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Review Article

Imperative Role of Technology Intervention and Implementation for Automation in the Construction Industry

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According to sustainable development goals, the construction industry is one of the vital industries that can build resilient and sustainable infrastructure for human settlements. As the traditional approaches in the construction industry are causing distinct challenges including environmental pollution and excess energy usage, however, the integration of emerging technologies will assist us to reduce the impact and also enhance the activities in the construction industry. Motivated by the facts, this study aims to address the significance of automation in the construction industry with distinct emerging technologies like the Internet of things (IoT), automation, radio frequency identification (RFID), building information modeling (BIM), augmented reality (AR), and virtual reality (VR). The large amount of data generated from the IoT, RFID, BIM, and AR/VR provided an opportunity for big data and artificial intelligence (AI) to extract meaningful insights related to the events in the construction industry. Furthermore, edge and fog computing technology encourages us to implement AI at the edge network for analytics at the end of the edge device. Based on the above analysis, the article discussed recommendations that could assist in further enhancement and implementation of automation in the construction industry. Cloud-assisted AR/VR, integration of AI with IoT infrastructure, 4D printing, adopting blockchain in the construction industry, and smart robotics are the recommendation addressed in this article.

1. Introduction

The sustainable development goals provide the construction industry with a new chance to shift its attention beyond the environmental aspect of sustainability [1]. Construction project delivery and supervision could be characterized as sustainable if economic, social, and environmental issues are incorporated into project delivery techniques, regulations, and practice [2]. Construction is a primitive industry that is combined with large-scale equipment and manual labor. According to the perception of industrialization, the construction industry is a distinctive manufacturing industry, in which products are accumulated with a sequence of discontinuous processes [3]. The complex mechanism in construction is responsible for the slow growth of industrial evolution and additionally the implementation of labor-intensive approaches in the construction industry results in environmental pollution and excessive energy usage. Despite the industry's enormous potential, the only way to boost safety, productivity, quality, efficacy, and project management is achieved through digitalization, new construction techniques, and innovations [4].

Industry 4.0 has brought intelligent machines, digital technologies, sensor systems, and smart materials into the construction industry for automation. IoT, RFID, AI, BIM, AR/VR, edge/fog computing, and cloud computing are the digital technologies of Industry 4.0 [5]. Prefabricated or modular construction is a novel construction approach that not only reduces project costs and time but also enhances productivity. This technique comprises offsite fabrication of structural elements such as a beam, column, flooring, and wall panels, followed by onsite assembly. The integration of RFID, sensors, and wireless communication protocol led to the implementation of IoT [6] in the construction industry for the identification of an individual on the site and also to sense the human health parameters, construction site health monitoring, and also monitoring the status of personal protective equipment (PPE).

The integration of sensors enables the generation of a large amount of data and applying analytics technology like AI empowers to predict anomalies and also enhances the activities in the construction industry. In cloud computing, the latency and computing sources are the few limitations for the decision-making with AI based on real-time data. To overcome this challenge, edge/fog computing is another cutting technology that delivers decision-making with AI at the edge network itself.

BIM is described as the process of creating and incorporating a digital model of a structure or construction and its attributes. BIM is more than just the creation of 3D models [7], and it may thus be used for a variety of purposes such as improved communication, decision-making enhancement, and visualization. Furthermore, BIM technology has changed and transformed the way designers, engineers, and managers think about buildings, allowing them to forecast and solve problems that may arise during a building's life cycle [8]. However, from the previous study, it is concluded that BIM has limitations such as BIM does not allow effective visualization for congested building sites [9], and BIM has several difficulties in real-time onsite communication [10]. AR is defined as a physical environment whose components are enhanced with and backed by virtual input, while VR is defined as a simulated virtual world that represents a physical environment. AR/VR technologies have the ability to overcome the limitations of BIM and improve BIM in a variety of ways, including real-time onsite communication [11]. AR/VR also enables better visualization for designers, engineers, and other stakeholders, enabling one-to-one completely immersive experiences [12].

Currently, the above technologies are enhanced in the distinct fields of the construction industry in terms of resource management, energy saving, reduction of emissions, optimization of design, and resource management [13, 14]. Figure 1 presents the transformation of the industry from Industry 1.0 to Industry 5.0, and it also shows that society is adopting and working on Industry 5.0 where the humans and machines will be working together with an amalgamation of blockchain + artificial intelligence + human for sustainable development.

1.1. Contribution of the Study. Prior to the sustainable development goals formulated by the United Nations, construction is one of the industries that requires technological advancement and automation to build resilient infrastructure sustainably. In this study, we have provided the reason behind the implementation of automation in the construction industry. Before discussion of automation with digital technologies, a detailed significance impact of prefabricated construction and building information modeling in the current scenario are discussed. Later on, the possible areas of automation in the construction industry with digital technologies such as IoT, RFID, AI, edge/fog computing, cloud computing, and AR/VR are discussed along with the architecture. Based on the analysis concerning automation in the construction industry, a few recommendations such as integration of AI with IoT infrastructure, cloud-assisted AR/VR, 4D printing, adoption of blockchain in the construction industry, and smart robotics are presented in the article.

1.2. Outline of the Study. In the outline of the study, Section 2 presents the overview of the construction industry including prefabricated and BIM in construction. In Section 3, the possibilities of automation in construction are addressed. In Section 4, the technologies like IoT, RFID, AI, edge/fog computing, cloud computing, and AR/VR that enable to realize of automation in the construction industry are presented in detail. In Section 5, a few recommendations are presented for future enhancement in the automation of the construction industry.

2. Overview of the Construction Industry

The construction industry contributes 13% of world GDP, in 2018, projected to be $14 trillion by 2025 [15]. However, the use of such technologies in the field of construction is still in the infancy stage, due to segmentation, site-specific activities, and resistance to change [16]. Figure 2 presents the ingredients of the construction industry that revolve around labor, material, equipment, and capital to create a built environment for achieving socioeconomic development. For the wide implementation of smart infrastructure in the construction industry, it is necessary to enhance the skills of the workforce because traditional tools and techniques are no longer meeting the future demand. Smart equipment in the construction industry advances productivity, accuracy, and efficiency. Most of the laboratory and field pieces of equipment are to be digitized and required to enhance the skilled operators for delivering a better customer experience. Excellent performance of the construction project, in terms of minimal time and cost, depends on the performance of the worker, equipment, timely procurement of the materials at the site, visualization, virtualization of the construction process, and satisfactory progress.

Major challenges faced by any construction industry are (i) unavailability of skilled laborers, (ii) communication gaps or delays, (iii) budget and time constraints, (iv) nonstandardization of construction techniques, and (v) lack of integrated information system to store, transfer, and share the resources. The following factors encourage the implementation of the smart construction site and automation in construction as follows.

2.1. Prefabricated/Modular Construction. Prefabricated or modular construction not only reduces the project cost and

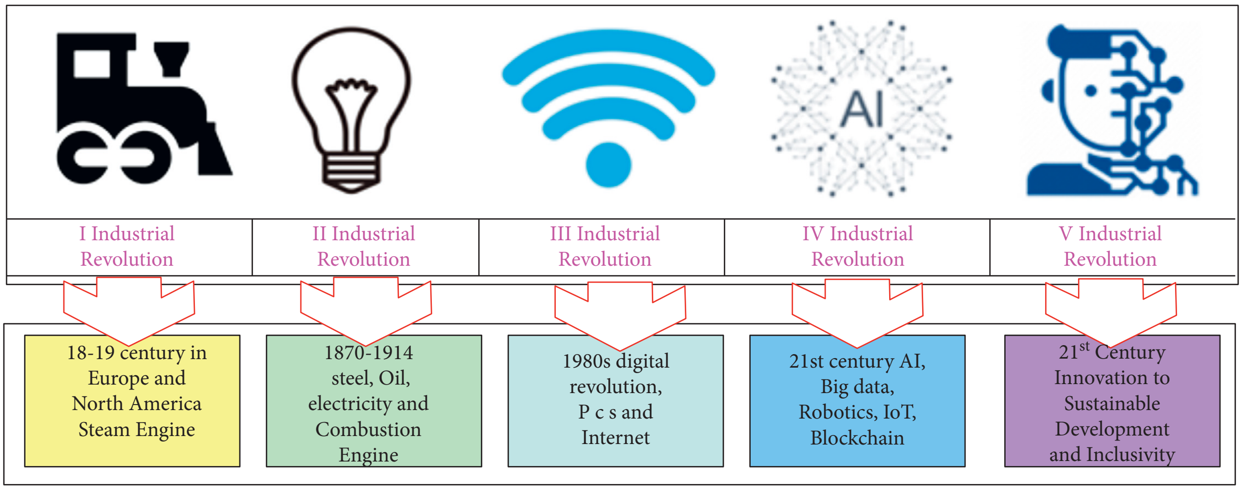


Figure 1: Transformation of the industrial revolution.

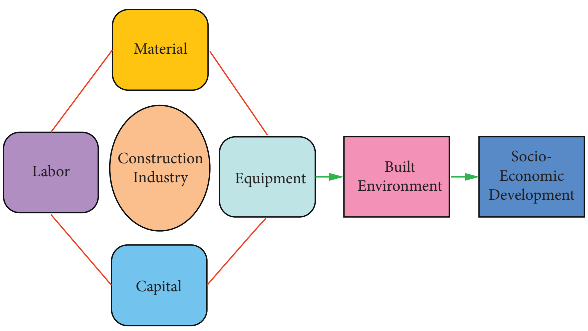


Figure 2: Ingredients of the construction industry.

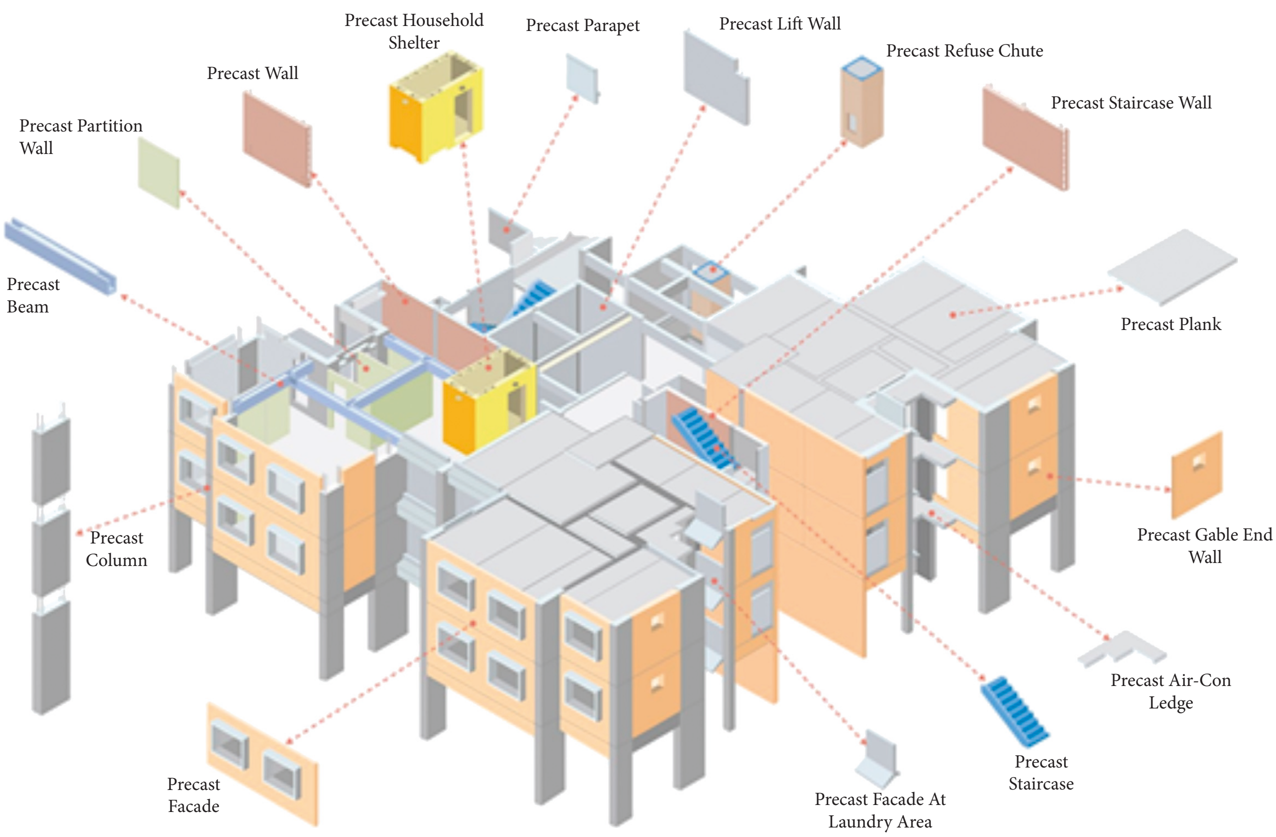
time but also improves productivity [17]. The technique both involves offsite production of structural elements, like a beam, column, flooring, and wall panels, and then assembles onsite as shown in Figure 3(a). Utilizing the 3D element (block containers) with all interior and exterior finishing, engineering facilities, built-in furniture, and equipment is presented in Figure 3(b). The first such technology for the former case was developed in China in the year 1988. It was proved that such construction techniques are cost-efficient, safe, and eco-friendly. Initially, it was used for the construction of low-rise buildings, individual offices and household buildings, warehouses, and sanitary and special purpose premises. Later, it was extended to multistoried as well as high-rise buildings. It is sometimes also called Rapid Construction Techniques and requires related technology for fast construction.

As every technology has some advantages and limitations, prefabricated or modular construction also comes with some drawbacks. Labor safety is one of the major concerns with high fatalities and injuries observed in the field during the assembling of the units. Other concerns are related to the quality of workmanship, damage to structural elements during transit and storage of elements constructed offsite in case of delay in government approval, or delay in demand due to some other reasons.

Looking at the normal construction schedule, the process involves (i) design and engineering, (ii) permits and approvals, (iii) site developments and foundations, (iv) building construction, and (v) site restoration. While adapting prefabricated or modular construction, major time is saved in steps (iv) and (v) as it requires only installation work, and the site is restored simultaneously, as it is presented in Figure 4. Modular and prefabricated construction has proven to be very promising for government policies on affordable housing, low-cost housing, or housing for all, and many developed countries have broken the myth that high-rise buildings are only for rich or specially abled people.

2.2. Building Information Modeling (BIM). As per US National Building Information Model Standard Project Committee's definition, Building Information Modeling (BIM) is a digital representation of the physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle, defined as existing from earliest conception to demolition (NBIMS-US, 2016). Figure 5 presents the evolution of BIM since its first conceptualization in the year 1974 with the name "Building Description System". The first time used the term "Building Information Model" in his work "automation in construction" [19]. Later, Autodesk [20] published work using the term "building information modeling," and since then, it is a common name given for the digital representation of the building process.

BIM [21] is a software tool that is predominantly used during the planning phase to visualize and understand the construction process and identify issues and resolve them before the actual execution of the work. Also, it has been widely used in project cost and time management. Recently, BIM is attached to IoT-based tools and technologies to control the ongoing construction process, monitoring, controlling, and managing machines, equipment, materials, and manpower. Also, it is incorporated and attached with automation to ensure quality control and quality assurance of the ongoing work, waste management, and ensuring a safe working environment. Figure 6 presents the utilization of BIM in the construction sector. It is a powerful tool to



(a)

(b)

Figure 3: (a) Prefabricated construction [18]. (b) modular construction using 3D element.

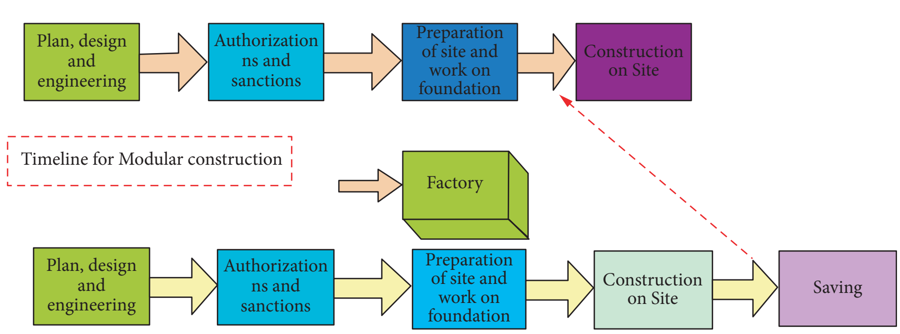


Figure 4: Comparison of modular construction schedule and site build construction schedule.

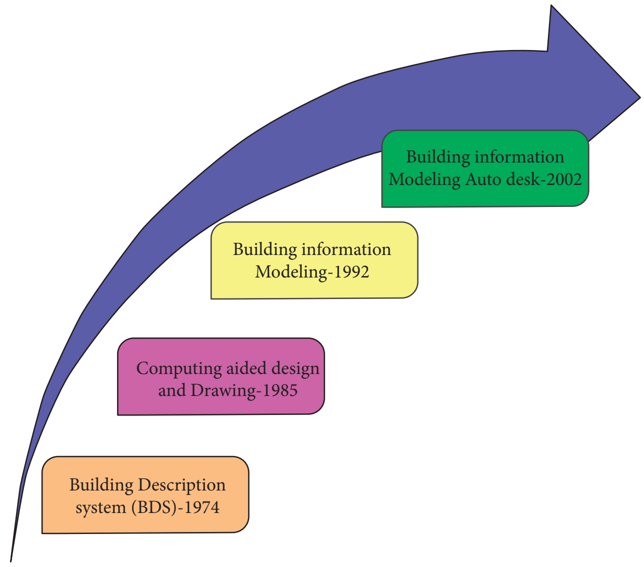


Figure 5: Historical development of BIM.

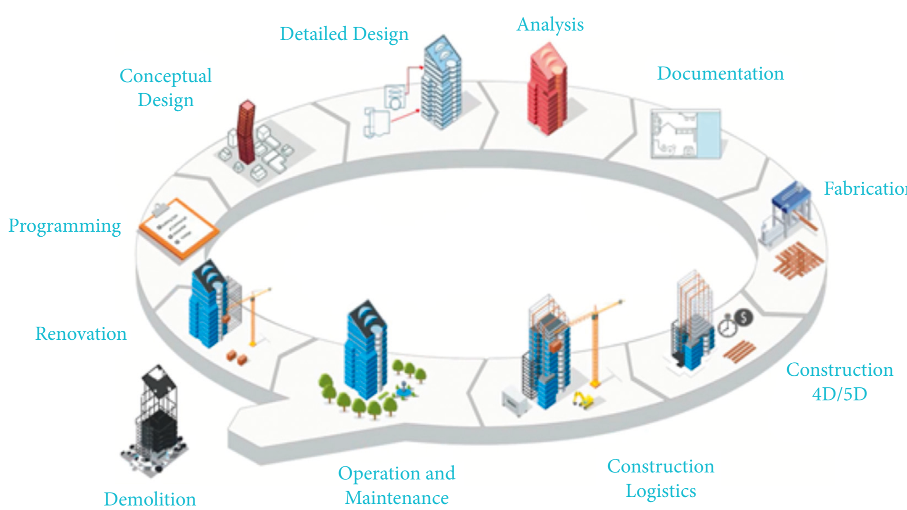


Figure 6: BIM utilization in a different area of construction.

manage big projects in the fields of design, planning and scheduling, estimating and cost control, construction operation, and control [22–25].

Further, the capability of BIM is improved by adding other dimensions like 3D (object model), 4D (time), 5D (cost), 6D (operation), 7D (sustainability), and even 8D (safety) presented in Figure 7. This multidimensional capacity is defined as the "nD" model of BIM which means that an infinite number of models can be added and executed in BIM [26]. By adding the 4^{th} dimension (time), it was possible to simulate real-time construction processes and progress, in sequential, spatial, and temporal domains [27]. This helped the engineers, architects, contractors, and owners to visualize, analyze and communicate on buildability and workflow and time scheduling for improved productivity. 5^{th} dimension adds cost to the model and this helps to generate the cost of the project in no time [28]. Also, it is error-free and helps stakeholders to rework costs with modifications and suggestions during the planning phase itself. Financial representation can also be made with time for ensuring the timely management of the fund as the work progress.

The 6^{th} dimension adds facilities management which means that each engineering element has a complete description of geometry, material, vendor data, and capabilities. BIM also provides a perfect platform for the facilities management database [29]. The 7^{th} dimension adds a sustainability component to help to reduce the carbon footprint of the project, by giving various options [30]. Further, the 8^{th} dimension was added to ensure safety and security at the construction site [31].

Figure 8 presents the highlights of different advantages of the use of BIM in the field of the construction industry.

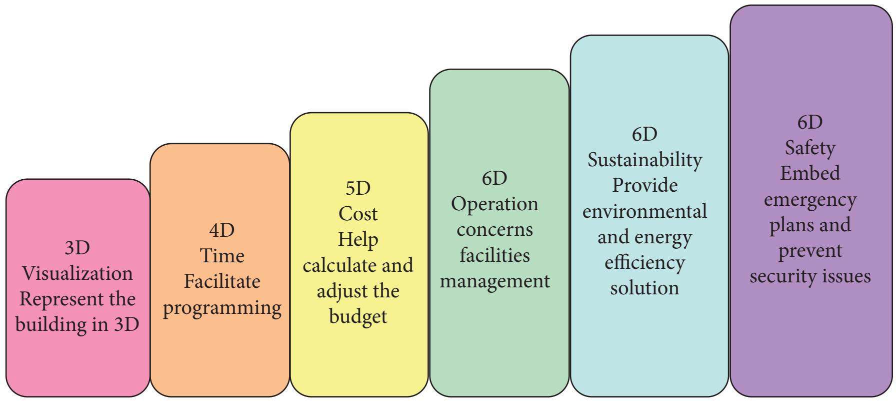


Figure 7: BIM dimensions (adapted from the work of Smith [26]).

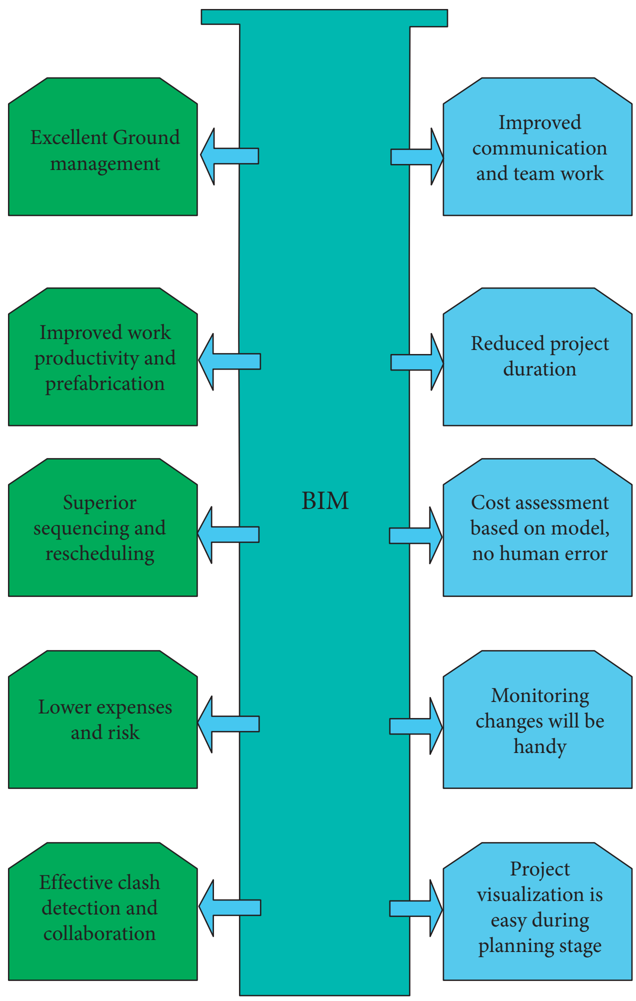


Figure 8: Specific impact of utilizing BIM in the industry.

Realizing the benefits involved, some countries, like Britain, Finland, and Singapore, have made it mandatory to use BIM in the field of the construction industry [32]. Figure 9 shares data on the percentage utilization of BIM by stakeholders in different areas of the construction industry [33]. It can be noted that BIM is maximum utilized for visualization, clash detection, and building design activities. Owning the capabilities of this powerful tool, it can be imagined that a lot more is left to explore, and future generations should develop capabilities of learning, understanding, and utilizing this tool, and the future of the construction industry is in BIM. A major challenge faced by BIM, to effectively implement at the site and in standardization of construction process, is unrecognition of its potential. People, working at

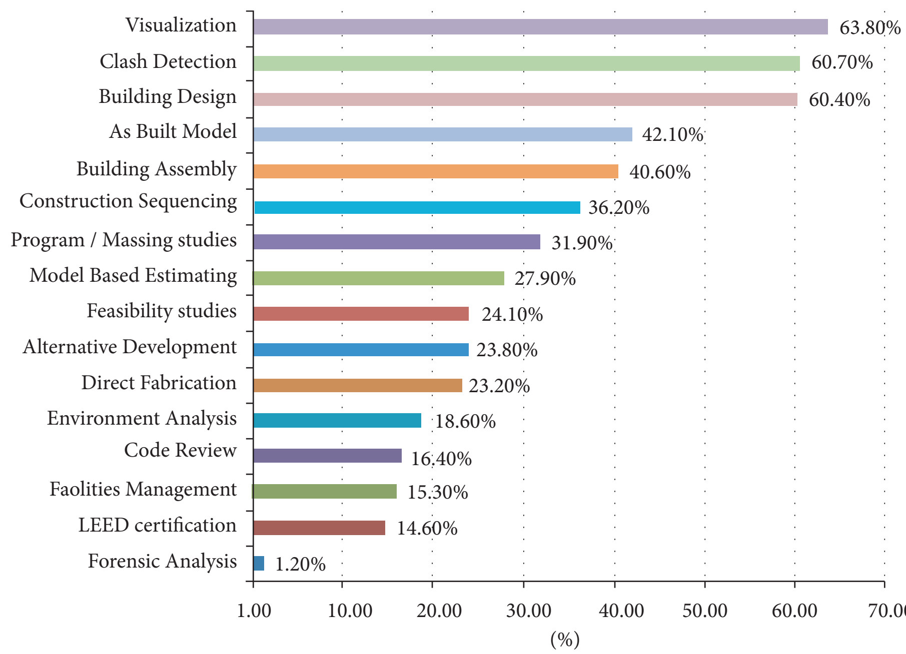


Figure 9: Percentage utilization of BIM in various fields of the construction industry [33, 34].

the site, are still comfortable with the 2D drawing, and they are slightly resistant to upgrading their skills as they have the opinion that BIM will add more confusion as the majority, still, do not understand the 3D representation of the model. Also, the construction process varies from site to site with different classification systems; it becomes difficult to apply the same. Nevertheless, acceptability and adaptability change the rules of the game, and with time, BIM in the construction industry is going to play a vital role in the near future [33, 34].

3. Automation in Construction

The scope of automation in the construction industry is wide, starting from material production, offsite construction of structural elements for prefabricated or modular construction, and onsite construction of a structure, operation, and maintenance purposes to demolition and recycling [35]. Figure 9 illustrates the witnessing of automation in construction work for following some of the specific fields of the construction industry, such as civil infrastructures like roads, tunnels, bridges, earthwork, and building sector, erection and assembly, concreting, and interior finishing work. It can be noted that majorly it is utilized in earthwork but it has huge potential in other fields of application.

Figure 10 presented the percentage utilization of automation in different fields of construction. Automation is extensively used in developed countries, but it is still in the infancy stage in most developing countries where labor-intensive construction is still a popular model due to the availability of a cheap labor force. Big projects and the huge site cannot reframe themselves from the use of automation and IoT-based tools and techniques due to inherent advantages achieved in terms of cost-cutting, time-saving, and ensuring efficiency and a safe working environment. It requires a skilled workforce, quality, and a conducive environment to work. A time has reached when robots will take over the major work of civil engineers and construction workers and demand will shift to skilled operators to use the machines and developers to build such machines. Table 1 summarizes the potential area of application of automation in the construction with a description of the approach and relevant references.

4. Technologies for Automation in Construction

In this section, we are discussing the technologies that support the realization of automation in construction. IoT, RFID/NFC technology, augmented, mixed, or virtual reality, edge and fog computing technology, big data and cloud computing, and artificial intelligence in the construction industry are detailed and addressed in this section.

4.1. IoT in Construction. IoT refers to the connection of devices through the Internet, i.e., internetworking of physical devices, with aid of sensors, actuators, software, and network connectivity that help these objects to operate or collect data remotely. Once you are connected with a device or human, its usage is beyond imagination as you get the opportunity to get real-time data and analysis helps you taking decisions spontaneously thus saving time and in turn money. We know that majority of large projects are delayed and overbudgeted. IoT supports the utilization of low-power sensors to communicate fast and cost-effectively. It is helping the construction industry to overcome some of the major issues related to productivity, safety, and process development and deployment with new tools. IoT is assisting stakeholders in collecting data on a real-time basis from

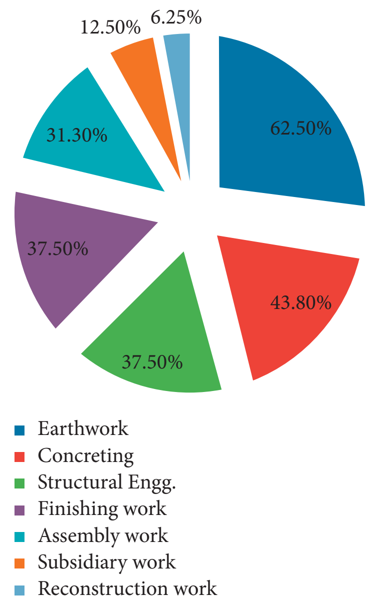


Figure 10: Percentage utilization of automation in different fields of construction [35].

Table 1: A potential area of application of automation in the construction industry.

Application	Description of approach	Reference(s)
Autonomous machines	Self-propelled machines can go the remote sites through difficult terrains without posing any threat to the safety of workers. This requires the integration of technologies like programming, GPS, sensors, robotics, and remote control devices, in terms of both software and hardware.	[36, 37]
Drone to survey	Automated inspection of a site without human intervention. It can reach inaccessible sites and perform a survey in much less time. Drone survey is especially used for project planning, monitoring of progress, and maintenance purposes.	[38]
Robotics in concreting	Automation is very much used in concreting work nowadays. From the mixing of concrete to laying, curing, and polishing, it is all can be done through automation. Recently, demolition robots are used for dismantling purposes. It helps to provide a safe working environment and reduces operational costs.	[38]
IoT sensors	Automation without sensors cannot be imagined. Sensors help to send critical data and information that can be utilized for decision-making. It requires mathematical models and computer programming to get the desired output before taking an appropriate decision.	[39, 40]
Virtual reality	Virtual reality allows planning for work before execution. It simulates a realistic condition through programmed 3D scans and helps to visualize the situation with zero error. One can judge and decide whether adequate infrastructure or facility is available to execute the work.	[41–43]

planning to actual construction as well as postconstruction maintenance and performance of the built environment. Table 2 presents the major concern in the construction industry in the area of productivity, safety, security, and maintenance and they are addressed through IoT. In addition to that, IoT has helped to monitor structural health through sensors by detecting vibrations, cracks, damaged or degraded materials in structural elements, stress, or strains at the critical locations of the structural members.

One such example is smart glass with a heads-up display that uses augmented reality (AR), virtual reality (VR), or mixed reality (MR) technology to help in the planning and modeling phase. Google Glass, Microsoft HoloLens, DAQRI smart helmet, sole power workboot, and site watch are some smart wearables available to utilize for monitoring, performing a specific task, and transferring real-time data or information to their colleagues or superiors through connectivity.

Figure 11 presents the usage of IoT for various applications in the field of the construction industry. BIM is used to create a 3D model, which is now integrated with the IoT to simulate the construction process in real time and allows monitoring the progress, finding deviations, and helping in decision-making with the use of sensors installed at critical locations, integrated with the local environment, etc. [52, 53]. IoT is helping humans to reduce expensive errors,

Table 2: IoT for addressing issues in key concern areas.

S. No	Concern area	Description of issues	Address through IoT	References
1	Productivity	Deadlines and targets and no backlogs allowed. Further, poor scheduling due to human error cause delay in the supply of materials that ultimately cause project delay	IoT helps to achieve readiness and efficiency through suitable sensors to estimate quantity and raise alarms or make automatic orders	[41–43]
2	Maintenance	Wastage of fuel and power due to poor management; handling issues, damages, and the expiration of the materials; environment conditions, humidity maintenance	Sensors deployed can provide real-time data on all issues to continuously monitor and maintain the equipment, fuel, and material	[44–46]
3	Safety and security	Human security agents cannot manage huge sites	IoT enables tags to help to prevent theft through real-time monitoring of locations and their movement	[39, 43, 47]
		Risk to a workplace or entering endangered locations	Sensors can also help to identify extreme environments or dangerous locations and set alarms for taking appropriate action	
		Fatigue and distress due to long working hours affect productivity	IoT helps to monitor signs of distress such as high pulse rate and raise an alarm	
4	Equipment handling	Tracking of equipment condition and location	IoT enables UAVs (drone) and autonomous vehicles to help to resolve the issues mentioned	[48]
		Humans working in unsafe locations or situations Access to remote locations or inaccessible sites	It not only improves efficiency and accuracy but also cuts costs and time	
5	Concreting and curing	Time management of critical activities, removal of formwork, scheduling, and cycling of formwork to avoid any delay	Embedded sensors in concrete help monitor real-time gain in strength and timely removal of formwork; it also helps manage labor and formwork cost, opening traffic on time, optimization of concrete mix design, etc.	[49, 50]
6	Waste management	Reduce the carbon footprint of the construction site Immediate cleaning of the site to create space and reduce hazards to avoid penalties from agencies	IoT trackers help to monitor waste disposal bins, or vehicles in a cost-effective way	[51, 52]

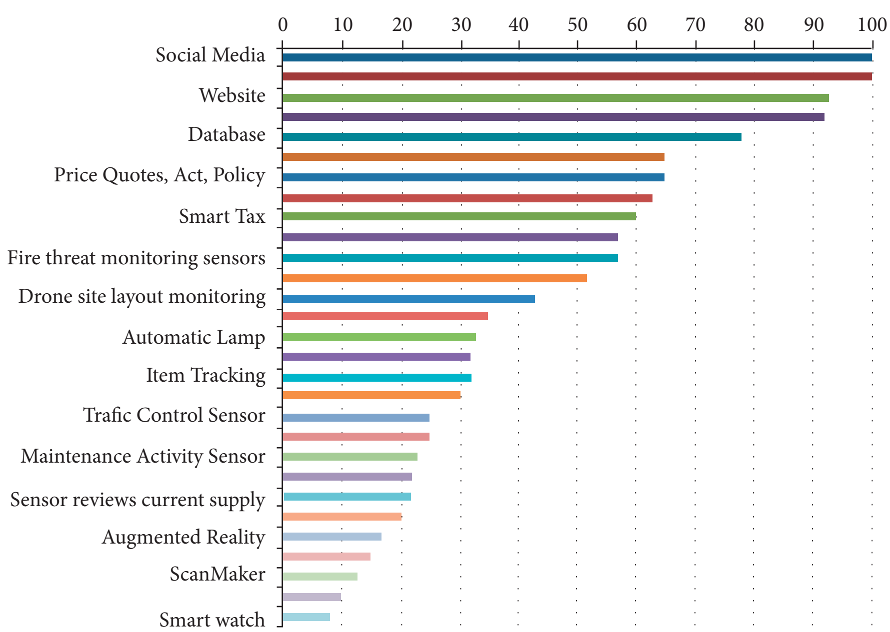


Figure 11: Summary of % usage of IoT in the construction industry.

ensuring security and safety at the workplace, and building operations more efficiently, and these days, it is the business model of the many construction industries. IoT is making a significant contribution toward processes that will be more efficient, less time-consuming, and provide data on a real-time basis for decision-making. Besides, IoT is helping in waste reduction and making the built environment smart through sensors that control the operations like air-conditioning, heating, lighting, etc. through an automated process.

4.2. RFID in Construction. RFID is increasingly used in varied fields like aviation, retailing, health, security, etc. as it helps to identify the movement of valuable assets as well as a human on a real-time basis even in extreme environmental conditions. The construction industry also realized the advantages of such technology and adapted it due to its usefulness in managing assets, managing the workforce, and reducing operational challenges thereby increasing efficiency, reducing cost, and saving time [54–56]. A construction site is a perfect place for the implementation of RFID as a lot more movement of equipment, tools, and materials and skilled and unskilled workers occur at a particular location and yards. Material storage and material selection for particular construction activities are done simultaneously during the construction work. Safety and security of such assets are a major challenge to avoid delay, loss, and unauthorized use as any mishappening, mishandling or misuse, and miscalculation will involve cost and time delay. Table 3 presents RFID technology implementation in the construction industry.

A long-range communication and IoT-based RFID/NFC architecture for the identification of materials and machines are presented in Figure 12. Moreover, this architecture is proposed for overcoming the challenge of Internet connectivity and high-power consumption for long-range transmission. "*n*" number of RFID/NFC readers are deployed on the premises of the construction. RFID/NFC readers are integrated with long-range communication protocol; the long-range communication protocol is having the capability of transmitting the information long-distance with minimum power consumption. RFID/NFC reader transmits the information to the gateway via long-range communication, as the long-range communication module is available in the gateway. Gateway is positioned at a location where Internet connectivity is available.

The gateway is integrated with a Wi-Fi module that allows logging the data of the RFID/NFC reader to the cloud server. Additionally, the RFID/NFC reader adds the location information of materials/machines during communicating with the cloud server. The user can access the data through the cloud server. Furthermore, the real-time events during the identification process of machinery/materials are also recorded in the cloud server. The featured advantages of the adoption of automation in the construction industry are following a continuous working environment that saves time and money, a safe working environment for workers, quality control, and quality check is precise. There is no human intervention and error, possible to work in a remote location and through difficult terrain, and construction is relatively fast.

4.3. AR/VR/Extended Reality (XR). XR is given a common name to all three as extended reality. Tools on virtual reality put you in the virtual world. The surroundings created are immersive, and it has nothing to do with real surroundings. One must have experienced (video) games using such technologies, for example, VR glasses, where you must have done roller coaster rides, bungee jumping, car racing, sky diving, etc. [59]. You are completely in the virtual world and do not see the actual space around you like offices, buildings, objects, etc. On the other hand, AR puts virtual information to a specific point, called markers, in the real world. You see the real world with virtually added information through a glass. A common example is Google Glass, which is used to view the real world with added information in the field. Through such glass, you will always be connected with others wearing the same glass and share the information on a real-time basis, just sitting in your office or remote place. Mixed reality is the amalgamation of virtual reality and augmented reality, meaning that you see the real world with virtually added objects around you. A device like Microsoft HoloLens allows you to place virtual objects in the real surroundings, and it is always visible and it helps you manipulate the surroundings. Figure 13 presented the comparison of VR, AR, and MR techniques.

Industrial Development Corporation (IDC) has predicted that the use of AR and VR is going to surpass 20 Billion Dollars in the economy. Such technologies can be used differently in the field of construction. Imagine you are checking a site and want to crosscheck and verify whether construction is going as per design or not. Augmented reality can play a major role in performing such activity. In the design itself, markers can be placed and one can crosscheck and verify whether such activity is performed or not [60]. However, it has a long way to go as technology does not allow differentiating different objects in real context; hence, it will be premature to say that technology can be used to control the construction process, vehicle movement, and people movement at the construction site through AR [61].

MR can be used in interior designing by placing virtual objects in the real surroundings, doing measurements for quantity estimation and clearing BOQs, and doing things in the planning stage. VR is already commercialized and very much used by many enterprises not only in the planning stage but also during sales and management, where you help customers to experience the building, house, and its surroundings using a "walk through" even before laying a single brick on the ground. Although these technologies require costly efforts in terms of hiring skilled personnel and arranging software and hardware support, their long-term benefits in terms of achieving efficiency, time-saving, and mitigating human errors are beyond doubt, and time will only tell when we all will be surrounded with devices supporting VR, AR, and MR. Advantages of such technology in the construction industry are as follows: improved

Table 3: RFID technology in major fields or areas of the construction industry.

Area of construction	Method or approach	Reference
Project management	Managing construction site by installing tags and readers on machinery, tools, and equipment, to ensure movement of equipment, materials, and labor at predefined and predicated locations and raise alarm if a discrepancy is observed Such technology is very much useful in large projects to save time and money and things can be controlled remotely through interconnected tags and readers and sharing the same on a real-time basis	[56]
Equipment and tool management	Deployment of RFID on high values equipment and tools helps control its movement and remove the threat of being lost. This is particularly useful when equipment and tools are utilized on multiple sites and then it becomes easy to identify its location, working condition, and movement and accordingly decide for replacement, engagement, or procurement of a new one	[57]
Inventory management	RFID helps to control and acquire excess inventory as well as reduce generating waste by scraping as real-time data and information available helps the concerned authority to know the date of inspection and certification and know in advance the date of expiry. RFID also helps in tracking the prefabricated structural element from the factory to the construction site. This helps to reduce the problem of storage at the site, reduce labor costs, and save time. Element of human error is also eliminated with the use of RFID	[57]
Workforce management	RFID helps in identifying the number of workers on the job site with identities and their movement can be monitored through a workforce management station. One can easily identify several workers at a particular station, their expertise, and competency to accomplish a particular task, their demography, and codes that help to identify several jobs created at a particular location	[58]
Safety and security	Through RFID, a lot can be done for the safety and security of personnel working at a particular location. Restricted movement, unauthorized access to a particular site, evacuation plan in case of emergency, cleaning and restoring site through control access, etc. are possible using technology	[21]

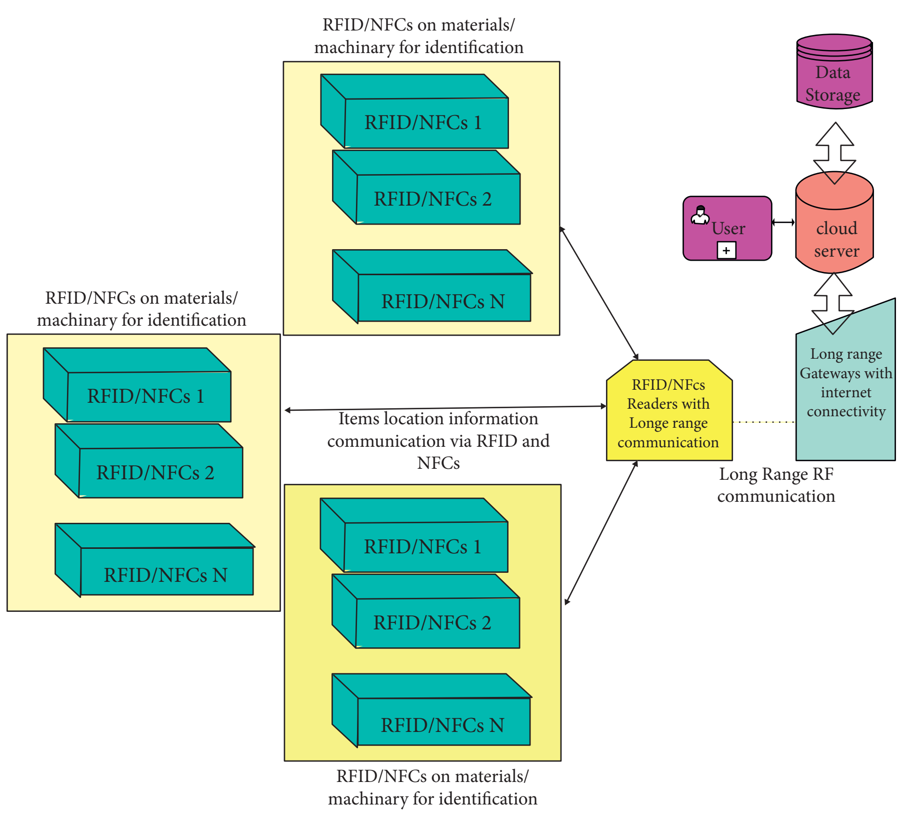


Figure 12: IoT and RFID in the construction industry.

efficiency and productivity by combining building information modeling (BIM) with data embedded that helps users to track the work progress, creating "walk through" during project planning and management, identifying issues onsite and resolving them in no time, avoiding chaos during construction and delay due to reworking on some of the

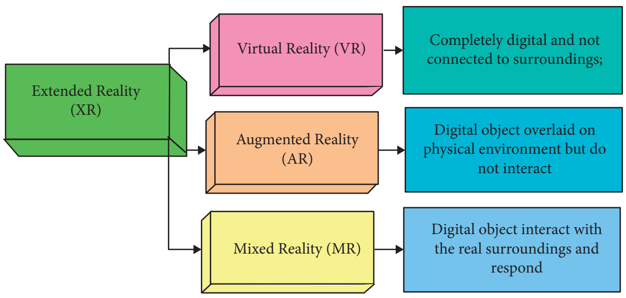


Figure 13: Comparison of VR, AR, and MR.

issues [62], ensuring better coordination among different stakeholders and workers by receiving exact instruction from their superiors and avoiding any conflicts, issues, or challenges between the model and the built environment [63], helping in quality control and quality assurance processes by identifying issues and clashes in the early stages, even before the execution of the work, thereby saving time and money, and enhancing confidence by avoiding reworking [64].

4.4. Edge and Fog Computing. The emergence of the IoT and the rise of wealthy cloud providers have brought a new model for computing and edge computing, which demands the management of data at the networking edge [65]. Edge computing will resolve issues related to the time required for response, battery life constraints, cost savings in bandwidth, and data security and privacy. The cloud computing model at the network edge is enhanced by fog computing allowing a new range of applications and services including low latency, mobility, broad-scale geographical distribution, strong wireless connectivity predominance, and a high number of nodes [19]. With the advantage of edge and fog computing, we have proposed edge and fog computing architecture in the construction industry for taking quick decisions in minimum response time.

Figure 14 illustrates the mechanism of the proposed architecture based on edge and fog computing. "*n*" number of sensor nodes are positioned at "*N*" number of construction sites for sensing and monitoring the distinct activities progress in the construction. These sensor nodes are interconnected with edge gateways through a wireless communication protocol. As discussed above, edge computing executes the events at the end of the edge device itself. Here, the edge gateways are integrated with edge computing technology. Moreover, the edge gateways communicated are interconnected fog gateways. Fog gateways support the cloud server in terms of latency. The data received at the cloud gateway can be utilized for applying big data analytics and ML analytics for delivering quick predictions. Additionally, the data is visualized on the graphical user interface.

4.5. Big Data and Cloud Computing

4.5.1. Big Data. In this digital age, smartphones, wearables, tablets, drones, and IoTs as well as digital machines or equipment are common features of a construction site [66]. Big data refers to a huge quantity of information or data available or stored from past activities, and it continues to grow in the present with additions of onsite work, as well as equipment, material, and manpower movement [67]. Data can be acquired from computers, sensors, as well as from other sources. Such valuable data that is obtained traditionally in most situations, if analyzed properly using sufficient and efficient tools and techniques, commonly known as big data analytics, can provide useful information for project planning and management, resolving financial issues and challenges, and help in improving efficiency as well as productivity and reducing overall time and cost of the project [68].

In recent times, all major decisions are based on data which is popularly known as a database management system (DBMS) that is not only utilized in a project lifecycle of analyze-design-build-operate-maintain with sustainability but also in waste management [69]. During the analysis-design phase, information gathered from various stakeholders, environmental data, data of feedback, discussion on the social media platforms, and historical data can help in deciding what to build and where to build. This way one can minimize the risk involved in creating a particular facility and can be assured of its success. It will be an informed decision with an acceptable risk level involved for any project to be initiated. During the construction phase, weather forecast data, traffic data, community activities, or any other major business activity data can be useful in channelizing the flow of machinery, equipment, and manpower [70]. Figure 15 presented the big data in the construction industry.

This helps in better management of project work under engineering, procurement, and construction management (EPC). Sensor technology helps in operation and maintenance, where data gathered is utilized for various shunting activities, prioritizing, and portfolio risk management [71]. Hence, big data analytics help the owner or stakeholder in decision-making in the following ways: (i) by providing updated and continuous information, (ii) by generating warnings for a specific situation, (iii) forecasting, and (iv) sensitivity analysis of parameters influencing the project output. Big data, when integrated with BIM (building information modeling), can create wonders through the integration of all 8 dimensions of BIM, as discussed in the previous section, provided that it is used with a sense of engineering [72]. Big data in the construction industry suggested its potential use in different domains of the construction industry with other technologies like BIM, AR, IoT, smart buildings, and cloud computing [73].

4.5.2. Cloud Computing. Cloud computing is considered the future of digitization [74]. It is noted that the construction industry has tremendously used cloud computing technology in the recent past; growth is almost 5–6 times with the availability of 4G network and mobile devices. With broadband Internet, the high Internet speed is ensured, data transfer is now much faster and continuous, and servers play

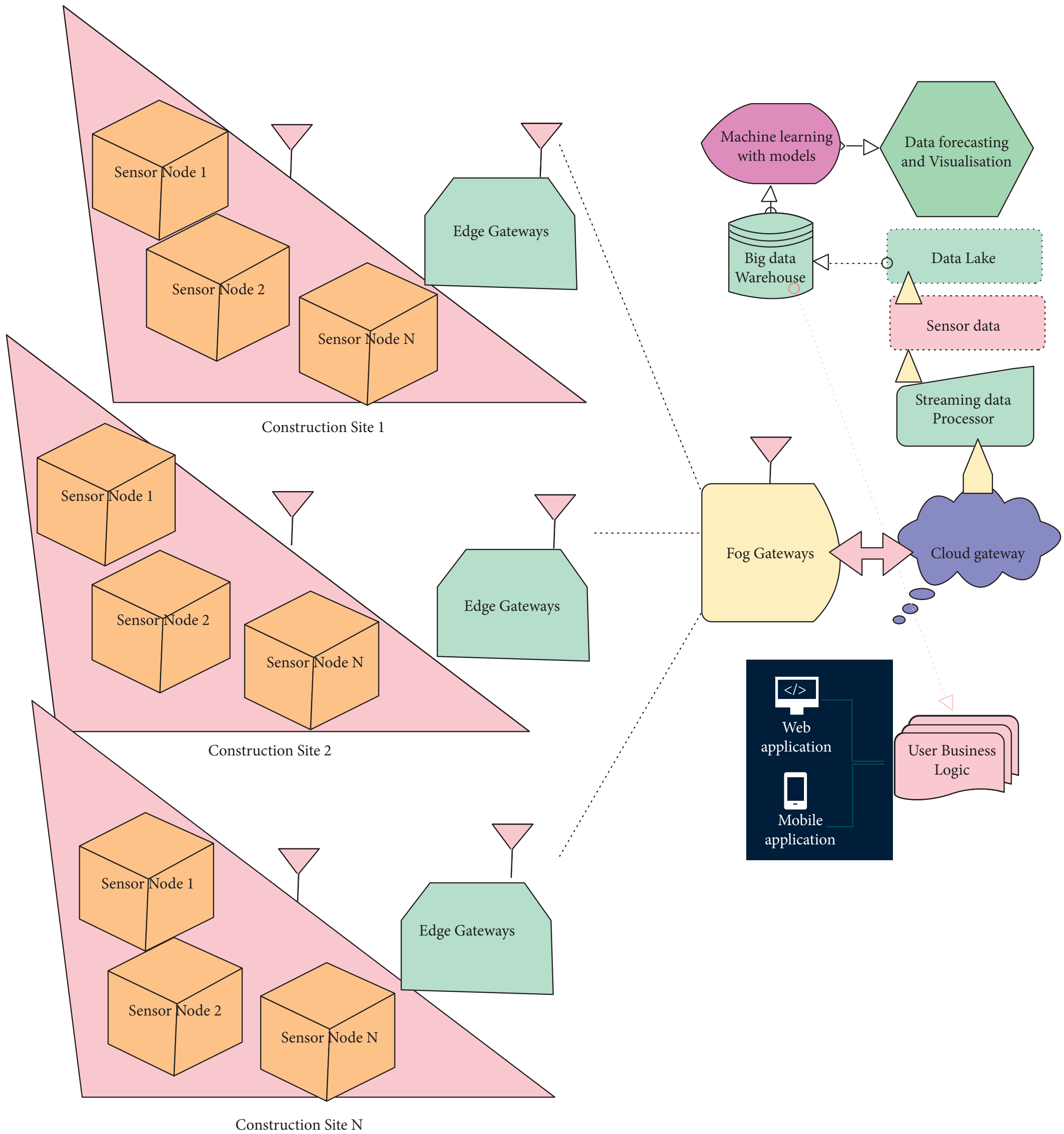


Figure 14: Edge and fog computing framework for the construction.

a major role to store and process data thereby eliminating the dependency on your local computer or mobile devices. Cloud computing is outsourcing data storage and processing so that it is accessible from anywhere depending on Internet availability [75]. This removes the chances of data being lost, ensures easy accessibility, and eliminates dependency on local hardware. With a cloud platform, it is easy to coordinate between the design office and the construction site. Cloud construction software has helped builders, contractors, and other stakeholders to generate online data, report, and track schedules.

From previous studies, the advantages of utilization of cloud platform in the construction industry are highlighted as easy accessibility from anywhere and anytime, better coordination between personnel at the design office and onsite officials, no travel required, one can be updated from anywhere anytime with the availability of Internet, tablet or laptop or even smartphone [76]. High computing speed

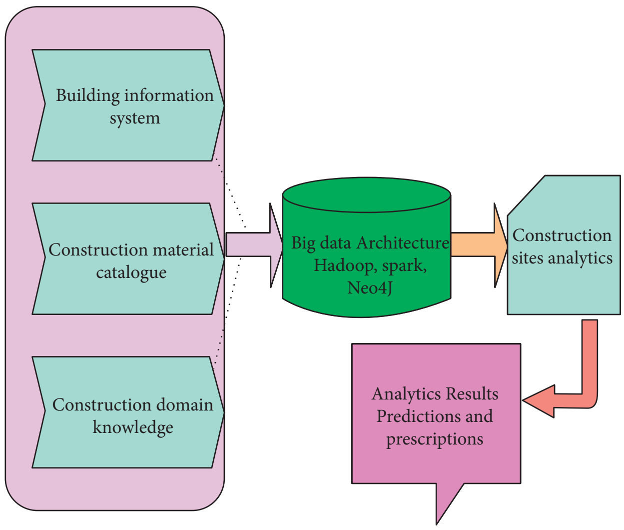


Figure 15: Big data in the construction industry.

through HPC servers helps to produce data in less time thereby improving productivity at a reduced cost. Flexibility in storage capacity allows utilizing the resources as and when required [77] No need to worry about restrictions on available resources, locally. Multitasking is easy, and coordination among different project sites is easy and less time-consuming. No need to have high-end IT infrastructure and related personnel to manage your server, locally, at your site, or office. This helps reduce the overburden of managing and maintaining the IT-related services, onsite. Chances of data loss, damage, or theft are eliminated; thereby eliminating disaster at the construction firm. The technology ensures data security, like firewall, authorization to accessibility, data inscription, multilevel storage, intrusion detection, prevention system, etc. Big data analytics and cloud computing capabilities, when combined, can give a major boost to the construction industry. Future is heavily relying on this as every industry needs cost-cutting, time-saving, improved efficiency, better decision-making based on data, and increasing margin of profit.

4.6. AI. The construction industry is considered to be confronted by the complexities of resource planning and risk management, which often lead to project delays, contract disputes, overruns of costs, and design errors [78]. However, the challenges in the construction industry can be overcome with AI technology, as it is believed that AI is capable of enhancing the optimization, decision-making, and prediction related to the construction industry [79]. AI also assists us to meet the rapid pace of automation and digitalization in the construction industry [80]. Generally, the AI is classified into four distinct groups including fuzzy logic, optimization algorithm, expert system, and ML. ML is a significant phase of AI in teaching machines to find trends in large data and to predict future tasks in a data-based manner [81]. In the course of ML, reinforcement learning and deep learning are evolving with new trends on a higher level [82].

Deep learning assists in diagnosing and prescribing triggers and preventative actions. AI provides many benefits to the construction industry; however, the considerable benefits of AI in the construction industry are as follows: automation, digitalization, risk mitigation, computer vision, and maximum efficiency [83]. AI directs the project management process to automation. It has been realized that AI-based solutions assist us to alleviate the distinct drawbacks of manual observation due to biasing in traditional construction management [84]. ML algorithms are utilized to intelligently learn accumulated data for finding the hidden knowledge, often incorporating in project management applications for automated data analysis and choice [85].

BIM played the leading role in digitalizing the building industry, which was much more than 3D modeling to provide a knowledge base on the full project life cycle. BIM can accurately be perceived as a digital backbone for working with AI to further enable the digitalization of knowledge in smart construction [86]. The BIM delivers a medium not only to collect vast amounts of information on all aspects of the project but also to analyze and exchange data in real time for collaboration and communication between different participants in time [87]. In the assessment of civil infrastructure conditions, automated and robust computer vision techniques have heavily dominated laborious and inefficient visual inspection [88].

Deep learning methods for automatically processing, analyzing, and understanding data in images or videos are currently advancing computer vision techniques [89]. To achieve the vision of intelligent management in the construction project, computer vision is primarily utilized for performing visual tasks for key purposes including monitoring and inspections, which can potentially facilitate a detailed, rapid, and reliable understanding of complex construction tasks or structural conditions [90]. Inspection applications, in particular, perform automated damage detection, structural component recognition, unsafe conduct, and condition identification. AI can identify, predict, and monitor the possible risk in terms of quality, safety, and efficiency. Further, this is useful for assessment, identification, and prioritization [91]. Probabilistic models, machine learning, fuzzy theory, and neural network can be implemented for training the captured data for predicting the possibility of failure occurrence and estimating the risk.

4.7. Theoretical Analysis. In this section, the theoretical analysis of the proposed framework is detailed presented. Generally, the implementation of IoT devices with RFID/NFC enhances the real monitoring of the construction site. However, the security and safety of IoT devices are a bit challenging in the construction industry, as they are susceptible to attacks and thefts. There is a requirement for additional infrastructure to protect IoT devices from attacks as part of security and safety. Connectivity is another complexity that will be faced during the implementation of the system in real time. Depending on the geographical location and weather conditions, the stability of the connectivity varies, so integration of a robust communication protocol is highly required for effective IoT implementation. While implementing the edge and fog computing framework for the construction, the complexity occurs in deciding the placement of the edge gateway, because in the implementation of edge and fog computing-based IoT devices, the computational requirement for processing and analyzing the real time is high. To match the high computational power, the IoT devices need to be integrated with additional co-processors. Moreover, there is also a requirement for continuous power supply to devices, as they perform the computation process.

The implementation cost of the IoT-based proposed framework is based on the following components: custom hardware, web application, web database, and desktop application. In custom hardware, the size of the device (medium), connectivity protocols (LoRa, Wi-Fi), the functionality of hardware (data preprocessing, data acquisition, user interaction), sensors embedded in a single device (5) waterproofness (waterproof), the accuracy of sensors (<3%), visualizing components (LED indicators, display screen, video capturing), and powering the device (battery) are the subelements that need to be defined. In web application development, real-time data, dynamic dashboards, additional modules like (AR/VR), and analytics need to be defined. In web databases, the implementation of big data analytics, AI analytics, and real-time data need to be defined. Based on a selection of these components for the construction industry, the estimated cost of a prototype is approximately $4512-$6768 with a lifetime of 150–226 hours and proof of concept is approximately $9024–$13,535 with the lifetime of 301–451 hours. Regarding the implementation of edge/fog computing, the implementation cost varies based on the type of processor and memory.

5. Recommendations

Automation in the construction industry is a necessary element for sustainable and resilient infrastructure. The integration of distinct technologies in the construction industry enables the implementation of adoption in the construction industry. However, the following suggestions are required for the enhancement and wide adoption of automation in the industry.

5.1. Cloud-Assisted AR and VR. AR/VR technologies assist the workers to train the distinct skills related to the construction industry in a real-time environment. Moreover, this will assist the cognitive learning and safety consciousness of the workers. The evolution of 5G encourages us to implement cloud-assisted AR and VR. In terms of future work on construction safety evaluation and instructions, it is intended to establish a cloud AR/VR additionally with integrated applications such as cloud computing, virtualization, edge computing, AI techniques, edge computing, and network slicing [92]. Moreover, cloud-assisted AR/VR enables the effective implementation of automation in building model generation. Cloud-assisted AR/VR approach also assists in BIM for visualizing the physical framework of the construction-related activities in real-time scenarios [93].

5.2. Integration of AI with IoT Infrastructure. The integration of AI with IoT infrastructure is necessary for enhancing the mechanism of IoT with data analysis. As a large amount of data is generated from IoT-based smart devices, it is an opportunity to utilize AI for extracting meaningful insights for effective decision-making and supervision. As AI enables the analysis of the data, it enables automation of the construction site in terms of predicting the future condition of maintenance and optimizing the performance of the project [48, 94]. Additionally, the emergence of edge computing and fog computing is also encouraging the effective integration of AI with IoT infrastructure. These computing technologies are embedded with AI models for predicting the events at the edge device itself. Furthermore, the collaboration of BIM with AI-assisted IoT creates efficient data processing, data transmission, and data collection [95].

5.3. 4D Printing. The evolution of 4D printing is having the capability to contribute to 3D printing, where the 4D printing empowers the 3D printing shapes to change their shape and properties concerning light, heat, and temperature. Generally, 3D printing utilizes the 3D models for generating the 3D objects under human surveillance for reducing the project duration [96]. 3D printing is having the capability of producing curved-shaped objects because of its significant geometric freedom. Moreover, the material utilized during the 3D printing is sustained for a long time because of its unique feature including corrosion resistance, great tensile strength, and high-temperature resistance [97]. Regulating structural safety and generating digital design workflow and architectural shifts are the challenges that exist in 3D printing. The novel innovation of 4D printing is having advantages over 3D printing in the parameters of the time dimension and intelligent behavior including self-repair and self-assembly [98].

5.4. Adopting Blockchain in Construction. Blockchain is a cutting edging technology that is utilized for enhancing the mechanism of the processing of the transaction between the entities [99]. The transaction in the blockchain is securely enabled with cryptographic technology. Blockchain is also known as distributed ledger technology, as the ledgers are distributed to all the users in the network. Even, minor modifications in the ledgers are informed to all the users in the network [100]. The integration of blockchain with BIM enables us to obtain a huge amount of data from the distinct phases of the project and it can be distributed among the entities for enhancing the project management [101]. The BIM model is updated concerning the availability of information from the next block. Further, it encourages automation in project delivery to enhance productivity, cost, and transparency. The payment system in the construction industry is achieved with the application of smart contracts

[102]. The smart contract is executed only when the conditions of the agreement are relevant.

5.5. Intelligent Robotics. Intelligent robotics have progressed rapidly to drive a broad variety of construction applications that are semi- or fully autonomous. Robots in construction can perform distinct activities like prefabrication, model generation, bricklaying, and mansion. Different roles, including bricklaying, mansion, prefabrication, model production, shafting, demolition, and others, were designed based on human needs. This allows them to automate certain manual processes and take on repeatable tasks. Moreover, robots overcome a few concerns in the construction industry like shortage of laborers and involvement in high-risk tasks. Aerial-based robot in the construction industry assists in field monitoring and structural health monitoring. This robot is capable of capturing high-resolution images and videos for predicting the occurrence of structural defects and other issues through artificial intelligence. However, the challenge that exists for the wide implementation of robots in the construction industry is less powerful. So, it is time to enhance the robotics for performing the task in critical environments.

6. Conclusion

Construction automation has the potential to raise construction productivity. Generally, the traditional approaches in the construction industry are having few constraints including environmental pollution and maximum energy utilization. The integration of distinct emerging technologies like IoT, AI, and edge and fog computing is empowering the possibility of automation in the construction industry. In this study, we have addressed the significance of automation in the construction industry. To address the technologies that drive the automation, we have classified the technologies like IoT, RFID, AI, edge and fog computing, big data and cloud computing, and AR, MR, and VR into different sections. Moreover, we have proposed architecture that integrates the long-range communication in RFID/NFC system for identifying the machines and materials. Further, the edge and fog computing-based architecture is also addressed in this article which supports automation in construction. The implementation of AI with computer vision assists us to monitor and understand complex construction tasks or structural conditions. AI with edge and fog computing enhances the automation of construction in terms of quick decision-making at the edge device. Finally, the article addresses a few recommendations including cloud-assisted AR/VR, integration of AI with IoT infrastructure, 4D printing in construction, and adoption of blockchain in construction to enhance the opportunities for wide implementation of automation in construction.

Data Availability

Data will be available on request. For the data related queries kindly contact to: Amit Srivastava - amitsrivastava.ce.@geu.ac.in.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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