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Internet of Things in the Construction Industry

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Abstract: The modernization of the construction industry is one of the major opportunities for investors, innovators, thought leaders, and professionals. The Internet of things (IoT) is a system of interrelated smart devices that are fitted with sensors, software, and other technologies that facilitates communication. IoT is revolutionizing industries worldwide, and construction is no exception. IoT technology in construction is improving safety, efficiency, and project management, revolutionizing construction operations and driving innovation. It will have a part to play in waste management and employee safety improvement, construction costs reduction, and helping match properties against the requirements of prospective tenants. Contractors and builders are leveraging the transformative power of IoT in construction to ensure maximized client satisfaction and minimized costs. In this chapter, we will explore how the construction industry is embracing the Internet of things (IoT) as a transformative tool.

Keywords: *Internet of things, IoT, industrial Internet of things, IIoT, construction industry*

I. INTRODUCTION

Digital transformation is the process of integrating technology to improve business processes. It allows for the automation of time-consuming tasks. Technology has come a long way when we refer to the construction industry. In the construction industry, IoT devices can help with digital transformation by allowing software construction companies to access real-time data. The industry is currently undergoing critical transformation that will improve efficiency, well-being, process improvement, and the introduction of new tools. It is poised for digital transformation, and companies that fail to adapt quickly risk being left behind.

Figure 1: A typical construction site [1].

The construction industry, also known as the building industry, is one of the oldest businesses that humans developed. All other industries rely on the construction to create their infrastructure and architecture. According to the Occupational Safety and Health Administration (OSHA), a division of the US Department of Labor, there are approximately 252,000 construction sites in the United States that employ around 6.5 million people. Construction serves as a base for urbanization and also for employment and generation of new complexes and buildings. With the rise of urbanization and population density, the construction sector has become one of the most important contributors to global prosperity. Construction efficiency and profitability have a direct influence on the global economy. Figure 1 shows a typical construction site [1], while Figure 2 shows a typical construction worker [2].

Figure 2: A construction worker [2].

However, the construction industry has been relatively slow in adopting and capitalizing on new technologies like IoT. Historically, construction has not been the most tech-centric industry, but that is changing. Project managers and investors are still wary about implementing IoT technology; some do not know how to use it, others doubt its efficiency. Today, the industry is embracing IoT technology to enhance productivity, optimize operational efficiency, and improve on-site safety.

II. OVERVIEW ON INTERNET OF THINGS

The concept of the Internet of things (IoT) has been around since the late 1990s, but it gained momentum in the 2000s with the rise of Internet-connected devices. The Internet began with some military computers in the Pentagon called Arpanet in 1969. It expanded throughout the 1980s as a set of four parallel military networks, each at a different security level. The core technology which gives the Internet its particular characteristics is called Transmission Control Protocol/Internet Protocol (TCP/IP), which is essentially a set of rules for communication [3].

Internet of Things (IoT) is a worldwide network that connects devices to the Internet and to each other using wireless technology. IoT is expanding rapidly and it has been estimated that 50 billion devices will be connected to the Internet by 2020. These include smart phones, tablets, desktop computers, autonomous vehicles, refrigerators, toasters, thermostats, cameras, alarm systems, home appliances, insulin pumps, industrial machines, intelligent

wheelchairs, wireless sensors, mobile robots, etc. Figure 3 illustrates the Internet of things [4].

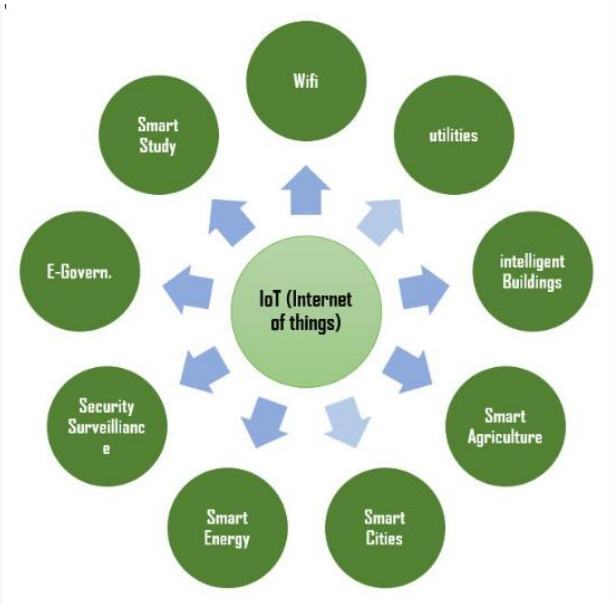

Figure 3: The Internet of things [4].

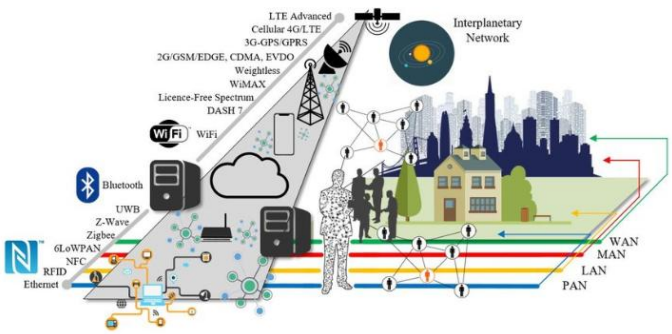

Figure 4: Communications technologies in Internet of things [6].

There are four main technologies that enable IoT [5]: (1) Radio-frequency identification (RFID) and near-field communication, (2) Optical tags and quick response codes: This is used for low cost tagging, (3) Bluetooth low energy (BLE), (4) Wireless sensor network: They are usually connected as wireless sensor networks to monitor physical properties in specific environments. Communications technologies in Internet of things are portrayed in Figure 4 [6].

IoT technology enables people and objects to interact with each other. It is employed in many areas such as smart transportation, smart cities, smart energy, emergency services, healthcare, data security, industrial control, logistics, retails, structural health, traffic congestion, manufacturing, and waste management. The Internet of things is extensively developed world-wide with a focus on civilian applications such as electric power distribution, intelligent transportation, healthcare, industrial control, precision agriculture, environmental monitoring, etc. Figure 5 shows a typical representation of IoT [7].

Figure 5: A typical representation of IoT [7].

III. INDUSTRIAL INTERNET OF THINGS

The growth of the internet of things (IoT) is drastically making impact on home and industry. While the IoT affects among others transportation, healthcare, or smart homes, the Industrial Internet of Things (IIoT) refers in particular to industrial environments. IIoT is a new industrial ecosystem that combines intelligent and autonomous machines, advanced predictive analytics, and machine-human collaboration to improve productivity, efficiency and reliability. It is bringing about a world where smart, connected embedded systems and products operate as part of larger systems [8].

The industrial Internet of things (IIoT) refers to the application of the Internet of things (IoT) across several industries such as manufacturing, logistics, oil and gas, transportation, energy/utilities, chemical, aviation and other industrial sectors. A typical industrial Internet of things is shown in Figure 6 [9].

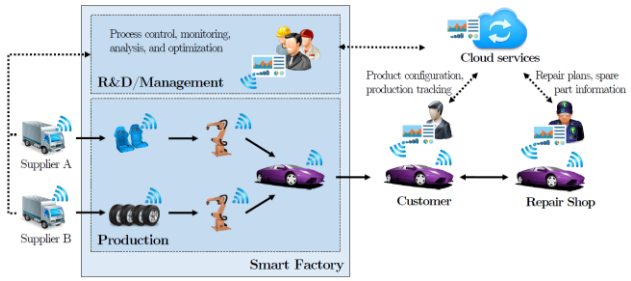

Figure 6: A typical industrial Internet of things [9].

IIoT is often used in the context of Industry 4.0, the Industrial Internet and related initiatives across the globe. Industry 4.0 describes a new industrial revolution with a focus on automation, innovation, data, cyber-physical systems, processes, and people [10]. With Industry 4.0, the fourth industrial revolution is set on merging automation and information domains into the industrial Internet of things, services, and people. The communication infrastructure of Industry 4.0 allows devices to be accessible in barrier-free manner in the industrial Internet of things, without sacrificing the integrity of safety and security [11].

IV. IOT IN CONSTRUCTION

The Internet of things (IoT) relies on connected sensors and embedded systems to collect data and control devices remotely. Connected sensors can tell the location of people or equipment, monitor security, collect data on job site conditions, and automate inspections. Cameras placed around the site or mounted on drones can help with monitoring and inspections, even if the inspector is in another location. For example, workers in the construction industry can use GPS

devices mounted on equipment. These can communicate the equipment's real-time location to construction managers, helping them streamline resource management.

The term IoT in Construction refers to the use of technological equipment or Internet of things and modern-day Internet software in the process of construction to be able to maximize the efficacy of the project. The IoT in construction market is categorized into hardware, software, connectivity, and services. The market is classified as residential and non-residential. It can also be classified into asset monitoring, predictive monitoring, fleet management, wearables, and others. The market forecast is analyzed across North America, Europe, Asia-Pacific, and LAMEA. China is the largest shareholder of the IoT in construction industry, owing to the large manufacturing and connectivity infrastructure and a strong foothold in the construction industry [12]. Figure 7 shows the symbol of IoT in construction [13].

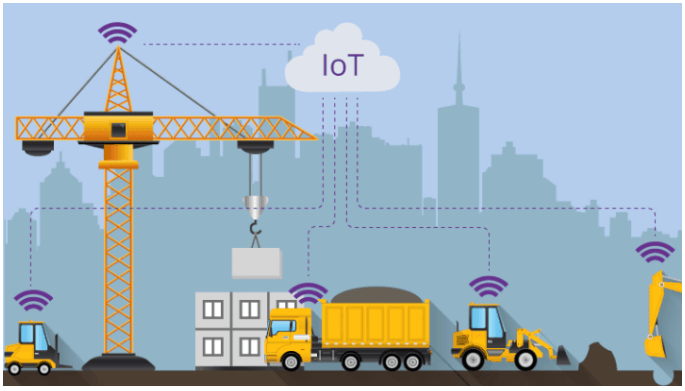

Figure 7: The symbol of IoT in construction [13].

A wide range of IoT devices are important in the construction industry. IoT devices include the following types:

- *Smart Sensors:* These are embedded in construction equipment and structures to monitor various parameters such as temperature, humidity, vibration, and structural integrity.
- *Wearable Devices*: Wearable devices, such as smart helmets, vests, and glasses, enhance worker safety and productivity.
- *Drones*: Drones equipped with cameras and sensors are used for site surveys, progress monitoring, and inspections. They provide high-resolution images and 3D models, enabling better planning and decision-making.
- *Connected Machinery:* IoT-enabled machinery and equipment can communicate with each other and central management systems. This connectivity allows for real-time monitoring, remote control, and predictive maintenance, reducing downtime and improving efficiency.

These IoT devices enable construction managers to monitor construction sites more effectively in various different ways. These IoT devices are available to optimize the process on a construction site in various different phases. They are key to tracking tools, equipment, and machines on construction sites. Here are some common IoT sensors and controllers in the industry [14]:

- *Wearable sensors* allow managers to track workers for safety and productivity.
- *GPS trackers* communicate the location of equipment and vehicles.
- *Embedded sensors* can track equipment performance for efficiency improvements and predictive maintenance.
- *Materials tracking* is possible with smart labels that provide location and quantity data.
- *Wearable sensors* allow managers to track workers for safety and productivity.
- *GPS trackers* communicate the location of equipment and vehicles.
- *Embedded sensors* can track equipment performance for efficiency improvements and predictive maintenance.

V. APPLICATIONS OF IOT IN CONSTRUCTION

The spectrum of IoT applications is vast, comprising wearables, traffic monitoring, e-health, agriculture, hospitality, smart grid, smart homes, energy saving, maintenance management, food production, etc. IoT has diverse applications in construction, from wearables for worker safety to sensors for structural health monitoring. Common areas of applications include [13,16,17]:

- *Site Monitoring:* This is a crucial component of IoT application in construction, encompassing the use of sensors to continuously record jobsite conditions. Construction sites are enormous and relying solely on manual security is not feasible or practical. IoT security strategy for a construction site can work on preventing intrusion and quick detection as well as recovery from unwanted activities. IoT enables remote monitoring of environmental factors like temperature, humidity, noise, and vibration, ensuring safety and regulatory compliance. IoT-connected surveillance cameras and various measurement sensors allow controlling and adjusting machinery remotely, increasing the accuracy of operations. All of that helps coordinate building activities more efficiently, reduce idle time, and link workers' performance with relevant tasks and processes on-site.
- *Site Safety:* One of the most primitive and raw issues on a construction site is the safety of the people working there from various disasters. Construction is known for one of the higher fatal injury rates worldwide. Everyone from the government to the owners, managers, and workers, people at every level, are concerned about the safety of people at the construction site. Construction sites frequently have risked such trench collapse, falls, scaffold collapse, insufficient protective equipment, repetitive motion injuries, and others. IoT devices can enhance efficiency and safety. They can make work sites safer by using IoT sensors to monitor access and track workers. The advent of IoT technology in construction has substantially heightened site safety standards. The tracking can allow for immediate response in an emergency. IoT solutions significantly boost on-site safety, integrating innovative technologies for hazard monitoring and worker protection in the construction sector. Smart wearable technologies, like helmets and boots connected to IoT systems, track vital signs and locations, thus alerting workers to imminent dangers and even enabling human resources managers to oversee personnel effectively. Figure 8 shows how IoT enhances safety in the construction industry [17].

- *Concrete Monitoring:* Construction sites can use IoT devices to monitor their materials. Concrete sensors are one of the most prominent examples. Concrete dries at different rates depending on environmental conditions and the type of mixture companies use. If decision-makers do not accurately estimate how fast a pour will dry, they could delay their entire project, potentially leading to lost revenue and unhappy clients. Construction companies can embed wireless sensors at multiple depths before a pour to track the drying rate of concrete. By placing connected sensors in concrete, construction teams can remotely check in on the curing process or see if it needs repair. Project managers can use pre-set triggers to receive an alert once the sensors detect the concrete has met a certain threshold or target. This feature eliminates the need for on-site visits, significantly increasing efficiency.
- *Project Management:* Completing a project within a limited budget is a key performance indicator for project managers as well as construction companies. The use of IoT in construction can help contractors utilize the resources available to them in an efficient way. IoT devices can facilitate cost-cutting by using site monitoring techniques for monitoring vehicles, equipment, material utilization, thereby keeping the project budget-friendly. IoT also helps in completing the project at a faster rate.
- *Fleet Management:* IoT technology has the potential to revolutionize fleet management in construction. The technological advancement in fleet management, powered by IoT, represents a significant shift in how construction companies manage their fleet of vehicles and machinery. It is a move towards more data-driven decision-making, where every aspect of the fleet is monitored and optimized for peak performance. IoT is steadily redefining fleet management, transcending traditional methods by introducing automated tracking of both vehicles and essential equipment. This advancement is pivotal in augmenting productivity, bolstering safety measures, and elevating site monitoring effectiveness.
- *Waste Management:* This not just calls for an environmental effect and degradation but it also calls for a dumping issue that needs to be resolved on-site of the waste and the debris. Construction business owners are obliged by the law to dispose of debris and recycle waste. Construction teams use IoT technologies to keep track of and minimize their waste. IoT tracking provides the insight the industry needs to reduce waste. Data from vehicle tracking systems can reveal inefficient usage patterns. The used IoT can help create a sustainable plan for using the recycled products, adopting zero waste terminology. Besides having to oversee waste management for the sake of compliance with governmental regulations, disposing of debris regularly allows property owners to create more space on the construction site and reduce the risks of hazards.
- *Machine Control:* This stands as a pivotal aspect of IoT in construction, delivering unparalleled precision in machinery operations and real-time updates on progress, movements, and status. Many heavy machines are involved in construction work and these machines are operated by humans. This task can further be simplified through IoT. Primarily utilized in heavy civil construction, the scope of machine control technology is expanding into diverse projects as the technology evolves. Incorporating IoT in machine control, such as through wearables and safety sensors, exemplifies its unique applications in construction, significantly boosting operational efficiency and on-site safety.
- *Theft Prevention:* This is another growing application of IoT in construction. Construction sites are prime targets for thieves, given their expensive equipment and relatively low security. Now, as construction material costs are rising, this theft could grow, but IoT devices help fight it. IoT trackers can transmit a vehicle or tool's location in real time without alerting the person who took it. Construction companies or police forces can then track down and recover the stolen goods.
- *Wearables:* These are the devices that need to be worn by the people working on a construction site, especially the laborers. This can be used to alarm the worker if he is too close to a dangerous zone. Also, this is used to track the location in the case of a disaster or injury that happens with a worker.
- *Augmented Reality* (AR): This is a very popular application of IoT. The construction industry has been using it for some time now. In AR, 3D models are created and combined with all building data. Users can wear an AR device and then they get to experience it in real-time. The most common applications of AR in the construction industry include project planning, automated measurements, project modification, onsite project information, team collaboration, and safety training. By using this technology, teams can organize presentations, discuss and examine every detail of the project. They can make changes before it becomes expensive to alter. Another vital use of AR is in safety training.
- *Equipment Maintenance:* Without technology, equipment breakdowns are challenging to anticipate. Someone has to manually check oil levels, emissions, and vibration rates manually, and use their expertise to determine how close the machine is to breaking down. With IoT, that process is automatic. IoT sensors can wirelessly measure vibration, pressure, temperature, and moisture in real-time, sending any unusual readings directly to a decision-maker's device.
- *Weather Forecasting:* Project managers have to consider environmental conditions when scheduling subcontractors, pouring cement, and approving the use of some equipment. Unfortunately, the local weather forecast is not always reliable. Fortunately, IoT offers a solution. Project managers can use wireless IoT sensors to track humidity, temperature, precipitation, and wind speed to forecast upcoming weather events.

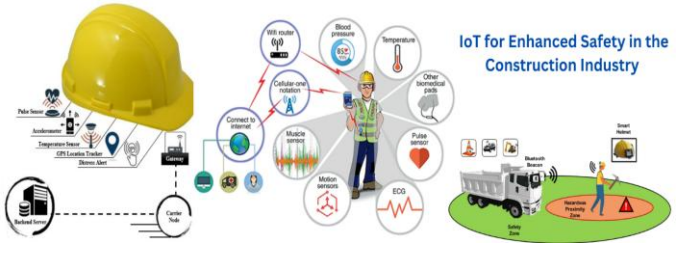

Figure 8: IoT enhances safety in the construction industry [17].

VI. BENEFITS

Applying IoT lengthens the life of your machinery and increases its resale value. IoT's integration into construction sites goes beyond mere tracking; it encompasses timely maintenance, efficient management of parts, and optimizes the utilization of machines. Several builders and construction companies are using mobile applications to improve efficiency, enhance safety, access real-time data, increase mobility and save time. With IoT-enabled sensors, you can track the location of the vehicle fleet and position landscaping equipment precisely. Other benefits include the following [14,18]:

- *Smart Construction:* This entails the integration of IoT devices and sensors into building materials, tools, and equipment used on construction sites. By monitoring energy consumption, waste generation, and environmental impact in real-time, construction companies can make informed decisions to minimize their carbon footprint and promote eco-friendly construction methods.
- *Smart Helmets:* One of the remarkable applications of IoT in the construction industry is the development of smart safety helmets. These helmets are integrated with sensors that detect and monitor environmental conditions, such as temperature, humidity, and toxic gases. By continuously collecting data in real-time, these helmets can alert workers and supervisors about potential hazards, enabling them to take immediate preventive actions
- *Sustainable Construction:* IoT plays a vital role in promoting eco-friendly practices. IoT devices can monitor energy consumption, optimize resource usage, and facilitate waste management, contributing to sustainable construction processes. The data collected through IoT can also support the implementation of green building certifications and aid in measuring environmental impact.
- *Fuel Saving:* The cost of each construction project corresponds to the fuel consumption because large sites require using machines that burn thousands of dollars per day. But with the appropriate control over expenditures, effective refueling management, timely maintenance, and the ability to upgrade machinery, you can reduce the project's final cost and its duration dramatically. All of that can be done using IoT-enabled fuel sensors on your construction site.
- *Concrete Curing:* With concrete curing sensors, you can speed up construction schedules. Such IoT-enabled devices provide monitoring of concrete's maturity via temperature probes and then transmit real-time data to the cloud. You have to embed the sensors in concrete during casting for tracking its curing. That allows managers to plan further construction work accurately.
- *Improved Workflow Management:* With real-time data from sensors, you can adjust operations to maximize efficiency and resources. IoT-informed operational optimizations can cut labor costs by up to 14.2%.
- *Data Security:* With the increase in connected devices, data security becomes paramount. Implement robust cybersecurity measures to protect your data and ensure compliance with relevant regulations.
- *Automation:* IoT will drive automation. Automated processes can streamline everything from cost estimation and quantity surveying to labor scheduling and materials ordering. By automating processes and enabling seamless data exchange, IoT devices simplify project management and keep managers abreast of project developments, facilitating informed decisions
- *Inspection:* IoT can help with inspections. For example, drones with cameras or sensors can inspect work to ensure quality and compliance with safety standards.
- *Elevated Efficiency:* IoT technology optimizes construction processes, reducing downtime and maximizing resource utilization. Real-time tracking and predictive maintenance are key examples of how IoT enhances efficiency.
- *Cost Reduction:* IoT technology helps in advanced budgeting and cost management. By monitoring and optimizing the use of resources, construction companies can save significantly on their budgets. Optimized resource use and predictive maintenance reduce operational costs.

VII. CHALLENGES

The application of IoT in the real world is still limited by restraints, including limited battery life, network capacity, and maintenance cost. Although there can be different predictions regarding the potential job losses, implementing IoT technology will not replace humans in the construction industry. Adopting IoT in construction sector operations is neither a simple nor inexpensive procedure. Other challenges include the following [14,19]:

- *Data Privacy:* This could arise if IoT devices are not properly secured. Hackers increasingly target IoT devices because their security systems are not as robust as computers, phones, or other devices.
- *Legacy Systems:* Holding on to outdated technology slows down the construction industry exponentially. Obsolete hardware-software systems are expensive to maintain, lead to missed financial opportunities, reduce employee productivity, and make it harder to assess business efficiency.
- *Network Security:* Connecting a large number of low-memory and low-power devices to the networks means providing more nodes for hackers to hack/attack the network through these connected nodes (devices). These devices are connected to the network with wireless links for gathering, storing, and transferring data, making them more prone to security threats. It is quite challenging to protect the network and its layers from external threats and attacks because of the large number of connected devices, connectivity to the Internet, and lack of installation and updating of strong malware protection software. All these weaknesses make IoT networks vulnerable to security threats.
- *Lack of Knowledge:* Fear of the adoption of IoT and failure to produce quality output is the consequence of a lack of knowledge about the advantages of IoT. Compared with large-sized companies, small-sized companies are more reluctant to adopt advanced technologies because of a negligible awareness of the potential merits and challenges associated with advanced technologies. Overall, there is a lack of educational resources to embark on IoT knowledge.
- *Lack of Trained Labor:* A critical challenge for the construction industry is to adopt IoT without

sufficient training. Adopting IoT means a reduction in labor because workers are not aware of and trained to handle IoT. Because the construction sector lacks competent IoT supporters, investment in training personnel is required to fill the skills gap.

- *Lack of Policies:* The lack of policies and implementation guidelines due to the heterogeneity of connected devices is significantly impeding IoT adoption in the construction industry. The lack of standardization of IoT architectures and slow progress in IoT research and development of Construction 4.0 makes organizations often adapt to their architectures and technologies, which impacts the market.
- *Resistance to Change:* The construction sector is incorporating new technology and communication strategies, but it should not be overlooked that this is still a somewhat slow process. Many builders and contractors are oblivious to the need for such devices and are unwilling to invest in them or change.
- *Power Management:* One of the major concerns impeding IoT adoption in the construction sector is energy and power control of intercommunicating devices.

  Most IoT devices are handheld with inbuilt battery. The limited battery life of IoT devices poses a constant challenge for IoT networks. Companies must constantly keep an eye on the battery status of the battery, i.e., when it needs to be recharged or replaced.
- *Interoperability:* The integration of IoT with the conventional Internet framework and network scaling is another challenge. The IoT infrastructure is an amalgamation of different devices and sensors. This leads to incompatibility between IoT devices and systems and communication and sharing service problems. This could make it impossible to integrate IoT devices with your existing project management or analytics software.
- *Expenditure:* It is a common fear among industrialists that adopting IoT infrastructure means great expense because extra funds will be required to acquire technology, implement it, and then train their employees. It is assumed to be very costly for small construction companies to support heterogeneous interfaces from diverse platforms. Power bills, spectrum license charges, and daily expenditure charges of an IoT node further add to the expense of adopting IoT technology.
- *Training Requirements:* This could add to the costs and deployment time if tradespeople who use the IoT systems are not familiar with them.

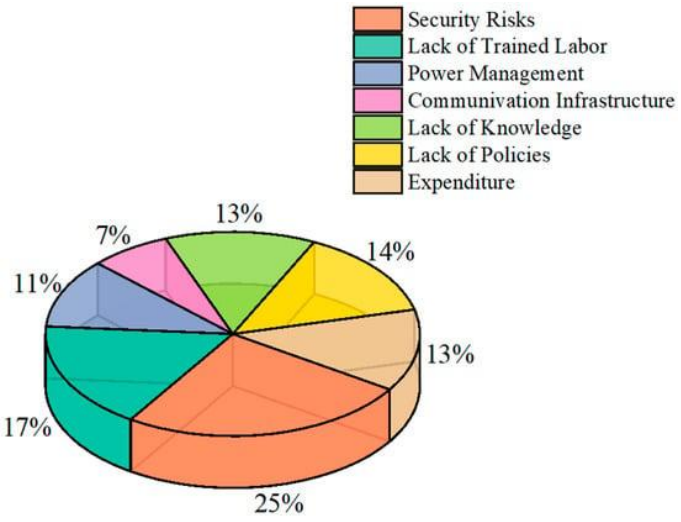

Figure 9: Some of the challenges related to IoT adoption [16].

Figure 9 displays some of these concerns or challenges related to IoT adoption [16].

CONCLUSION

The construction industry is in the research stage of the IoT adoption journey. In terms of IoT adoption, project managers and investors are still cautious to employ the technology; some are unsure how to utilize it, while others doubt its effectiveness. Things are changing as more construction companies are turning toward technologies like the IoT for help and many useful applications of IoT in construction have emerged. The construction industry, known for its inherent risks, has been embracing the IoT as a transformative tool to enhance safety measures on construction sites. IoT technology has proven to be a magnificent innovation in the construction industry by improving its working condition, reducing waste and increasing its efficiency. As IoT solutions for the construction sector become more omnipresent, they are having a huge impact on how the construction industry pivots.

The future of IoT in construction seems bright. Recent statistics show that IoT in construction will soon become a must-have technology. More information about Internet of things in the construction industry can be found in the books in [20-22] and the following related journal: *IEEE Internet of Things Journal*.

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