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Internet Of Things (IoT): Real-Time Monitoring for Decision-Making Among The Malaysian Contractors

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ABSTRACT

The complexity of construction projects and the poor decision-making process often result in cost and time overruns. With the rapid growth of the Industrial Revolution (IR4.0) in Malaysia, the Internet of Things (IoT) is being expanded in the construction industry to improve project efficiency and performance. One of the benefits of IoT is it provides a real-time monitoring function to ensure that the construction players can access accurate data and information at the exact time throughout the project life cycle and assist in their decision-making. Most studies have focused on how decision-making is aided through the application of IoT during the design phase, with few studies focusing on the construction phase, particularly from the perspective of contractors. Without IoT, contractors need to use their professional experiences and limited data to make their decisions. As the contractors have to make a lot of decisions during the construction phase, the adoption of IoT can help the contractors to make fast and precise decisions. Despite its benefits, the adoption of IoT in the Malaysian construction industry is still low. With the focus on Grade 7 (G7) contractors in Malaysia, this paper intends 1) to study the types of IoT-based real-time monitoring technologies for decision-making among the contractors, and 2) to explore the potential improvements of decision-making by the contractors after the adoption of IoT. The research adopted the qualitative method via semi-structured interviews. Based on the findings, there are 10 types of IoT-based real-time monitoring technologies being used and they have been utilised in several areas e.g. machineries and equipment, materials, labours, project sequences, waste management, risk management, productivity and quality of works, cost control and environmental protection. The functions of the real-time monitoring of IoT such as real-time data and report, sudden changes reporting, agentless real-time monitoring, root cause analysis, alerts and warnings, and predictions, help the contractors in making their decisions timely and accurately. The findings reported herein are considered significant towards raising industry players' awareness and acceptance of IoT in construction projects, thereby improving project efficiency and performance.

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1. Introduction

Along with the growth of the Internet and Industrial Revolution 4.0 (IR4.0), Internet of Things (IoT) has been developing well. The number of the usage of IoT devices keeps increasing every year and it is estimated that around 75.46 million devices with IoT will be used by 2025 [1]. IoT has contributed to smart cities, smart homes, smart transportation, pollution control and energy savings [2-8]. Some countries have successfully adopted IoT in several sectors like manufacturing, automobile, banking, city development as well as the construction sector [9].

Construction industry, one of the largest industries in the world, is adopting the IoT in the construction process to successfully overcome the workplace challenges and smoothen the operations [1]. With the high engagement and encouragement of governments and construction agencies over the world, the construction industry has moved towards Construction 4.0 by utilising IoT in the construction sector [10].

Slow decision-making among all the project teams is one of the common issues in construction projects [11]. The main parties that usually cause this failure in decision-making are the contractors, clients and the employers or the managers of the team [12]. Contractors are the most important party for decision-making during the construction stage. The contractors usually use their professional experiences and limited data to make decisions [13]. One of the functions of IoT is real-time monitoring which can strengthen the information collection, storage and analysis for improved decision-making. With IoT, the contractors can make fast and good decision-making at the construction site to ensure the construction can be run smoothly and produce high quality products [14].

In Malaysia, the construction players are currently implementing the IoT in the construction projects. However, it is just at the beginning stage where the IoT is just starting to be implemented [10]. The growth of IoT in the Malaysian construction industry is still far away from the other Asian countries like South Korea, Singapore, China and Hong Kong [10,15]. The IoT is not fully utilised in the Malaysian construction industry, hence, the construction players in Malaysia have not discovered more on the benefits of IoT to help them in improving project efficiency [16]. Despite there is a great number of prior studies and research papers that have investigated on the adoption of IoT in the construction industry in different countries and its benefits for the construction players [1,8-10,14,16-19], there is lack of literature that discuss more about real-time monitoring for decision-making in construction project, especially in Malaysia.

This research is conducted with the aim to create industry players' awareness and acceptance of IoT in construction projects to improve project efficiency and performance. The research objectives are 1) to study the types of IoT-based real-time monitoring technologies for decision-making among the contractors, and 2) to explore the potential improvements of decision-making by the contractors after the adoption of IoT.

2. Literature Review

2.1 Definition of IoT

There is no official definition for IoT [20]. According to Gbadamosi *et al.,* [21] IoT is a network of things that has a unique identification (UID) or Internet Protocol (IP) address which can send and receive data. Arslan *et al.,* [22] explained that IoT is a worldwide network of things that are interconnected with each other and uniquely addressable according to its standard communication protocols. Chanal & Kakkasageri [23] stated that IoT is a network that connects physical and virtual objects globally to transmit information in digital form via the Internet. Gamil *et al.,* [17] defined IoT as the possibility of the things that are connected to the Internet to form a platform to execute the activities. Al-Amleh [14] and Oke *et al.,* [24] both defined that IoT is the network of the physical and virtual objects that are embedded with sensors, software and other technologies to connect and exchange data within each other by using the Internet. Kevin Ashton, a British technologist from the United Kingdom, who introduced the term IoT defined IoT as the combination of plenty of different objects that are physically connected to the Internet via sensors [25,26].

In this study, IoT is defined as the things around the world that are embedded with the interconnected smart devices that use the Internet to collect and share data among each other. IoT in construction refers to the application of Internet-connected technical equipment or modern-day Internet software to share data for the improvement of the construction project efficiency [14].

2.2 Adoption of IoT in Malaysian Construction Industry

The growth of the construction industry in Malaysia is moving towards the IR4.0 and IoT is the basis of this industry revolution [1]. Most of the construction industry players have low awareness of the development of IoT in construction activities and are not yet fully prepared for the IoT adoption [10,17,27]. Even though it keeps improving, it is still lagging the other Asian countries such as Singapore, China, Japan, South Korea and Hong Kong. It is because there is a lack of experts to operate the IoT systems and lack of awareness of the construction players towards the IoT functions [10,17]. However, the Public Works Department (PWD) and Construction Industry Development Board (CIDB) have taken initiatives to encourage the construction players to adopt IoT in their construction projects by conducting the seminars, workshops and trainings for them. Moreover, some of the tertiary education institutions such as universities, polytechnics and vocational colleges have exposed the students to the IoT world to let them be IoT-literate as they will be leading the construction industry in the future. Continuous improvement is needed in the Malaysian construction industry for it to stand in the global competitiveness [10].

Meanwhile, the IoT devices that are widely used in the construction industry in Malaysia are the 1) smart communication tools for information sharing and communication purposes [1,10,22,27], 2) location services software for tracking delivery of resources [1,10,28], 3) drones for monitoring the construction site and building surveying [10,27], 4) sensor devices for monitoring the utilisation of equipment and construction hazards [10,16], and 5) radio frequency identifications (RFIDs) for tracking materials on site [10].

2.3 Areas of Decision-making by Contractors at Construction Site

Based on the literature review, there are five areas of decision-making that the contractors always need to pay attention to during the construction stage (see Table 1). First is regarding machineries and equipment. The contractors have to check on the location and the status of the machineries and the equipment that have to be used at the construction site [10,29]. By knowing the status and details of the machineries and equipment, e.g., fuel consumption, temperature and the working-hours, the contractors are able to decide on preventive maintenance to make sure that the machines and the equipment are good to function [1,10].

Same as the machineries and equipment, the contractors also have to always track the materials from time to time [10,29]. Not only to track the location of the materials, but the contractors are also in-charge of checking the availability of the materials on site so that they can make proper resources management [10,30]. The contractors should also check on the suitability and quality of the materials at the construction site, e.g., the concrete's grades, the formwork's types, the types of bricks, etc. [14]. If the materials are not suitable or of low quality, the contractors must immediately change the materials before the work commences. In addition, the contractors must be alert on the utilisation of the materials to make sure the inputs and outputs of the materials are correctly matched [10,14].

A contractor is the person-in-charge of managing the workers at the construction site. Hence, it is undeniable that the contractors have to always track the workers' activities and their safety at the construction site [10,29]. However, there are a great number of workers at one site. It is impossible for a human to monitor the whole construction site at all times, especially when it comes to a large and complex construction site. Furthermore, there are many risks at a construction site [31]. Al-Amleh [14] said that there are around one percent of workers injured in the construction site and out of them an average of 1000 workers died from the injuries each year. Besides safety and health of the workers, the contractors have to track the man-hours of the work for the payment to the workers [32].

In terms of the project sequences, the contractors always have to be clear about which work has to be done first, which work has to be done next or which work can be done at the same time. In order to decide on this, the contractors should have the information about the time when an activity is needed [29]. Besides, they should always know the project progress to either rearrange the project sequence or maintain if any problems are occurring during the construction process. The contractors may have to decide on how many workers and man-hours needed for each activity. By arranging or changing the project sequences, the contractors must be able to know the availability of the materials on site and the conditions at the site. In simple words, to have a good project sequence, the contractors may need massive information especially at the site to decide the project work arrangement [10].

Lastly is waste management. A contractor has to manage the waste that is generated at the construction site and clean the trash [10]. Trash at the construction site must be immediately cleaned to create space and reduce hazards. Therefore, the contractors have to always monitor the trash levels. Failure to handle the trash properly may lead to penalties from the authorities. This will then increase the cost of the projects and the contractors bear the highest risk of these penalties [33].

Table 1
Areas of decision-making of a contractor

No.	Areas of decision-making	References
1	Machineries and equipment	[1],[10],[29]
2	Materials	[10],[14],[29],[30]
3	Labours	[10],[14],[29],[31],[32]
4	Project sequences	[10],[29]
5	Waste management	[10],[33]

2.4 Types of IoT for Real-Time Monitoring at Construction Site
2.4.1 Sensors

A sensor is used to detect and gather data, then the data will be transferred to the relevant software application through Internet access [10,13]. Sensors are the big sources of the IoT where the wireless sensor networks are usually referred to as IoT [34]. There are diverse types of sensors available. Different sensors provide distinct types of monitoring techniques, namely vision-based technique, ranging-based technique, location-based technique and identification-based technique. With all these sensing tools, the contractors can track the machineries and equipment from time to time by detecting the location of the machineries and equipment as well as controlling the machinery maintenance period, fuel usage, machinery temperature and the equipment health [1,10]. The information that are recorded by the sensors can be assessed through mobiles, tablets and computers [10]. Once the contractors obtain all these data, they can decide on the preventive maintenance and repair for the construction equipment to prevent the downtime of the machineries [10,17]. When the equipment is overused, a signal sign and warning will be sent to the operators and the equipment will switch off automatically [1,10].

2.4.2 Drones

Drones, which are also known as unmanned aerial vehicles (UAVs), can fly quickly, be operated easily and used to access the areas that are hard or impossible to reach by using conventional ways [35]. Hence, it can be used as accurate survey maps, improve safety and communication as well as provide real-time images of the construction site [1,14,36]. This is because drones are equipped with webcams for the contractors to visualise and monitor the construction progress closely [1,14,27,37]. With that, the contractors can have a clear and accurate view on the construction progress and produce the site progress report by using the photos received from the drones [27]. Drones can also be used to show any potential issue that requires immediate attention [1,14]. If there are any problems like wrongly placing the materials, it can also easily find the location of the materials by using drones. Besides, it is also a tool to monitor employees' health and safety [1]. It can be used to track workers' location and inspect the construction site, especially the hazardous area to ensure that the workers work in a safe environment [10,17,27]. When potential danger is detected, safety alerts will be sent out to the workers to prevent any accidents from happening. In addition, the trash at the construction site can also be monitored remotely by drones and a schedule can be made for managing the accumulated waste [14].

2.4.3 Radio frequency identifications (RFIDs)

RFID is an early form of IoT [38]. RFID has diverse sensing function which can improve object identification, product tracking and logistics applications with the help of digital communications [39]. RFID systems have a reader that releases a signal to the labels or tags [36,40]. Then the microchips inside the labels or the tags will receive the signal and start to collect and process the data. RFID technology will be replacing barcodes as it has high data capacity and it is easier to reprogramming the information if compared to the barcodes [39]. RFID helps to improve the project efficiency, arrange assets and minimise theft [14]. If the materials are supplied with RFID, the materials can be automatically counted at the site [1,24]. This can drastically reduce the cases of loss or stolen materials [14]. If the materials are insufficient or the stock is at a low rate to carry out the activities, an alert will be sent to the central system to call for more orders or the supply is requested [1,24,32]. It is because the tags are able to register the minimum materials to be available at the site [32]. In short, RFID is said to be part of the material delivery system [34]. The location and transportation of the materials and equipment can also be accessed and traced easily [1,26,32,40,41]. This can help to overcome the problems like incorrect deliveries and misplaced construction equipment [32]. Information such as the suitability of temperature for the materials, damages to the materials and the expiration of the materials can all be accessed easily [1]. Besides, RFID can be used to track the number of workers at the construction sites, detect safety risks, provide restricted access to the site, prevent counterfeits and enhance supply chain management [14,40].

2.4.4 Wearable devices

Wearable devices are devices that are composed of sensors and internet-enabled devices to ensure that the data can be collected and communicated with other computing tools. It is advanced electronics that are worn by the workers to collect and deliver data that are usually in the areas of health and safety. Since it is worn close to the surface of the skin, it can be used to gather, analyse and send out information regarding the body signals. The devices can help to detect and give an early warning to the user if there are any potential dangers around them to ensure the workers' safety at the site [14,27,31]. Besides the safety and health of workers, the wearable devices can also track the location of the workers to inform the managers or the contractors to be alert of the location of the workers [14].

There are two (2) types of wearable devices, one is the separate devices and the other is the one that has been embedded in personal protective equipment (PPE). The separate wearable devices that are mostly applied in the construction site are the smart watches and sensor worker badges. A smart watch with the smart health sensing system can be used to record pulse rate, heart rate, body temperature and blood pressure [8,10,14]. A sensor worker badge is usually used to track the existence of the workers for the contractors to calculate the labour-hours of the workers so that the contractors can properly arrange the incentive for the labours based on the man-hours of their works [10]. In some companies, wrist bands are also used to detect driver alertness and health [14,24]. The ones that are embedded in PPE are usually smart helmets [14]. It can be used to track the location and warn the workers of potential hazards at the time the hazards occur or are going to happen at the next moment. It can also sense the real-time workers' health and safety conditions and send notifications to the project managers or contractors. The workers can receive first-hand help when they are facing any accidents like slipping, falling or tripping. Same as the function of the smart watches, it is also able to measure the heart rate and body temperature of the workers. Besides, it can detect the surrounding humidity and temperature to warn the workers who are at risk of heatstroke to reduce the workers' incidents [27]. Using health sensors in wearable devices to track workers' health by recording the pulse rate and body temperature can make sure the workers are in good health when working. Contractors can manage and arrange the duties of the workers easily after knowing their health conditions [14].

2.4.5 Security cameras

A security camera, which is also called a closed-circuit television (CCTV), consists of a proximity sensor along with sounds and videos. It provides video surveillance systems for the contractors to oversee the construction workers, observe the construction site and decide on resource allocation. The security camera also can assist the contractors to complete the daily log that contains construction activities, actual resources, inspections, field observations and problems, document updates and progress with photos presented. Then the contractors may analyse the inputs from the daily log to further arrange project sequence to have good project performance outcomes. By using the security cameras, it can minimise the movement and supervision of the contractors at the site, indirectly reducing the cost of project management. Further, the cost of purchasing a security camera is also affordable [42].

2.4.6 Conservation data analytical model (CDAMs)

The day-to-day activities at the construction site are dependent on the weather conditions. The condition of the weather can be predicted by using the information that is given on the weather forecasting applications. A conservation data analytical model (CDAM) is designed to mitigate errors in weather forecasting [43]. CDAM is used to monitor the real-time weather condition and predict dynamic climate change such as rainfall, humidity, temperature, soil contents, etc. [14,43].

2.4.7 Smart meters

Smart meters can provide real-time monitoring on the services usage at the site such as electricity, gas, water and other utilities, record the consumption level and information including the time and location where the resources are used [14,40,44]. Besides, the smart meter can be used to determine the utilisation of the smart devices that are used at the construction site [37].

2.4.8 Equipment telematics

Equipment telematics is a combination of GPS technology, on-board diagnostic and monitoring sensors. It is used to track and monitor the performance and the operations of the equipment at the site. Data such as real-time location, fuel consumption, idle time and machine alerts will be sent to the contractors for the allocation of the assets, maintenance and repairs requirements for the machineries and equipment, the performance of the operator of the equipment, theft control and the management of the construction activities. With that, the contractors can work more productivity and efficiency especially working with the equipment [14].

2.5 Benefits of Real-Time Monitoring in Decision-making

2.5.1 Provide real-time data and reports

Traditionally, the decision makers use reports to make analysis, predictions and decisions towards the failure. This process took a lot of time. When doing the report, it takes time and the report only shows what has happened. Then comes the analysis part, it also takes time that they have to analyse the report, collect the relevant information, identify the trends, then predict the failure that may occur. When IoT comes into this aspect, things may get easier. The monitoring tools of IoT have the function of real-time monitoring. This can help to save a lot of time because the managers will be notified when an issue occurs. They will also be receiving the real-time data and reports to enable the managers to make fast decisions and take actions to deal with the issue immediately [17,21,38]. The data will be collected from numerous systems and software and aggregated in one place, which is usually the cloud. Then, the real-time reporting will be displayed with all the data collected [21].

2.5.2 Report sudden changes

With the use of IoT, the decision makers or analytical people may easily identify the trends when the actions are applied. If anything goes wrong, they may quickly change their plan to reduce the loss to the minimum and take the necessary corrective measures. It is because real-time reporting records the sudden changes and shows the impact of the changes at the very moment. This may help to speed up the problem resolution process and minimise the losses [21]. Arrow [45] said that the teams that have effectively shared the data will more effectively respond to the changing conditions or the risks than others who do not have such insight.

2.5.3 Promote agentless real-time monitoring

Real-time monitoring can record the smallest details regarding capacity tracking. The resource managers may easily identify the resource utilisation throughout the day with minimal manual effort. With the information on resource utilisation, resource managers may find better decisions on the allocation of resources [21].

2.5.4 Detect root causes of problem easily

Real-time monitoring, as the name implies, is always monitoring from second to second, which means that the data is always up-to-date and the changes for every second can be traced. The reports are in real time and it may be very accurate for the decision makers to make their decision. The staff can immediately detect serious problems from the relevant and current data that have been received. When a problem occurs, the person-in-charge can have a fast troubleshooting to figure out the root causes and come up with an effective solution immediately [46].

2.5.5 Provide alerts and warnings

The managers can set up alerts for some undesirable situations. If the undesirable activities happen, alerts or warnings can be sent to the employees. The alerts can be immediately reachable to the related staff or the automated systems. The system can automatically be shut down or restarted to avoid a bad situation. Besides, the IoT like sensors can trigger alarms when it detected something suspicious [46].

2.5.6 Allow accurate predictions

The real-time monitoring can be used to monitor the weather parameters, such as rain, snow, temperature, humidity, wind velocity and pressure. Besides, it can provide accurate predictions on the weather or water resources like the flood situation [47]. IoT provides support in terms of forecasting for the exponentially growing data to obtain necessary solutions through predictive analysis mechanisms [48]. By using the data from real-time monitoring, the organization can make predictions on trends and performance [46].

3. Methodology

The research flowchart is illustrated in Fig. 1. The literature review was conducted to provide background study on the IoT and identify the areas of decision-making, types of IoT-based real-time monitoring technologies and their potential benefits. The literature review was carried out by searching the documents available online with the keywords such as “Internet of Things”, “IoT”, “Construction Industry”, “Malaysian Construction Industry”, “Contractor”, “Construction Players”, “Real-Time Monitoring” and “Decision-making”.

For this study, a qualitative research method via semi-structured interview was conducted because not many contractors are familiar with IoT as it is still new to the Malaysian construction industry. Besides, there is limited data from the literature review regarding the implementation of

IoT real-time monitoring technologies in Malaysia, thus the answers are hard to be predetermined where the quantitative methodology is usually using preset answers. By adopting qualitative methodology, the researcher can get more in-depth data where the thoughts and experiences of the respondents can be obtained. The requirement for the respondent should be someone who has knowledge of IoT in construction. Thus, G7 contractors were chosen as the population of this research as they are the ones who have a higher potential to adopt the IoT technologies in their company. Non-probability sampling with snowball method was used, where the respondents interviewed were asked to recommend another potential respondent who meet the criteria.

The invitation letters had been sent to a total of 750 G7 companies via email, LinkedIn, Facebook and WhatsApp from 13th March 2023 to 15th May 2023. However, only fifteen of them replied and they met the requirements. From the fifteen potential respondents, a formal email was sent to them to explain the details and objectives of the interview. There were only four respondents, (they are coded as R1, R2, R3 and R4 in this paper), replied that they were willing to join the interview for the data collection. The semi-structured interviews were conducted where some questions were predetermined based on the findings from literature review.

The narrative analysis was used to analyse the data. First, the interviews that were constructed in verbal words and sentences were transcribed into structured text with proper grammar written in English. With the transcribed text, the data were sorted based on the required data that had been predetermined to achieve the objectives of the interview. Once the data were properly sorted, some specific codes were developed to analyse the messages that received from the selected text. After the coding was done, all the codes were reviewed to group into a theme. The name of the theme must be clear enough to reflect the meaning of the text. The data are reviewed to show the connection if there is any relationship between the given data. This process is known as data deciphering where the data are de-contextualised and re-contextualised. The data are distinguished into smaller pieces and consolidated into larger pieces to show whether the connection of the data exists. After all the data were analysed, the results were presented in tables and graphical forms.

STAGE 1

Literature review
To achieve objective 1 & 2:
GOAL: to provide the background study on IoT and achieve the followings:
1) Areas of decision-making by contractors at construction site
2) Types of IoT-based real-time monitoring technologies for decision-making among the contractors
3) Benefits of real-time monitoring in decision-making

STAGE 2

Interview
GOAL: to obtain contractors' input regarding the types of IoT being used in their company and the benefits of using IoT in improving decision-making
- Qualitative research method
- Semi-structured interview (3 sections: Section A: Demographic information, Section B: Types of IoT-based real-time monitoring technologies, Section C: Potential improvements on decision-making by IoT and real-time monitoring)
- Potential respondents – G7 contractors
- Non-probability sampling - Snowball method

STAGE 3

Data analysis
- Narrative analysis

Fig. 1. Research Flowchart

4. Results

4.1 Types of IoT-Based Real-Time Monitoring Technologies among the Malaysian Contractors

From the literature review, there are eight identified IoT-based real-time monitoring technologies. According to Table 2, both the primary and secondary data showed that the types of IoT that have been implemented in Malaysia are sensors, drones, RFIDs, wearable devices, security cameras and CDAMs. The smart meters and the equipment telematics are yet to be adopted in Malaysia according to the primary data collected. The smart meters provide the function of recording the energy consumption of the construction personnel [14]. According to one of the respondents and Jia *et al.,* [40] the smart meters are yet to be used in the Malaysia context because the energy is less consumed at the construction site, the smart meter is more useful for the commercial buildings rather at the construction site.

According to the respondents, the IoT-based real-time monitoring technologies that are mostly used in Malaysia's construction industry are drones and wearable devices. Drones are mostly used to take photos for weekly and monthly progress updating and reporting. The photos are taken from the same angle every time at several intervals to see the progress. Drones have eased the work of the management team to monitor all the progress. They do not need to go to the site, but they can still know the progress. Not only looking for the progress, but also knowing the conditions at the site and making relevant decisions then. In addition, drones are useful for the contractors for situation control. If there are any emergencies or problems occur, especially in dangerous situations, e.g. building collapses, the contractors can send a drone to see what is happening there and make the right decision in the shortest possible time.

Wearable devices that are used in the construction industry are smart lanyards, smart watches, smart helmets and smart wristbands. The wearable devices are mostly used for ensuring the safety and health of the person at the construction site. It is because it could trigger an emergency, especially when a person walked inside the building and fell into a deep and secured place where others did not notice. It also allows the employer to have motionless monitoring and track the labour's work progress, thus increasing the labour productivity. For example, the employers are able to know the motion of the labours whether they are moving or being motionless for how long.

The respondents also added that the types of IoT-based real-time monitoring technologies includes the document management system, BIM software, AR and CPS. CPS is a very new system among all the technologies that have been implemented. It is very useful for the contractors to monitor all the things at the construction site in order for them to make decisions. The data from the CPS system is online, helping the decision makers to conduct data analysis, realize the control of construction site progress, quality, safety, materials, etc. and make project management more convenience. The contractors can access all the construction information in front of the computer.

Although AR has been stated as an IoT-based real-time monitoring technology, from the literature review, AR is another category according to the nine pillars of IR4.0 [1,10,49]. Sometimes, people will confuse that AR as an IoT because AR can actually integrate with IoT and they have quite similar definition. IoT is the bridge to link the physical world and digital world while AR is creating the digital world by interacting with the physical environment. AR can improve the visualisation as an additional value to serve IoT data [50]. In this paper, the AR is included since the contractors has included AR as IoT based on their experience.

Table 2
Types of IoT technologies that are implemented in Malaysian Construction Industry

No.	IoT Technologies	Literature Review	R1	R2	R3	R4
1	Sensors	/		/	/	
2	Drones	/	/		/	/
3	RFIDs	/			/	
4	Wearable Devices	/		/	/	/
5	Security Cameras	/	/		/	
6	Conservative Data Analytic Models (CDAMs)	/			/	
7	Smart Meters	/				
8	Equipment Telematics	/				
9	Document Management System		/	/		
10	Building Information Modelling (BIM) Software		/			/
11	Augmented Reality (AR)			/	/	
12	Cyber Physical System (CPS)					/

4.2 Potential Improvements for Decision-making of a Contractor

Based on Table 3, both the primary data and the secondary data showed that there are six benefits of real-time monitoring. The real-time monitoring function allows the contractor to assess the real-time data and reports at any time. The contractors also can have agentless real-time monitoring with the use of IoT. With the sudden change notifications, alerts and warnings, the contractors are able to react to the sudden changes quickly and trigger their next actions. The IoT allows the contractor to have accurate predictions and root causes analysis so that they can plan for their work along the project [46].

The contractors can use the benefits stated above to improve their decision-making in several areas as shown in Table 4, such as machineries and equipment, materials, labours, project sequences, waste management, risk management, productivity and quality of works, cost control and environmental protection.

For the machineries and equipment, IoT reminds the contractors when the next maintenance schedule is. The contractors are then able to monitor the status of the equipment in real time by installing sensors and monitoring devices. This allows the contractors to find faults, repair and replace the equipment failure in time and further avoid project delays and cost overruns caused by the equipment failure. This is where the contractors can implement the predictive maintenance. In other words, IoT provides a basis for optimising usage and maintenance of the equipment where the contractors can analyse the collected equipment data to understand the usage of equipment. Besides, the GPS detector installed in the machine is able to know the geolocation of the machine.

In terms of the materials, it is not easier for the contractors to monitor, detect and do the tracking of where all the materials go. The real-time monitoring of the IoT can greatly help the contractors to track all those materials, especially for the larger scale projects. It is a huge benefit for the contractors where it can check the transportation and delivery of the materials to the site and the utilization of materials at the site. In addition, the contractors can monitor the quality and status of the materials in real time with the use of IoT. The problems can be detected in time to avoid the use of low-quality and damaged materials. The consumption of the materials also can be monitored for the contractors to make plans on the materials. Moreover, the IoT can prevent materials from being stolen or lost to ensure the safety of the construction site and related personnel.

The IoT devices can detect the workers' location, know how long they have been working and track their work progress. All the data collected can help the contractors to optimise the management process and improve management efficiency. This IoT implementation is believed to increase the labour productivity by monitoring on the labours' working hours. It can also help to increase the labours' safety and health management. Through smart helmets, the contractors can monitor the labours' behaviours and discover the unsafe behaviours and situations in time. With the smart watches or smart bracelets, the contractors can monitor the health status and physical data of the labours. This provides the contractors with timely discovery of the health problems of the labours and risks at the construction site. If there is anything that happens, e.g. when the labours are facing any emergencies, the IoT can trigger the actions by sending a signal to the contractors to let them make immediate decisions.

Besides those main areas, the additional area that is important to the contractor according to one of the respondents is cost control. IoT can help contractors in terms of cost savings by tracking the incoming and outgoing costs of the project. Cost is the major factor that joints productivity, comfortability and sustainability for the construction industry. The contractors can make use of the IoT to deliver a cost-efficient project.

By making the right decisions in these few areas, the project can be running smoothly, thus increasing the project's efficiency. This shows that the implementation of the IoT-based real-time monitoring technologies can greatly improve the decision-making of a contractor. The main findings of this research are presented in Figure 2 below.

Table 3
Benefits of real-time monitoring function of IoT towards improvement of contractor's decision-making

No.	Benefits of Real-Time Monitoring	Literature Review	R1	R2	R3	R4
1	Provide real-time data and reports	/	/	/	/	/
2	Report sudden changes	/	/	/	/	/
3	Promote agentless real-time monitoring	/	/	/	/	/
4	Detect the root causes of the problem easily	/		/	/	/
5	Provide alerts and warnings	/	/	/	/	/
6	Allow accurate prediction	/	/	/	/	/

Table 4
Areas of decision-making that can be improved by the IoT implementation

No.	Areas of Decision-making	Literature Review	R1	R2	R3	R4
1	Machineries and equipment	/	/	/	/	/
2	Materials	/	/	/	/	/
3	Labours	/	/	/	/	/
4	Project sequences	/	/	/		/
5	Waste management	/	/	/	/	/
6	Risk management			/		/
7	Productivity and quality of works			/		/
8	Cost control			/		
9	Environmental protection					/

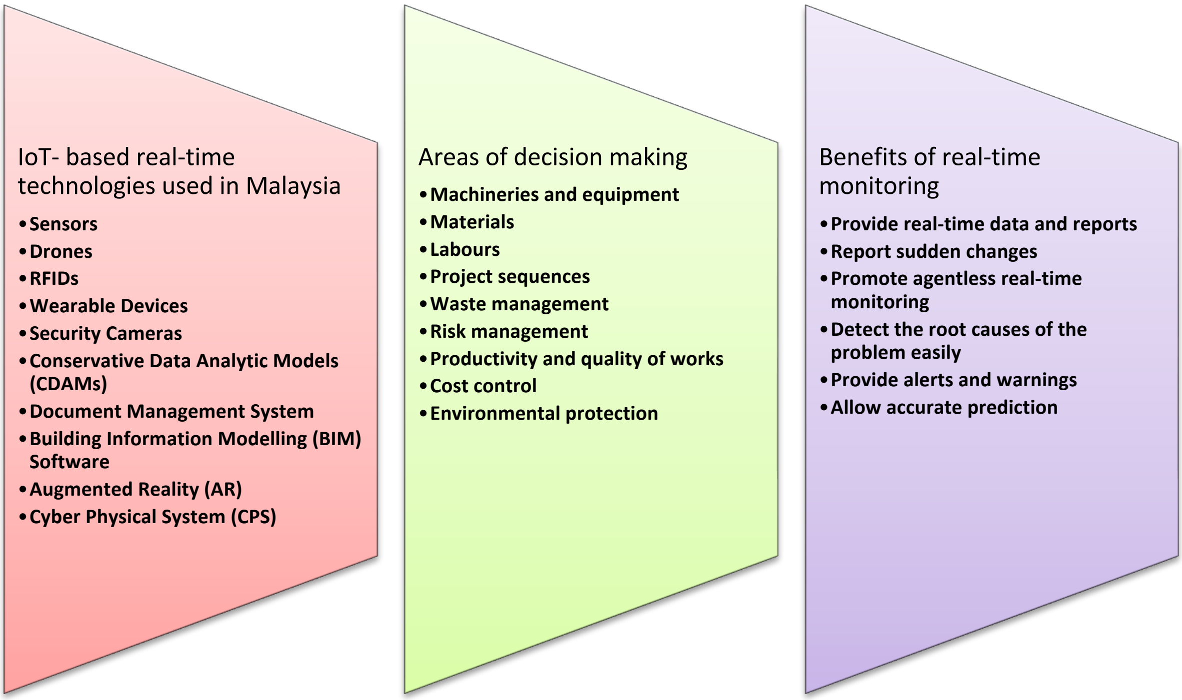

Fig. 2. The main findings on the types of IoT technologies, areas of decision-making and benefits of real-time monitoring

5. Conclusions

The types of the IoT-based real-time monitoring technologies that have been used in Malaysia by the contractors are sensors, drones, RFIDs, wearable devices, security cameras, CDAMs, document management system, BIM software, AR and CPS. These IoT-based real-time monitoring technologies have been utilised in several areas by the contractors such as machineries and equipment, materials, labours, project sequences, waste management, risk management, productivity and quality of works, cost control and environmental protection. The contractors can use the IoT technologies to improve their decision-making in these areas to ensure that they are developing a good project progress, provided that the contractors can utilise well the function of the real-time monitoring of IoT such as the real-time data and report, sudden changes reporting, agentless real-time monitoring, root causes analysis, alerts and warnings, and the predictions.

Throughout the process of conducting this research, some limitations have been faced. First, the researcher faces difficulty in finding the right respondents. Even though the research used the snowball method, the person suggested was not someone who fulfil the criteria of the respondents for this research. Besides, some respondents did not know anyone to recommend. As a result, the respondents for this research ended up with four. Apart from that, the lack of previous research studies that consists of both the IoT and real-time monitoring in the construction industry also posed a challenge to the researcher to conduct this research.

Some recommendations for future researchers are to explore the benefits of IoT based real-time monitoring according to each type, and to investigate other functions of real-time monitoring besides the decision-making (for example, communication, and relationship management).

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