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DIGITAL TRANSFORMATION OF THE CONSTRUCTION INDUSTRY UNDER THE FOURTH INDUSTRIAL REVOLUTION

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ABSTRACT

Purpose: This study presents the result of an investigation of the fourth industrial revolution and digitalisation within the Nigeria construction industry from the construction firm's perspective.

Design/methodology/approach: The study adopted a qualitative research approach through the interview, carried out among eight case companies in Abuja, Nigeria. Thematic analysis was used in analysing the data generated. The specific method of thematic analysis adopted was conversational analysis.

Findings: The study revealed that fourth industrial revolution systems and processes such as: RFID, BIM, and cloud computing have 87.5% level of adoption; internet of things witness 100% level of adoption; drones with 75% level of adoption and Big data witness 62.5% level of adoption. However, augmented reality, robots and 3D printing have 37.5%; 12.5% and 0% level of adoption respectively, indicating a low level of adoption of the systems and processes that constitute fourth industrial revolution.

Originality/value: The study concluded that the adoption of the fourth industrial revolution and digitalisation in the construction industry has started but its full adoption has been slow and foreign construction firms have adopted more of the systems and processes of the fourth industrial revolution when compared to indigenous construction firms. The study recommends an increase in awareness of the fourth industrial revolution through seminars, workshop and training on the fourth industrial revolution.

Keywords: Construction industry; digitalisation; industry 4.0; Nigeria; qualitative research.

1. INTRODUCTION

The world is currently at the beginning of a fourth industrial revolution, it began at the turn of this century and it is building on the digital revolution (Schwab, 2016). The fourth industrial revolution is characterised by a much more ever-present and mobile

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internet, by smaller and more powerful sensors that have become cheaper, and by artificial intelligence and machine learning (Schwab, 2016). Li and Yang (2017) referred the fourth industrial revolution as an era employed by intelligence at its peak. Before the fourth industrial revolution, they were other revolution such as: first industrial revolution was characterised by water and steam power to mechanise way of doing things; second industrial revolution focused on electric power for the mass production process, and the third industrial revolution used electronics and information communication technology to automate production. One of the major challenges of the existing industrial revolutions is the fact it does not support machine to machine communication and transfer of data between two devices (Lavanya *et al*., 2017). On this platform the fourth industrial revolution was introduced.

The fourth industrial revolution can be traced to Germany in early 2012 (Rojko, 2017). The manufacturing industries in Germany sought for way to overcome its challenges and the solution arrived at, ushered the industry to the fourth industrial revolution and outcome of this revolution has helped the construction industry stay competitive, and also today Germany's manufacturing industry is one of the most competitive industries in the world. Since the introduction of the fourth industrial revolution, it has swept around Europe and also in Asia, and this revolution has enabled a total connection of people and the work environment (Rojko, 2017; Osunsanmi *et al.,* 2018). The fourth revolution is characterised by the internet and also the speed at which work is done and an important part is that it is customer friendly.

The introduction of multiple technological advancements in areas, such as; artificial intelligence, advanced robotics, automation systems, big data, 3-D technology, virtual/augmented reality and the internet of things (IoT) has changed and alter the way worked is done and life is lived (Lavanya *et al*., 2017). Therefore, the fourth industrial revolution is built on a vision of having a future, where work is done is automated. The fourth industrial revolution consist of systems and processes such as; mobile solutions, cloud computing, internet of things, data analytics, cyber physical systems and advanced manufacturing technologies such as robots, laser scanner, and 3D printing (CGI, 2017; Osunsanmi *et al*., 2018; Berger, 2016; Leal *et al.,* 2018; Rojko, 2017; Crnjac *et al*., 2017). Lavanya *et al.* (2017) argued, the fourth industrial revolution is not just about its components but an introduction of new inter-disciplinary field that combined both the cyber physical systems, the internet of things and service and smart factories.

Furthermore, several studies reviewed did not take into cogitation the systems and processes that constitute the fourth industrial revolution adopted among construction firms, and this reflects a gap in the evaluation of the adoption of the fourth industrial revolution in the Nigeria construction industry. This demand the need for the study.

Having gone through the variables that constitute the background of the study, it can be understood that there is a need to carry out a study on the fourth industrial revolution and digitalisation of the construction industry in Nigeria with a view to focus on the adoption of the systems and processes that constitute the fourth industrial revolution by the construction industry. The aim of the study is to investigate the fourth industrial revolution and digitalization of the construction industry in Nigeria, with a view to determining the fourth industrial revolution systems and processes currently adopted by construction firms in Nigeria.

2. REVIEW OF RELATED LITERATURE

The specific challenge facing the construction industry around the world is the challenge of slow or low adoption and application of digital technologies. The case might not be different in the Nigerian construction industry, as low adoption to the digital trend is an identified problem that has inhibited the growth of the construction industry (Ezeokoli, *et al.,* 2016; Osunsanmi *et al.,* 2018). However, the authors above revealed that the level of adoption and application of digital technology was at infancy stage, moreover, this could be due to lack of capacity, technical knowledge and digital transformation dynamism among managerial teams. This challenge has contributed to the low productivity of Nigeria indigenous construction firms. Aniekwu and Audu (2010) revealed that Nigeria construction firm's productivity is at a low level when compared to that of foreign counterpart.

However, since the introduction of multiple technological advancements in areas, such as; artificial intelligence, advanced robotics, automation systems, big data, 3-D technology, virtual/augmented reality and the internet of things (IoT) has changed and altered the way worked is done and life is lived (Lavanya *et al*., 2017). Therefore, the fourth industrial revolution is built on a vision of having a future, where work is done is automated. The fourth industrial revolution consist of systems and processes such as; BIM, RFID, Drones, cloud computing, internet of things, data analytics, cyber-physical systems, augmented reality, automation, and advanced manufacturing technologies such as robots, laser scanner, and 3D printing (CGI, 2017; Osunsanmi *et al*., 2018; Berger, 2016; Leal *et al.,* 2018; Rojko, 2017; Crnjac *et al*., 2017).

Osunsanmi *et al*. (2018) asserted that systems and processes of the fourth industrial revolution such as BIM were one of the first innovation providing the background for the fourth industrial revolution in the construction industry. Azhar (2011) added BIM was conceived to revolutionise construction sector in many aspects. BIM involves capturing the additional layers of information throughout the entire lifecycle. BIM is used on construction sites due to its ability to provide a simulation about the technical information of the building regarding cost estimate, material inventories, collaboration and time for completion.

The fourth industrial revolution systems and processes such as radio frequency identification (RFID), is used in tracking equipment, tools, monitoring, theft prevention and inventory management, and also the device is attached with sensors that can act as a tracker to locate stolen equipment. Augmented reality is a technology that coordinate virtual objects or images in real-world images (Ismail *et al*., 2018). Augmented reality is deployed to create or provide an efficient way to visualise the progress of construction projects and marker-based AR are used to facilitate on-site information for construction site activities.

According to Leal *et al*. (2018), the fourth industrial revolution is based on cyber-physical systems (CPS) and these systems deals with a deeper interaction of the real and virtual world. The fourth industrial revolution is an execution system that is based on the connections of cyber-physical building blocks and these blocks are embedded system with decentralised control, advanced connecting that are collecting and exchanging real-time information to identify, locate, tracking, monitoring and optimising the production (Rojko 2017). CPS is defined as a concept that combines the physical and cyber world. Lee (2010) these systems act as if they were one, and this means everything that happens in the physical impacts on the virtual and vice versa.

Automation is a key concept in the fourth industrial revolution. Automation of the construction process makes day to day construction operation easier, faster, better and even free construction firms from labour and monotony of repetitive tasks (Madakam, Holmukhe, and Jaiswal, 2019). Robots are electromechanical designed machine,

programmable by a computer and are capable of carrying out a complex series of action automatically, robots have the intelligent connections of perception to action and these robots carry out the task by moving into the real world (Madakam *et al*., 2019). For instance, Hadrian robots are designed for bricklaying. These Hadrian robots can build a house in two days with the ability to lay 1000 bricks per hour and can be part of construction activity where work is to be performed in dangerous conditions to optimise the operation and improve safety in work environment (Singh *et al*., 2017; Berger, 2016).

3D technology is relatively at its infant stage in developing countries like Nigeria (Raji, 2017). Hager, Golonka, and Putanowicz (2016) agreed 3D printing is still young and presents a lot of limitations, but there are high expectations and hopes for the future of 3D printed buildings and building components. Tay, Panda, Paul, Noor Mohamed, Tan, and Leong (2017) stated that 3D printing of full-scale construction components is still an emerging technology and as an alternative construction method is attracting increasing attention.

According to Balogun, Otanocha, and Ibhadode (2018), 3D printing technology is currently used in prototyping and distributed manufacturing with applications in architecture, construction, industrial design, automotive design, aerospace, military, engineering, and so on. From a construction perspective, 3D printing can be used different stages of the design process (Leal *et al.,* 2018). Balogun, *et al*., (2018) further suggested 3D printing can be applied in an area which could include for example, in Engineering, this technology is adopted in iterative designs, robust parts and precision prototyping and could enhance designs and help engineering (project) teams manage risks and understand the performance implications of designs. Andrade (2016) asserted in the conceptual stage, the 3D printing technology can help understand the relationship between building and its environment, testing a constructive feature, visualising the design solutions, and also combining the study of complex form.

There lies an opportunity in adopting fourth industrial revolution systems and processed such as big data, as construction firms are leveraging big data to lead its market (Maaz *et al*., 2018). Since the introduction of big data, construction firms that adopt it will gain insight and improve productivity, customer experience, reducing business cost and opportunity to new business, and also big data will increase from 5% to 6% profitability of construction firms (McAfee and Brynjolfsson, 2012). Therefore, there are need to utilise the potentials of big data (technological advancement) which will require having a place in the system and capabilities to make sense of the unprecedented flood of data.

One of the major or main advancements of the fourth industrial revolution, which bridge the gap between the physical and digital application is called the internet of things and sometimes referred to the internet of all things (Schwab, 2016). Mahmud *et al*. (2018) further explained the concept of internet of things as a man-made technology invented by the involvement of intelligent virtual objects, which are capable of knowing all things and also allows devices to connect and interact automatically without human control. Chandanshive and Kazi (2017) the internet of things (IoT) as a combined division of forthcoming internet, it involves the combination of prevailing and rapid development and also the internet of things is a branch of information technology which generates a connectivity link between the internet and actual physical things.

There has been significant adoption of ICT by the construction industry over the past 35 years (Teicholz, 2004). Xiao, Yamani, and Md (2018) posited an important advancement in the delivery of information technology (IT) in the construction industry is cloud computing. Redmond, Hore, West, and Alshawi (2010) argued that the construction industry has been traditionally recognised as a fragmented sector associated with a poor level of implementation and penetration of Information Communication Technology (ICT).

The new Information and communication technologies (ICTs) promising significantly change in the construction industry is cloud computing technologies and this technology is not new to construction stakeholders, as they have utilised it in one way or the other, informally or formally and the examples of cloud service are Google App Engine, Google Drive, Google Doc, Microsoft Office Live and Dropbox are commonplace to construction professionals (Afolabi, Ojelabi, Fagbenle, and Mosaku, 2017).

Drones such as an unmanned aerial vehicle (UAV) is an aircraft operating under remote/autonomous control without a human pilot on board and this type of drones do not carry pilot, instead, the drone can fly autonomously or be remotely piloted (Dastgheibifard and Asnafi, 2018). Drones are capable of sensing and responding to their environment, drones will be able to perform tasks such as checking electric power lines or delivering medical supplies in war zones (Schwab, 2016). Janssen (2015) opined drones are aerial modules that are deploying to be operated by a manned remote or by a predetermined flight path. Drones have been greatly used in different construction and operation applications of various types of construction projects. Drones can be deployed to many areas of construction activities. Cajzek, Gradnje and Klanšek (2016) developed an unmanned aerial vehicle for multiple purpose usage in the construction industry such as construction site monitoring, the examination of construction, infrared thermography, photogrammetry, transport application, and also for marketing activity. The unmanned aerial vehicle is needed in construction projects to collect visual data in form of images, videos, as well as 3D models from the most relevant locations and views of a construction site (Dastgheibifard and Asnafi, 2018).

3. RESEARCH METHODOLOGY

This study adopted a case study research approach and qualitative data were gathered from construction firms operating in Abuja, Nigeria. Towards meeting the objectives of the study, which entails assessing the fourth industrial revolution systems and processes currently adopted by construction firms. Since the study deployed a case study approach, hence it is right to adopt a purposive sampling technique. Purposive sampling is extremely useful when a researcher wants to construct a historical reality, describe a phenomenon or develop something about which only a little is known and also purposive sampling strategy is more commonly used in qualitative research. The instrument for data collection for the study was the interview. The interview was employed to have an in-depth understanding of the fourth industrial revolution and digitalisation and also to gain an understanding of underlying reasons, opinions and motivation to uncover trends in thought, thereby diving deeper view into the fourth industrial revolution. Eight construction firms were interviewed in a category of four foreign and four indigenous construction firms. The study has an attribute of multiple case studies. Eisenhardt (1989) posited some cases between four and ten in multiple case studies, reasons that with less than four cases it might be difficult to generalise as you cannot get much complexity and with more than ten cases the complexity and volume might become too heavy. To analyse the qualitative data generated, the study adopted a thematic analysis. Guest (2012) posited the most common forms of qualitative analysis are thematic analysis. Thematic analysis is deployed in pinpointing, examining, and recording patterns of meaning or themes within data and the specific method adopted was conversational analysis. The conversation analysis focus on a detailed exploration of the conversation between two or more people. The purpose of data analysis in qualitative

research is to recognize or identify similarities, differences and patterns and description of the matter studied.

4. DATA ANALYSIS, RESULTS AND DISCUSSION OF FINDINGS

4.1. Details of 'Case' Companies Representative

Table 4.1 indicates the information of the case companies' representative from the position held in the company, to the profession of the representative and also their respective working experience in the company and the construction industry at large.

Table 4.1: Details of case companies' representatives

S/N	Company Type	Categorisation of the company	Position Held	Profession	Working experience
1.	Company A	Foreign	Asst. IT manager	IT Eng.	12years in IT business and 3years in the company
2.	Company B	Foreign	Project Manager	Quantity Surveying	21years in the construction business and 20years in the company
3.	Company C	Foreign	Asst. IT manager	IT Eng.	12years in IT business and 3years in the company
4.	Company D	Foreign	Project Manager	Quantity Surveying	20years in the construction business and 15years in the company
5.	Company E	Indigenous	Project Manager	Architecture	10years in construction business and years in 3years
6.	Company F	Indigenous	Cost Accountant	Quantity Surveying	20years in the construction business and 17years in the company
7.	Company G	Indigenous	CEO/Project Manager	Architecture	20years in the construction business and 12years in the company
8.	Company H	Indigenous	HOD Technical Unit	Quantity Surveying	11years in the construction business and 11years in the company

Table 4.1 indicates the categorisation of the case companies are into foreign and indigenous construction firms (four foreign and four indigenous, in a total of eight), were interviewed to have an in-depth understanding of the fourth industrial revolution. Table 4.1 also indicates the position held by the case companies' representatives. Four representatives are project managers (company B, D, E and G). While representative of company 'A' and 'C' are assistant I.T managers. Company 'F' representative position held as the cost accountant of the company and company 'H' held the position of the head of the technical

unit. Table 4.1 further indicates the profession of the case companies' representatives. Company B, D, F and H, representatives are registered quantity surveyors and company E and G representative are registered architects and also company A and C are information technology engineers.

Table 4.1 shows the working experience in the respective case companies and the construction industry at large. Company A and C worked in the I.T business for 12 years and both worked for the company for 3yrs. Company 'B' representative worked in the construction business for 21 years and 20 years with the company. Company 'D' worked in the company for 15 years and have been in the construction business for 20 years and company 'E' had 10 years working experience and have worked with the company for 3 years. Furthermore, company 'F' worked in the construction business for 20 years and worked with the company for 17 years and company 'G' representative worked in the construction business for 20 years and worked with the company for 12 years. Company 'H' representative has been in the construction business for 11 years and has been with the company for 11 years.

4.2. Fourth Industrial Revolution Systems and Processes Currently Adopted by Construction Firms in Nigeria

Table 4.2 revealed major findings on the fourth industrial revolution systems and processes currently adopted by construction firms in Nigeria. Systems and processes such as; RFID, BIM, internet of things, cloud computing, drones, big data, augmented reality, robots and automation were revealed.

As revealed in Table 4.2, indicates the analysis of the major findings and issues addressed concerning the fourth industrial revolution systems and processes currently adopted by construction firms in Nigeria. The major interviewed findings show company 'A, C, D and E' have adopted the fourth industrial revolution and also the application was high for the respective company. While company 'B, F, G, and H', just started the adoption of the fourth industrial revolution systems and processes but at a slow pace of adoption, and also the application of this systems and processes has been low (Table 4.2). the fourth industrial revolution systems and processes such as; RFID, BIM, internet of things, cloud computing, big data, drones, augmented reality, robots, and automation was adopted by various case companies interviewed.

Table 4.2 further showed the case company representatives response on systems and processes of the fourth industrial revolution currently adopted by their respective companies. According to Company 'A' claimed,

"Many of these things from what I know we have many of these things in place that is why I said there is room for improvement because in many of our construction sites, you see drones and it gives us real-time situation on the ground on sites".

Company B' also claimed "the one we are trying to work on presently is BIM, which I think we deploy on one of the projects", the project was an international project and all those things have to be synchronised before we commence. Company E' indicated the company have adopted much innovation so as it can facilitate the construction of smart homes,

"We adopted BIM, RFID, drones, augmented reality, cloud computing, internet of things and before I forget automation, which is the foundation the company is built.

Company C' indicated the company use drones for monitoring project due to their sizes, they also do BIM, "We have to understand what we are building, we have to make it look

real, so we that with BIM.

Table 4.2: Major Findings on the Fourth Industrial Systems and Processes Currently Adopted

Key info. Provider	Major Interview Findings	Issues Address
Company 'A'	"We have adopted the fourth industrial revolution, we have gone far in the application and the adoption for the company has been high"	Company 'A' adopted; RFID, BIM, IoT, cloud computing, drones, Big data, augmented reality, robots, and Automation.
Company 'B'	"The company is just at the beginning stage of the adoption of the fourth industrial revolution, although the adoption and the extent of application has been low for the company"	Company 'B' adopted; RFID, BIM, IoT, cloud computing, and Big data
Company 'C'	"The company have adopted the fourth industrial systems and processes, the rate adoption and extent of application has been high but there is room for improvement"	Company 'C' adopted; RFID, BIM, IoT, cloud computing, drones, Big data, augmented reality, and automation
Company 'D'	"The company have started the adoption of the fourth industrial revolution and the rate of the adoption and the extent of application has been satisfactory to the company"	Company 'D' adopted; RFID, BIM, IoT, cloud computing, drones, Big data, and automation
Company 'E'	"The company are currently building smart homes with the aid of the fourth industrial revolution, the adoption and also extent of the application has been high and the company process and operations have been automated for some time now"	Company 'E' adopted; RFID, BIM, IoT, cloud computing, drones, Big data, augmented reality, and automation
Company 'F'	"The company just started the adoption of the fourth industrial revolution, the adoption and the extent of application of these systems and processes have been low/poor"	Company 'F' adopted; RFID, BIM, IoT, cloud computing, and automation
Company 'G'	"Honestly speaking the company just started the adoption of the fourth industrial revolution systems and processes, the extent of application has been low, due to fact the company just started"	Company 'G' adopted; BIM, IoT, cloud computing, drones, and automation
Company 'H'	"The company just introduce about two to three systems and processes of the fourth industrial revolution, the adoption and the extent of application has been low"	Company 'H' adopted; RFID, IoT, and drones

Company D' claimed the company have adopted internet of things, BIM, RFID, drones and automation, while company F' added the company have adopted BIM, internet of things, "We are at the early adoption of cloud computing and we try as much as to automate our processes". Company H' said "For now, one adopted by this company is radio frequency identification and company G' had to wait for follow up questions to indicate which system and processes currently adopted by the firm.

4.2.1. RFID

Radio frequency identification is innovation-based tools to help stakeholders in the construction industry, by collecting and managing data over the portable database and this tools also assists stakeholders in the construction industry in communication various routing and control instruction. RFID based systems collect and distribute information among construction stakeholders or construction professionals at the construction sites.

Seven out of eight case companies agreed to have adopted RFID only company G have not adopted the RFID. The companies that adopted the RFID use it to track their equipment, product to prevent it from been stolen. According to Company 'A' claimed that all their vehicles and equipment use a tracker that sends the location of equipment and this enables their construction firms to keep records and prevent theft. Company 'B' added since we started using RFID we have not to record any theft of equipment. Company 'C' suggested the adoption of RFID will help construction companies to track, monitor materials and equipment which in turns develop automated timesheets.

The RFID offers and provides a wireless medium for gathering and storing data, this will enable the construction firms to trace the real-time information of any tracked equipment or vehicles. RFID deploy tags, these tags provide information on specification, dates, detects, vendor original equipment manufacturers, maintenance records, operating parameters and among other application.

4.2.2. BIM

The major point of the fourth industrial revolution and digitalisation of the construction industry is the connection of embed sensors on equipment and at each stage of construction projects to monitor progress with the help of virtual simulation such as BIM. BIM allows the digital simulation of construction projects before the construction starts. Company H' have not yet adopted BIM, while the rest have adopted BIM. Company 'A' revealed

"For more than a decade now, we have been planning our projects in a 3-dimensional way and we have been handling all our projects using BIM, it helps us to ensure quality and safety of operations, it also helps us to reduce waste and improve our overall performance".

According to company 'E' claimed

"We use BIM to simulate our projects before it starts, so we can minimise errors and in turn reduce waste and ensure quality and safety".

BIM provides all needed information on the entire lifecycle of a proposed project from inception to completion. Company F' claimed,

"Honestly you cannot be relevant in the construction industry without BIM, the BIM is here to assists us to have a view on how this project will be in real life and we adopted BIM to help us minimise waste".

Company 'C' claimed that you cannot be in this construction business and you operate without BIM.

"BIM gives you an advantage in stiff competition, you complete projects on time, you eliminate errors and even reduce waste of materials and even before the project commence it gives you the view on how the project will be after completion" Company 'C'.

4.2.3. Internet of things

The internet of things has been adopted by all case company representative interviewed. Company G' revealed that their devices are highly connected and company C' added the internet of things is about making everything even non-living thing smart and these

technologies are already integrated into the company,

"We need them to be smart, we need them to be connected".

Company 'A' suggest internet of things is a smart network that can detect, control and program objects automatically and also the important potential areas of the application of internet of things in construction operation/industry could include logistics, transport, assets recording, energy-saving, intelligent homes and buildings. Internet of things offers great connections of devices.

Company 'H' added internet of things is the way of life now, the world is more connected than ever before, and also the internet of things offers smart communication such as social media. Company 'B' claimed

With this internet of things, you are capable of knowing all things and connect at any point without stress and the good things about this internet of things, it can view any context anytime, can be used by anyone, can be used on any device, can be used at any place and anytime, work on any network or any path and can be adapted for any business.

Internet is a way of life and the smart connectivity and ease of access to the internet of thing are what makes it unique for the construction business. Company 'F' added internet of things has helped us improve on our decision making, better our communication, which before now has been poor.

4.2.4. Cloud computing

Cloud computing is a disruptive innovation of the internet of things, which on-demand access to a shared pool of configurable resources is provided. Cloud computing is applied in the construction industry in various including but not just limited structural analysis cost estimating, architectural design, procurement management, and project planning and control.

Company A – G' have adopted cloud computing, only company H' still have many of their information in hard copies. Company C' claimed

"As you can realise we can't continue to rely on on-premises computing, we have to move to the cloud as an augmentation or though we augment it with the cloud, having our data on the cloud and stuff like that it makes us more secure than when we just had them on sight and premises".

The advantage of using cloud computing in the construction industry is to make better use of distributed resources, combined them to achieve greater output. Also, cloud computing supports the construction industry and its currently available collaboration tools such as desktops, internet networks, tablets, smartphones and laptops.

4.2.5. 3D printing

All case companies interviewed agreed not to have adopted 3D printing. 3D printing involves the printing of full-scale construction components is still an emerging technology and as an alternative construction method is attracting increasing attention. However, 3D printing is a concept of creating the entire building which is now being explored around Europe already and also there exists a prototype printer system which utilizes concrete as well as other specialised materials to make a structure comparable to a small house. The 3D printing starts with loose materials and then build objects into a 3D dimensional shape by using a digital template, by so doing makes 3D printing products are to be easily customised. 3D printing is a system of the fourth industrial revolution that needs to be adopted.

4.2.6. Drones

The adoptions of drones are still at the early stage in the construction industry in Nigeria. Construction firms that have adopted the drones, use drones to take aerial views, pictures and to monitor work progress.

Company 'A' claimed that drones are unmanned aerial vehicle (aircraft) operating under a remote control without a human pilot, drones are capable of sensing and responding to their environment. Company E' claimed that the company have adopted drones,

"Yes, we have drones, we use them to take shots, we take the aerial view, we take the landscape of our so many sites",

And company C' gave a holistic response,

"Drones are a very important part of what we do, we need to capture the moment, we need to ensure that there is monitoring", you can't be with the workers in person but we can be with them with drones and then ensure they are doing the right thing.

Company D added drones are flying objects,

"We use it to capture real-time images, monitor and have an aerial view and communicate these images to our office or client as part of progress report".

Only company B and F have not adopted drones.

4.2.7. Big data

Big data offers great benefits, notwithstanding the adoption of big data is still at the infancy stage. Company A, B, C, D, and E' adopted big data. Company C' responded to the follow-up question by saying

"yes, we have to keep analysing stuff, we have to keep analysing our data, keep knowing so that we can make trend, we can look at the trend in the construction industry and see how we can improve on them, so yes big data, very well we analyse data".

Company 'B' claimed big data reflects the situation of an extremely large amount of data for the current technology capacity to store, manage and process efficiently. The big data has attributes which are; volume (terabytes, petabytes of data), variety, (texts, sensors, audio, video, graphs), velocity, (continuous streams of data).

Company D' added that the company have adopted big data and it has helped the company decision making. Company A' claimed by saying "we have a big data centre and we are building a very big, big data centre in the country". Company F, G, and H' that have not adopted big data. Company 'E' claimed big data helped us turn data into actionable insights, which has to improve our decision making and reduce operational costs.

4.2.8. Augmented reality

Company A, B, C, and E' have adopted augmented reality. Company E' claimed

"We use it to place a model of a proposed project or design on an existing space; this is made possible via mobile devices and 3D model, the application of augmented reality in this company ranges from project planning, automated measurements, project modification, team collaboration, safety training and on-site project information, so you see how augmented reality has been an important tool for this company".

Company B' also claimed, "I think we do with the help of the architectural department, they come with a model and we try to synchronised everything that has to be in that building, we do use that". Company 'C' also added, we adopted augmented reality to provide an efficient way to visualise the construction projects. Augmented reality gives the clients or construction stakeholders that the object is present in view even though it is absent physically. Company B, F, G, and H' have not adopted augmented reality.

4.2.9. Robots

Only company A' adopted robots. Company 'A' claimed,

"We have adopted robots; we deploy it on repetitive, predictable activities and it has optimised operation and improved safety in work environments. These robots offer to us an effective way of mechanisation of our company, thereby increasing productivity, speed, and quality of products we put out there".

Company 'A' further added robots are artificial intelligence which involves the simulation of human intelligence in machines; they are programmed to think like a human. Robots are gaining popularity; influencing the way we live, interact and improve client experience.

4.2.10. Automation

Company F' started the company to some extent automate its processes and company C' also agreed "Yes, we try as much as possible to automate our processes to the extent we can, though we still need a lot of manpower". Company 'C' claimed that the company use sophisticated technology, highly automated which makes activities fast and easier. Company G' responded by saying "Well, some clients do request for that and we apply it". Company 'A' claimed that their construction processes are highly automated which makes the day to day site operation easier, faster, better and also free the company of monotony of repetitive tasks and also free the company from labour.

Company E' gave more insight,

"Yes we automate our processes, and let me tell you it is a way of simplifying our day to day activities or construction, like for us as a company is a way that you simplify interaction between you and your homes, commanding things for you without you making effort to do, the automation comes in different part, you have the security part of automation, you have the convenient part of automation, you have the entertainment part of automation and lastly the access part of automation".

In summary, fourth industrial revolution systems and processes such as: RFID, BIM, and cloud computing have 87.5% level of adoption; internet of things witness 100% level of adoption; drones with 75% level of adoption and Big data witness 62.5% level of adoption. However, augmented reality, robots and 3D printing have 37.5%; 12.5% and 0% level of adoption respectively, indicating a low level of adoption of the systems and processes that constitute fourth industrial revolution.

Company A, C, D, and E' rate the adoption of the systems and processes of the fourth industrial revolution very high but still believe there is still room for improvement while company B, F, G, and H' rate the adoption very low for their respective companies (Table 4.3). The internet of things and RFID, BIM, and cloud computing were adopted by seven case companies. Follow by drones and automation, adopted by six case companies and big data adopted by five case companies. Augmented reality was adopted by three case companies (A, C, E), only company A' adopted robots. 3D printing was not adopted by all case companies.

Only company A' had 90% level of adoption on the systems and processes that constitute the fourth industrial revolution, while company C, and E' witnessed 80% level of adoption and company D' had 70% level of adoption of the systems and processes that constitute the fourth industrial revolution. Company B, F, and G' witnessed 50% level of adoption and company H' had 30% level of adoption of the systems and processes that constitute the fourth industrial revolution systems and processes, and this company that adopted the least.

Table 4.3: Cross Case Analysis of Interview Findings on Fourth Industrial Revolution Systems and Processes Currently Adopted

S/N	Similarities of Issues Address	Differences of Issues Address
1.	RFID was adopted by both foreign and indigenous construction firms (company A, B, C, D, E, F, and H)	Company 'G' did not adopt RFID. RFID was adopted more by foreign construction firms (company A, B, C, and D) when compared to indigenous construction firms
2.	BIM was adopted by both foreign and indigenous construction firms (company A, B, C, D, E, F, and G)	Company 'H' did not adopt BIM. BIM was adopted more by foreign construction firms (company A, B, C, and D) when compared to indigenous construction firms
3.	Internet of things (IoT) was adopted by both foreign and indigenous construction firms (company A, B, C, D, E, F, G, and H)	No difference in the adoption. Internet of things witness the same level of adoption between both foreign and indigenous construction firms
4.	Cloud computing was adopted by both foreign and indigenous construction firms (company A, B, C, D, E, F, and G)	Company 'H' have not adopted cloud computing. Cloud computing was adopted more by foreign construction firms (company A, B, C, and D) when compared to indigenous construction firms
5.	3D printing was not adopted by both foreign and indigenous construction firms (company A, B, C, D, E, F, G, and H)	No difference, since none adopted it. 3D printing witness the low level of adoption between both foreign firms and indigenous firms
6.	Drones were adopted by(company A, B, C, D, E, F, G, and H) (company A, C, D, E, G, and H)	No difference in the adoption. Drones witness the same level of adoption between both foreign and indigenous construction firms
7.	Big data were adopted by both foreign and indigenous construction firms (company A, B, C, D, and E)	Company F, G, and F have not adopted Big data. Big data was adopted more by foreign construction firms (company A, B, C, and D) when compared to indigenous construction firms (Company 'E' was the only indigenous firm to have adopted it
8.	Augmented Reality was adopted by both foreign and indigenous construction firms (company A, C, and E)	Company B, D, F, G, and H, did not adopt augmented reality. Augmented reality witness low level of adoption when compared to other systems and processes of the fourth industrial revolution
9.	Robots witness low adoption by both foreign and indigenous construction firms. It was not adopted by (company B, C, D, E, F, G, and H)	Only Company A (foreign firm) adopted robots
10.	Automation was adopted by (company A, C, D, E, F, and G) Automation witness the same level of adoption between both foreign firms and indigenous firms.	Company ‘B’ and ‘H’ have not adopted Automation No difference in adoption as automation witness the same level of adoption between both foreign firms and indigenous firms

Table 4.3 revealed the similarities and differences in the issues addressed by both foreign and indigenous construction companies on the fourth industrial revolution systems and processes currently adopted. Systems and processes of the fourth industrial revolution such as; RFID, BIM, internet of things, cloud computing, drones, big data, automation are evident in both foreign and indigenous construction firms while 3Dprinting augmented reality and robots witness low adoption by both foreign and indigenous construction firms.

In conclusion, Table 4.3 shows no difference between both foreign and indigenous construction firms in the adoption of the internet of things, 3D printing, drones, and

automation. The major difference in the adoption of the fourth industrial revolution systems and processes by construction firms in Nigeria was the fact that these fourth industrial revolution systems and processes were adopted more by foreign construction firms when compared to the indigenous construction firms (Table 4.3). The indigenous construction is still saddled with the problem of low adoption to digital trend, this low adoption will hamper the growth of indigenous construction firms and also the indigenous construction firms might find it difficult to compete with the foreign counterpart.

4.3. Discussion of Findings

This study recognised the fourth industrial revolution in the construction industry is driven by the need to have an improved construction industry. The result from this study shows that the systems and processes of the fourth industrial revolution such as the internet of things have been largely adopted by foreign and indigenous construction firms in Nigeria. The adoption of the internet of things is to make things smart, construction of smart homes, use of smart devices and get things connected. This finding agrees with Bilal *et al*. (2016) suggested the primary vision behind the adoption of the internet of things is to bring together smart devices and objects together.

The results of the finding revealed the adoption of RFID in the construction industry was at a peak and their applications in the tracking of equipment are evident in the construction industry. This finding supports Osunsanmi *et al.* (2018) observed RFID in construction processes are a device used in the tracking of equipment and tools, monitoring, theft prevention and also the device is attached with sensors that can act as a tracker to locate stolen equipment or tools.

Another significant finding of the fourth industrial revolution systems and processes currently adopted is the BIM, the adoption was high, as its application involves the simulation of projects before it starts, minimises errors, eliminates waste and provides needed information on the entire lifecycle of a proposed project from inception to completion. This similar to the finding from Azhar (2011) observed that BIM involves the capturing of additional layers of information throughout the entire lifecycle of the building. Furthermore, BIM has five features; simulation, visualisation, coordination, optimisation, the ability to create and providing information about the whole life cycle of any projects, therefore eliminate waste and minimise errors. The adoption of BIM is evident in both foreign and indigenous construction firms.

The result from the finding shows the adoption of cloud computing is evident in both the foreign and indigenous construction firms in Nigeria. This finding is similar to Afolabi *et al*. (2018) observed, cloud computing has a significant change the construction industry, and it is not new to construction stakeholders and construction stakeholders have utilised cloud computing in one way or the other, informally or formally.

The results from this study show the high adoption of drones by both foreign and indigenous construction firms and were used to capture real-time scenario/images and monitor construction works. This finding is in line with findings from Tatum and Liu (2017) who suggested that drones collect real-time information from the location of personnel, equipment, hazards materials, moving equipment as well as the blind spot of a construction site to prevent the unsafe condition.

The findings of the study show the adoption of automation is evident in the construction process, much of the construction processes in Nigeria, are automated which in turn makes construction work easier, faster, and it simplifies day to day construction activities. This

finding collaborates with Madakam *et al*. (2019) suggested that automation of the construction processes makes day to day operation easier, faster, better and even free from construction labour and monotony of repetitive task.

The finding of this study shows the adoption of big data is moderate and still at the infancy stage in the construction firms in Nigeria. This finding confirms Maaz *et al.* (2018); Ismail *et al*. (2018) both observed big data from the lens of the construction industry is limited in contrast to the other industries resulting to primitive understanding. However, construction activities generate a high volume of data exchange from many stakeholders to be gathered and processes, the construction is indiscrete in dealing with a huge amount of miscellaneous data. Construction firms or stakeholder that adopt and utilise big data will gain insight and improve customer experience, reduce business cost, improve productivity, and it will increase the profitability of construction firms. The finding also indicates the adoption of big data was evident in foreign construction firms.

The finding of this study shows the low adoption of augmented reality and robots by construction firms in Nigeria and this could be due to lack of technical knowledge or expensiveness and complexity of these systems and processes that constitute the fourth industrial revolution. This finding is similar to the findings of Ezeokoli *et al.* (2016) who observed the application of digital technologies was at infancy stage due to lack of critical and technical knowledge among other managerial terms. This finding also confirms Oke *et al.* (2018) revealed the expensiveness and complexity of digital technological innovations which makes it hard to buy and operate, in operating, will require specialised training which will make all process expensive to acquire.

Furthermore, the finding of this study indicates that both foreign and indigenous construction firms in Nigeria have not adopted 3D printing. This finding is similar to the finding of Raji (2017) suggested 3D technology is relatively at its infant stage in developing countries like Nigeria. The finding is also similar to Hager *et al.* (2016) agreed 3D printing is still young and presents a lot of limitations, but there are high expectations and hopes for the future of 3D printed buildings and building components. *Tay et al.* (2017) also added 3D printing of full-scale construction components is still an emerging technology and as an alternative construction method is attracting increasing attention.

The finding of the study shows the low adoption of the fourth industrial revolution by indigenous construction firms compared to foreign construction firms. The foreign construction firms have adopted more of the fourth industrial revolution which has improved the way they work and also improves their productivity. This finding is in line with Aniekwu and Audu (2010) posited that Nigeria construction firm's productivity is at a low level when compared to that of foreign counterpart.

The finding of this study revealed the low adoption of indigenous construction firms. This finding confirms Ezeokoli *et al., (*2016); Osunsanmi *et al., (*2018) revealed that the level of adoption and application of digital technology was at infancy stage; moreover, this could be due to lack of capacity, technical knowledge and digital transformation dynamism among managerial teams.

In summary, the finding of this study revealed the adoption of fourth industrial revolution systems and processes such are internet of things, BIM, RFID, cloud computing, drones, and automation are more evident in the construction industry in Nigeria.

5. CONCLUSION AND RECOMMENDATIONS

The fourth industrial revolution has been slow to penetrate the construction industry in Nigeria; this is due to the low level of awareness on the fourth industrial revolution. The concept of the fourth industrial revolution has been understood, with it been limited to the advancement of ICT, automation, artificial intelligence and BIM. Most construction firms are uninformed about the concept of the fourth industrial revolution. It can be concluded that the adoption of the fourth industrial revolution and digitalization in the construction industry has started but its full adoption has been slow and foreign construction firms have adopted more of the systems and processes of the fourth industrial revolution when compared to indigenous construction firms.

The adoption of fourth industrial revolution systems and processes such are internet of things, BIM, RFID, cloud computing, drones, and automation are more evident in the construction industry in Nigeria. The benefits of digital transformation under the fourth industrial revolution are so many that it cannot be ignored. It offers benefits such as increased operational efficiency improve accuracy, makes working easier, mass customisation of products, improve productivity and performance, among many others. Therefore, the study recommends an increase in awareness of the fourth industrial revolution through seminars, workshop and training on the fourth industrial revolution.

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