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Applications and Challenges of Adopting the 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 were 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 using 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 was low and there was no difference in the opinions of the respondents on the adoption and challenges of adopting IoT technologies in the construction industry. The study recommends the spread of 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 USD15 trillion by 2030 (Osei, Ennin and Aglobitse, 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 Labor Organization, 2018). Despite this acknowledged growth, the industry appears to be largely dominated by traditional construction techniques, which lack the adoption of digital technologies such as the Internet of Things (IoT),

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artificial intelligence, virtual reality and three-dimensional (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). The IoT has been noted to have the ability to improve sustainable construction management, communication among stakeholders and business activities (Halim, Rusuli and Yaziz, 2021). Also, the adoption of IoT ensures that project lifecycles become more manageable, employees' productivity on-site improves, project progress on-site is better tracked, environmental sustainability is 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 has already taken advantage of the improved performance of its construction industry. Also, many construction professionals are still reluctant to adopt it due to organisational, environmental, social and political reasons.

Islam, Hendra and Asan (2018) investigated the adoption of IoT by government agencies, developers, architects, engineers, quantity surveyors and class G7 contractors in Malaysia. Chen et al. (2020) assessed factors influencing practitioners' willingness to adopt IoT in Taiwan's construction industry. Arslan, Ulubeyli and Kazaz (2019) investigated IoT technologies and the practical implications of their adoption in the Turkish construction industry. Kumar and Shoghli (2018) analysed the role of the IoT 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, Charanya and Madhumitha (2020) examined smart home automation in India using IoT. Halim, Rusuli and Yaziz (2021) investigated the adoption of IoT among contractors in the Malaysian construction industry. Based on the studies, it is evident that researchers have made efforts to determine the state of adoption of IoT in their respective countries in order 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 were to investigate the level of adoption, application and challenges of adopting IoT technologies in the Rwandan construction industry. This study supplements existing studies on the adoption of IoT in the construction industry. It also provides 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. 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 is 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, Okwara and Ugboaja, 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) discovered that the IoT technologies that were mostly used in the Sri Lankan construction industry were 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 modelling (BIM) and site sensors. Maru, Pitroda and Raval (2020) found that the IoT technologies that were used for construction work in India were microcontrollers, Wi-Fi, e-health monitoring, drones, smartwatches, CCTV, enterprise resource planning (ERP), RFID, Google Maps, 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, email, 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.

Meanwhile, Ibrahim et al. (2021) revealed that the most adopted IoT technologies in Malaysian construction sites for smart communication were WhatsApp, Telegram, social media (Facebook and Instagram), video calls and email. In addition, Mahmud, Assan and Islam (2018) discovered that the IoT technologies adopted by government agencies, developers, architects, engineers, quantity surveyors and class G7 contractors in the Malaysian construction industry were WhatsApp, Telegram, Facebook Messenger, email and GPRS, and the least-adopted IoT-based technologies are sensor technology, Scan-Marker and Smartwatch, among others. Mahmud, Assan and Islam (2018) added that the IoT technologies used on Malaysian construction sites were 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.

Ibrahim et al. (2021) explained that social media platforms assist in 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 also used for material tracking on the site. Maru, Pitroda and Raval (2020) revealed that the applications of IoT for construction projects were smart communication, supply chain, remote operation, maintenance of machines, augmented reality (AR), fuel and energy management, BIM, efficient transportation, workers' management, security control, workers' health check, environmental monitoring and waste management. Ghosh et al. (2019) also noted that IoT was useful for safety monitoring, data visualisation, structural engineering applications, prefabricated construction, cloud-based platform and construction waste management.

Cheung et al. (2018) explained that applications of IoT included localisation and safety management, facility and environmental monitoring, building and infrastructure monitoring, resource management and optimisation, equipment automation and efficient management. Kochovski and Stankovski (2018) found that IoT was 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 were the 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) found the use of simulated IoT water management for efficient rice irrigation in Rwanda as IoT could increase the resilience of the agricultural sector, where there was high demand for water efficiency.

In short, the reviewed literature indicates that IoT was utilised in construction projects in developed and developing countries. However, there has been limited empirical data to establish the level of application of IoT in the Rwandan construction industry. Hence, this study investigated the application of IoT in the Rwandan construction industry.

Challenges of Adopting IoT Technologies in the Construction Industry

Organisations adopt IoT with the expectation of certain benefits that may lead to unexpected structural changes that require mitigation on construction projects (Brous, Janssen and Herder, 2019). Some organisations underestimate the potential of adopting IoT technologies and fail to fully understand the organisational conditions and consequences associated with the successful adoption of IoT. Nevertheless, the benefits of adopting IoT technologies are only achieved when institutional conditions are met and their consequences are 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) note that the challenges of adopting IoT include the limited number of experts who know how to operate IoT devices, the additional cost to the organisation to train employees on the use of IoT devices, the high cost of getting IoT devices, the conduct of regular maintenance, the unavailability or limited availability of internet connectivity, the lack of awareness among construction players, the reluctance to change, the lack of regulatory standards, the lack of budget to purchase and install new technologies and the lack of government enforcement on the adoption of IoT. Ghosh et al. (2018) also find 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) establishes that the major challenges hindering the adoption of IoT in the construction industry are the hesitation to adopt IoT technologies, the lack of categorised and shared project knowledge, the low acceptance rate, the poor data security and protection, the high implementation costs, the changes in organisational and process, the lack of standards and reference architecture, the incompliance of regulatory, the legal and contractual uncertainty, the post-construction issues, the need for enhanced skills, the higher requirements for a computing environment, the need for enhancement of the existing communication network, the lack of documentation of the results of adopted IoT solutions, the issues with selecting the best IoT solution, the complexity of IoT technologies, the lack of information exchange in decision making and the scalability issues with existing IoT solutions.

Furthermore, Tang et al. (2019) affirm 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 are the challenges of adopting IoT in the construction industry discovered by Musfira and Cassim (2018). However, Chen et al. (2020) find 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.

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

Challenges	**Sources**	**Country/Methodology**
The expectation of certain benefits sometimes leads to unexpected structural changes that require mitigation.	Brous, Janssen and Herder (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 architecture, engineering and construction journals

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Table 1. *Continued*

Challenges	Sources	Country/Methodology
The limited number of experts who know how to operate IoT devices, additional cost to the organisation 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 categorised and shared project knowledge, low acceptance rate, data security and protection, high implementation costs, organisational 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.	Takki (2019)	Finland and Sweden
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

From the literature review, IoT technologies were adopted in developed and developing countries to benefit construction stakeholders and the project. However, in Rwanda, there has been 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 examined the level of adoption and the challenges of adopting IoT technologies in the Rwandan construction industry. The study supplements existing studies on IoT by establishing 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 generalise its findings (Bird, 2009). The variables tested for the adoption and challenges of IoT technologies in the construction industry were based on the extant review of relevant literature.

The population of the study was the professionals working on construction projects and had offices in Kigali, Rwanda. Kigali was used for the study because most construction projects in Rwanda were executed in Kigali, a business hub, capital city, centre of government administration and the most populated part of the country. The Rwandan government recognises two professional bodies in the construction industry. They are the Rwanda Institute of Architects (RIA), which consists of architects and 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 both professional bodies (RIA and IER).

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 was 801 engineers, 95 architects and 62 quantity surveyors. The study adopted the stratified random sampling technique. The strata were 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 was 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 on Google Forms and administered via online means (emails, WhatsApp and telegram) between August 2021 and December 2021 since physical access and visits to offices were prohibited during this period due to the COVID-19 restrictions. The questionnaire was divided into two sections which were Section One: General information of respondents and their organisations and 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 required respondents to describe the use of each IoT technology in 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").

A total of 66 copies of the study questionnaire, representing 38.15% of the sample size of the current study, were filled and used for the study. A low response rate is common in the construction industry, as indicated by Dosumu (2013), who received a 21% response rate and by Bamgbade, Nawi and Kamarudeen (2016), who received a 25% response rate. The Statistical Package for Social Scientists (SPSS) was used to analyse the data collected for the study. Section One was analysed with frequency and percentages. Section Two was analysed with inferential statistics such as mean, *t*-test and analysis of variance.

RESULTS AND DISCUSSION

Table 2 indicates the general information of the respondents of the study. The male respondents comprised 81.8% and the female respondents comprised 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 worked 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%. The percentage of quantity surveyors in the study was 36.37% and of architects was 21.21%. In addition, 30.3% of the respondents offered consultancy services and 69.7% offered contracting services. There were 24.24% of respondents with advanced level certificates, 72.76% with bachelor's degrees and 3.00% with master's degrees. In addition, 51.55%, 45.45% and 3.00% of the respondents had less than 2 years, 3 years to 5 years and 6 years to 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 respondents of this study, it could be affirmed that the information provided for the study was reliable and usable for analysis.

Table 2. General information of the respondents

General Information of Respondents	Option	Frequency	%
Gender	Male	54	81.80
	Female	12	18.20
	Total	66	100.00
Work sector	Public	24	36.40
	Private	42	63.60
	Total	66	100.00
Type of project	Commercial projects	21	31.82
	Institutional projects	16	24.24
	Residential projects	29	43.94
	Total	66	100.00

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Table 2. *Continued*

General Information of Respondents	Option	Frequency	%
Academic qualification	Architecture	14	21.21
	Quantity surveying	24	36.37
	Engineering	28	42.42
	Total	66	100.00
Nature	Consultants	20	30.30
	Contractors	46	69.70
	Total	66	100.00
Academic qualification	A-Level	16	24.24
	Bachelor of Science (BSc)	48	72.76
	Master of Science (MSc)	2	3.00
	Total	66	100.00
Working experience	Less than 2 years	34	51.55
	3 years to 5 years	30	45.45
	6 years to 9 years	2	3.00
	Total	66	100.00
Professional qualification	RIA	38	57.58
	IER	28	42.42
	Total	66	100.00

Table 3 presents 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 were Wi-Fi (3.53), Google Maps (3.21), social media (3.21), websites (3.21), GPS (3.05) and BIM (3.00). 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). For the architects and quantity surveyors, the most adopted IoT technologies were Wi-Fi (3.80), Google Maps (3.70), social media (3.40), websites (3.20), e-tender (3.20), gas/air quality monitoring sensors (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).

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

IoT Technologies	Engineers	Rank	Architects/Quantity Surveyors	Rank	Overall Mean	Overall Rank	Decision	Sig. (2-tailed)	Decision
Wi-Fi	3.53	1	3.80	1	3.67	1	A	0.612	NS
Google Maps	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
BIM	3.00	6	2.80	13	3.09	5	AA	0.737	NS
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
CCTV	2.42	12	3.20	4	2.76	9	AA	0.147	NS
Gas/Air quality monitoring sensors	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

Note: 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 ($p < 0.05$).

In summary, out of the 35 IoT technologies investigated, Wi-Fi and Google Maps were the most adopted IoT technologies. Websites, social media, BIM, GPS, e-tender, automatic lamps, CCTV, air quality, fire threat and building monitoring sensors were adopted at an average level. The rest of the technologies were only adopted at a minimal level. The current study then adopted the *t*-test statistics to establish if there was 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 ($0.02 < p < 0.05$).

Table 4 presents the level of adoption of IoT technologies between consultants and contractors. The most adopted IoT technologies among consultants were Wi-Fi (3.20), Google Maps (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 sensors (1.70), e-Health monitors (1.70) and RFID (1.70) were the least adopted IoT technologies among consultants. The most adopted IoT technologies among 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 among contractors. Collectively, the most adopted IoT technologies among consultants and contractors were Wi-Fi, Google Maps, social media, websites, BIM and GPS. In contrast, the least adopted were 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 Maps were mostly adopted. The website, social media, BIM, GPS, e-tender, automatic lamp, CCTV, air quality, fire threat sensors and building monitoring sensors were averagely 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 was a difference in the level of adoption of IoT technologies between consultants and contractors. The study found no significant difference ($p > 0.05$) in the level of adoption of IoT technologies between consultants and contractors. This means that the IoT technologies adoption level among contractors and consultants was similar. Therefore, improved methods of IoT adoption should be applied to both categories of respondents.

Table 5 displays 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, thereby requiring the respondents to respond to the types of technologies used. A content analysis of the responses was done and presented in Table 5. It was found that 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 contractors, GPS and Google Maps were used for general surveying and efficient transportation, ERP was used for project management, smartwatches were used for time management and Wi-Fi and e-tendering were used for smart communication and sharing of information. Also, 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.

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

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 Maps	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
BIM	3.10	5	3.09	6	3.09	5	AA	0.982	NS
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
CCTV	2.90	9	2.70	10	2.76	9	AA	0.705	NS
Gas/Air quality monitoring sensors	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

Note: 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 5. Application of IoT technologies in the construction industry

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 Maps	General surveying, Production of site plans and efficient transportation
	Fire threat, temperature and humidity sensors	Environmental monitoring
Contractors	GPS and Google Maps	General surveying and efficient transportation
	Smartwatch	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 Maps	efficient transportation and production of site plans
	E-tenders, websites and social media	Smart communication and sharing of information
	Smartwatch	Time management
	Lighting, electricity and fuel-usage sensors	Power, fuel and energy savings
Engineers	GPS and Google Maps	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

Similarly, the architects and quantity surveyors applied the GPS and Google Maps for the production of site plans and efficient transportation, e-tendering, websites and social media were used for smart communication and sharing of information and smartwatches were used for time management, lighting, electricity and fuel usage sensors were used for power, fuel and energy savings. The engineers applied GPS and Google Maps 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 and BIM for 3D building plans and collaboration. The result of the study showed that IoT technologies were used in the Rwandan construction industry for project management, production of site plans, transportation management, environmental monitoring, collaboration among project stakeholders and designers, security control, smart communication, information sharing, general surveying, time management, power, fuel and energy savings.

Table 6 showcases the challenges that hinder the adoption of IoT technologies in the Rwandan construction industry based on the responses of consultants and contractors. The top significant challenges of 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), the 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 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). In general, the most significant challenges for 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 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 consultants and contractors on the challenges of adopting IoT technologies in the construction industry.

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

Challenges of IoT Adoption	Consultants		Contractors		Overall		Probability Value	Dec.	Sig.
	Mean	*R*	Mean	*R*	Mean	Rank			
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 the 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
Legalisation 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

Note: 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.

DISCUSSION OF FINDINGS

This study investigated the level of adoption, the application and the challenges of adopting IoT technologies 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. Only a total of two 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 organisations were willing to adopt IoT technologies. The current findings also agree with Mahmud, Assan and Islam (2018), Maru, Pitroda and Raval (2020), Dilakshan et al. (2021) and Ibrahim et al. (2021) on the adoption of wearable devices, websites, e-tenders, CCTV, GPS tracker, GPRS, BIM, site sensors, social media, Wi-Fi, smartwatches, ERP, Google Maps, 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 current finding is inconsistent with those in the study by Gamil and Alhagar (2020), which noted that 63% of stakeholders, such as government, clients, consultants, contractors and professional bodies, have prior knowledge of IoT technologies and adopt them.

This study further indicates 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 IoT technologies have not been used in the Rwandan construction industry. Hence, the findings of the current study agree with Maru, Pitroda and Raval (2020), Kochovski and Stankovski (2018) and Ibrahim et al. (2021) on the application of IoT technologies for smart communication, BIM, efficient transportation, security control, site security, project management, environmental monitoring and power, fuel and energy management. The agreement between these studies is expected because IoT technologies 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, Pitroda and Raval (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. However, the current 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. These results emphasise that many challenges associated with adopting IoT technologies in many countries require urgent attention, especially in the transition era to the fifth industrial revolution, where human creativity meets machine intelligence.

CONCLUSIONS

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 investigated 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 is concluded the level of adoption of IoT technologies in Rwandan construction is still low. This is evident in the opinions of the respondents that none of the investigated technologies was "Well adopted", 2 were "Adopted", 11 were "Averagely adopted" and 22 of the technologies were "Slightly adopted". The study concludes that there is no significant difference in the adoption of IoT technologies between 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 engineers, architects and quantity surveyors.

Based on the low adoption and the limited number of IoT technologies, only GPS, GPRS, Google Maps, social media, BIM, temperature and humidity sensors, smartwatches, e-tender, Wi-Fi, ERP and CCTV were applied by respondents in the current study. It is discovered that IoT technologies are only applied for project management, production of site plans, transportation efficiency, environmental monitoring, BIM, security control, smart communication, information sharing, general surveying, time management and 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 might have 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 is recommended that awareness of the various IoT technologies, their benefits and mitigation strategies for the challenges of adopting the technologies be done through professional bodies, academia and concerned government parastatal. Also, there is a need to include the adoption of IoT technologies in the enactment of government policies. Even though the current study covered building construction projects, a similar study conducted on other construction projects like highways and telecommunication would be interesting as the study could make comparisons of the level of adoption, application and challenges of adopting IoT technologies between construction projects. Also, future studies can 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 and fifth industrial revolutions in the construction industry cannot be overemphasised. 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 and the need for challenges to be mitigated.

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 and complements existing studies on the application and challenges of adopting IoT technologies in the construction industry. This study informs stakeholders of the level of application of IoT technologies among consultants and contractors, which is still low. It 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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