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Enhancing Safety Level at Construction Site Using Internet of Things (IoT)

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Abstract

The construction sector is infamous for having a poor safety record, requiring rapid safety instructions for workers and efficient safety management efforts to improve construction site safety. According to research in the underground construction industry, 80 to 90 percent of accidents are caused by workers' dangerous behavior, hazardous working circumstances, or inadequate equipment. Fatalities have increased frequently as building projects have grown in size, height, and complexity. This study intends to determine the variables impacting the use of IoT (Internet of Things) to improve safety on construction sites, explore the difficulties involved in IoT implementation, and investigate efficient methods for increasing construction site safety using IoT. To meet the needs of the research methodology, semi-structured interviews were conducted with assistant engineers and site safety supervisors working in Grade 7 companies that have utilized IoT to enhance safety on construction sites. As a result of the research, sensors, RFID tagging, GPS, and drones are among the IoT tools or devices that respondents use most frequently. The importance of IoT as a tool for enhancing safety on construction sites has been proven through research. The usage of real-time monitoring systems, wearable device integration, predictive maintenance using IoT sensors, automation of safety procedures, data-driven decision-making, and improved worker communication are a few additional results. The construction sector is predicted to have a decrease in fatalities, injuries, and accidents due to the successful deployment of these IoT technologies, making the workplace safer and making it easier to follow safety requirements. The government will also gain from worker protection, improved regulatory compliance, and financial gains from decreased accidents and higher production. Academic institutions play a significant role by promoting information interchange, education, training, and research to enhance IoT technology and safety processes.

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1. Introduction

The construction industry in Malaysia has the highest death rate of any industry due to constant disregard for safety and health precautions, as well as the fact that accidents can happen anywhere and at any time on building sites (Yin et al., 2016). The contractors have much trouble with this issue; therefore, instead of placing themselves in danger, they should ensure that the construction workers are safe while carrying out their duties. When the contractor completely utilizes the safety and health precautions offered, they can reduce the chance of accidents, but this problem can be resolved. Safety is one of the most important factors in a project's success, as incidents will impact the project's time, cost, and quality (Yin et al., 2016). The safety of data and information about the construction project is also mentioned while talking about safety at the construction site, in addition to the safety of employees and employers. A sector that offers job chances to people from all backgrounds is the construction industry. Regrettably, because of the fourth industrial revolution (4IR), data management has difficulties with data security (digitalization) (Ornella Tanga, et.,2022).

1.1 Research Background

Employees frequently experience potential safety and health hazards throughout the whole construction process as a result of the dangerous working environments at construction sites (Seo et al., 2015). Construction safety has historically been assessed and managed reactively by reacting to unfavorable injury patterns (Hallowell et al., 2013). The danger of work-related injuries and accidents is also decreased by construction site safety, in addition to the risk of injuries to the general public. In accordance with OSHA estimates, the construction sector accounts for over a quarter of all work-related deaths, in addition to a significant number of other injuries. The four most frequent causes of unintentional fatalities and other injuries are falls, being struck by an object, electrocution, and becoming entangled in between pieces of machinery. The likelihood of these kinds of accidents is lowered by a culture of safety (Ambegaonkar, 2020). The Internet of Things is being built atop this, and RFID is its networking core. Users were able to bring tangible things into the realm of the digital world thanks to the IoT. This was made feasible by various tagging technologies, such as NFC, RFID, and 2D barcode, which enabled the identification and referencing of real items through the internet.

1.2 Problem Statements

The construction industry has ongoing issues with worker safety at construction sites because of potential risks like operating dangerous machinery and falling from a height that can result in fatalities or serious injuries. The industry struggles to provide timely and appropriate safety instructions despite efforts to implement them; this is frequently because of supervisors who lack the necessary skills and the size and complexity of construction projects. The current safety management system is generally ineffective regarding timeliness and individualization. A large percentage of accidents in the construction industry are also caused by unsafe working conditions and equipment, a lack of supervision, and a lack of knowledge of risky behaviors. Integrating the IoT and other innovative technologies provides a promising way to overcome these issues. However, there is a lack of adoption of IoT technologies to improve worker safety in construction. Despite the potential benefits of the IoT, smart technologies that can improve safety protocols are difficult for the construction industry to implement and adopt. This is demonstrated by incidents like the collapse of the Xi'an metro line 3, where a lack of real-time monitoring and alerts caused a terrible result. The increase in construction site accidents is not effectively solved by current safety training programs, highlighting the urgent need for creative thinking and comprehensive approaches to effectively implement IoT and ensure a safer working environment for construction workers.

1.3 Research Questions

(i) What factors influence the use of IoT applications to improve safety at construction sites?
(ii) What are the challenges of applying IoT to increase safety at construction sites?
(iii) What is the strategy of IoT application to increase the construction site safety?

1.4 Research Objectives

(i) To identify the influencing factors of IoT application to increase the safety at construction sites.
(ii) To determine the challenges of IoT application at construction sites to increase safety.
(iii) To investigate the strategy of IoT application to increase the construction site safety.

1.5 Research Scope

Johor, Selangor, and Pahang were chosen for the research because of their varied development and rapid growth. These states were selectively selected because of the resources and various industries, including housing. The focus of the study was G7 Grade Contractors, who were acknowledged by S. Sabri et al.'s (2020) research as major IoT users in the construction industry. CIDB's (2021) report, which highlights Selangor's lead with 2,314 registered G7 contractors, aligns with the targeting of assistant engineers, project managers, safety officers, and site supervisors under G7 Grade Contractors. Johor's severe accident rate, highlighted in the press release "Big Data Analytics: National Occupational Accident Statistics 2021," adds even more support to the list. With 5,489 cases, Johor had the highest number, followed by Selangor (4,195 incidences) and Pahang (1,077). The research's primary goal to enhance construction site safety through practical IoT solutions is supported by this data, which highlights the research's focus on areas with high construction activity. A key component of the research process is conducting qualitative interviews to get information about using IoT technology to enhance safety at construction sites.

1.6 Significance of Research

The significance of research focused on enhancing safety at construction sites by using IoT is significant for the construction industry. The construction sector is the one that will benefit the most from IoT since it makes workplace safety safer through proactive compliance with safety standards and constant equipment monitoring. This lowers mankind’s cost of accidents while simultaneously improving industry-wide efficiency, which increases production and minimizes delays. Improved worker well-being also helps the government meet requirements by enabling effective safety regulation enforcement through real-time monitoring and data-driven insights from IoT systems. The financial benefits, which include lower healthcare expenses and higher worker productivity, enhance the general economic health of the country. Finally, through information sharing, instruction, training, and research projects, academic institutions contribute significantly to advancing IoT technology and safety standards. Through this cooperative effort, a culture of continuous development develops, and the construction sector is continuously benefited by modern technology and updated safety regulations. To put it simply, the realization of the full potential of IoT in building safer and more productive construction environments depends on the dynamic collaboration among multiple parties.

2. Literature Review

2.1 Definition

a) Safety in Construction Site

The construction industry, vital for employment and economies, faces substantial financial losses due to its labor intensity and high-risk procedures. Globally, with approximately 337 million annual workplace accidents, construction stands among the riskiest occupations, causing distress, project delays, and increased costs. The sector confronts diverse risks, including mechanical, electrical, thermal, physical, and chemical hazards, exacerbated by the dynamic and disorderly nature of construction sites. Ensuring safety is paramount for general contractors, as accidents and fatalities not only impact lives but also impede project progress and escalate expenditures.

b) Internet of Things in Construction Site

Safety British technologist Kevin Ashton coined "Internet of Things" in 1999, envisioning a system where real-world objects connect to the Internet through sensors. The Internet of Things (IoT) has since become a transformative field with profound technological, social, and economic implications. In high-risk industries like construction, where accidents are prevalent, the acceptance of IoT technologies by workers is crucial. A hazard-prevention technology system, integrating IoT for hazard source positioning and worker task deployment, offers a promising approach to enhance safety in construction processes (Rose et al., 2015).

2.2 Scenario

a) Safety on the Construction Site in the U.S

The U.S. construction industry, anticipating a workforce of nearly 8 million by August 2022, is poised for growth despite labor shortages and supply chain disruptions. Construction spending is projected to increase by nearly 9% in 2022 and an additional 6% in 2023. Safety remains a paramount concern in this high-risk sector, prompting the adoption of technological solutions such as Internet of Things (IoT) devices

and wearable sensors. Telematics devices facilitate tracking of equipment location, speed, and health, while wearables like smartwatches, smart boots, and augmented reality glasses enhance worker safety through real-time alerts, health monitoring, fall detection, and improved communication. These technologies contribute to advancing safety measures and optimizing equipment performance in the construction industry.

b) Smart helmet for workers in Malaysia

Telekom Malaysia's research division, TM R&D, has developed a smart safety helmet with various sensors to enhance employee morale and productivity. The helmet incorporates voice communication, personal tracking, geolocation, geofencing, and geologizing technologies. It offers Wi-Fi, LTE, and Bluetooth connectivity for remote communication and features a built-in camera for on-site and off-site collaboration. The helmet's sensors can detect its usage and alert supervisors if employees are not wearing it. It can also detect impacts and predict potential injuries. TM R&D received recognition for this innovation at the MSC Malaysia APICTA awards in 2018. The smart safety helmet is set for market release and will find applications in industries such as utilities, oil and gas, construction, manufacturing, and mining. It aligns with TM's efforts to improve operational excellence and customer experience (Lim, 2019).

2.3 Factors Application of IoT on Construction Sites.

The underlying causes of the application of IoT on construction sites are determined in Table 1. The construction industry has experienced an increase in safety concerns due to high accident fatalities, and it is crucial to address the various risks present on construction sites Accidents often occur due to collisions between personnel and large equipment, emphasizing the need for identification and warning systems to prevent such incidents. Existing studies lack adaptive techniques for detecting hazardous behavior in different zones without incurring high costs (Zhang et al., 2023). Proximity detection on construction sites can significantly improve safety by capturing near-miss accidents and identifying antecedents. Recognizing the inadequate safety regulations in the construction industry, additional safety precautions are necessary to protect construction workers (Green et al., 2013).

Table 1 *Factors application of IoT on construction sites*

Authors	Factors
Green et al., (2013)	Inadequate safety standards.
Kanan et al., (2018)	Price.
Chung et al., (2020)	Lack of understanding.
Zhang et al., (2023)	Various types of accidents.
Waqar et al., (2023)	Identifying potential.
Jin et al., (2020)	Raise awareness.

2.4 Challenges of IoT at Construction Sites to Increase the Quality of Safety.

Based on Table 2, RFID systems in the construction industry are limited by factors such as interference from other radio systems and the inability to identify moving objects due to the lack of a tag (Zhang et al. 2023). As a result, additional technologies like Lidar or video integration are required. While 4G networks, Zigbee-based wireless sensor networks, and ad hoc networks are considered for construction site safety, they have limitations, such as reliance on cellular coverage and delays. It is acknowledged that there are privacy concerns about tagging construction workers and difficulties in monitoring traffic vehicles in highway construction projects. To address these concerns, protocols and a strong network safety framework are required (Zhu et al., 2016).

Table 2 *Challenges of IoT at Construction Sites to Increase the Safety*

Authors	Challenges
Chen et al., (2014)	Strong network.
Zhu et al., (2016)	Health issues.
Nnaji et al., (2018)	Monitor safety.
Zhang et al., (2023)	Interference.

2.5 Effective Strategy of IoT Application to Increase Construction Site Safety

The implementation of proximity detection for safety measures can be achieved through software modifications and antenna positioning, allowing equipment operators to receive alerts when workers are nearby (Zhu et al., 2016). The RFID-based technology offers flexibility and interoperability by adhering to the widely accepted EPC standard (ALCUMUS, 2022). Creating an IoT wireless network using LoRa technology is a cost-effective solution that enables efficient data transfer and reduces the number of hops compared to other wireless technologies (Woodhead et al., 2018). Mobile RFID detection is necessary for scenarios where static conditions do not apply, and the placement of antennas should be based on blind spot areas. Using computer vision algorithms and Kalman filtering allows for predicting equipment and personnel locations to prevent accidents proactively (Lindsey et al., 2016). Accurate recording of encounters between employees, tools, and materials is crucial to ensure the security of construction operations, and GPS technology is commonly used for on-site location tracking (Kim et al., 2013).

Table 3 *Effective Strategy of IoT Application to Increase the Construction Site Safety Level*

Authors	Strategy
Kim et al., (2013)	- GPS system can locate and track.
Zhu et al., (2016)	- Computer vision techniques.
Lindsey et al., (2016)	- Kalman filter.
Woodhead et al., (2018)	- LoRa technology.
Alcumus (2022)	- Employ alternative types of tagging.

3. Research Methodology

Research methodology is an essential component of any research project as it establishes a structured and systematic procedure that guides researchers in achieving their research objectives. It acts as a roadmap for conducting the study and ensuring the research questions or objectives are effectively addressed. The methodology encompasses a structured approach involving various techniques and methods throughout the research process. These techniques encompass data collection methods, such as surveys, interviews, observations, or experiments, and data analysis techniques, such as statistical analysis, qualitative coding, or thematic analysis. Using these techniques, researchers gather pertinent data, analyze it, and derive meaningful conclusions. Moreover, the methodology provides researchers with a framework to design their studies efficiently. It assists in determining the appropriate sample size, sampling techniques, and data collection methods that align with the research goals. Researchers also consider ethical considerations and potential limitations associated with their chosen methods.

3.1 Research Design

The research design is a comprehensive framework that guides the implementation of a research study. It acts as a roadmap, allowing researchers to address their research questions or objectives effectively. This design encompasses selecting appropriate methods, procedures, and techniques for data collection and analysis. Its primary purpose is to ensure the credibility and dependability of the findings. By providing a structured plan, the research design facilitates the systematic and organized conduct of the study, ultimately leading to valid and reliable results.

(a) Stage 1: Early Research - In this stage, researchers explore their research topic, identify gaps in knowledge, and refine research questions and methodology.
(b) Stage 2: Literature Review - Researchers thoroughly review existing literature to gain insights, identify research gaps, and support their research design.
(c) Stage 3: Data Collection - Researchers collect primary data through interviews and utilize secondary data from various sources, ensuring relevance and reliability.
(d) Stage 4: Content Analysis - Researchers analyze collected data through organization, coding, statistical analysis, and interpretation to draw meaningful conclusions.
(e) Stage 5: Conclusion - A comprehensive report is created to communicate the intended audience's research findings, analysis, and conclusions. Overall, these stages encompass early research, literature review, data collection, data analysis, and creating a research report, contributing to developing and disseminating knowledge in the field.

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3.2 Data Collection

Data collection involves systematically gathering information to investigate research questions or test hypotheses. It can be classified as primary or secondary data. Primary data is original information collected directly by researchers through methods like surveys, interviews, and experiments, providing detailed insights tailored to the research objectives. While primary data collection offers control and specificity, it can be time-consuming and costly. On the other hand, secondary data is information gathered from external sources such as books, articles, and government reports. It is cost-effective, time-efficient, and provides access to diverse datasets. The researcher implemented primary data collection techniques for this study, including surveys and interviews. The researcher then implemented the secondary data method, compiling information from books, journals, and reports to support the data further.

3.3 Research Population and Sampling

In research, the population refers to the entire group of individuals, objects, or events the researcher aims to study and draw conclusions from. In this study, the target population consists of grade 7 contractors in Johor, Selangor, and Pahang who utilize IoT technology to enhance safety in construction sites. However, due to practical limitations, researchers employ sampling techniques to select a smaller representative subset of the population, known as the sample. Sampling involves the process of choosing individuals or units from the population to be included in the study. For this research, three grade 7 contractors from Johor, Selangor, and Pahang who implement IoT in their construction site safety practices were selected as interview respondents. This approach ensures that accurate information can be gathered while managing the study within practical constraints.

3.4 Research Instrument

The term "research instrument" refers to the tool or process used to gather data, including tests, analyses, observations, interviews, surveys, and questionnaires. The selection of a research instrument is based on various criteria, including the research objectives, target population, data requirements, and available resources. Semi-structured interviews with grade 7 contractors utilizing IoT technology to enhance site safety will be used to collect data for the required research. Despite the more significant startup costs, big companies are more likely to adopt IoT because of its enhanced long-term efficiency and cost-effectiveness compared to traditional technologies. The study's results will be shown in tables, and according to Ghosh et al. (2020), there may be extra economic effects from using IoT technology in construction.

(a) Interview

In research, interviews are a valuable data collection tool through interactive conversations between researchers and participants. Interviews can have different structures (structured, semi-structured, unstructured). They can be conducted in various formats, such as in-person, phone, or video calls, enabling researchers to explore topics in-depth and gain valuable insights. However, conducting interviews requires careful preparation, attentive listening, and ethical considerations. The interview data is transcribed, coded, and analyzed to identify important themes, patterns, or significant findings. Based on the information presented in Table 4, the interview process can be summarized into five distinct sections.

Table 4 *Distribution of The Interview Questions*

Part A	Respondent information
Part B	General question regarding the safety method applied on the construction site.
Part C	Identify the factors of IoT applications to increase safety at construction sites.
Part D	Determine the challenges of IoT applications at construction sites to increase safety.
Part E	Recommend the effective strategy of IoT application to increase the construction site safety level.

3.5 Content Analysis

Qualitative data, such as text, pictures, or audio/video recordings, is studied through the systematic and objective research process known as content analysis. Its objective is to look at and evaluate the data, finding any patterns, themes, or correlations that may be there. Researchers obtain insightful knowledge and a greater comprehension of the issue through this study.

4. Results and Discussion

This section explains primary data, a qualitative research technique from semi-structured interviews, and secondary data, which describes data collected through books, journals, and reports. This section also provides answers to all questions and research objectives.

4.1 Demographic

Background information about the three respondents who participated in the research is provided in Table 5. The three participants are assistant engineers and site safety supervisors, each with a specific job position. This diversity implies that several departments, such as technical, structural, health, safety, and environment, may be able to use IoT to improve safety on construction sites. Along with their contributions, the responders work on various background projects in the commercial, residential, and infrastructural sectors. Additionally, the majority of them are between the ages of 26 and 31, suggesting that middle-aged professionals are the ones using IoT and that technology requires deep understanding and focus. The study emphasizes the importance of work experience by showing that these professionals have been using IoT for more than five years, suggesting that the depth of expertise of people working in safety departments and on construction sites influences their use of IoT.

Table 5 *Respondents' Background*

No	Position	Department	Types of Projects	Age	Work experience
1	Site Safety Supervisor	Health, Safety and Environments	Commercial	26	8
2	Assistant Engineer	Technical (Site)	Residential	31	7
3	Assistant Engineer	Structure	Infrastructure	28	5

4.2 Safety Rules and Precautions Applied at The Construction Site

This section focuses on finding out if workers regularly comply with safety regulations and, if not, the steps respondents took to solve the issue. It also aims to discover how IoT is applied in construction sites and answers.

4.2.1 Safety Regulations

Construction sites are able to choose to comply voluntarily or through regulatory enforcement to implement health and safety regulations. (Eyiah et al., 2019). Respondent 1 stated that some construction sites and projects still lack adequate safety measures, referring to Table 4.2 as a reference.

"On construction sites, there is still a lack of compliance with safety regulations and unsafe work practices. This is due to the fact that employees work whenever it suits them, regardless of how it may affect their safety." (Respondent 1)

Respondent 2 supports Respondent 1's statement, however, for different reasons, including:

"On construction sites, the habit of complying with safety standards is still lacking since workers regularly disobey the regulations. This is also supported by superiors who do nothing to encourage staff members to behave in a way that complies with safety regulations. They ignore it as long as the task can be finished quickly." (Respondent 2)

Respondent 3 provided a different point of view, suggesting that the following methods can be used to achieve compliance with safety standards:

"I think that depending on the company and the construction site, there can be significant differences in compliance with safety regulations and standards. While some companies may be less careful with what they do, others may take safety extremely seriously and make sure to follow all regulations and requirements completely. Adherence to safety regulations and standards is essential to the project's success and the workers' well-being. Along with ensuring everyone's safety on the site, it also helps avoid pricey incidents, delays, and legal issues." (Respondent 3)

Construction accidents are greater when there are no standard procedures in place. With a drop from 13.1% in 1992 to 5.4% in 2007, the contrast between accidents and safety culture is obvious. Safety prioritization is emphasized, but managerial interest and involvement in safety development and regulation are clearly lacking (Slim et al., 2015).

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Table 6 *Perspectives of respondents regarding Safety standards*

Respondent	Item	Remarks
1	Safety regulations	• Still weak in specific construction sites or projects
2		• Employees disobey the rules; the organization seems unconcerned.
3		• Consistent regulatory compliance ensures worker safety and project success.

4.2.2 Current practices of IoT

Table 7 shows the data that indicates the utilization of IoT tools by the three respondents at the construction site. They utilize it not only to ensure that construction sites follow safety regulations but also to keep workers comfortable and safe while they work. Respondent 1 uses Internet of Things (IoT) devices, like a gas tester, walkie-talkie, and sensors, to enhance safety on the construction site.

"We communicate with each other using walkie-talkies since they are easier to operate and do not require internet access. Since the internet network is still difficult to detect during the site clearance and excavation phase, walkie-talkies are often used. Our job of testing gas pressure is made easy by the gas tester. The gas pressure level can be remotely adjusted using this gas tester. We utilize sensors to monitor the temperature and humidity at the construction site. Using these sensors, we can monitor things and ensure the building site is safe and stable while work is being done." (Respondent 1)

Respondent 2 is also utilizing walkie-talkies, just like Respondent 1. However, they also utilize the use of tagging sensors and drones.

"We utilize walkie-talkies for communication because not every location has access to the internet or phone service. When we are in areas where it is challenging to receive a signal, walkie-talkies can transmit messages effectively and precisely. We also use tagging sensors connected to machines and hand tools. This enables us to both locate the object and prevent theft. Drones are used to monitor conditions at construction sites. This is due to the fact that certain areas of the construction site, including high or narrow areas, cannot be monitored." (Respondents 2)

Respondent 3 said that using IoT tools like sensor tagging, GPS, and drones can guarantee the safety of workers on construction sites.

"We have the chance to provide a better and preventive approach to safety management by remotely monitoring the situation at the construction site through the use of tagging sensors, GPS, and drones." (Respondent 3)

Innovations in electrical and computer science enable intelligent construction sites to grow rapidly. Architects and stakeholders will benefit from automated and intelligent services provided by sensor-based safety management (Yang et al., 2020).

Table 7 *Perspectives of Respondents regarding Current practices of IoT*

Respondent	Item	Remarks
1	Current practices of IoT	• Walkie-talkie, gas tester, GPS, and sensors
2		• Walkie-talkie, drone, and sensor tagging
3		• Sensors tagging, GPS, and drone.

4.3 Factors of Applying IoT to Enhance Safety at The Construction Site.

Regarding the factors that influence the application of IoT to enhance safety at construction sites, all three respondents agreed that inadequate safety standards, a lack of understanding, real-time monitoring, various types of accident types, and the ability to identify potential threats are the influencing factors.

4.3.1 Inadequate Safety Standards

Respondents express different opinions on inadequate safety regulations impacting IoT use in construction safety in Table 8. According to the first response, worker safety cannot be ensured by complying with standards only.

"Expect that rules and safety regulations alone will not ensure workers' safety on construction sites. This results from employees' preference to work quickly using their own techniques while ignoring established safety guidelines. Therefore, workers may perform their jobs in accordance with safety regulations and standards by utilizing IoT as an additional tool to increase safety on construction sites." (Respondent 1)

Although the second respondent provided a different explanation, they both agreed with this factor.

"Using IoT devices like drones and CCTV, companies may monitor how employees work on construction sites and charge penalties if work is not done following established safety standards. This helps to solve the issue of workers not fully complying with safety regulations. We do not need to be at the construction site to carry out this monitoring task from a distance." (Respondent 2)

However, the third respondent agrees that inadequate safety standards have an impact on the usage of IoT for improving safety at construction sites; they have a different opinion.

"Workers with different abilities cannot comply with safety standards because they are too general. To ensure the safety of workers on construction sites, standards for skilled personnel must be developed. Even if workers comply with standard safety regulations, they can still work in safe environments thanks to the Internet of Things." (Respondent 3)

The construction industry has a terrible safety record, and researchers and safety professionals in the construction sector feel that the current standards on site safety are insufficient. To protect construction workers, additional safety precautions must be taken (Green et al., 2013).

Table 8 *Perspectives of Respondents Regarding Inadequate Safety Standards*

Respondent	Item	Remarks
1	• Inadequate Safety Standards	• IoT helps ensure standard compliance; rules alone cannot guarantee safety.
2		• Safety regulation non-compliance can be solved by remote monitoring.
3		• IoT-enabled customized safety standards for skilled workers increase site safety.

4.3.2 Real-time Monitoring

According to all three respondents, real-time monitoring IoT devices are a big help when it comes to monitoring worker safety and monitoring the activities on the construction site. Respondent 1 agreed that they could monitor the condition at the construction site by utilizing IoT, which has the benefit of real-time monitoring.

"Using IoT devices that offer real-time monitoring, like drones and CCTV, can greatly enhance safety on construction sites by giving employers an up-to-date view of the site's state. This is advantageous since it allows the employer to act quickly to assist workers in providing first aid in case of an accident on the construction site. Videos that have been filmed can also be saved as records." (Respondent 1)

Respondent 2 also has the same opinion as Respondent 1 but has a different justification.

"Drones allow us to monitor locations that are either small or too high for conventional access, like ladders. The construction site is very large. Therefore, manual monitoring would take much time. Drones allow us to monitor our assigned areas from a distance at times that is best for us, saving time and energy by eliminating the requirement for on-site presence." (Respondent 2)

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The third respondent shared the same opinions as the first and second respondents regarding this factor, however he gave different explanations.

"We use drones as a substitute for CCTV because not every part of the construction site is suitable for its placement. Gas storage areas and exposed and high parts are a few locations that should not have CCTV installed. We use drones to survey those areas and take backup videos." (Respondent 3)

IoT and sensor innovations provide automated, real-time constructing process monitoring. Consumers can communicate easily and overcome skills gaps by using mobile devices. By alerting workers to possible dangers in real-time, this technology improves efficiency, economy, and safety (Rou et al., 2022).

Table 9 *Perspectives of Respondents regarding Real-time monitoring*

Respondent	Item	Remarks
1	• Real-time monitoring	• IoT devices, such as CCTV and drones, provide real-time safety monitoring.
2		• Drones save time and energy by monitoring inaccessible areas efficiently.
3		• In unsuitable areas, drones are CCTV, surveying, and recording.

4.3.3 Various Types of Accidents

Those involved agreed that utilizing IoT may reduce possible accidents on construction sites, increasing overall safety in the construction site environment. First responders said that the type of construction also affects the type of incidents at construction sites.

"The requirements for construction sites change due to the various types of construction projects. This may also be applied to the various types of accidents on different construction projects. I work at a gas storage premises, therefore the safety regulations that apply here are also different. Additionally, the kind of accident that happens here is a gas release that results in increased radiation. Using a gas tester meter, you can measure the gas pressure in a location and get alarms if it reaches a harmful level." (Respondent 1)

Regarding various types of accidents influencing the use of IoT, the second respondent has different opinions.

"The type of project also influences the types of accidents that often happen on construction sites. As an example, I work at a residential construction site where accidents frequently occur due to workers falling from high places because they are using scaffolding that has not been maintained in a long time and is not safe to use." (Respondent 2)

The third responder viewed the variety of accident scenarios at construction sites from a different perspective. According to him, using various hand tools and machines at different construction sites can result in various incidents at every site.

"Extensive tools and many construction supplies are typically used on infrastructure construction sites, which are also usually large. This kind of thing impacts the accident factor since, in my experience, these kinds of accidents include workers getting stuck in machines or struck by big objects." (Respondent 3)

The factors influencing IoT to enhance safety at construction sites revealed the following results: respondents are more interested in adopting several kinds of Internet of Things (IoT) devices due to their unique advantages. Construction sites are considered among the riskiest workplaces for employees. There are many possible hazards and risks (Kanan et al.,2018).

Table 10 *Perspectives of Respondents regarding Various types of accidents*

Respondent	Item	Remarks
1	• Various types of accidents	• Different construction projects require different safety rules and equipment, such as gas testers.
2		• The type of project influences accidents.
3		• Infrastructure sites face threats from objects and machinery.

4.4 Challenges of Applying IoT to Enhance Safety at The Construction Site

The following objective of the study is to determine the challenges respondents face when using IoT to enhance safety on construction sites. Challenges include the need for reliable IoT networks, concerns about possible bad health effects on workers, interference with safety monitoring, and other challenges.

4.4.1 Strong Network

Respondents experienced a number of challenges both before and after implementing IoT to increase safety on construction sites. Among the challenges are the need for stable IoT networks, possible adverse health effects on workers, interference, and worker safety monitoring. Using IoT devices in areas with poor internet networks causes difficulties, as the first respondent stated.

"We employ walkie-talkies to deal with the problem of the internet network, which is frequently interrupted and affects communication. Sometimes, there is no internet network, so the GPS cannot determine the location accurately. As a result, we go in the incorrect direction and become lost." (Respondent 1)

In different circumstances, the second respondent also discussed the challenges encountered while connecting with IoT devices.

"This becomes a challenge when we need IoT on an upcoming construction site. These kinds of construction sites typically have poor network connections and are located in forests. As a result, we begin communicating with each other over walkie-talkies." (Respondents 2)

The third responder agrees with the first respondent's perspective, stating that a weak network is the main problem.

"Some of us experienced severe network issues, which prevented the drone's recording from being completely finished and resulted in the loss of some footage. We encountered additional challenges due to insufficient time to back up the footage for storage." (Respondent 3)

According to Zhang et al. (2023), 4G networks and wireless sensor networks must use multi-hop transmissions, which can cause too much delay, have a limited transmission range, and mostly rely on personal mobile phones. Nevertheless, using mobile phones to relay data is unreliable or impossible on certain construction sites since they are not connected to cellular networks. In these situations, the distribution of data is not accurate.

Table 11 *Perspectives of Respondents regarding Strong network*

Respondent	Item	Remarks
1	• Strong network	• Interrupted internet is replaced with walkie-talkies to ensure reliable communication.
2		• IoT establishment faces challenges in distant forest areas.
3		• The drone footage was lost due to severe network problems.

4.4.2 Interference

Based on Table 12 interference may be experienced by respondents who are utilizing tagging to determine the location of an object or employee. Interference can also occur when several objects are moving at once. The inaccuracy of the sensor's object detection may cause confusion. Since the location codes were nearly identical, the first respondent encountered a GPS-related issue that caused confusion.

"When using GPS, we sometimes have to deal with situations like entering an incorrect location. This occurs because there is a possibility that the location code entered is almost identical, confusing both the GPS device and the employee." (Respondent 1)

The second respondent used IoT tools, they also encountered disruptions, such as workers or products being stolen from construction sites.

"We sometimes mislocate an object or worker at the construction site because there are a lot of things and workers that use tagging. In other words, we must look for the worker or object ourselves. Consequently, it will take

a lot of energy and time." (Respondent 2)

According to the third respondent, utilizing a malfunctioning sensor when operating heavy machinery on a construction site will result in accidents or disruptions.

"When workers use sensors and heavy machinery is present in one area, there may be accident or interference when the machinery's warning alarms malfunction or respond slowly to alerts when they are near the workers." (Respondent 3)

The identical tagging problem was eventually observed by Zhang et al. (2023), which prevented them from recognizing any more moving objects that required labels.

Table 12 *Perspectives of Respondents Regarding Interference*

Respondent	Item	Remarks
1	• Interference	• Confusion results from GPS mistakes caused by similar location codes.
2		• Many tagging results in misallocation, which requires manual search and takes time.
3		• Sensor use near heavy machinery causes alarm confusion and delays.

4.5 Strategy of IoT applications to increase construction site safety

The third objective is to develop IoT-based techniques to improve construction site safety. Three key strategies are computer vision techniques, various kinds of tagging, and GPS-based tracking and location.

4.5.1 GPS Can Locate and Track

Table 13 shows that respondents agree that tracking and monitoring of employees or objects is possible with GPS. They also think that GPS-enabled tagging will show employers where their staff and equipment are at any given time, even if they are not physically there. The first respondent agreed with the tracking and locating strategy using GPS. This is because they have used the technique on their construction site, which has successfully reduced the issue of people getting lost or confused.

"We have utilized GPS to get to distant locations without manually opening the map because the gas storage location is a huge area. This is because we can enter the area code and receive directions to the location because the area is already stored in the GPS." (Respondent 1)

This strategy was supported by the second respondent, who offered the idea of utilizing GPS technology to improve safety on building sites.

"On construction sites, we utilize tagging that is GPS-enabled. We find that having GPS on the tagging that employees wear helps us a lot in tracking their whereabouts while working on the construction site. Additionally, we are able to locate the employees in this case of an accident." (Respondent 2)

The third respondent utilized GPS to avoid confusion or getting confused when determining the location, just as the first respondent did.

"In my experience, workers find that using a GPS on a big construction site can be beneficial since it can assist them in avoiding becoming lost, confused, or approaching places that are prohibited." (Respondent 3)

The most common on-site tracking system is GPS, which has an accuracy margin of 20 meters. The GPS locates and tracks the whereabouts of people and machinery using sensors found in numerous pieces of equipment. Over four 24 communication satellites receive information transmitted by equipment (Kim et al., 2013).

Table 13 *Perspectives of Respondents regarding GPS can locate and track*

Respondent	Item	Remarks
1	GPS can locate and track	• GPS provides efficient route guidance in huge gas storage plants.
2		• GPS-enabled tagging helps in emergencies by tracking the location of workers.
3		• GPS prevents worker confusion and ensures site navigation accuracy.

4.5.2 Employ alternative types of tagging

Table 14 provides some examples of how to use the different tagging strategies that responders suggested. The first respondent took part in this part of the interview but skipped responding to this question. The second and third respondents responded to this question and their corresponding opinions. According to the second respondent, there are a few factors that should be prioritized while selecting labeling, including:

"Before selecting any labeling, it is crucial to consider its purpose. Whether it is to be used indoors or outdoors, the area in which it will be utilized is the most important consideration. The tag's battery life, precision, and data accuracy are further factors. In order to ensure the long-term usage of tagging, this is important. (Respondent 2)"

By attaching tags to the scaffolding, the third respondent used this strategy at the construction site.

"We have taken the initiative to tag not just the machinery and workers but also the scaffolding, as lost scaffolding is common at our construction sites. The use of this method helps in lowering cases of scaffolding and improper storage. Additionally, it saves time and money because used scaffolding will be kept in good condition, minimizing the need to manually seek lost scaffolding and purchase new scaffolding. (Respondent 3)"

Depending on demand, the RFID reader's reading and scanning capabilities may be expanded and enhanced rather than buying new equipment for various scenarios. RFID-based systems display a high degree of compatibility as well. Provided that both the tag and the reader correspond to the generally accepted EPC standard (ALCUMUS 2022), workers are free to use other kinds of tags, such as regular vibrating tags.

Table 14 *Perspectives of Respondents regarding Employ alternative types of tagging*

Respondent	Item	Remarks
1	•Employ alternative types of tagging	
2		• Consider purpose, location, and battery life for effective tagging selection.
3		• Tagging includes machinery, workers, and scaffolding, preventing loss and damage.

4.6 Discussion

The respondents stated that real-time monitoring, addressing various types of accidents, and insufficient safety standards were the main factors impacting the implementation of IoT for enhanced safety at construction sites. The respondents' opinions on inadequate safety standards varied; some highlighted the need for new tools, such as IoT, to strengthen current laws, others suggested using drones and CCTV for remote monitoring, and the third suggested customizing safety standards based on workers' skills. Every respondent acknowledged the critical function that real-time monitoring via IoT devices plays in keeping updated on situations on construction sites and immediately handling emergencies. This highlights the construction industry's worries about inadequate safety regulations, leading to requests for further safety measures for the safety of employees (Green et al., 2013).

Respondents agreed that various types of construction-related incidents, including falls from heights and radiation exposure, show the significance of customizing Internet of Things technologies to meet the needs of the project. The first respondent, who worked in a gas storage site, emphasized the importance of taking safety measures to prevent radiation and gas leaks, and the second respondent, who was involved in residential construction, focused on events connected to height. The third respondent highlighted the challenges that come

with using a lot of tools in infrastructure projects. Customizing IoT systems is essential because dangerous areas on construction sites have different features, so safety precautions work in different situations (Zhang et al., 2023).

Strong network needs and interference challenges were identified as the two main barriers to using IoT to improve safety at construction sites. In places with poor internet networks, respondents found it challenging to deploy IoT devices, which had an impact on GPS accuracy and communication. A weak network infrastructure is reflected in the reliance on walkie-talkies as a substitute mode of communication. Using tagging systems to find items or workers was shown to have interference concerns, with respondents reporting thefts, misplacements, and malfunctioning safety alarms as frequent issues. According to Zhang et al. (2023), these difficulties are consistent with previous research, which highlights how crucial it is to handle network stability and interference issues to apply IoT to construction safety successfully.

All respondents agreed that GPS-based monitoring and location are workable ways to keep an eye on and find workers or things on construction sites regarding IoT application techniques. The benefits mentioned were enhanced safety, decreased confusion, and increased efficiency. In addition, different tagging strategies were also discussed, considering data accuracy, precision, battery life, indoor or outdoor use, and purpose. To solve common problems with scaffolding loss and inappropriate storage, the third responder emphasized the effectiveness of marking scaffolding. These strategies follow a wider trend in research on construction safety, highlighting the potential of RFID and GPS tagging systems to improve location-based safety applications and real-time monitoring (Kim et al., 2013; ALCUMUS, 2022). The discussion as a whole emphasizes the many viewpoints of industry experts on the elements, difficulties, and approaches associated with utilizing IoT to enhance safety on construction sites.

5. Conclusion and Recommendations

The study on this issue will come to a final stage, with recommendations for further research and a conclusion of its limitations. This chapter summarizes the outcomes of the thesis, which aims to use IoT to enhance safety at construction sites.

5.1 Conclusion

The utilization of IoT to enhance safety on construction sites is thoroughly investigated in the literature review, which includes benefits, influencing factors, challenges, and strategies. Three objectives have been determined by an in-depth study of relevant research, IoT for construction site safety:

I. To identify the factors of IoT application to increase safety at construction sites.

II. To determine the challenges of IoT application at the construction site to enhance safety.

III. To investigate the strategy of IoT applications to increase construction site safety.

The next step involves collecting primary data via interviews and secondary data from various sources. Data analysis continues with the objective of solving the main problems that lead to the research's results.

(a) Research Objective 1: Factors of applying IoT to enhance safety at the construction site.

In conclusion, using analytical semi-structured interviews with three respondents, the study effectively addressed important issues impacting the use of IoT to enhance safety at construction sites. The research pointed to the complicated problem of inadequate safety regulations in the construction industry, presenting various viewpoints on resolving this issue. These included using IoT as an extra safety tool, enforcing monitoring and enforcement regulations, and creating specific requirements for workers with different skill levels. The results emphasize the limitations of a standardized approach to safety regulations. They agree with previous research that shows weaknesses in the safety standards already used in the construction industry (Green et al., 2013).

The importance of real-time monitoring made practicable by IoT devices like drones and CCTV in enhancing construction site safety was emphasized by all responders together. This aligns with previous research that highlights the value of real-time information for fast accident response and remote monitoring, which eventually improves resource efficiency (Rou et al., 2022). The study also showed the variety of incidents in construction projects, highlighting the need for customized IoT solutions that address certain hazards related to various work types. Understanding the changing various issues found in construction situations gives support to the potential of IoT devices to offer specialized safety solutions (Kanan et al., 2018). Despite these insightful findings, the study acknowledges the limitations of a small sample of respondents. It emphasizes the need for

additional research with a larger and more varied sample to improve the generalizability of the results. Supporting current research is also necessary to stay current with the rapidly changing technological and safety standards in the rapid construction industry.

(b) Research Objective 2: To determine the challenges of IoT applications at construction sites to increase safety.

In conclusion, according to the results presenting semi-structured interviews with three participants, the research effectively identified challenges construction professionals face when using IoT for safety enhancement. A strong Internet of Things network is important, especially in remote or difficult-to-access construction sites. This is one of the main issues observed. The inaccuracy of GPS, communication problems, unstable connections to the internet, and general safety efficiency of tools were among the problems brought up by respondents. Zhang et al.'s (2023) findings, which highlight the problems and possible errors of the current network infrastructures, especially in places with inadequate connectivity, agree.

Interference is a major additional challenge, especially for IoT devices that use tagging to determine their location. Interviewees talked of misplacements caused by personnel or multiple tagged objects and confusion resulting from GPS that led to false location reporting. This interference also includes possible threats to public safety, such as heavy machinery failures, thefts, and accidents. According to Zhang et al. (2023), the results support the difficulty of using IoT-based systems to manage and track numerous moving items effectively manage and track numerous moving items.

To summarize, the practical challenges of incorporating IoT technologies into the construction sector for safety improvement were well-represented in the semi-structured interviews. To optimize the implementation of IoT in construction site safety, it is imperative to overcome network instability and interference difficulties, as highlighted by the challenges outlined. Considering the challenges of a small sample of respondents is important, even though the insights provide useful information for future research and development initiatives. The generalizability of the results can be improved by conducting additional studies with a more varied group. Additionally, to keep up with the ever-changing environment of construction site safety, continuous investigation of new technologies and network infrastructure advancements are crucial.

(c) Research Objective 3: Strategy of IoT applications to increase construction site safety.

In conclusion, the research achieved its objective by identifying key strategies for utilizing IoT to enhance safety on construction sites via insightful semi-structured interviews with three respondents. Three main strategies were found in the study: GPS-based tracking and location, several types of tagging, and computer vision methods. Out of all of them, the GPS-based monitoring and location approach stood out as a key component, as all respondents agreed that it effectively addressed issues with position awareness and navigation on construction sites. GPS-enabled tagging was widely praised for its effectiveness in tracking the locations of workers and equipment, especially on expansive and complicated construction sites. The responders' insightful observations highlight the benefits of incorporating GPS technology for on-site tracking.

The results align with previous research, with Kim et al. (2013) showing the wide acceptance and accuracy of GPS devices for monitoring workers and equipment in the construction sector. This acknowledgment contributes to the general acceptance of GPS as an effective and reliable on-site tracking solution. The study also explored other tagging methods, providing factors such as data accuracy, precision, battery life, indoor/outdoor use, and purpose. This thorough investigation expands on our knowledge of how to customize tagging tactics to fit particular requirements in construction sites' dynamic and diverse settings.

To sum up, the semi-structured interviews effectively provided an understanding of the practical methods construction industry experts use for IoT to enhance safety, particularly on GPS-driven monitoring. The knowledge acquired from these insights is invaluable for upcoming research and development projects that aim to improve these strategies and further the use of IoT in building site safety. However, the study emphasizes how important it is to keep up with the rapidly changing field of construction site safety through continual research and technology improvements.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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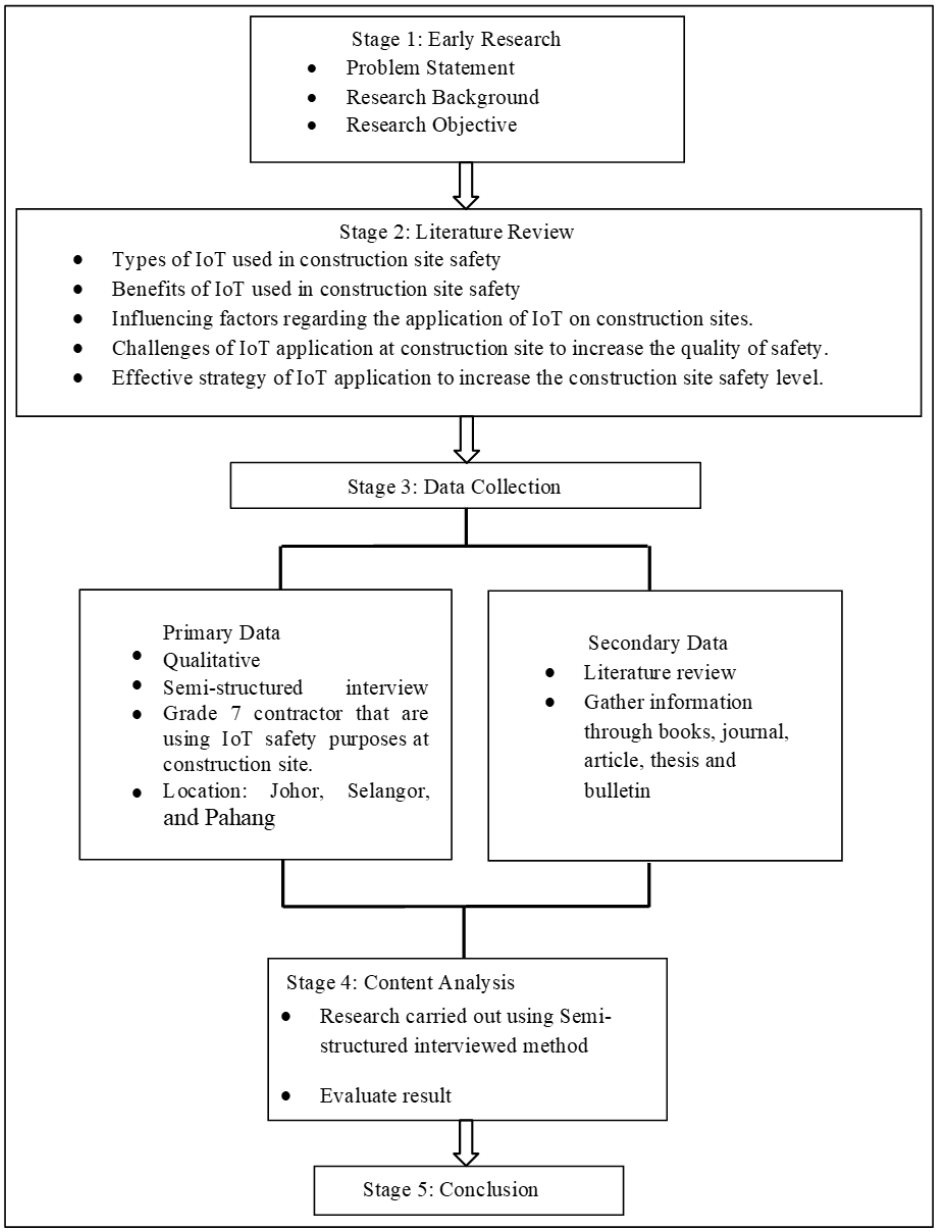
Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Adibah Sajri, Roshartini Omar;* ***data collection:*** *Adibah Sajri;* ***analysis and interpretation of results:*** *Adibah Sajri;* ***draft manuscript preparation:*** *Adibah Sajri, Roshartini Omar, Norliana Sarpin, Zailawati Khalid. All authors reviewed the results and approved the final version of the manuscript.*

Appendix A: Research Methodology Flowchart

Figure 1.0 Research methodology flow chart



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