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Automation in Construction: an Exploration of Emerging Technologies for the Nigerian Construction Industry

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Abstract

This study explores the potential of emerging technologies aiming to transform the Nigerian construction industry. The technologies offer innovative solutions to persistent challenges such as inefficiencies, project delays, cost overruns, and safety risks. The Nigerian construction industry (NCI) is, however, reluctant to implement the technologies because of a lack of substantive comprehension of the features of the innovative technologies. Hence, it has become necessary for the NCI to fully understand the benefits and challenges of the emerging technologies for construction project efficiency. The exploratory literature review identified and examined seventeen (17) emerging technologies, revealing sufficient practical benefits such as enhancing productivity, improving safety, saving costs, and increasing transparency. It also identifies some barriers to their adoption, such as high implementation costs, a lack of skilled professionals, resistance to change, and a technological knowledge gap. The findings suggest that while NCI has started adopting these technologies, significant efforts are needed to address infrastructural limitations and promote

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skill development. The study concludes by discussing the implications of the findings for construction firms and policymakers and recommendations for future research on the adoption of automation technologies in developing economies, particularly Nigeria.

Keywords: Automation; Emerging technologies; Construction; Nigerian Construction Industry

INTRODUCTION

The construction industry is known for its wide range of activities and engagement in the production of various infrastructural developments like buildings, roads, railways, waterways, bridges, airports, and seaports, among others, and comprises different stakeholders such as clients, consultants, contractors, manufacturers, distributors, suppliers, sub-contractors, end-users, etc. (Tanko, et al., 2017). It is one of the biggest and strongest promoters of the national economy, employing millions of people; thus, its importance cannot be overstated. It is interesting to also note that there is a growing adoption of automation technologies in the construction sector. These technologies will help address persistent challenges in the industry, such as low productivity, poor quality of construction products, health and safety issues, cost overruns, and delays in project completion (Baduge et al., 2022).

According to Kamaruddin, et al. (2016), automation can be described as a self-regulating process performed by using programmable machines to carry out a series of tasks; it consists of interconnections between mechanical, electronic, computing, and internet technologies. The programmable machines work in accordance with the program that regulates the behaviour of the machine. Olanipekun and Sutrisna (2021) reported that; construction professionals, and government agencies around the world have voiced their views on integrating automation technologies in construction. Their request was considered since automation technologies are being adopted by many industrialised countries.

Nevertheless, there is reason for worry, as the implementation of these innovative technologies in the Nigerian construction industry (NCI) is still comparatively low (Oke et al., 2023). This implies that NCI is not yet technologically developed enough to use innovative technologies to automate construction-related tasks. The issue may arise from a lack of awareness and the country's lack of access to relevant technologies (Oluseye et al.,

2022). Like its competitors in industrialised and other developing nations, the NCI must fully adopt modern technologies for global best practice competition. This is due to the fact that a strategy for resolving challenges associated to quality, productivity, health and safety, prevalent delays, and budget extensions in the CI is to industrialised the sector by means of automation (Vishwakarma & Solanki, 2022).

Various automation technologies in construction were uncovered by many researchers recently. However, they primarily concentrated on the level of awareness and adoption of the technologies in the NCI by identifying the technologies exclusively. The most recent study in the Nigerian context is that of Oke et al. (2023), which is mainly intended to examine the level of awareness and application of automation technologies. Thirty (30) automation technologies were explored, out of which only six (6) were discussed. The studies did not explore the potential benefits and limitations of each identified technology. In order to effectively compete in the global automated construction market, there is a need for the NCI to have an in-depth comprehension of the features of these emerging technologies for effective utilisation. Therefore, the purpose of this study is to investigate new construction automation technologies for relevant NCI stakeholders. This will help increase adoption by revealing potential benefits and drawbacks.

METHODS

This study used exploratory literature review to identify and analyse emerging automation technologies for the NCI. The review intended to bring together existing knowledge and highlight developments, gaps, and implications of automation for construction process, focusing on technologies relevant to the specific potentials and the challenges faced by the construction industry. The literature review examined wide range of academic journals, conference proceedings, and industry reports. Sources were selected using electronic databases such as Google scholar, Scopus, and IEEE Xplore. Phrases and keywords used in the search includes: “automation in construction,” “emerging technologies in construction,” “fourth industrial revolution in construction,” “Nigerian construction industry,” and “digital transformation in construction.” The search was limited to articles published between 2014 to 2024 to ensure coverage for recent technological developments, and only publications available in English language were considered.

Exploratory review of emerging technologies

The speed growth of infrastructure in developing economy like Nigeria will require the construction industry to drive technological advancement through the use of automation to improve performance and remain competitive in business both national and international. Construction automation (CA) is defined as the application of electrical, computer and mechanical tools in the construction industry to ensure safe operation of skilled and unskilled workers, control and smooth operation to increase progress in creating quality products, efficient workforce, and completing the project on time (Fadamiro & Oke, 2019). The application of these new technologies can be carried out in various manners throughout the entire construction life circle, from the planning of the construction projects to the final assembly of the facility and post construction. After the project is completed, some of these technologies are developed to improve, operate, and eventually demolish the structure (Borja et al., 2019). Some emerging technologies used for construction process are thus explored for NCI stakeholders to take advantage.

Additive manufacturing/3D printer

3D printer (also known as additive manufacturing) is a way of creating three-dimensional items using computer-aided design (CAD) and a stacking procedure. It refers to 'the fabrication of objects by depositing a material (layer-by-layer) using a print head, nozzle, or other printer technology' (Pan et al., 2021). It is also known as additive manufacturing because it involves layering materials such as plastics, composites, or bio-materials to build items that vary in shape, size, rigidity, and colour. 3D printing is widely utilised in the manufacturing and automotive industries, where 3D printers are used to create tools and parts. The procedure has been in use since 1980s, when Charles W. Hull devised it and produced the first 3D printed part. Since then, the field of 3D printing has expanded rapidly and offers limitless opportunities (Daley, 2022). Historically, 3D printing was only used in manufacturing sector. It was used to create prototypes with small part sizes, low production volumes, and complex design. The manufacturing sectors include aerospace, automotive, food, healthcare and medical, architecture, the building and construction industry, fabric and fashion, and the electric and electronic industries (Shahrubudin et al., 2019; Wu et al., 2016). Since the beginning of the twenty-first century, the building and construction industry has embraced 3D printing to create architectural

models. It was believed that due to the size of 3D printers, medium or large-scale models or buildings could not be produced using 3D printing methods.

However, in recent years, there has been substantial progress in developing large scale 3D printers, usually termed 3D concrete printers, to address the requirement for industrial-scale 3D printing (Wu et al., 2016). A 3D digital model is the starting point for any 3D printing process, and it can be made using a range of 3D software programs (for makers and consumers, simpler, more accessible tools are available) or scanned with a 3D scanner. The model is further sliced into layers, transforming the design into a file that the 3D printer can read. The 3D printer material is then layered according to design and technique. As previously stated, there are various sort of 3D printing technologies that process various materials in various ways to generate the final product. Functional plastics, metals, ceramics, concrete and sand are now frequently employed for industrial prototyping and manufacturing. Each type of 3D printer uses various sorts of 3D printing technologies that process various materials in distinct ways. Contour crafting, D-shape printing, and concrete printing are the three (3) 3D printing techniques used in building construction. All of these technologies rely on material extrusion through a nozzle to create the layers (Sakin & Kiroglu, 2017).

Studies have proven that 3D printing technology in building constructions lowers construction cost, labour requirements, construction time, material waste, and environmental impact, it improves quality and safety while also allowing for design freedom and the ability to build complex structures (Bedarf et al., 2021; Luhar & Luhar, 2020; Waqar et al., 2023). Despite the aforementioned benefits, it is important to note that 3D printers have some limitations. El-Sayegh et al. (2020) have revealed several challenges, they categorised the challenges under material, 3D printer, design and construction (architecture and design), regulations (regulation and liability), software related, construction management, and stakeholders. Pan et al. (2021) also pointed the large capital investments and a lack of building rules make it difficult to put 3D printing into construction practice, and existing printing technology cannot currently generate items for the construction sector due to limited printing materials, processes, and systems. 3D printers are useful for creating new structures on-site and/or prefabrication of building components off-site for later use.

Artificial Intelligence (AI)

Artificial intelligence (AI) is an umbrella term for when a machine imitates human cognitive functions such as problem solving, pattern recognition, and learning. It has been created since the advent of information technologies in the 1950s (Eber, 2020). AI is the oldest and most wide-ranging branch of computer science, dealing with all elements of emulating cognitive capabilities for real-world problem solving and developing systems that learn and think like humans (Holzinger et al., 2019). The issue of AI's practicality has been renewed by new sophisticated algorithms and, in particular, the availability of the internet as a massive storage of unrecognised data as computing power has increased (Eber, 2020). Artificial intelligence is gaining popularity due to its capacity to offer more accurate findings in uncertain and complex context. As a result, numerous countries have already used artificial intelligence in construction projects (Basaif et al., 2020). Although AI is currently in its infancy in the construction sector worldwide within the project lifetime, Bang and Olsson (2022) revealed that application of AI in building construction projects has increased in recent years, and it is thought to hold tremendous potential for enhancing industry output and effectiveness.

Manzoor et al. (2021) pointed out that traditional design, manufacturing, and building technologies have been fundamentally transformed by AI. Adopting technology like AI has numerous benefits for the building and construction sector. Visualisation, clear communication, site planning, logistics, and health and safety management are some of the examples (Tjebane et al., 2022). AI can also handle more complicated, uncertain, and susceptible cos-risk network interactions in building and construction projects (Islam et al., 2017). In addition, AI assists with onsite tasks such as automatic welding, bricklaying, and has the ability of warning an operator with a cautionary signal, hence reducing risky circumstances (Chakkravarthy, 2019). The processing of natural language, speech detection, and machine learning have all been made possible by AI. Construction schedules are organised using natural language, while text-to-speech technology is employed in the development of quantity software, and machine learning is used in construction for site supervision, automatic detection, and intelligent maintenance, among other things (Hong et al., 2021). AI has implications in a variety of sectors and disciplines, including economics, geopolitics, sociology, the environment, demographics, and security (Yeh & Chen, 2018). However, recent studies have revealed some factors that influence the application of AI in construction. For example, Tjebane et al. (2022) presented that: information processing

management, knowledge and competency, improved performance, cost to organisation, organisational culture, government pressure, collaboration, firm size, organisational readiness, top management support, attitude to innovation, time-saving, competitive pressure, risk involved in using AI technologies, standards, reputation, decision making support, work culture, and work place relationship of staff are factors that influence an organisation to adopt AI.

Augmented reality (AR)

Many technical and management operations throughout the lifecycle of a construction project necessitate sufficient data to interpret their intricate connections to the surrounding environment and objects. With the ability of augmented reality (AR) to seamlessly link the real-world construction setting with digital content, it has become one of the most exciting technologies in the construction industry (Chen & Xue 2022). AR uses the physical world while also integrating virtual element to give the impression that both are present at the same time. Kwiatek et al. (2019) noted that adoption of AR in construction has the ability to significantly increase construction efficiency, lower rework, and enhance communication of design purpose. According to Ahmed et al. (2017), this modern technology can be utilised effectively for scheduling construction projects, monitoring progress, training workers, addressing safety problems, managing time and costs, and managing quality and defects. AR can be applied in the following areas of the construction projects: safety control, collection of data, communication, visualisation, education in the construction management, tracking project progress, scheduling, management of defects and quality, and facility management. The type of AR that will be applied in various areas of the construction projects will defend on its application. The following is how Devagiri et al. (2022) classified AR: marker-based AR: AR that makes use of markers to determine the markers of an object or image; marker less AR: it enables users to position the virtual object wherever they like without requiring them to move any objects in the environment; location-based AR: by determining the user's location, it improves the content; projection-based AR: it is possible to misrepresent an object's orientation, depth, and position; outlining-based AR: detects line and limitations that are imperceptible to the unaided eye.

Although AR has benefits, Kolaei et al. (2022) however, observed that it is still in its infancy and that various issues in this area need additional in-depth research to be

resolved. The main issues, according to Masood and Egger (2019), include hardware and software problems, weight, ergonomic problems, low user adoption, problem with virtual fatigue and concentration, incorporating and data transfer problem, content authority problems, adaptive instruction problems, marker monitoring reliability issues, and cost. In addition, Heinzel et al. (2017) observed that the problems in using AR in construction are locating the user and visual occlusion; others include problem with precision in the alignment of the user's field of view with the location of the model being viewed. Also, cameras used to trouble detecting aspects of the real environment that needed to be compared to models.

Big data

As the construction industry closes the productivity gap and adopts disruptive and creative technologies that depend on massive amount of data and information, big data in building construction projects has emerged as a trend. The ability to analysed and derive value from data will enable the construction industry to keep up with the transformation and maintain pace with technological advancements. But data management procedures and the tendency towards data storage presented challenges for CI. This phenomenon promotes a demand for big data (Yousif et al., 2021). According to Hatoum et al. (2020), big data can be characterised by the following five features in the construction industry; volume, variety, velocity, value, and veracity. Big data is predicted to help create new approach for the construction project management and boost the effectiveness of design and construction operations (Yu et al. 2020). However, the construction industry is underperforming in utilising big data, in spite of the availability of data and the emergence of technology. The main issue in big data handling is finding the relevant data and converting it into useful information via data refinement (Munawar et al. 2022).

Block-chain

Over the past few years, block-chain technology which is also known as distributed ledger technology (DLT) has been widely debated. The technology, which was first developed by Satoshi Nakamoto, the inventor of bitcoin, has been extensively studied and is rapidly changing various industry globally, including the construction (San et al., 2019). The construction sector, which is frequently described as being extremely dispersed, complicated, and fragmented, has continuously attempted to take advantage of the potential that new technologies offer in order to increase performance (Prakash &

Ambekar, 2020). It is widely seen as a sector with enormous prospects for using DLT, primarily because of the huge number of transactions that occur between various business entities. DLT is a financial technology invention that function as a worldwide ledger to store and record financial operations and offer a safe, decentralised data administration solution that can address a number of typical issues that the CI faces (Hamma-adama et al., 2020). According to Scott et al. (2021), triple-entry accounting is made possible by this technology, which permit various stakeholders to conduct financial operations using a single coordinated ledger. With the potential to provide safe, decentralised, and unchangeable data, DLT brings up new opportunities. San et al. (2019) uncovered various prospects for DLT utilisation in the CI, which include contract management, electronic document management, BIM, property management, supply chain management, and funding management.

Similarly, Li et al. (2019) used seven groups to present the concise overview of the evolving uses of DLT in the construction sector: smart energy, smart cities and the sharing economy, smart government, smart homes, intelligent transport, BIM and construction management, and business models and organisational structures. The enormous benefits that DLT adoption offers to CI have been pointed out by San et al. (2019). These include work flow and time efficiency, cost efficiency, transparency and trust, data security and international construction. However, according to Hamma-adama et al. (2020), policy, awareness, and level of technological readiness all hindered the application of DLT in the industry. Similarly, San et al. (2019) pointed out that one of the biggest obstacles to the adoption of DLT in the CI is national government regulation of the technology, namely initial coin offering (ICOs) which are mostly used to fund projects.

Building Information Modelling (BIM)

According to Sidani et al. (2021), the construction industry has recently been compelled to embrace new, effective digital technologies and approaches as a result of rising demands on construction projects, and building information modelling (BIM) is gradually establishing itself as a key technique among the several digital solutions available, with its practices technologies being implemented more often than ever. BIM has been defined as a construction management tool, process, and system, with benefits for construction projects including eradication of errors and omissions, encouragement for teamwork and visualisation, and facilitation of construction ability reviews, procedure

integration, and clash detection (Olugboyega et al. 2021). It is not an exclusive product or piece of software but a combined procedure rooted in accurate and reliable project information from conception to construction and utilisation.

BIM has been found to improve exchange of information about a building or facility across its entire lifespan, from initial design to running a facility, enabling excellent outcomes in construction procedures (Abd Jamil & Fathi, 2018). It is an effective technology that can support 3D models, planning, cost control, assessment, safety training, and sustainability in addition to construction management (Sinenko et al., 2020). BIM offers an effective integration and teamwork tool for construction management by enabling all members of the project team to collaborate effectively, the project managers to efficiently coordinate the project delivery process, and the project information to be effectively communicated, exchanged, and integrated (Olugboyega et al. 2021). However, Ahmed (2018) discovered five (5) top challenges of the adoption of BIM: social and ingrained aversion to change, conventional ways of contracting, high training cost, and the steep learning curve, high software purchase costs, and a lack of knowledge of BIM.

Cloud Computing (CC)

In many nations, cloud computing (CC) has developed into an effective tool for environmentally friendly practices (Oke et al., 2021). CC is an innovative approach to information technology services, makes use of software, the web, and other application interfaces as a service. It is an information technology (IT) service concept that allows people to receive computer services (including hardware and software) regardless of their device or location (Sahin et al. 2017). The use of CC in the construction industry is a new field that offers a variety of potentials (Bello et al. 2021). Remarkably, however, according to Oke et al. (2021), the level of awareness of CC in the NCI is 96.2%. Consequently, NCI is prepared to use CC in a variety of construction-related areas, such as waste reduction, construction safety, construction energy management, supply chain management in construction, and project management informatics, as described by Bello et al. (2021). Bello et al. (2021) likewise identified some challenges of CC implementation in construction; they include latency, trust, data privacy and security, data availability, data governance, poor broadband connectivity of construction sites, cost implication of long-term use, high chances for scoring dark data, threats of edge computing, and other associated technologies.

Deep Learning (DL)

Deep learning (DL) is a subset of ML that seeks to imitate the human brain, although with limited success, allowing system to regroup data and generate predictions with astounding precision. It is made up of numerous layers of nodes that are linked together, with each layer building on the preceding one in order to improve prediction or categorisation (Zhang et al. 2022). In the last few years, the application of DL has grown in the construction industry, which has seen an increase in the number of projects and breakthrough information. With the emergence of DL, new potential for exploiting this massive amount of data to tackle construction-related difficulties has been developed (Khallaf & Khallaf, 2021). According to Kim et al. (2021), one of the challenges in construction projects is financial loss. The study affirmed that DL technology can be used to predict and mitigate this loss. In addition, Pal and Hsieh (2021) reported that DL based approaches have proven their ability to analyse complicated visual data and derive significant findings (Pal & Hsieh, 2021). Equipment tracking, crack detection, construction site management, sewer assessment, and 3D point cloud enhancement were the six (6) good areas where DL is applied in construction, as revealed and elaborated by Khallaf and Khallaf (2021). The study, however, identified three (3) major challenges for DL application in construction: functional issues, informational issues, and technical issues.

Digital Twin (DT)

Digital twin (DT) is a virtualised version of a physical asset that relates to sensory data and is used to display information in real time. DT concept holds that every system is made up of two systems: a virtual system that stores all the data associated with the physical system, and the physical system, or an actual space that existed at all times (Lee et al., 2021). The advent of this offers many industries (including construction industry) enormous opportunities (Madubuike et al., 2022). Although the concept of DT is still not very clear when it comes to construction, however, Opoku et al. (2021) opined that the technology has the capacity to revolutionise the construction sector and offer solutions for certain challenges that arise within it. Hence, the idea of DT has gained a lot of interest and is evolving swiftly in the construction sector, bringing about a lot of benefits to the construction process. Some of these according to Madubuike et al. (2022) are efficient data management, access control and management, and anomaly detection for efficient maintenance. An overview of the benefits of DT revealed the following: automated

progress tracking, updated as-built drawings and models, resource planning and logistics, safety monitoring, quality assessment, equipment usage optimisation, worker monitoring and tracking, facility monitoring, facilities management and operations, decision-making, and sustainable development (Madubuike et al., 2022).

Opoku et al. (2021) also explored the benefits of DT at each phase of the construction project life cycle: design and engineering, construction, operation and maintenance, and demolition and recovery. However, Madubuike et al. (2022) highlighted some barriers to DT usage in the CI; they explained that huge volumes of data must be acquired and processed for DT, and this data must come from multiple end-points, each of which could be a potential source of vulnerability. Employee disinterest stemming from a fear of job loss is another potential barrier facing the CI. Another barrier to DT's widespread adoption in the construction sector is the challenge of uniting the many stakeholders to operate as a single team.

Internet of Things (IoT)

Internet of things (IoT) is an artificial innovation that is envisioned by virtual items that are sentient and are capable of knowing everything. These objects can interact with their environment on their own without the need for human intervention (Mahmud et al., 2018). It is a system of interconnected gadgets that are integrated with programs, sensors, and network connectivity, allowing them to collect and transfer data and become proactive (Oke et al., 2022). According to Gamil et al. (2020), the application layer, perception layer, network layer, and physical layer are the four levels that make up the internet of things. The perception layer, in contrast, refers to technology like sensors and devices that internet with other items. The application layer relates to common activities like smart cities, smart transportation, and intelligent housing. The network layer describes the elements of network coverage as well as network communication. The hardware, which includes smart appliances and other gadgets, is referred to as the physical layer. According to Mahmud et al. (2018), the basic principle behind how the IoT operates is that, things are connected to the internet and then remotely monitored or controlled via the connection. To maximise their prospects, many contractors have begun incorporating IoT system for both service generation and delivery in the construction sector (Dilakshan et al. 2021).

However, Arowoiya et al. (2020) found that the most widely used IoT component in the construction sector include wireless fidelity, visualisation, Bluetooth, wireless sensor

networks, electronic product codes, and internet protocol. While the use of barcodes, Zigbee, gateways, near-field communication, and actuators, as well as data storage and analytics, is limited. Nigeria is not taking advantage of the key implications of IoT adoption, such as speedy reporting, total process control, an explosion of data leading deep data analytics, and strong ethical and legal requirements within the construction sector, due to a lack of comprehension and knowledge of the idea (Ghosh et al. 2021). Other prominent difficulties in IoT deployment are lack of safety and security, lack of established standards, lack of benefit awareness, incorrect introduction of IoT, and lack of endurance in connectivity (Gamil et al. 2020).

Machine Learning (ML)

The advancement of AI technology has recently opened up new potential in the construction sector. Machine learning (ML) is an attractive subject in the discipline of AI, and it plays a critical part in the process of making building 'smart' (Xu et al., 2021). Zhang et al. (2022) defined ML as "a branch of AI and computer science which focuses on the use of data and algorithms to imitate the way that humans learn". Application of ML in construction is very critical to solving many project issues with ease. It entails more than just designing predictive models (Bilal & Oyedele, 2020). ML can render a wide range of benefits, including site supervision, automatic detection, and intelligent maintenance plus profit margin estimation (Bilal & Oyedele, 2020; Xu et al., 2021). Similarly, Gondia et al. (2020) revealed that ML provides an appropriate set of tools for dealing building project delays. According to Arage and Dharwadkar (2017), ML can also make injury predictions with greater precision on construction sites and can be used for cost estimation of construction projects.

Photogrammetry

The CI is faced with the challenges of inadequate site progress monitoring because the manual and tedious method has been in use for many years, which has detrimental effects on swiftness and reliability of decision-making (Omar et al., 2018). It is anticipated that automated construction progress monitoring will greatly improve the accuracy and efficiency of this procedure (Qu et al., 2017). The development photogrammetry and automated vision has led to the application of new methods for construction management to the operations and procedures of construction activities (Bognot et al., 2018). The

technology tracks progress and identifies deviations throughout the construction process by comparing the as-planned state with the existing built state; therefore, timely response is possible due to an automated notification system that notifies decision-makers by SMS and email. This method underwent extensive testing in an actual case study of a construction site that was still under development (Omar et al., 2018).

Robotic

Robotic is one of the cutting-edge technologies that are being utilised in the construction sector today. Robotic technology in construction offers various benefits by enhancing job efficiency, boasting production, and completing tasks more quickly (Boulos et al., 2020). A robot can simply be defined as "a programmable, self-controlled device consisting of electronic, electrical, or mechanical units" (Mihret, 2020). According to Yahya et al. (2019), five big companies: Shimizu, Obayashi, Takenaka, Taisei, and Kajima, were the first to come up with robotic machines for the construction sector. Robots are specifically developed for specific kinds of jobs since they never get tired, can perform in airless environments, withstand physically challenging or even dangerous situations, and cannot be diverted from the assignment at hand (Mihret, 2020). That is why they are classified into four major groups: robots for structural work, finishing or completion work, inspection work, and maintenance work in the construction sector (Yahya et al., 2019).

In concurrence, Brosque and Fischer (2022) evaluated ten (10) specific task robots in construction: Hilti; a concrete drilling robot, Obayashi; a material handling robot, Kewazo; a liftbot scaffolding assembly robot, Exyn robot system, autonomous drones, safe AI, autonomous construction machinery, Boston dynamics; a spot reality capture robot, Canvas; a drywall finishing robot, Civ robotics; a drone, CivDot; exterior layout robot, and TyBot; a rebar tying robot. Robot can be effectively utilised in every stage of construction through the allocation of specific tasks to suitable robots, from on-site jobs to roofing installation tasks and finishing works. Brosque and Fischer (2022) also discovered that robots in construction projects demonstrated the ability to reduce time spent on risky operations by 72% and redundant site work by 25 to 90%, while rework can be decrease by more than 50% and accuracy can be increased by 55%.

Despite these advantages, it was discovered that, deploying robots in construction is still hindered by organisational cultures of both clients and contractors, employee technological challenges, and project teams' reluctant to innovate. In addition, Yahya et al.

(2019) noted that the primary challenges to the adoption of construction robotics were the high cost of maintenance and the high cost of technology update processes.

Terrestrial laser scanning (TLS)

Modern technologies, such as terrestrial laser scanners (TLS), are becoming a good substitute for time-consuming, costly, and dangerous conventional maintenance and inspection procedures for construction projects. As a result, the CI is using these technologies more and more (Wu et al., 2022). TLS, which is frequently employed in geodesy, offers a lot of promise for usage in a variety of applications in the CI. According to Aryan et al. (2021), TLS is a secure and effective way of obtaining point clouds, which are used for a variety of tasks in the construction sector. Owing to its significant benefits over traditional range sensors, TLS has found extensive application in a variety of fields, such as tracking construction progress, measuring earthwork volume, reconstructing as-built models, historical conservation, and monitoring structural health (Wang et al., 2016). Whereas, Wu et al. (2022) identified five (5) main uses of TLS in the construction sector, which are: object detection, 3D model reconstruction, deformation measurement, quality assessment, and progress tracking.

Unmanned aerial vehicle (UAVs)/Drones

Unmanned aerial vehicles (UAV), unmanned aerial systems (UAS), and remotely piloted vehicles (RPV) are some of the names for drones that are well-known (Li & Liu, 2018). In recent years, the employment of drones, or UAVs, has steadily shifted away from the military, where they originally found use, and toward surveying, facility management, and other important sectors (Agapiou, 2020; Li & Liu, 2018). More recently, however, technology advancement has made them more practically and affordably useful in the areas of architectural engineering, construction management, and monitoring (Anwar et al., 2018). When outfitted with various types of powerful detecting and surveying equipment, remotely controlled minor aircraft can be flown without a pilot on board and do so at low cost, and high efficiency, which can be advantageous for the construction of infrastructure (Agapiou 2020; Fan & Saadeghvaziri 2019).

The use of drones in the architectural and engineering construction sector is divided into five (5) categories by Nwaogu et al. (2023): inspection and mapping, data processing and management, safety and health management, challenges and risks associated with drones use, and training aids. Tkáč and Mésároš (2019) also discovered that the

construction industry swiftly accepted UAVs as a tool that reduces costs, increases efficiency, and improves safety and control. Whether used for topographic terrain mapping, building surveys land surveys, construction site inspections, remote monitoring, progress reports, thermal image recording, or integration with laser scanners, drones have proven to be invaluable tool throughout the lifespan of a construction project (Tkáč & Mésároš 2019). In the same way as other technologies, UAVs have their challenges. According to Fan and Saadeghvaziri (2019), the major challenges are restricted plight time, signal robustness, post-data analysis, multi-drone collaboration, weather conditions, and drone-related traffic disturbances.

Virtual reality (VR)

Like augmented reality, virtual reality (VR) is found to be among the most promising technologies for utilisation in the construction industry. VR can be described as a computer simulation that creates a perspective that appears to the user's senses in a manner similar to how they see the real world (Albahbah et al. 2021). It creates realistic environments that allow users to gain new perspectives on how the real-world functions (Li et al. 2018). The ability of VR to meet the growing need for visual forms of communications during the designing, execution, and management of construction projects is being acknowledged by the Architecture, Engineering, and construction (AEC) sector (Zhang et al. 2020). And has shown positive outcomes, offering answers to problems with communications and teamwork, particularly between partners or stakeholders with various personalities.

The areas of adoption of VR technology in construction project management as identified by Albahbah et al. (2021) include construction safety management, visualisation, communication, data acquisition, scheduling, construction management education, and project progress tracking. The application of VR technology can be done using three broad techniques, as presented by Zhang et al. (2020): head-based VR: this device is a helmet or head-mounted display that shows graphic pictures on one or more displays, one for every eye, with an in-built position-tracking detector that react to the user's vision; stationary VR: the stationary VR normally remains in place and shows the visual content of the immersion of the projectors and/or huge screen displays; hand-based VR: this concept is a gadget that the users may hold in their palms and position in front of their eyes, like a smartphone or a smart tablet. However, VR usage has some challenges that Li et al. (2018) have recognised.

These challenges include: hazard identification: comprising inefficient experiment outcomes, capability differences on hazards evaluation, and hazard prediction; safety education and training: expensive for hazardous job training; little practical training; inadequate education or memory growth; weak compatibility of VR/AR-CS information and workers with poor visual literacy are two issues that need to be addressed during safety inspection and teaching.

Wearable sensing technologies (WST)

The advancement of wearable sensors has greatly enhanced the biomechanical examination of construction workers (Valero et al. 2017). They have shown tremendous possibilities for supplying the construction industry with a procedure that is secure, efficient, and of high quality (Arabshahi et al. 2021). Wearable sensing technologies are extensively utilised in the construction sector for managing and monitoring occupational health and safety (Antwi-Afari et al., 2019). Zhang et al. (2017) divided sensing technologies safety management into three (3) categories: vision-based sensing techs, wireless sensing network, and locating sensor-based tech which include: GPS, UWB, Zigbee, RFID, WLAN, and ultrasound. Sensing technologies have been investigated in academic settings; however, human, technological, and adoption process issues have made it difficult for them to be widely adopted (Arabshahi et al. 2021).

RESULTS AND DISCUSSION

The exploration of emerging automation technologies for utilisation in the NCI uncovered a range of technologies with varying level of adoption and potential impacts in construction industry. Through the review, a number of important technologies came to light as being crucial in changing the global construction perspective, even though Nigeria is still hesitant to their adoption. The findings shed light on the type of technologies that are becoming popular, the challenges to their widespread adoption, and the opportunities for improving the construction processes.

The review identifies several emerging technologies such as; BIM, IoT, and AI, that can significantly improve productivity, simplify construction processes, and enhance project management in the NCI. These technologies have the potential to reduce time wastage, minimise human errors, and improve communications among stakeholders. If the NCI adopts these technologies, it could see improvements in project delivery times and

cost-efficiency. Drones, wearable sensing technologies, and IoT can be used to monitor construction sites in real time, improving safety procedures and reducing accident rate. These technologies enable early detection of hazards, ensuring a safer work environment. By implementing these technologies, Nigerian construction companies, particularly those in area that have restrictions on supervision, may be able to improve compliance with regulations and lower the rate of workplace accidents.

The review highlights the potential of 3D printing and robotics to minimise material waste and labour cost. In a Nigerian construction market where resources are often limited, implementing these technologies can result to substantial cost savings. This is particularly relevant in addressing Nigeria's housing deficit, as affordable and rapidly constructed homes using 3D printing could transform residential construction in the country. Block-chain technology is identified as a tool that can improve transparency in contractual agreements. This has significant implications for reducing financial misappropriations, frauds, and payment disputes in NCI, which has historically faced issues with accountability. Block-chain technology can be utilised by construction firms and government to promote transparency and trust in project management and execution.

Challenges to adoption

Despite the uncovered potential benefits of these technologies, several challenges that hinder their widespread adoption were also revealed from the review for NCI's stakeholders' consideration. The challenges include but not limited to:

High initial cost: many emerging technologies requires significant upfront investment, which could be a barrier for smaller firms and low level clients' projects.

Resistance to change: many construction organisations are reluctant to adopt new technologies due to concern over disruption of the existing processes.

Lack of expertise: the implementation of these new technologies requires skilled professionals, which are currently in short supply in Nigeria.

Lack of infrastructure: the lack of stable internet connectivity and digital infrastructure in Nigeria limits the effectiveness of some emerging technologies.

Contributions

The review adds to the growing body of literature on technology adoption within the construction industry, particularly in a developing country context like Nigeria. By

exploring the challenges and opportunities associated with emerging technologies, the review provides a foundation for future studies on how technological innovations can be utilised to improve projects outcome in the construction industry. The review also highlights the practical barriers to technology adoption, these insights can inform academic discussion on technology adoption model (TAM), future research could investigate how theoretical models can be adjusted to account for specific socio-economic and infrastructural challenges in the region like Nigeria.

CONCLUSION

In conclusion, this study has discovered numerous benefits from the investigation of emerging technologies for automation of the construction project. The comprehensive analysis of the explorative literature highlights the major benefits in terms of improving the overall quality of construction, ensuring construction cost effectiveness, promoting safer working conditions, speeding project schedules, offering accurate material estimates, and reducing waste significantly, among other benefits. Nevertheless, the implementation of these emerging technologies is not without challenges. Low awareness of the technologies, skill gaps, organisational culture, high acquisition costs of the technologies, some government policies, and adherence to laws and regulations remained the causes of obstacles to the technologies' implementation. Recognising the applicability and/or non-applicability of each technology for construction projects demonstrates the need for a comprehensive approach to implementation. As the Nigerian construction industry grows, looking for a way to adopt these emerging technologies and overcome the implementation barriers will be its most important task in ensuring a sustainable and technologically advanced future for construction projects in Nigeria. This study encourages the relevant sectors to take the stage of comprehensive awareness to educate stakeholders in the NCI, including construction professionals, policymakers, and clients. It is also important to develop training initiatives to enhance the skills of the workforce, explore avenues for providing financial support to construction firms willing to invest in automation technologies, and improve collaboration between the government, private sector, and educational institutions towards increasing adoption of the technologies.

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