Journal of Information Systems and Informatics
Vol. 7, No. 2, June 2025 e-ISSN: **2656-4882** p-ISSN: **2656-5935**
DOI: 10.51519/journalisi.v7i2.1138 Published By DRPM-UBD

Mapping the Global ICT Research Trends in the Construction Sector

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Abstract

Information and communication technology (ICT) has not been widely adopted in the construction sector, despite its promise to improve productivity, safety, communication, efficiency, and sustainability. Prior research has made clear that further research and development in this field are required to improve its application for project delivery and organisational performance, particularly in developing countries. To determine the area of focus of earlier studies, this paper reviewed ICT in fields relevant to construction. Utilising a bibliometric methodology, the data for this study were taken from the Scopus database. Keyword searches were used to search the database, such as "Information communication technology/technologies", "Information communication", "Communication technology", and "Construction or Construction industry", to obtain pertinent papers. The papers analysed were 96 in number from 2014-2024. Using VOSviewer, a network and overlay visualisation map of the co-occurrence keywords was produced based on the gathered bibliographic data. The findings indicated that earlier research in ICT gave priority to information and data management, project design, sustainable project management, power transmission and smart grids, construction project communication, and safety management and training. Furthermore, research in this area is currently concentrating on big data applications, smart city applications, and sustainable development applications. The results highlight a knowledge vacuum in which South American and African nations might investigate to enhance construction project delivery and organisational performance. This work adds to the conversation around ICT, which has not gotten much attention in recent scientometric and bibliometric research.

Keywords: Bibliometric Analysis, Construction Digitisation, Construction Industry, Emerging Technologies, Information Communication Technology.

1. INTRODUCTION

The construction industry (CI) is fraught with complex and dynamic activities as well as complex relationships, requiring the need for an efficient communication system. The CI accounts for 6–13% of the global economy and 8% of developing countries' gross domestic product (GDP) [1, 2]. An efficient communication system will enhance the actualisation of the organisational goals in industry, which will, in turn, contribute to the improvement of the GDP contribution. It is also

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evident that improving project performance is still a crucial component of the global CI's gradual improvement, and as such, it merits careful thought [3, 4]. Similarly, there is a long-standing need for incessant advancement in the current construction processes to help solve the issues of delayed access to vital information that could boost worker safety, better material and construction management, and improve participant communication in projects [5, 6].

However, conventional practices are still prevalent, particularly in developing countries. According to Afolabi et al. [7], the CI's dependence on the conventional way of paper-based data processing, transmission, and storage has resulted in information and communication gaps and related downsides. Also, there have been hitches in free-flow communication that have negatively impacted on organisational performance [8]. Construction errors can result from inadequate communication, which can cause design blunders, incomplete or outdated drawings, delays, overspending, subpar work, and design conflicts [9]. Besides, construction organisations are faced with competitive pressure to deliver projects faster, with higher quality and greater value, along with clients seeking the availability of current information at every stage of the project [6, 10]. Additionally, firms' primary challenge in fulfilling client expectations is figuring out how to enhance construction project performance and increase the efficacy of project management expertise [8, 11, 12]. Using innovative technologies such as ICT applications in construction projects has been identified as one of the solutions for project delivery efficiency and sustainability performance [8, 11, 13], something the CI sorely needs, particularly in developing economies. ICT applications will reduce the difficulties of communication surrounding the CI. "The quality, quantity, and timeliness of information play a critical role as they can either hinder or facilitate successful outcomes" [6].

Unfortunately, the CI worldwide has lagged in embracing new technologies compared to the finance, manufacturing and telecommunication sectors [14, 15]. For instance, compared to other industries, the building and construction industry invests very little in ICT [16]. "ICT could be used to manage the site and improve integration, collaboration, knowledge management and procurement processes" [16]. ICT is needed to manage a variety of documents and information, make decisions, and provide information in the CI that is consistent and reliable [8, 17]. Despite the growing academic emphasis on the adoption of ICT in construction studies. No recent work has attempted to bibliometrically assess and analyse what has been recently reported in the literature or identify the present and future trends. A decade ago, [18] investigated the impact of ICT on construction projects with a literature review. Other studies with literature review on ICT include [11, 19]. Several studies have also investigated the challenges to ICT adoption in construction [20, 21, 22, 23]. Likewise, studies in developed nations have highlighted the essence/benefits of adopting ICT [24] and the impact of ICT [18,

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25]. However, there is a dearth of bibliometric reviews on the concept. A study by [6] investigated the Influence of ICT Application in Construction Jobsites using bibliometric analysis, considering the period from 2009 to 2023. Consequently, the current study is unique and novel because it provides a broad scope and recent bibliometric review on ICT adoption research, which is different from what others have done. The objective of this study is to determine the ICT research trends and highlight the areas of emphasis as well as recommended areas for improvement in construction-related studies. The study considered publications from 2014 to 2024. This work is divided into five principal sections: the first section is the study's background, the second is the literature review discussing an overview of ICT, its application and adoption in construction. The third covers the methodological steps taken. The fourth presents the results and discussion, while the fifth section presents the conclusion of the study.

2. LITERATURE REVIEW

2.1 Overview of Information Communication Technology (ICT)

ICT is described as any technology that is utilised for information collection, transfer, retrieval, storage, access, display, or modification [8, 26]. It addresses how information can be converted, stored, protected, processed, sent, and securely retrieved using electronic computers and computer software [8, 27]. Similarly, the ICT Association of America (ITAA) defined it as the "study, design, development, implementation, support or management of computer-based information systems, particularly software applications and computer hardware" [27]. Moreover, "construction ICT entails the use of computer systems that are capable of capturing, organising, storing, analysing, exchanging, transmitting, and sharing information, namely, video conferencing, web-based project management, DBMS, data warehousing, and data mining" [11].

ICT innovations have been progressively expanding throughout many different countries in recent decades [13]. Consequently, this advancement made a major contribution to the international commerce of ICTs, such as semiconductors, office supplies, telecom equipment, and IT goods [13]. Organisations become more competitive when they use ICTs [13, 28]. Hence, it is impossible to minimise the importance of ICT in our present society. ICT has improved and eased many human tasks, and it has played an important role in many areas of life [29]. Its positive impact has been acknowledged in industries such as telecommunication, banking, the education sector, design and construction, and so on [15, 29]. Likewise, its contributions have been vital in both the industrialised and developing nations [29]. It has been observed that ICT is beneficial in cost reduction irrespective of its application in any field [30]. It has also been recognised for its contribution to time management efficiency [29]. Generally, it is widely

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acknowledged that ICT may greatly enhance an organisation's performance by facilitating the creation of innovative and creative project management techniques [8]. Eliwa et al. [31] further opined that the collaboration, cooperation, communication, and coordination of team members are improved in an organisation with a robust ICT infrastructure.

2.2 Information and Communication Technology in the Construction Industry: Application and Benefits

ICTs are being promoted by the global CI at the project and organisational levels [32, 33]. ICTs are currently being used by the CI more and more in areas including project management, design and construction, design, budgeting, cost control, computer-aided facilities management, scheduling and planning of projects, increased construction safety, and on-time project delivery [6, 33, 34]. Numerous ICT technologies used in the construction sector have been the subject of published works [35, 36, 37]. The predominant ICT-enabling technologies include virtual reality technology, wireless technology, web-based management systems, electronic data interchange/electronic data management systems, and BIM [6, 35]. Similarly, several scholars have affirmed that ICT applications like BIM, artificial intelligence, smart wearables, drones, virtual reality (VR) and augmented reality (AR), and data collection applications (DCA) have transformed traditional construction practices, thereby promoting the industry's progress [6, 38, 39]. Moreover, Pandey and Thampi [12] highlighted the applications of emerging ICT technologies such as drones, 5G, artificial intelligence and machine learning (ML), cloud computing/big data analytics, internet of things (IoT), AR and VR in construction. For instance, drones can be commonly used for mapping, surveying, and keeping a watch over building projects [12]. Drones provide aerial views for better site assessment, aid in logistics management, and increase safety by reducing the need for physical inspections in dangerous circumstances [12, 40]. 5G technologies enable faster data transmission and communication amongst linked construction devices. It can facilitate real-time cooperation and communication, enable the usage of IoT devices, and improve the speed and low latency of on-site operations and machinery [12]. Cloud computing can facilitate remote access to real-time project details, data storage, coordination, and collaboration, leading to flexibility of construction procedures and enabling teams to operate more safely and effectively [12, 41]. AI and ML can be applied to improve predictive analytics, project planning, decision-making, and risk management and can optimise resource allocation and project productivity [12]. Using AR and VR in construction can result in more productive and effective projects by boosting teamwork, decision-making, safety, and streamlining different procedures [12]. Furthermore, BIM can be utilised for project design, scheduling and estimating using tools like Revit, Navisworks and Cost-X [16, 42].

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In summary, increasing building efficiency requires innovation in the industry. ICT adoption promotes innovation in the sector and facilitates the adoption of new techniques and technology. This flexibility is essential to maintain competitiveness in a changing market [43]. By processing information and developing new paradigms for construction project management, ICT may help the CI achieve its goals. Additionally, it can boost the efficiency of building design and construction processes [43, 44]. In other words, higher productivity can be attained with ICT tools since possible problems can be found and fixed quickly. By reducing coordination errors and promoting improved communication among project participants, ICT can increase client satisfaction by facilitating more effective handling of requirements and obstacles [13]. Likewise, Dutta [45] also highlighted that ICT can foster collaboration among project participants and facilitate better communication. ICT allows for centralised data storage, minimising errors and enhancing collaboration by allowing all team members to update information in real time [45]. According to Camngca et al. [16], project managers find it simple to monitor the project formulation using ICT. Hence, with ICT tools like project management software, project management can be enhanced. Project drawings and other documents can be made accessible at any time, to anyone who needs them, from anywhere in the world, with ICT tools [16, 46]. ICT applications can be advantageous in managing projects on schedule and within budget [38]. ICT contributes to lower project costs overall by facilitating faster corrective actions and enhancing mistake tracking. It also reduces waste and maximises the use of resources [45]. Similarly, by maximising resource use and cutting waste, ICT helps promote more environmentally friendly building techniques. It also encourages the application of green building guidelines and procedures [45]. Overall, ICT applications improve safety by decreasing personnel's need to enter hazardous places and by assisting in more efficient monitoring and management of safety procedures [6]. It is widely acknowledged that ICT is not just a support tool but a critical component in modernising and improving the CI [6, 16, 44].

2.3 Adoption of Information and Communication Technology in the Construction Industry

The planning and adoption of ICT are critical for overall performance improvement, including sustainability initiatives in the construction industry. Many studies have been conducted regarding ICT predominantly in developed countries [6, 37]. Still, there remains a paucity of studies on the concept in developing countries, and the adoption of ICT has been slow [37]. This is because of several hurdles. Moshood et al. [37] highlighted the reluctance to shift from conventional practices in Nigeria. According to Moshood et al. [44], the adoption of ICT is still in the infancy stage, whereby construction organisations still rely on hand-operated channels like faxes, phones, and emails. Also, resistance to change is predominant in other developing countries [12, 16, 47]. Waqar et al. [47] categorised the ICT-

p-ISSN: **2656-5935** http://journal-isi.org/index.php/isi e-ISSN: **2656-4882**

impeding factors into five categories, namely, technological barriers, database barriers, privacy barriers, operational barriers, and management barriers. The study of Mutesi & Kyakula [48] in Uganda highlighted the issues of the high cost of investment, system and computer malfunction and virus attacks, poor security and privacy, cost of software upgrade, management commitment and so on. Ahuja et al. [17] study in India highlighted issues like poor supply-chain management among project stakeholders, silos in project stages, lack of standards and protocols that would inform any ICT investment decision, fragmentation of the CI characterized by companies small and big with different set of requirements and different level of ICT knowledge, cost of training of staffs, initial cost of ICT infrastructure installation, cost of upgrade with the technological developments in hardware/software and so on. These challenges were also echoed by Dixit et al. [33]. Aghimien et al. [49] study in South Africa discovered the predominant risks associated with digitalisation, which include an increase in unemployment, lack of required technical skills, additional cost requirements, data security/cyber-attacks and so on. Consequently, these risk factors have impeded the adoption of innovative technologies. Similarly, Camngca et al. [16] highlighted the underutilization of ICT in South Africa due to "lack of digitalization in construction projects implementation, inadequate system upgrades, lack of adequate ICT resources at the department, lack of financial resources for internet and software application subscriptions and lack of training leading to ICT skills insufficiency" [16]. Durdyev et al. [50] discovered cost issues and resistance to change from conventional practices as the top critical barriers encountered in Cambodia. Generally, the challenges mentioned have been the case for most developing/emerging economies.

3. RESEARCH METHODOLOGY

The purpose of this study was to determine the main topics of interest in publications about ICT construction. Therefore, a bibliometric methodology was employed to map the knowledge areas and identify research trends. For the investigation, relevant publications were found using the Scopus search engine. SCOPUS has been discovered to have wider coverage and indexes most papers on other databases like Web of Science, ScienceDirect, and Google Scholar [51]. Similarly, several studies acknowledged the prominence of Scopus as a more current and rapidly expanding database and a top option for literature searches [52, 53, 54, 55, 56].

The keywords utilised were "information communication technology/technologies", "Information communication", "Communication technology", and "Construction or Construction industry". The researchers adopted a 10-year time frame (2014 to 2024). The search took place on September 14, 2024. Only journals and conference papers were counted. The intention was

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to draw attention to the most important sources of knowledge [55]. Compared to other sources, journal articles and conference papers have been acknowledged as trustworthy sources of information that go through a rigorous peer review process [53, 57]. The search was first conducted without any field or language restriction, which yielded 214 publications. However, the search yielded 96 papers when it was limited to the English language domains related to construction. The construction-related fields the study considered were comprised of engineering, environmental science, computer science, social science, and energy. VOSviewer, a program appropriate for bibliometric literature evaluations, was used to graphically analyse the data [58]. Figure 1 depicts the process of research. The measures used to display the results include: "number of yearly publications", "publication per country", "publications by document source", "most cited papers", and "co-occurring analysis (keyword network and visualisation)". To better comprehend the subject being studied, the study additionally employed content analysis.

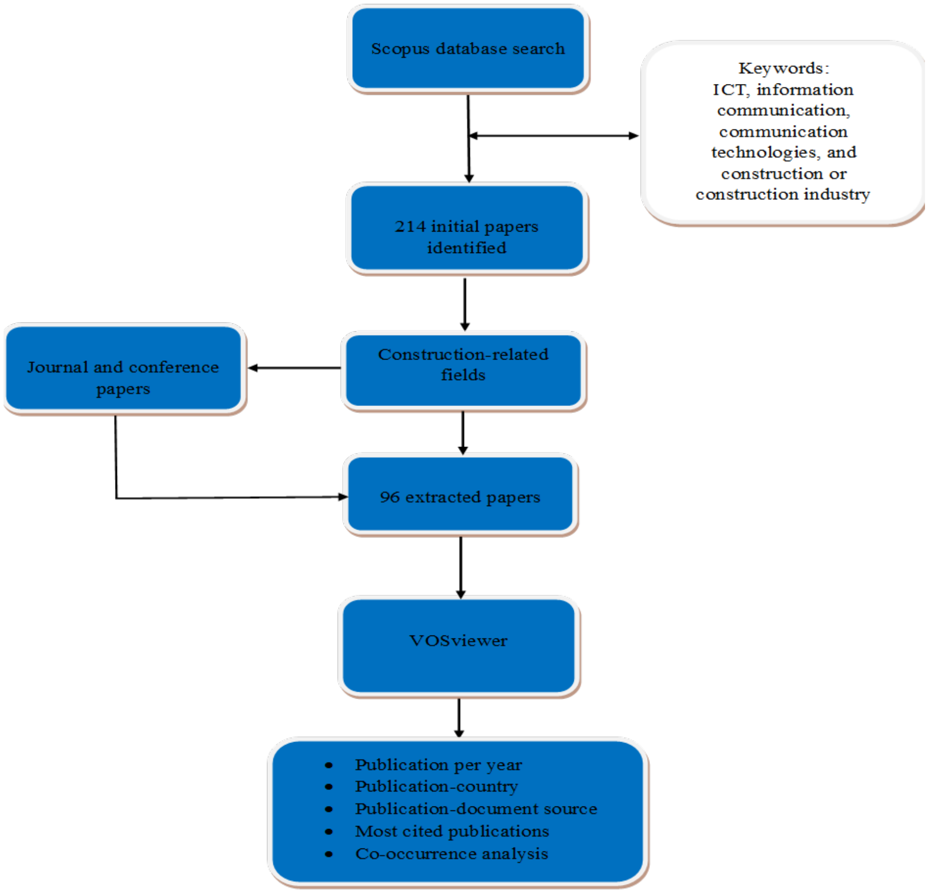

Figure 1. Research methodology flowchart

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4. RESULTS AND DISCUSSION

4.1. Publications Per Year

A total of 96 papers on ICT were extracted, 38 of which were conference papers, and the remaining 58 were journal articles. The yearly publications in disciplines connected to construction from 2014 to 2024 are depicted in Figure 2. Results showed eight publications in 2018, but decreased to six publications in 2015. However, there was a rise in 2016 and 2017 with 9 and 10 publications, respectively. Similarly, 2018 was the year with the most publications (14), following which there was a sharp decline to seven publications in 2019 and 2020. However, there was another rise to 9, 10, and 11 publications from 2021 to 2023, respectively and a drop to 5 publications in 2024. The results of this study generally show that there is little research on ICT in the CI in published works. The findings support the assertions by Moshood et al. [37] and Turk [59] that in CI, there is a dearth of research in ICT studies, adoption is slow, and implementation is rare. This contrasts with other industries that have adopted ICT concepts [14, 15]. The study's findings also imply that the construction industry needs additional articles that are indexed in Scopus.

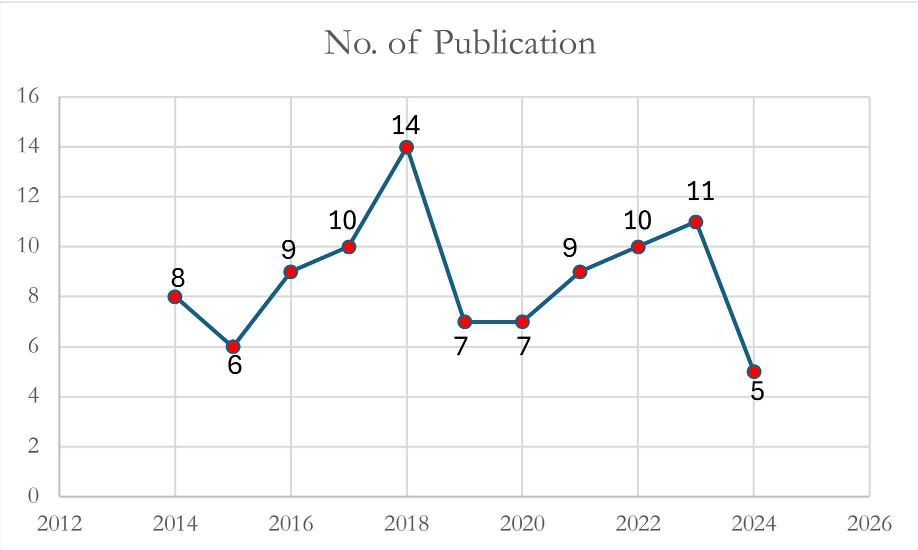

Figure 2. Number of yearly publications

4.2. Publication Per Document Source

From the 96 retrieved articles, 82 sources were found in the first search results with a minimum threshold of "1" document and citation. Nevertheless, 13 sources

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were identified as the most noteworthy sources after applying a criterion of two papers. With three papers and 65 citations, the Journal of Management in Engineering topped the list, as shown in Table I. The other top five sources included Automation in Construction (2 papers; 173 citations), Environmental Science and Pollution Research (2 papers; 45 citations), Journal of Engineering, Design and Technology (2 papers; 38 citations), and Sustainability (2 papers; 22 citations). Although the number of documents from the top-rated sources signifies their relevance and interest in ICT, the overall results indicate very scanty publications in these sources. Therefore, there is a need for additional document publications in sectors relevant to construction that are indexed using Scopus.

Table 1. Number of documents per source

Source	Number of documents	Citations
Journal of Management in Engineering	3	65
Automation in Construction	2	173
Environmental Science and Pollution Research	2	45
Journal of Engineering, Design and Technology	2	38
Sustainability	2	22
Matec Web of Conferences	2	11
Proceedings of the 37th International Symposium on Automation and Robotics in Construction, ISARC 2020: from Demonstration to Practical Use - to New Stage of Construction Robot	2	11
Jurnal Teknologi	2	10
IOP Conference Series: Earth and Environmental Science	2	6
IOP Conference Series: Materials Science and Engineering	2	4
Journal of Engineering and Applied Sciences	2	2
Advances In Environmental Biology	2	1
ACM International Conference Proceeding Series	2	0

4.3. Most Cited Publications

To fully comprehend the ICT research, it was necessary to analyse the retrieved publications to identify the most referenced papers and their main topics. Eleven of the 96 documents that were originally found were extracted with a 30-citation threshold. The most pertinent papers from studies of ICT were distinguished using the threshold. Hence, the papers with high citation counts indicate the importance and interest in advancing ICT for project execution and organisational performance. Similarly, most of the studies were case studies and experimental. This indicates that technological adoption is still evolving in construction, although receiving increasing attention [60].

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Table 2. Most cited documents

Source	Title	Citations	Method
[61]	On Condition-Based Maintenance Policy	248	Case Study
[62]	Factors for effective BIM governance.	148	Structured Interview
[63]	Artificial-intelligence-driven customised manufacturing factory: key technologies, applications, and challenges	131	Case study
[64]	Development of an early-warning system for site work in hot and humid environments: A case study.	115	Experimental
[65]	Predicting cyberbullying on social media in the big data era using machine learning algorithms: review of literature and open challenges.	110	Review
[66]	A framework of innovative learning for skill development in complex operational tasks.	58	Experimental
[9]	The development of building information modelling (BIM) definition.	51	Review
[67]	Cloud-based smart manufacturing for personalised candy packing application.	49	Experimental
[68]	Exploring the benefits of cloud computing for sustainable construction in Nigeria.	37	Questionnaire
[69]	The Aadhaar scheme: a cornerstone of a new citizenship regime in India?	34	Case Study
[32]	Understanding behavioral logic of information and communication technology adoption in small-and medium-sized construction enterprises: Empirical study from China.	31	Questionnaire

4.4. Publications per Country

Ten countries were extracted based on 5 document thresholds to ascertain which nations have dominated the field from the 96 publications that were downloaded. The revealed countries are shown in Figure 3. With 21 publications and 303 citations, China was first on the list. Followed by Malaysia (13 publications; 300 citations), Australia (8 publications; 209 citations), South Korea (7 publications, 452 citations), the UK (7 publications; 330 citations), and the US (7 publications; 189 citations). The findings show that more publications that are Scopus-indexed are critically required, particularly in developing African countries. Nigeria was the only country to meet the requirement. Therefore, there's a chance for other African nations to join the ICT conversation and add something substantial. Aghimien et al. [53] verified China, the UK, and the US as leaders in digital technologies research, and these conclusions are consistent with their findings. Similarly, the

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findings on Australia and South Korea are consistent with the study of OECD [70], as the countries were recognised as among the top-listed countries worldwide in digitalisation. Notably, the top-listed countries have also been acknowledged for their top ranking in digital competitiveness [71, 72].

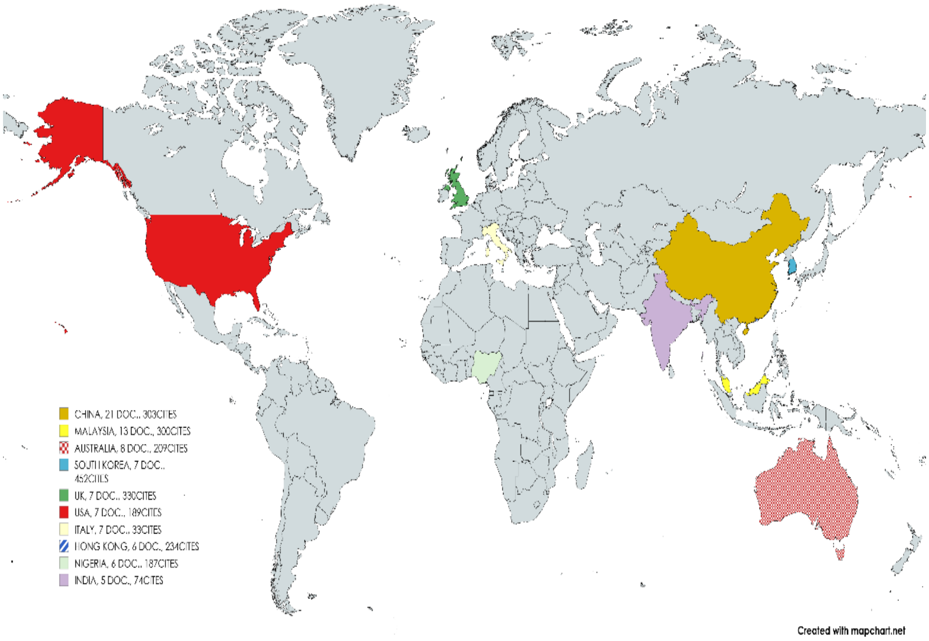

Figure 3. Publications per country

4.5. Research Focus Based on Co-occurring Networks

The focus subjects from the previous study were appropriately clarified with the creation of a keywords co-occurrence map. Author and indexed keywords were among the keywords. As a result, 958 keywords were contained in the 96 papers that were downloaded. As a result, grouping the keywords into summaries was necessary. When VOSviewer's default value of 5 co-occurrences was used, the number of keywords dramatically dropped to 15. Nevertheless, a 4-co-occurrence criterion was used to prevent the scarcity of terms, leading to the grouping of 27 co-occurring keywords into 6 clusters. A similar strategy was previously used by Aghimien et al. [53] and Aliu et al. [55]. In Figure 4, the keywords are mapped.

1) Information and Data Management (Cluster One)

Comprising eight items mapped with red, with a total link strength of 144. The items in their descending order of link strength include information

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communication technology, information and communication technology, information communication technologies, Internet of Things, Decision making, big data, smart city, and China. However, five keywords were considered after the removal of the redundant items. This cluster arrangement can subsequently be seen as keywords relating to ICT for information and data management - a methodical and astute approach to managing information and data across the many stages of building projects. Because the CI is so fragmented, efficient data and information management is essential to the success of projects, as it guarantees that all stakeholders have access to accurate, pertinent, and up-to-date information [6]. Recent studies have started to beam their lights in the direction of information and data management, especially in developing nations. Adekunle et al. [73] advocated the uptake of digital technologies for information management in South Africa. The findings revealed that utilising digital technology for information management in construction can advance wise decision-making, better resource utilisation, and sustainable economic growth [73]. Similarly, Li et al. [74] corroborate that the construction process should be improved throughout its whole life cycle by effectively utilising the enormous amount of various big data from several sources. It was also believed that construction sites would be safer with the use of big data applications in construction analytics [74]. Furthermore, Gbadamosi et al. [75] evaluated the contribution of IoT to smart construction and acknowledged its potency regarding information management and communication. For Li et al. [74], IoT has revolutionised the CI in the Industry 4.0 era. However, information and data management have been affected by network issues. For instance, because of poor internet speeds, the adoption of IoT has been sluggish, particularly in most African countries [53, 55, 76]. The cluster also confirms the McKinsey and Company [77] report that the future of digital innovation is being shaped by China's contributions to information and data management technologies, which have enormous global ramifications. Likewise, UP2China [78] reports that data management in the nation has expanded significantly due to China's dedication to becoming one of the world's leading tech powerhouses.

2) Project Design (Cluster Two)

This cluster, represented in green, is characterised by 5 items with a total link-strength of 90 (construction industry, building information modelling, building information modelling, architectural design, and surveys). Hence, this resulted in four keywords after the removal of redundant keywords. These keywords relate to ICT for project design in construction. Woodhead et al. [79] state that the shift from a reactive to an anticipatory approach to event control is made easier by the incorporation of BIM into IT infrastructure. Similarly, Emere et al. [80] corroborate that BIM is a vital modern building technique that can be used to achieve sustainable and efficient designs in construction. BIM speeds up the design and construction phases, lowering costs and shortening project completion times

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[81, 82]. A schedule, cost, sustainability, and maintenance are just a few of the factors that are integrated by BIM, which makes it possible to make better decisions at every stage of the project lifecycle [83]. Conversely, surveys appearing as keywords may suggest that quantitative studies have received notable attention on ICT, especially around project design.

3) Sustainable Project Management (Cluster Three)

Represented in blue, has four items with a total link strength of 62. The key keywords in their descending order of link strength include Project management, Sustainable development, Robotics, and agricultural robots. The keywords relate to sustainable project management, which refers to a method that incorporates environmental, social, and economic factors into the planning and execution of projects [84]. Project sustainability is more crucial than ever in our ever-changing world. This is corroborated by Hoeft et al. [85], who acknowledged that the creation of environmental, social, and economic sustainability ultimately depends on the sustainability of project management in construction projects. To ensure that output, outcomes, and benefits are sustainable throughout their life cycles as well as during their development, disposal, and decommissioning, projects must be sustainable on both an individual and organisational level [84]. Emere et al. [80] affirm that corporate dispositions such as commitment to innovative construction add to sustainable building construction. Similarly, Hoeft et al. [85] acknowledged the importance of robotics and automation in influencing the sustainability of public-private partnership (PPP) infrastructure projects. Robots are used in building/construction projects to carry out repetitive or hazardous jobs, increasing efficiency and safety while leaving a smaller environmental impact [86]. It can be beneficial for waste management and energy saving. To ensure effective and sustainable energy production, robots are used to maintain renewable energy infrastructure, such as solar panels and wind turbines [86]. This application, especially solar panels, has received increased attention in building construction [87]. Furthermore, agricultural robots like tractors and harvesters may be useful in construction when clearing sites for proposed new dwellings [86].

4) Power Transmission and Smart Grids (Cluster Four)

Represented in yellow are four items, which include construction, information management, electric power transmission, and smart power grids, with a total link strength of 62. Studies on the incorporation of ICT into power systems are evident. ICTs play a major role in the development of smart grids nowadays. ICT has made it possible to improve grid control, which has improved these systems' dependability and adaptability [88]. ICT plays a pivotal role in developing and managing smart grids within the CI [89]. Smart grids are modernised electrical grids that use digital technologies to improve sustainability, dependability and efficiency

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[89]. Real-time power flow measurement, control, and monitoring are made possible by ICT, thus improving energy distribution and lowering losses [90]. ICT makes it easier to integrate renewable energy sources—like solar and wind—into the grid, guaranteeing a steady and long-lasting supply of electricity [91]. ICT is used by smart grids to promptly identify and handle problems, reducing downtime and enhancing power distribution dependability [92]. In summary, more intelligent, effective, and sustainable power transmission systems can be built by utilising ICT.

5) Construction Project Communication (Cluster Five)

This cluster is mapped with purple. It includes keywords like communication, construction projects, ICT and factor analysis with a total link strength of 34. The need for sound communication in the CI cannot be overemphasised. It is fundamental to everyday social and working life. According to Mandičák et al. [93], one of the most important components of actively using cutting-edge technologies for the management of sustainable construction projects is having ICT and communication competencies. "This digital age requires systematic communication and project management" [93]. Harikrishnan et al. [94] explored the feasibility of augmented reality technology for communication. AR was perceived to be valuable for enhancing the communication between design and construction teams as well as aiding in inspections [86]. Similarly, several studies have emphasised the use of ICT for improving construction project communication [6, 95, 96]. Unfortunately, unclear/poor communication processes adopted by construction professionals, especially in developing nations, have caused disputes and deterred the performance and efficiency of the CI [97, 98, 99].
6) Safety Management and Training (Cluster Six): This cluster, represented in sky blue, has two keywords, which are accident prevention and personnel training. Hence, it was named Safety Management and Training. The application of ICT for safety management and training has been noted in past studies [100, 101]. According to Industry Tap [102], the CI's use of ICT is revolutionising safety management by improving real-time monitoring, predictive analysis, and overall safety measures. For instance, IoT and wearable technologies like smart helmets, vests, and watches monitor workers' vital signs, detect falls, and alert supervisors in case of emergencies [101, 103]. Similarly, by streamlining compliance, training, and documentation, digitising safety procedures helps guarantee that safety procedures are regularly followed and easily accessible [102, 104]. Additionally, offering detailed 3D models of construction sites through integrating BIM with VR and AR improves safety training and helps workers better perceive possible hazards and comprehend safety procedures [102]. Besides, by utilising drones for site inspections, monitoring places that are difficult to access, and spotting possible risks, personnel can spend less time in hazardous zones [104]. Furthermore, AI and big data can be utilised to assess safety incidents, forecast possible hazards, and create mitigation plans [105].

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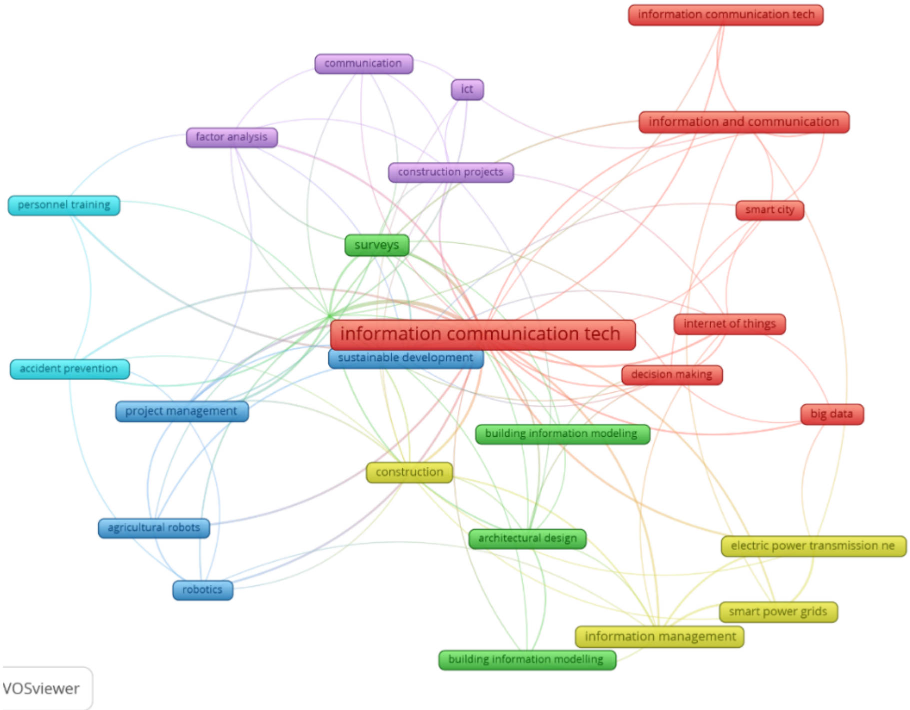

Figure 4. Network visualisation map for co-occurring keywords

4.6. Research Focus Based on the Year of Publication

Figure 5 displays the overlay visualisation network map for the co-occurring keywords. It was observed that, in at least four keywords, studies on ICT for project design and construction project communication became more noticeable between 2018 and 2019. The applicable keywords were depicted in purple and blue. Also, ICT was evident in accident prevention. From 2019 to 2021, ICT was emphasised in Power Transmission and Smart Grids, personnel training, and sustainable development. However, from 2021 to date, more focus has been on the use of big data for information and data management, decision making, project management and smart cities. Big data derives its true value from big data analytics, whereby a group of advanced technologies is used to manage enormous volumes of data [87, 106]. Big data analytics is the "process of analysing massive and diverse data sets to find hidden patterns, undiscovered correlations, market trends, customer preferences, and other valuable information that can help organisations make better business decisions, increase sustainability, and move society toward the circular economy" [87]. Big data powered by ICT allows for increased efficiency in the utilisation of data and better decision-making. Besides, it allows for the forecasting of future patterns and behaviours, which aids companies in

p-ISSN: **2656-5935** http://journal-isi.org/index.php/isi e-ISSN: **2656-4882**

foreseeing shifts in the market and client demands. Therefore, the effective utilisation of the enormous amount of data from various sources will improve the construction processes [74]. Li et al. [74] further assert that construction sites will be safer with the use of big data applications in construction analytics.

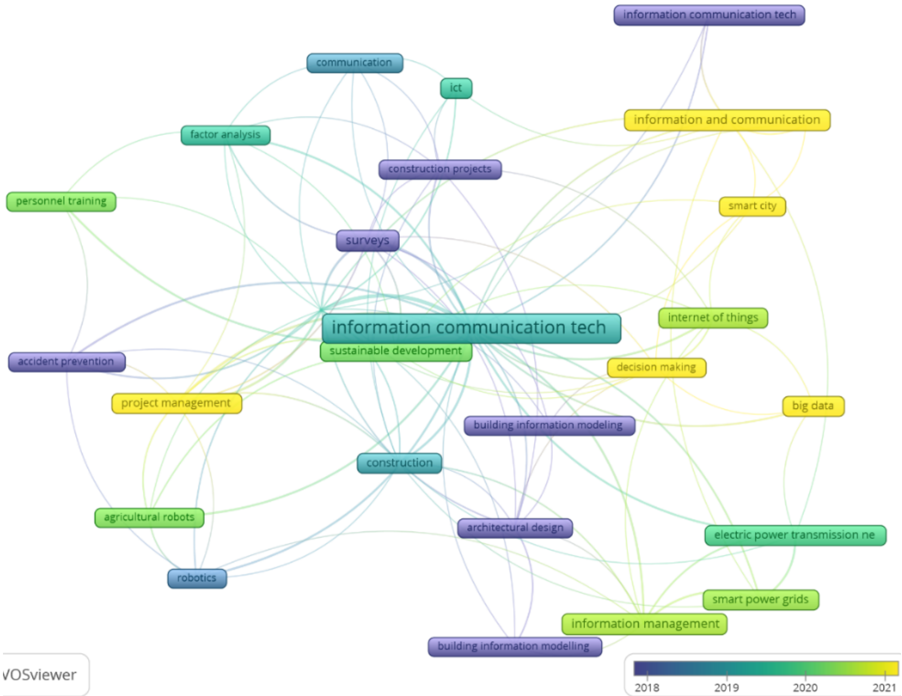

Figure 5. Overlay visualisation map for co-occurring keywords

Conversely, ICT smart city applications have yielded tremendous benefits. ICT is used in smart cities to enhance communication between citizens and city stakeholders, reduce costs and resource consumption, and enhance the effectiveness, calibre, and interactivity of urban services [55]. In other words, Smart cities use ICT to improve operational efficiency, disseminate information to the public, and provide better public services and citizen welfare [107, 108]. Additionally, ICT in smart cities can be used to improve public transit, minimise traffic, and optimise traffic flow through real-time data analysis and intelligent traffic management systems [109]. Similarly, ICT is used by smart meters and smart grids to monitor and control energy use, increasing energy efficiency and lowering carbon footprints [109, 110]. Furthermore, ICT can be used to improve public safety in smart cities through surveillance cameras, emergency response systems and so on [110]. As a result, the study's focus is evolving in step with technological advancement and the rising need for more construction that is digitally integrated.

p-ISSN: 2656-5935 http://journal-isi.org/index.php/isi e-ISSN: 2656-4882

Unfortunately, the uptake of new technologies has been sluggish in developing nations [55]. A few of the obstacles include a lack of knowledge, insufficient funding to assist this technological advancement, unclear regulations, and reluctance to embrace information technology [55, 80]. It can also be diagnosed from the study that the area concerning industrialised building systems (IBS) has been neglected worldwide, as the keyword was found missing in the co-occurrence keyword analysis. IBS integrates ICT tools such as BIM and Common Data Environments (CDE) to streamline the design-to-make process [111]. Hence, there is a need for thorough research in this area. Furthermore, as more research on ICT in construction emerges, the focus areas in this study require careful consideration, especially in developing countries, to facilitate adoption and practice.

5. CONCLUSION AND RECOMMENDATIONS

To ascertain the concentration of ICT research across domains relevant to building, this study employed a bibliometric technique. The extracted publications were included in the Scopus database and published within the last 10 years. The findings showed that there is a paucity of research articles on ICT, especially in developing nations. The ICT Scopus-indexed research recorded the maximum number of publications in 2018 at fourteen. This suggests the need for more recent publications. The benefits of ICT in construction call for a full embrace of the concept in the built environment. China, Malaysia, and Australia have the highest number of ICT publications, with a threshold of five publications. Only one African nation, Nigeria, met the threshold with six publications. Similarly, no South American country was listed. This suggests that more study is required to bridge the knowledge gap and improve ICT implementation for the delivery of construction projects and the enhancement of organisational performance throughout the continents. For policy and practices, the following are recommended:

1) The study recommends government funding and incentives, such as tax breaks, subsidies, or grants to encourage construction companies in these countries to engage in ICT solutions like cloud computing, BIM, IBS and so on.
2) Tech companies and academic institutions can also collaborate to pilot ICT innovations on public infrastructure projects.
3) Capacity-building and training programs should be developed to improve employees' proficiency with digital tools and ICT literacy, and curb the skill-related barrier to adoption, particularly in small and medium-sized enterprises.
4) To foster transparency and compliance, mandatory use of digital documentation and reporting should be established. The use of ICT-related tools like e-Tenders, Compranet and so on for publishing tenders and

p-ISSN: **2656-5935** http://journal-isi.org/index.php/isi e-ISSN: **2656-4882**

submission of bids can be made mandatory for most of these countries. This will help reduce paperwork, ensuring compliance with submission requirements and guaranteeing fair competition.

5) Investment in digital infrastructure is highly recommended, especially in most African countries that have been hindered due to a lack of internet access. Consequently, expanding broadband access and digital infrastructure in rural and underserved areas will ensure equitable access to ICT tools across the construction industry.

Considering the revealed clusters, research on ICT in construction-related domains has focused on Information and Data Management, Project Design, Sustainable Project Management, Power Transmission and Smart Grids, Construction Project Communication, and Safety Management and Training. Current studies in this area point towards the use of ICT in managing big data, smart cities and sustainable development. The study also recommends studies on the use of ICT and industrialised building systems. Furthermore, while some have majored in barriers, awareness and adoption, more studies should be conducted on the effects of ICT implementation, especially in developing nations. By highlighting areas where ICT-related research has concentrated on construction-related domains, this study contributes to the body of knowledge. Its conclusions have also outlined possible directions for ICT study in the CI, particularly in developing economies where there is a paucity of literature. However, it is noteworthy that the study only considered publications from the Scopus database; hence, care should be taken when inferring its conclusions. To compare the results and gain a more thorough grasp of the research issue, the study suggests looking into alternative databases or integrating Scopus with other databases.

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