technologies used in this industry. One of the effects of the Internet of Things on the future of the construction industry is that it will create integrated systems with construction equipment and machinery that are more tangible to project managers.

III. IoT-Based Smart Buildings

Design process of an IoT system architecture lies in the heart of enabling the functionality of an IoT system, which is interconnecting heterogeneous components anytime and anywhere through the Internet. The main structure of an IoT system is typically divided on a layering basis, and many researchers have proposed their models to fulfill certain needs. Some common architectures include three-layer (as shown in figure 1), SOA-based, middleware based, and five-layer; for additional details refer to: (Al-Fuqaha et al. 2015; Stojkoska, and Trivodaliev 2017; Hui, Sherratt, and Sánchez 2017; Trappey et al. 2017; Silva, Khan, and Han 2018).

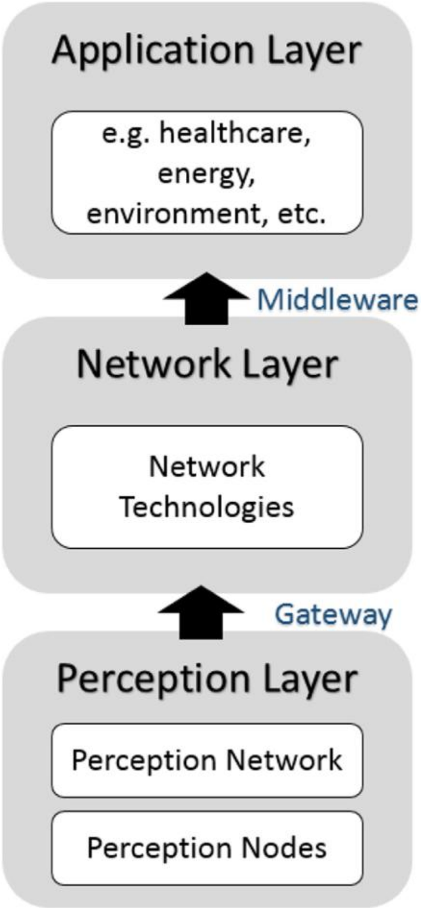

Fig 1. Three-layer IoT architecture (Jia, Komeily, Wang, and Srinivasan 2019)

IV. Application of IoT in smart buildings

Smart buildings cover a wide variety of sensors, actuators, devices, and control systems that are interconnected and jointly function to improve the service for its occupants. A part of the concept of smart buildings involves integrating a communication network within the buildings' elements so that they can be manipulated or monitored remotely (Jie et al. 2013). For instance , before the air conditioner is turned on, an action that is triggered by temperature change, all the windows must be automatically closed. Thus, a sensor must trigger the air conditioner, and then information should be exchanged between the air conditioner and windows. From a viewpoint of technical interoperability, it is more likely that the systems controlling the windows and the air conditioner are made by different manufacturers. This calls for an integration process for an automating control and management of the building (Jia, Komeily, Wang, and Srinivasan 2019).

4.1 Occupants localization

Interior localization is of great value for improving building performance. As an instance, occupants that are unfamiliar with a building could be provided with navigation to destination; the occupancy information acquired from localization information could be used to distribute resource in a balanced way; building managers could locate any equipment or facilities that needs maintenance or repair to increase their work productivity. Moreover, occupants' localization will help understand occupant behaviors and predict unique events inside buildings (Jia, Komeily, Wang, and Srinivasan 2019).

At this time, the role of building occupants has not been sufficiently taken into consideration and occupants' behavior is assumed to be static, and in some cases one or few representative profiles are used for building operation and management (Fabi et al. 2011; Jia, Srinivasan, and Raheem 2017). This leads to consequences such as inefficient resource use or energy waste. In order to perceive the concept of occupants' behavior is complicated while a challenging part is the ability to locate them while they are inside the buildings. Undoubtedly, current GPS technologies do not possess desired accuracy inside the buildings as they are mostly designed for geo-fencing and zone-based services. A promising part of IoT is improvements in micro-location technologies, which can locate any entity with a very high accuracy - possibly up to few inches. Essentially, micro-location is a geo-fence with high certainty, providing the ability to position and track any object inside the building, and consequently used for better and more efficient service provision (for instance thermal comfort, lighting, preference-based services, etc.) (Zafari, Papapanagiotou, and Christidis 2015).

4.2 Efficient Energy Management

Energy efficiency in buildings is one of the most significant research topics so far, not only in smart buildings development, since buildings account for 40% of the total energy consumption in the world (Cristino, Faria Neto, and Costa 2018). Besides, a smart building should not compromise the service level for building users or occupants to realize this goal, which calls for a solution to satisfy both sides. Some commercial Building Energy Management Systems (BEMS) (Jia, Komeily, Wang, and Srinivasan 2019) are already available that help control, monitor, and optimize building energy use currently. These systems are often installed non-intrusive meters at electric circuits to collect energy use data for users and managers. However, there is much improving potential at this point. Smart buildings are required to be configured according to specific requirements and this requires a certain level of context awareness. Meaning that the status of both the environment and the occupants plays a key role in how a smart building should operate. For example, the HVAC system needs to be set in accordance with the number of people in the room and the lighting system should monitor the lighting intensity outside of the building and set the lighting inside in accordance to that. With the support of IoT, this mechanism could be achieved, as studied by many researchers.

Pan et al (2015) first examined the statistical relationship between total energy use, heating and cooling energy use and environmental factors/occupancy status. Conclusion was drawn that energy is wasted although it was designed to be "green". To overcome this problem, the researchers designed a location-based automated energy control framework. They used the cellphone of the experimental objects, with GPS location sensors and many other auxiliary facilities. Wi-Fi was used as the communication technology. The system saved location information and thus calculated the distance between the destination building and the mobile device and if the distance is less than a specific threshold, the energy policy plan will be updated, for example turn on/off air conditioning, to save energy use and still have the same level of service. They tested the result with electricity meter and simulated scenarios to demonstrate the effectiveness of the IoT-based framework.

4.3 Facility Management

During a building life cycle, operation phase takes up the longest period. As a result, facility management is another goal of smart building, which integrates organizational activities to maintain efficient and effective services. Facility management (FM) requires timely preventive maintenance and malfunction detection of building equipment to ensure the facility's optimal condition. Conventional FM has problems of lower data quality, longer notification time, and delay in relevant operation and maintenance. Under this circumstance, IoT provides adaptive and realtime access to building facilities for relevant personnel. Functional FM will gather many benefits, including potential to improve health and comfort of occupants, enhance quality of facility services overall, reduce cost of repair and building energy use, having means for efficient planning and resources use, etc. Several applications of IoT in smart facility management are available, which are described below.

Maintenance of a smart building platform by D'Elia et al. (2010) realized a set of context-aware smart maintenance applications that utilized environmental sensors to monitor related variables, such as temperature and humidity, and automatically report feedbacks. For example, if "temperature-out-of-range" message is generated, this platform is able to detect the location and the possible faulty equipment, HVAC in this case, and notify the corresponding human operator through personal device. Additionally, suggested corrective intervention instance will be provided to both the personnel and tenant as to facilitate the repair process. The pattern of the platform could be applied to all building systems within a smart building, as well as building structure for automatic monitoring of the whole building. More recently, Srinivasan et al. (2017) and Nirjon et al. (2017) are developing an acoustic-based HVAC maintenance system by collecting, transmitting the audio signals via the Internet, processing, and characterizing the audio signature with corresponding HVAC system-related component data.

Bashir and Gill (2016) proposed an integrated framework of IoT big data analytics (IBDA) for monitoring and controlling the building in real time. They implemented simulation on three environmental data including oxygen, smoke/hazardous gases, and luminosity in five different zones, and fed the data to Cloudera Hadoop Distributed Files system to make control decisions when the data value is out of the pre-defined comfortable range. Some of the research challenges are: 1) No energy concern, as the control strategies only care about occupant comfort; 2) No real IoT system test, since the researchers focused on real time data analysis and visualization.

It should be mentioned that occupant comfort and building energy saving sometimes stand on the adversarial sides, therefore it is always meaningful to address both issues together when designing intelligent solutions for buildings. In fact, it turns out that this balance could be achieved with the use of IoT. Therefore, the authors claim that occupant information should be involved in any comfort versus energy efficiency research, which requires the identification of useful parameters and the development of IoT technologies (Moreno, 2014) is a trial for this concern, which tested three buildings for results comparison.

4.4 Occupant safety and health security

Most building occupants value occupant safety and healthcare, and this concern can also be improved by IoT implementation (Demirkan 2013) is an example for healthcare systems that is automated, intelligent and sustainable. Unobtrusive sensors that monitor the environment as well as the patient condition are linked to wearable interactive devices to enable a thorough evaluation of the health of a particular space as well the people in them. Advantages of IoT that enable the smart healthcare systems are: 1) Being portable and unobtrusive: Small instruments that are embedded in the environment or unobtrusively on patient bodies to monitor patient health and communicate wirelessly; 2) Easy scalability and deployment: majority of devices will be deployed; 3) Real-time and always-on: Both the environment and the patient need to be continuously monitored so that response to any kind of emergency can be immediate; and 4) Reconfiguration and self-organization: Sensors can be removed or added any time by medical professionals. These changes should be accommodated easily and the sensor network should be self-organizing.

Piscitello et al. (2015) suggested a danger-system, which is able to detect safety-related emergency and provide alert and rescue solutions for building occupants. The system’s application can be installed in users' smartphones to detect events such as user running or loud noise, and aggregate all the information to generate potential emergency activation. By the time the message is confirmed by building manager, notifications are sent to all users according to their current geographic location and the building alarm is turned on simultaneously.

4.5 Building health control

To consider health monitoring of structures, Wang, Fu, and Yang (2017) suggested an IoT-based integrated information system with early warning function. The system architecture incorporate sensor data collecting layer, data management layer, and structural health monitoring service layer. For the sensor data collection layer, steel stress gauge, inclinometer, and earth pressure cell sensors were employed at the pivotal locations of monitoring target, and multi-standard communication was applied for data transfer and processing. The system also had a module for uniform data parsing to abstract the different message formats of heterogeneous devices for data integration. Finally, the structural health monitoring layer directly linked to supervision department to inspect potential failure conditions.

V. Conclusion

Moving in the direction of making buildings smarter is associated with obstacles. Two of these challenges are: customers' ignorance and customers' perception of the luxury of Internet of Things applications. Therefore, it is suggested that companies active in the field of smart homes emphasize more about the applications of the Internet of Things in the building and the benefits that these applications create for people, so that customers are aware of its benefits. In order to deal with the perception of the luxury of Internet of Things applications in the building, it is suggested that companies look for cheaper technologies to develop the Internet of Things applications in the building so that they can reduce the cost and finally reduce the price of their products or services. In addition, there is another challenge for the implementation of Internet of Things applications in the building and that is the intangibility of the benefits that smart homes bring to customers; therefore, it cannot be expected that people will use these applications by themselves. Therefore, it is expected that the upstream requirements and laws will be compiled in order to implement these applications.

The emergence of advanced technologies and its integration with different types aspects of our lives have opened new horizons for improving the service performance of buildings, communities and cities. Focusing on an important part of the prospects, this paper reviewed the current research contributions and future potentials of the Internet of Things in line with the anticipated goals of smart buildings. Typical IoT enabling technologies were introduced in a sequence of three-layer general IoT architecture, i.e. 1) understanding layer, 2) network layer and 3) application layer. The advanced technologies used in each layer, the standards/protocols for the development of each layer and the communication of the construction industry in each layer were explained. After that, the current applications of IoT are discussed in line with the development goals of smart buildings, which include academic and industrial uses in the past decades. The main criteria of smart buildings were abstracted to map these applications. Although this is not a complete list of applications, it can serve as a good starting point for future research in related fields. It is concluded that the current technologies - hardware, software and computational algorithms - have already become an important part of the development of intelligent buildings. However, to successfully implement the vision of advanced smart buildings in the future, continuous research efforts in IoT applications are needed. Based on this, the technical requirements of the Internet of Things standard and its integration needs with the building industry were identified. It is worth noting that a significant amount of problems and challenges remain to be studied as summarized in this paper. These challenges will be valuable and ideal research problems for researchers and practitioners who are interested in using the IoT concept and system in building research areas and will further progress in both technical and practical aspects of the Internet of Things.

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