Journal of Construction in Developing Countries

Manuscript Title	Application and Challenges of Adopting Internet of Things (IOT) in the Rwandan Construction Industry
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Submitted Date	25-May-2022 (1st Submission)
Accepted Date	30-Oct-2022
DOI	https://doi.org/10.21315/jcdc-05-22-0098

APPLICATION AND CHALLENGES OF ADOPTING INTERNET OF THINGS (IoT) IN THE RWANDAN CONSTRUCTION INDUSTRY

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Abstract: The adoption of the Internet of Things (IoT) is essential because it facilitates project information, saves time, and cost and reduces risks on construction sites. The objectives of the study are to investigate the adoption, application, and challenges of IoT technologies in the Rwandan construction industry. The survey research design (open and close-ended questionnaire) was adopted for the study. The questionnaire was administered to registered construction professionals in Rwanda. The stratified random sampling technique was adopted for the study. The data for the study was analysed with frequencies, mean scores and student t-tests. The findings of the study indicated that none of the IoT technologies was well adopted, two were adopted, eleven were averagely adopted and twenty-two were slightly adopted. Also, IoT technologies were used for project management, efficient transportation, time management, and production of site plans. The significant challenges with the adoption of IoT technologies were a lack of training centres, lack of IoT awareness, lack of expertise, poor network connectivity, a requirement for extra budget to acquire IoT technologies, and poor collaboration among construction stakeholders. The study concluded that the level of adoption of IoT technologies in the Rwandan construction industry is low and there is no difference in the opinions of the respondents on the adoption and challenges of adopting IoT technologies in the construction industry. The study recommended that there is a need to create more awareness of the adoption of IoT technologies, and enact laws and policies that can foster the adoption of IoT technologies in the construction industry.

Keywords: Application of IoT, Challenges of IoT, Adoption of IoT, Rwanda, Construction industry

INTRODUCTION

The construction industry is an important aspect of every economy which contributes to the national Gross Domestic Product (GDP), employment, and environmental development of developed and developing countries (Berk and Bicen, 2016). In addition, the global output of the construction industry is expected to grow by 85% to $15 trillion by 2030 (Osei et al. 2017). In Rwanda, the construction industry is one of the fastest-growing sectors and available data indicates that the sector contributes about 7% of the national GDP and 8% of national employment (International Labour Organization, 2018). Despite this acknowledged growth, the industry appears to be largely dominated by traditional construction techniques and lacks the adoption of digital technologies like the Internet of Things (IoT), artificial intelligence, virtual reality and 3D printing among others. The traditional procurement technique is characterised by poor project performance in the form of rework, errors, variations and delays among others (Dosumu, 2018).

The application of IoT has brought about a paradigm shift in the delivery of construction projects (Viren and Kazi, 2017). However, many construction professionals are still reluctant to adopt it due to reasons that are organisational, environmental, social and political. The IoT was noted to have the ability to improve sustainable construction management, communication among stakeholders, and business activities (Halim et al. 2021). Also, the adoption of IoT ensures that project lifecycles become more manageable, employees' productivity on-site improves, project progress on-site and environmental sustainability become better monitored, and construction waste is better managed (Ibrahim et al. 2021). Despite the benefits of adopting IoT, it is not clear if the Rwandan construction industry is already taking advantage of the improved performance of its construction industry.

Islam et al. (2018) investigated the adoption of IoT by government agencies, developers, architects, engineers, quantity surveyors, and class G7 contractors in Malaysia. Chen, Ha, Tai, and Chang (2020) assessed the factors that influence practitioners' willingness to adopt IoT in Taiwan's construction industry. Arslan et al. (2019) investigated IoT technologies and the practical implications of their adoption in the Turkish construction industry. Kumar and Shoghli (2018) analyzed the role of the Internet of things in providing a real-time update on the delivery and data for material handling in supply chain management on construction sites in the United States. Supriya et al. (2020) examined smart home automation in India using IoT. Halim et al. (2021) investigated the adoption of IoT among contractors in the Malaysian construction industry. From the above studies, it is clear that many researchers have made effort to determine the state of the adoption of IoT in their respective countries to take advantage of its benefits for improved project performance.

In Rwanda, only a few studies have been conducted on IoT (Inagbire, 2022). These studies however concentrated on the agricultural and government sectors. Thus, the level of adoption, application and challenges of adopting IoT in the Rwandan construction industry is barely documented in the literature.

This has precluded an understanding of the impact of IoT on the activities of the construction industry and project delivery. Without an empirical study of the level of adoption, application and challenges of adopting IoT in the Rwandan construction industry, it may be difficult to curtail the persistent poor project performance occasioned by the lack of adoption of IoT technologies. Therefore, the objectives of this study are to investigate the level of adoption, application and challenges of adopting IoT technologies in the Rwandan construction industry. This study will supplement existing studies on the adoption of IoT in the construction industry. It will also provide empirical knowledge on the level of adoption and application of IoT in the Rwandan construction industry.

LITERATURE REVIEW

IoT is a global infrastructure for the information society and it enables advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies (Dilakshan et al. 2021). IoT was described by Le-Phuoc and Hauswirth (2009) and Cheung et al. (2018) as a system of smart devices that uses the internet or a private network to connect and communicate with each other with minimum human engagement. The basic idea of IoT is to equip objects of day-to-day life with the detection, sensing, networking, and processing capabilities that enable them to communicate over the internet with each other and other devices to achieve a common goal (Ezechina et al. 2015). Hence, IoT allows people and things to be connected at any time, any place, with anything and anyone.

IoT technologies and their application in the construction industry

Dilakshan et al. (2021) found that the IoT technologies that are mostly used in the Sri Lankan construction industry are Radio Frequency Identification (RFID), wearable devices, weighing sensors, flowmeters, drones, 3D printing, websites, site robots, e-tendering, Close-Circuit Television (CCTV), Global Positioning System (GPS) tracker, General Packet Radio Service (GPRS), Building Information Model (BIM) and site sensors. Ibrahim et al. (2021) discovered that the most adopted IoT technologies on Malaysian construction sites for smart communication are WhatsApp, Telegram, social media (Facebook and Instagram), video calls, and email.

Maru et al. (2020) noted that the IoT technologies that are used for construction work in India are microcontrollers, wi-fi, e-health monitoring, drones, smartwatches, CCTV, Enterprise Resource Planning (ERP), RFID, google map, General Packet Radio Service (GPRS), BIM, Augmented Reality (AR) with google glass, fuel-saving sensors, lighting and electricity sensors, autonomous machinery, scan marker, e-tendering, websites, social media, GPS tracker, Autocad, e-mail, databases, online price quote, online ordering, fire threatening sensors, Microsoft project, automatic lamp, smart lock, maintenance activity sensors, air quality monitoring sensors, waste management sensor, primavera and robotics. Mahmud et al. (2018) discovered that the IoT technologies that are adopted by government agencies, developers, architects, engineers, quantity surveyors, and class G7 contractors in the Malaysian construction industry are WhatsApp, Telegram, Facebook Messenger, email, and GPRS and the most less-adopted IoT-based technologies were sensor technology, Scan-Marker, and Smartwatch among others.

The IoT technologies used on Malaysian construction sites are smartwatches, waste management sensors, Scan Marker, flood threat monitoring sensors, AR, air quality monitoring sensors, building structure health monitoring, maintenance activity sensor, fuel usage control sensor, traffic control sensor, BIM, item tracker, workers' productivity monitoring drone, automatic lamp, site layout monitoring drone, working progress monitoring, fire threat monitoring sensors, smart locks, internet for tender, online ordering, GPRS, websites, email, and social media (Islam et al. 2018).

Ibrahim et al. (2021) explained that social media platforms assist with the regular exchange of information such as progress reports and pictures. Operated devices such as drones were used for site monitoring, machine control, construction safety, fleet and project management, remote operation, location services, augmented reality, smart communication, and big data. RFID was used for material tracking on the site. Maru et al. (2020) noted that the applications of IoT for construction projects are smart communication, supply chain, remote operation, maintenance of machines, Augmented Reality (AR), fuel and energy management, Building Information Modelling (BIM), efficient transportation, workers' management, security control, workers' health check, environmental monitoring and waste management. Ghosh et al. (2019) also noted that IoT is useful for safety monitoring, data visualization, structural engineering applications, prefabricated construction, cloud-based platform, and construction waste management.

Cheung et al. (2018) explained that applications of IoT include localization and safety management, facility and environmental monitoring, building and infrastructure monitoring, resource management and optimization, equipment automation, and efficient management. Kochovski and Stankovski (2018) found that IoT is used for construction site management, material supply and management, maintenance of the security and safety of sites, and real-time information and communication. Tang et al. (2019) agreed that construction operation and maintenance, on-site environmental monitoring, resource monitoring, communication and collaboration, construction performance and progress monitoring, health and safety management, health and safety training, automation in fabrication, lean construction, facility management, building operation and management, building performance and management, energy management, and disaster and emergency response are major applications of IoT technologies in construction.

In Rwanda, Inagbire (2022) developed a unified platform for integrating IoT into the implementation of e-Government services to track the progress and achievement of national goals by using the case studies of smart air quality monitoring, waste collection and water quality monitoring. Also, Bamurigire et al. (2020) simulated IoT water management for efficient rice irrigation in Rwanda and found that IoT can increase the resilience of the agricultural sector where there is high demand for water efficiency. Therefore, the reviewed literature indicates that IoT has been applied to construction projects in developed and developing countries. However, there is no empirical data to establish the level of application of IoT in the Rwandan construction industry. Hence, this study investigates the application of IoT in the Rwandan construction industry.

Challenges of adopting IoT technologies in the construction industry

Organizations choose to adopt IoT with the expectation of certain benefits that have sometimes led to unexpected structural changes that require mitigation on construction projects (Brous et al. 2019). Sometimes, organizations often underestimate the potential of adopting IoT technologies and fail to fully understand the organizational conditions and consequences associated with the successful adoption of IoT. Hence, the benefits of adopting IoT technologies are only achieved when the institutional conditions have been met and its consequences have been accepted.

Another challenge, according to Tang et al. (2019) is that IoT requires the adoption of both hardware and software networking technologies which are often supplied by multiple providers. As a result, the field of IoT is filled with a variety of technologies, protocols, and devices, all of which have different requirements, characteristics, conditions and stakeholders. Ibrahim et al. (2021) noted that the challenges of adopting IoT include the limited number of experts who know how to operate IoT devices, additional cost to the organization to train employees on the use of IoT devices, high cost of getting IoT devices, the conduct of regular maintenance, no or low internet connectivity, lack of awareness among the construction players, reluctance to change, lack of regulatory standards, lack of budget to purchase and install new technologies, and lack of government enforcement on the adoption of IoT. Ghosh et al. (2018) found that incompatibility and unclear value propositions, data privacy and security, bureaucratic governance structures, and business planning and models hamper the adoption of IoT.

The study by Takki (2019) established that the major challenges hindering the adoption of IoT in the construction industry are hesitating to adopt IoT technologies, lack of categorized and shared project knowledge, low acceptance rate, data security and protection, high implementation costs, organizational and process changes, lack of standards and reference architecture, regulatory compliance, legal and contractual uncertainty, post-construction issues, need for enhanced skills, higher requirements for a computing environment, the need for enhancement of the existing communication network, lack of documentation of the results of adopted IoT solutions, issues with selecting the best IoT solution, the complexity of IoT technologies, lack of information exchange in decision making, and scalability issues with existing IoT solutions.

Furthermore, Tang et al. (2019) affirmed that the need for a strong internet connection, network security, physical protection of IoT devices, authentication and access control, data accuracy, energy efficiency, high cost of implementation, and lack of professional skills are the major challenges of adopting IoT in the construction industry. Scalability, software complexity, security and privacy, and fault tolerance were the challenges of adopting IoT in the construction industry discovered by Musfira and Cassim (2018). Chen et al. (2020) found that anticipated benefits, anticipated efforts, and societal expectations significantly affect the users' willingness to adopt IoT. Table 1 summarises the challenges of adopting IoT technologies in the construction industry according to the countries of investigation.

Challenges	**Author**	**Country/methodology**
Expectation of certain benefits that sometimes lead to unexpected structural changes that require mitigation	Brous *et al.* 2019	Netherland
IoT requires the adoption of both hardware and software networking technologies (which are often supplied by multiple providers) all of which have different requirements, characteristics, and conditions, and stakeholders, need for a strong internet connection, network security, physical protection of IoT devices, authentication and access control, data accuracy, energy efficiency, high cost of implementation, and lack of professional skills.	Tang *et al.* (2019)	Literature review of 14 AEC journals
Limited number of experts who know how to operate IoT devices, additional cost to the organization to train employees on the use of IoT devices, high cost of getting IoT devices, the conduct of regular maintenance, no or low internet connectivity, lack of awareness among the construction players, reluctance to change, lack of regulatory standards, lack of budget to purchase and install new technologies, and lack of government enforcement on the adoption of IoT.	Ibrahim *et al.* (2021)	Malaysia
Incompatibility and unclear value propositions, data privacy and security, bureaucratic governance structures, and business planning and models.	Ghosh *et al.* (2018)	Literature review of scientific publications from Scopus and web of science databases
Hesitation to adopt IoT technologies, lack of categorized and shared project knowledge, low	Takki (2019)	Finland and Sweden

acceptance rate, data security and protection, high implementation costs, organizational and process changes, lack of standards and reference architecture, regulatory compliance, legal and contractual uncertainty, post-construction issues, need for enhanced skills, higher requirements for a computing environment, the need for enhancement of the existing communication network, lack of documentation of the results of adopted IoT solutions, issues with selecting the best IoT solution, the complexity of IoT technologies, lack of information exchange in decision making, and scalability issues with existing IoT solutions.		
Scalability, software complexity, security and privacy, fault tolerance.	Musfira and Cassim (2018)	Literature review
Effects of anticipated benefits, anticipated efforts, and societal expectations on the users' willingness to adopt IoT.	Chen *et al.* (2020)	Taiwan

Table 1: Challenges of adopting IoT technologies in the construction industry

From the review of the literature, it is apparent that many technologies have been adopted in developed and developing countries to the advantage of construction stakeholders and the project. However, in Rwanda, there seems to be paucity or slow adoption of these technologies due to reasons that are not clear. This may be due to the lack of empirical studies on the level of adoption, application and challenges associated with the adoption of IoT technologies in the construction industry. Therefore, this study examines the level of adoption and the challenges of adopting IoT technologies in the Rwandan construction industry. The study will supplement existing studies on IoT and also establish the level of adoption of IoT technologies to improve construction management practices and project delivery.

RESEARCH METHODOLOGY

The study employed the descriptive survey research method using a questionnaire (closed and open-ended) to collect the relevant data on the adoption, application and challenges of adopting IoT technologies in the Rwandan construction industry. The questionnaire was used for the study because of its ability to reach a wider audience, provide the required information for a study and generalize its findings (Bird, 2009). The variables that were tested for the adoption and challenges of IoT technologies in the construction industry were based on an extant review of relevant literature.

The population of the study are the professionals working on construction projects in Kigali, Rwanda. Kigali was used for the study because most construction projects in Rwanda are being executed in Kigali which is the business hub, capital city, centre of government administration, and the most densely populated part of the country. The Rwandan government recognizes two professional bodies in the construction industry. They are The Rwanda Institute of Architects (RIA) (which consists of the architects and the quantity surveyors) and the Institute of Engineers in Rwanda (IER) (which consists of structural/civil, mechanical and electrical engineers). The list of registered construction professionals was obtained from the professional bodies (RIA and IER) and those with offices in Kigali were adopted for the study.

As of December 2021, the total number of registered engineers with IER in Kigali was 801 and the number of registered architects and quantity surveyors with RIA in Kigali was 95 and 62 respectively. Therefore, the total population of this study is 801 engineers, 95 architects and 62 quantity surveyors. The study adopted the stratified random sampling technique. The strata are the engineers, architects and quantity surveyors. The random sampling technique was applied to each stratum to determine the sample size for the study. The sample size for the study was determined with the use of an online sample size calculator which is available at https://www.calculator.net. The calculator was set to a 95% confidence level and 10% margin of error to obtain a sample size of 86 engineers, 49 architects and 38 quantity surveyors.

The questionnaire for the study was prepared in google form and administered via online means only (emails, WhatsApp, and telegram) between August 2021 and December 2021 (since physical visits to offices were prohibited during this period due to COVID-19 restrictions). Thus, 66 copies of the study questionnaire (which represents 38.15 per cent of the sample size of the study) were filled and used for the study. The data for the study was collected via online means and during a pandemic era that precludes physical access and effective communication with the respondents. A low response rate is not uncommon in the construction industry as indicated by Dosumu (2013) who got 21 per cent and Bamgbade et al. (2016) who got 25 per cent respectively.

The questionnaire was divided into two sections which are: section one: general information of respondents and their organisations; section two: level of adoption of IoT technologies (measured with 1 = not adopted, 2 = slightly adopted, 3 = Averagely Adopted, 4 = Adopted, and 5 = Well adopted), application of IoT technologies (open-ended questions that require respondents to describe what each IoT technology is used for on construction projects), and the challenges of adopting IoT technologies (measured with 1 = not significant, 2 = slightly significant, 3 = Averagely significant, 4 = Significant, and 5 = Very significant). Section one was analysed with frequency and percentages. Section two was analysed with inferential statistics such as mean, t-test, and analysis of variance. The Statistical Package for Social Scientists (SPSS) was used to analyse the data collected for the study.

RESULTS AND DISCUSSION

Table 1 indicates the general information of the respondents for the study. The male respondents were 81.8% and the female respondents were 18.2%. The skewness in the genders of the respondents could be due to the global male dominance of the construction industry. Also, 36.4% of the respondents work in the public sector and 63.6% were from the private sector. The respondents that provided information for the study based on commercial, institutional and residential projects were 31.82%, 24.24%, and 43.94% respectively. The respondents with an engineering background were 42.42%. Quantity Surveyors were 36.37% and Architects were 21.21%. Also, 30.3% of the respondents were into consultancy services and 69.7% were into contracting services. The respondents with advanced level certificates were 24.2%, those with 'bachelor's degrees' were 72.7% and those with 'master's degrees' were 3%. In addition, 41.5%, 45.5% and 3% of the respondents had 0-2, 3-5 and 6-9 years of work experience. Lastly, 57.58% of the respondents were members of the RIA and 42.42% were members of the IER. Based on the quality of the respondent of this study, it could be affirmed that the information provided for the study were reliable and usable for analysis.

General information of respondents	**Option**	**Frequency**	**Percentage (%)**
Gender	Male	54	81.80
	Female	12	18.20
	Total	**66**	**100**
Work sector	Public	24	36.40
	Private	42	63.60
	Total	**66**	**100**
Type of project	Commercial projects	21	31.82
	Institutional projects	16	24.24
	Residential projects	29	43.94
	Total	**66**	**100**
Academic qualification	Architecture	14	21.21
	Quantity Surveying	24	36.37
	Engineering	28	42.42
	Total	**66**	**100**
Nature	Consultants	20	30.3
	Contractors	46	69.7

	Total	**66**	**100**
Academic qualification	A Level	16	24.24
	Bsc	48	72.76
	Msc	2	3.00
	Total	**66**	**100**
Working experience	0-2 years	34	51.55
	3-5 years	30	45.45
	6-9 years	2	3.00
	Total	**66**	**100**
Professional qualification	RIA	38	57.58
	IER	28	42.42
	Total	**66**	**100**

Table 2: General Information of the respondents

Table 2 indicates the level of adoption of IoT technologies in the Rwandan construction industry based on the professional affiliation of the respondents. The most adopted IoT technologies by professional engineers are Wi-Fi (3.53), Google Maps (3.21), social media (3.21), websites (3.21), GPS (3.05), and BIM (3.00) respectively. The least adopted IoT technologies by professional engineers were drones (1.58), fuel-saving sensors (1.68), e-health monitoring (1.74), motion sensors (1.74), and Augmented Reality with Google Glass (1.74), and RFID (1.74) respectively. For the architects and quantity surveyors, the most adopted IoT technologies are Wi-fi (3.80), google map (3.70), social media (3.40), websites (3.20), e-tender (3.20), gas/ air quality monitoring sensor (3.20), GPRS (3.20), quick response code tags (3.10), fire threat monitoring sensors (3.00), and temperature sensors (3.00). The least adopted technologies were drones (1.50) microcontrollers (1.60) flood threat monitoring sensors (1.90), RFID (1.80), and Augmented Reality with google glass (1.90). The most adopted IoT technologies by the engineers, architects and quantity surveyors were Wi-fi (3.67), Google Maps (3.55), social media (3.27), websites (3.18), BIM (3.09), and GPS tracking (3.06). The least adopted IoT technologies were drones (1.67), RFID (1.70), augmented reality with google glass (1.73), microcontrollers (1.79) and smart caps (1.94).

In summary, out of the 35 IoT technologies investigated, wi-fi and google Maps were adopted. The website, social media, BIM, GPS, e-tender, automatic lamp, CCTV, air quality, fire threat sensors, and building monitoring sensors were average adopted. The rest of the technologies were only slightly adopted Consequently, the study adopted the t-test statistics to establish if there is a difference in the level of adoption of IoT technologies between the engineers and architects/quantity surveyors. The study found that there was no significant difference ($P > 0.05$) in the level of adoption of IoT technologies between the engineers and architects/quantity surveyors except for the adoption of scan markers ($0.02 < 0.05$).

IoT technologies	Engineers	Rank	Architects/ quantity surveyors	Rank	Overall mean	Overall Rank	Decision	Sign(2-tailed)	Decision
Wi-Fi	3.53	1	3.80	1	3.67	1	A	0.612	NS
Google map	3.21	2	3.70	2	3.55	2	A	0.342	NS
Social media	3.21	2	3.40	3	3.27	3	AA	0.667	NS
Websites	3.21	2	3.20	4	3.18	4	AA	0.984	NS
Building Information Modelling (BIM)	3.00	6	2.80	13	3.09	5	AA	0.737	NS
Global Positioning System (GPS) tracking	3.05	5	2.90	11	3.06	6	AA	0.730	NS
E-Tender	2.58	7	3.20	4	2.91	7	AA	0.289	NS
Automatic lamp	2.47	10	3.20	4	2.85	8	AA	0.185	NS
Closed-Circuit Television (CCTV)	2.42	12	3.20	4	2.76	9	AA	0.147	NS
Gas/Air quality monitoring sensor	2.58	7	2.60	20	2.73	10	AA	0.965	NS
Fire threat monitoring sensors	2.47	10	3.00	9	2.70	11	AA	0.294	NS
Smart Lock	2.32	14	2.90	11	2.52	12	AA	0.295	NS
Building monitoring sensors	2.42	12	2.70	16	2.52	12	AA	0.575	NS

NA – Not Adopted = < 1.50, SA – Slightly Adopted = 1.50 - 2.49, AA – Averagely Adopted = 2.50 - 3.49, A – Adopted = 3.50 - 4.49, WA – Well Adopted = > 4.50. NS = No significant difference (P > 0.05), S = Significant difference (P < 0.05).

Table 3: Adoption of IoT technologies among engineers and quantity surveyors

Table 3 presents the level of adoption of IoT technologies between the consultants and the contractors. Thus, the most adopted IoT technologies by the consultants were wi-fi (3.20), google map (3.20), social media (3.20), websites (3.20), BIM (3.10), e-tendering (3.10), GPRS (3.10), and GPS tracking (3.0). The drones (1.30), microcontrollers (1.40), augmented reality with google glass (1.60), waste management sensor (1.70), e-Health monitors (1.70), and RFID (1.70) were the least adopted technologies by the consultants. The most adopted IoT technologies by the contractors were wi-fi (3.87), google Maps (3.70), social media (3.30), websites (3.17), automatic lamps (3.13), and BIM (3.09). The smart cap (1.96), microcontrollers (1.96), drones (1.83), augmented reality with google glass (1.78), and RFID (1.7) were the least adopted IoT technologies by the contractors. Collectively, the most adopted IoT technologies by the consultants and contractors were wi-fi, google map, social media, websites, BIM, and GPS. The least adopted were the drones, RFID, augmented reality with google glass, microcontrollers, smart caps and ERP.

In summary, out of the 35 IoT technologies investigated in this study, wi-fi and google map were adopted. The website, social media, BIM, GPS, e-tender, automatic lamp, CCTV, air quality, fire threat sensors, and building monitoring sensors were average adopted. The rest of the technologies were only slightly adopted in the Rwandan construction industry. The study adopted the t-test statistics to establish if there is a difference in the level of adoption of IoT technologies between the consultants and contractors. The study found that there was no significant difference (P > 0.05) in the level of adoption of IoT technologies between the consultants and contractors. This means that the level of adoption of IoT technologies by the contractors and consultants is the same. Therefore, improved methods of IoT adoption should be applied to both categories of respondents.

IoT technologies	Consultants	R	Contractors	R	Overall mean	Overall rank	Decision	Sig(2-tailed)	Significance
Wi-Fi	3.20	1	3.87	1	3.67	1	A	0.191	NS
Google map	3.20	1	3.70	2	3.55	2	A	0.322	NS
Social media	3.20	1	3.30	3	3.27	3	AA	0.811	NS
Websites	3.20	1	3.17	4	3.18	4	AA	0.961	NS
Building Information Modelling (BIM)	3.10	5	3.09	6	3.09	5	AA	0.982	NS
Global Positioning System (GPS) tracking	3.00	8	3.09	6	3.06	6	AA	0.837	NS
E-Tender	3.10	5	2.83	8	2.91	7	AA	0.643	NS
Automatic lamp	2.20	16	3.13	5	2.85	8	AA	0.093	NS
Closed-Circuit Television (CCTV)	2.90	9	2.70	10	2.76	9	AA	0.705	NS
Gas/ Air quality monitoring sensor	2.60	12	2.78	9	2.73	10	AA	0.723	NS
Fire threat monitoring sensors	2.80	10	2.65	12	2.70	11	AA	0.782	NS
Smart Lock	2.30	14	2.61	13	2.52	12	AA	0.579	NS
Building monitoring sensors	2.30	14	2.61	13	2.52	12	AA	0.532	NS

NA – Not Adopted = < 1.50, SA – Slightly Adopted = 1.50 - 2.49, AA – Averagely Adopted = 2.50 - 3.49, A – Adopted = 3.50 - 4.49, WA – Well Adopted = > 4.50. NS = No significant difference (P > 0.05), S = Significant difference (P < 0.05).

Table 4: Adoption of IoT technologies by consultants and contractors in the construction industry

Table 4 indicates the applications of IoT technologies based on the types of services rendered and professional qualifications. As explained in the research methodology, this section of the questionnaire was open-ended and required the respondents to write what the technologies were used to do. A content analysis of the responses was done and presented in Table 4. Hence, the consultants used e-tendering, social media and GPRS for smart communication and sharing of information; the BIM for drafting 3D construction plans and collaboration; the GPS and Google Maps for producing site plans, efficient transportation, and general surveying; and the temperature and humidity sensors for environmental monitoring. For the contractors, the GPS and google maps were used for general surveying and efficient transportation; ERP was used for project management; smartwatch was used for time management; wi-fi and e-tendering were used for smart communication and sharing of information. Similarly, smart locks, automatic lamps and CCTV were used for security control; fire threat and temperature sensors were used for environmental monitoring, and BIM was used for Producing 3D building plans.

Similarly, the architects/quantity surveyors applied the GPS and google map for the production of site plans and efficient transportation; e tendering, websites and social media were used for smart communication and sharing of information; the smartwatch was used for time management; lighting, electricity and fuel usage sensors were used for power, fuel and energy savings. The engineers applied GPS and google map for general surveying and efficient transportation; ERP for project management; social media, e-tending, wi-fi and GPRS for smart communication and sharing of information; smart lock, automatic lamp and CCTV for security controls; fire threat, humidity and temperature sensors for environmental monitoring; BIM for 3D building plans and collaboration. The result of the study showed that IoT technologies are used in the Rwandan construction industry for project management, production of site plans, transportation management, environmental monitoring, collaboration among project stakeholders/designers, security control, smart communication, information sharing, general surveying, time management, power, fuel and energy savings.

Category of respondent	IoT technologies	Application of IoT technologies
Consultants	E-tenders, social media, and GPRS	Smart communication and sharing of information
	BIM	Drafting 3D construction plans and collaboration

	GPS and google map	General surveying, Production of site plans and efficient transportation
	Fire threat, temperature and humidity sensors	Environmental monitoring
Contractors	GPS and google map	General surveying and efficient transportation
	Smart watch	Time management
	ERP	Project management
	Wi-fi and e-tenders	Smart communication and sharing of information
	Smart lock, automatic lamp, and CCTV	Security control
	Fire threat, temperature and humidity sensors	Environmental monitoring
	BIM	Production of 3D Plans and collaboration
Architects/quantity surveyors	GPS and google map	efficient transportation and production of site plans
	E-tenders, websites and social media	Smart communication and sharing of information
	Smart watch	Time management
	Lighting, electricity, and fuel-usage sensors	Power, fuel and energy Savings
Engineers	GPS and google map	General surveying and efficient transportation
	ERP	Project management
	Social media, e-tenders, wi-fi, and GPRS	Smart communication and sharing of information
	Smart lock, automatic lamp and CCTV	Security control
	Fire threat, humidity and temperature sensors	Environmental monitoring
	BIM	3D building plans and collaboration

Table 5: Application of IoT technologies in the construction industry

Table 5 indicates the challenges that hinder the adoption of IoT technologies in the Rwandan construction industry based on the responses of the consultants and contractors. The top significant challenges of the consultants were lack of IoT awareness (3.60), lack of expertise in IoT (3.40), Lack of training centres (3.20), lack of support from the government (3.20), Improper introduction of IoT into construction process (3.20), poor collaboration among construction stakeholders (3.10), lack of awareness of the benefits (3.10), and requirement of extra budget to acquire IoT technologies (3.00). For the contractors, the significant challenges were poor network connectivity (3.17), lack of training centres (3.13), lack of data confidentiality and encryption (3.09), the requirement of extra budget to acquire IoT technologies (3.04), and lack of confidence in the technologies (3.04). collectively, the significant challenges for the consultants and contractors were a lack of training centres, lack of IoT awareness, lack of expertise, poor network connectivity, the requirement of extra budget to acquire IoT technologies, and poor collaboration among construction stakeholders.

All the challenges investigated were found to be averagely significant for the respondents of the study except for heterogeneity of connected technologies, and naming and identity management issues which were slightly rated to be significant. The study further tested if there were differences in the opinions of the consultants and contractors on the challenges of adopting IoT technologies in the construction industry. The findings established that there were no significant differences (P > 0.05) in the opinions of the consultants and contractors on the challenges of adopting IoT technologies in the construction industry.

Challenges of IoT adoption	Mean Consultants	R	Mean contractors	R	Overall mean	Overall Rank	P. Val.	Dec.	Sig.
Lack of training centres	3.20	3	3.13	2	3.15	1	0.888	AS	NS
Lack of IoT awareness	3.60	1	2.91	10	3.12	2	0.172	AS	NS
Lack of expertise	3.40	2	2.91	10	3.06	4	0.268	AS	NS
Poor network connectivity	2.70	13	3.17	1	3.03	5	0.329	AS	NS
Requirement of extra budget to acquire IoT technologies	3.00	9	3.04	5	3.03	6	0.934	AS	NS
Poor collaboration among construction parties	3.10	6	2.96	7	3.00	7	0.758	AS	NS
Lack of support from government	3.20	3	2.87	13	2.97	8	0.480	AS	NS
Improper introduction of IoT	3.20	3	2.78	17	2.91	9	0.432	AS	NS
Lack of IoT technology	2.80	10	2.96	7	2.91	10	0.748	AS	NS
Legalization issues	2.70	13	2.78	17	2.76	18	0.841	AS	NS
The complexity of use/not user-friendly	2.70	13	2.74	19	2.73	19	0.932	AS	NS
Lack of documented standards	2.30	22	2.87	13	2.70	20	0.220	AS	NS
The negative impact on society	2.20	26	2.91	10	2.70	20	0.097	AS	NS
Big data issue	2.40	19	2.74	19	2.64	22	0.498	AS	NS
Interoperability issue	2.40	19	2.70	22	2.61	23	0.457	AS	NS
Compatibility and longevity	2.70	13	2.52	27	2.58	24	0.681	AS	NS
Inaccuracy of data	2.40	19	2.61	25	2.55	25	0.667	AS	NS
Heterogeneity of connected things	2.30	22	2.57	26	2.48	26	0.530	SS	NS

Naming and identity management issues	2.00	27	2.65	24	2.45	27	0.126	SS	NS

NS – Not significant = < 1.50, SS – Slightly significant = 1.50 - 2.49, AS – Averagely significant = 2.50 - 3.49, S – significant = 3.50 - 4.49, VS – Very significant = > 4.50. NS = No significant difference (P > 0.05), S = Significant difference (P < 0.05). Dec. = Decision, Sig. = significance

Table 6: Challenges of adopting IoT technologies in the construction industry

Discussion of findings

This study investigated the level of adoption, the application and the challenges of adopting IoT in the construction industry. From the results, it is apparent that the level of adoption of IoT technologies in the Rwandan construction industry is still low as none of the IoT technologies is well adopted. Two of the technologies were adopted and eleven were averagely adopted. These findings are similar to the work of Tang et al. (2019) in Malaysia where only a few construction organizations were willing to adopt IoT technologies. The findings also agree with Islam et al. (2018), Maru et al. (2020), Dilakshan et al. (2021), and Ibrahim et al. (2021) on the adoption of wearable devices, websites, e-tenders, Close-Circuit Television (CCTV), Global Positioning System (GPS) tracker, General Packet Radio Service (GPRS), Building Information Model (BIM), site sensors, social media, wi-fi, smartwatches, Enterprise Resource Planning (ERP), google map, fuel-saving sensors, lighting and electricity sensors, scan marker, e-tendering, websites, social media, GPS tracker, online price quote, fire threatening sensors, automatic lamp, and smart locks. However, the result is not consistent with the study of Gamil et al. (2020) which noted that 63 per cent of stakeholders (government, clients, consultants, contractors, professional bodies, etc.) have prior knowledge of IoT technologies and adopt them.

This study further indicated that the level of adoption and application of IoT technologies is still very low. This is evident in the opinions of the respondents on the level of adoption of IoT technologies which is currently at the level of averagely adopted. The application further shows that many of the IoT technologies are not used in the Rwandan construction industry. Hence, the findings of the study agree with Maru et al. (2020), Kochovski and Stankovski (2018), and Ibrahim et al (2021) on the application of IoT technologies for smart communication, Building Information Modelling (BIM), efficient transportation, security control, site security, project management, environmental monitoring and power, fuel and energy management. The agreement between these studies is not unexpected because IoT technologies are expected to have universal applications across the construction industry.

In addition, the findings of this study agree with Ibrahim et al (2021) on the significance of lack of expertise, the requirement of extra budget to acquire IoT technologies, lack of training centres, lack of benefit awareness, the improper introduction of IoT into the construction process, and poor network connectivity as the challenges of adopting IoT technologies. The findings also concur with Maru et al. (2020) on the improper lack of expertise, poor collaboration among construction parties, lack of IoT experience, lack of support from the government and poor network connectivity. Furthermore, the findings are in agreement with Takki (2019) on information privacy issues, lack of data confidentiality and encryption, lack of documented standards, high cost of implementation, lack of support from the government, and the complexity of use/not user-friendly. These results are a pointer that there are still many challenges associated with the adoption of IoT in many countries and these challenges require urgent attention, especially in the era of transition to the fifth industrial revolution where human creativity meets machine intelligence.

Conclusion

Generally, the adoption of IoT technologies in the construction industry is increasing across the globe and it is becoming unavoidable for professionals in the fourth industrial revolution. The study investigates the level of adoption, the application and the challenges of adopting IoT technologies in the Rwandan construction industry. Based on the findings of the study, it was concluded the level of adoption of IoT technologies in Rwandan construction is still low. This is evident in the opinions of the respondents which indicated that none of the investigated technologies is "well adopted", two are "adopted", eleven are "averagely adopted" and twenty-two of the technologies are "slightly adopted". The study also concluded that there is no significant difference in the level of adoption of IoT technologies between the consultants and contractors except in the adoption of scan markers. There is also no significant difference in the level of adoption of IoT technologies between the engineers and the architects/quantity surveyors.

Based on the low adoption of IoT technologies, the applications are also few and basically at a low level as only the GPS, GPRS, google maps, social media, BIM, temperature and humidity sensors, smartwatches, e-tender, wi-fi, ERP and CCTV were applied by the respondents. Hence, IoT technologies are only applied for project management, production of site plans, the efficiency of transportation, environmental monitoring, Building Information Modelling, security control, smart communication, information sharing, general surveying, time management, power, fuel and energy savings. Furthermore, there are many averagely significant challenges hindering the adoption of IoT technologies in the Rwandan construction industry. The respondents probably rated the challenges as averagely significant because they do not hamper the traditional construction management techniques that the respondents are very familiar with.

Therefore, it was recommended that awareness of the various IoT technologies, their benefits and mitigation strategies for the challenges of adopting the technologies need to be done through the professional bodies, the academia and the concerned government parastatal. Also, there is a need to stir the adoption of IoT technologies with the enactment of government policies. This study covers building construction projects. It will be interesting to have a similar study conducted on other types of construction projects like highways and telecommunication. This will enable the comparison of the level of adoption, application and challenges of adopting IoT technologies with that of building projects. Also, future studies are required to investigate the factors influencing the adoption of IoT and the benefits of adopting IoT in the Rwandan construction industry.

Theoretical and managerial implications of the study

The importance of adopting IoT technologies in the fourth/fifth industrial revolution in the construction industry cannot be overemphasized. While the applications and challenges of adopting IoT technologies in developed and developing nations have been identified, the Rwanda construction industry is bereft of empirical data to substantiate the level of application and challenges of adopting IoT technologies in its construction industry. This situation precludes effective mitigation strategies to the barriers to adopting IoT technologies. This study provides a direction for the effective adoption of IoT technologies in the construction industry as it indicates the specific significant challenges to be mitigated. It complements existing studies on the application and challenges of adopting IoT technologies in the construction industry.

This study is useful to construction stakeholders as it gives vital information on the application and challenges of adopting IoT technologies in the construction industry. This study informs the stakeholders that the level of application of IoT technologies for both the consultants and the contractors is still low. It also indicates that there are many significant challenges to be mitigated if the adoption of IoT technologies is to be significantly improved. Similarly, the findings of the study are beneficial to the government/policymakers as it provides a basis for the specific challenges to be tackled with policy creation to improve the application of IoT technologies.

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