International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Opportunities and Barriers for Adopting Robotics in Nigerian Construction Industry

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ABSTRACT

Construction is a critical global industry that is challenged to address issues of productivity, safety, quality, completion time, profitability, shortage of labour and waste management. Robotics has a tremendous potential impact on all these challenges. This study assessed the opportunities and barriers for adopting robotics in Nigerian construction industry. A survey method was adopted for the collection of primary data through a well-structured questionnaire distributed to fifty (50) professionals in the construction industry in the South East region of Nigeria. Data obtained were analyzed using Weighted Mean and Relative Importance Index (RII). The study identified fifteen (15) types of robots applicable for construction works. The opportunities for adopting robotics were assessed and ranked accordingly. These are: increased productivity, increased speed and reduced workload on operators, improved safety, promote standardization and better reliability & accuracy, improved quality, optimized work environment, enhanced supervision, cost effectiveness and enhanced constructability. Above all, there are limitations and barriers for adopting robotic technologies in construction which this study has also assessed and ranked accordingly. These are: human related, site/environment related, finance related, technical related, material / market related, government / ethics related and cultural related barriers. The study therefore recommends that government of Nigeria should get involved in assisting the construction users with incentives to promote the use of such innovative technology in construction since robotics involves high initial cost. The government needs to assist the contractors by paying incentives to reduce cost of such machinery and as well provide loan at a lower interest rate to construction robotics user. Training and education of construction professional should be given a priority. Workers need to be retrained to upgrade their skills in order to be able to operate the robots. The curriculum for training construction professionals should incorporate robotics and innovative technologies. This will help produce graduates that are knowledgeable in robotics applications. Lastly, the private and public sectors, and tertiary institutions in Nigeria should embark on research and commercial projects to study and produce automated machines for local construction processes.

Keywords: Robotics in construction, Barriers and Opportunities

1.1 Introduction

The construction industry is increasingly under pressure due to an aging workforce, lack of skilled trades people, and decreasing productivity, all of which could be alleviated through more efficient and streamlined processes that automation and robotics deliver (Bock, 2015). The Nigerian construction industry is particularly characterized withmany challenges that have hindered its growth and led to extremely low productivity levels when compared with other industries such as manufacturing. Some of these inherent challenges include: shortage of labor, occupational health and safety, decrease in quality and productivity, wastage of construction materials, cost and time overrun (Delgado & Oyedele, 2021). This view is supported by Sofait & Lukumon, (2021) when they opined that the growth of the construction industry is severely limited by the myriad complex challenges it faces such as cost and time overruns, health and safety, productivity and labour shortages. Indeed, construction industry is one of the least digitized industries in the world and most stakeholders acknowledge the age-long culture of resistance to change (Young, Panthi, & Noor, 2021). This inadequate adoption of digital technology and overly manual nature of the industry makes the management of projects more complex and unnecessarily tedious thereby making it difficult for it to tackle the problems it currently faces (Delgado & Oyedele, 2021).

However, Kumar, Prasanthi, & Leena, (2008) emphasized that Construction is an industry requiring strategies and new approaches to achieve a successful construction with time, cost, safety, and quality. These new strategies and approaches is the heartbeat of technological innovation which robotics is one of them. Automation showed a rapid increase in the manufacturing industry of mechanical and industrial products because of the quality results of robotics, hence construction industry embraces the use of pre-fabricated component such as precast concrete due to high usage of robotics in pre-fabrication of component. It has become apparent that the construction industry must embrace digitization and rapidly improve technological capacity especially with challenges of existing labour shortages, COVID-19 pandemic and the need to provide sustainable infrastructures (Delgado & Oyedele 2021).

Construction robots have experienced more than one hundred years of development, and have experienced two generations regarding mechanical transmission and hydraulic pressure. The now robotized construction machinery is called the third generation, which is a milestone in the development of construction machinery. It can be controlled remotely, automatically and semi-automatically, and can perform a variety of operations, in which natural operation is the primary feature (Jingyi & Shanshan, 2020). Construction robots can be based on remote operation, autonomous navigation and obstacle avoidance, path planning and motion control, intelligent environment perception, unmanned driving and other technologies (Melenbrink, Werfel, & Menges, 2020). It is transformed to reduce the workload of operators, optimize the working environment, improve operation safety and efficiency, and promote the standardization and refinement of construction operation (Gheisari, & Esmaeili, 2019)

1.2 Objectives of the Research

This study is anchored on three (3) objectives:

i. to identify different types of robotics available for construction works
ii. to assess the opportunities for adopting robotics in Nigerian construction industry
iii. to assess the barriers for adopting robotics in Nigerian construction industry

2.0 Literature Review

2.1 Robotics: Meaning and Origin

The word “robot” from the Czech robota (forced labour), is used to describe an incredibly wide range of machines that can perform tasks automatically. Robots are technically, machines that can perform complex activities automatically.They are highly automated devices that carry out physical activities in the real world. According to Dario, (2019), robots are required to have a certain degree of “intelligence”, otherwise for as complex as they can be, they are simple machine. Intelligence in this context, is the capacity of a machine to put itself in the environment in which it is operating and to interact with it. Robots are extremely precise and fast machines that can repeat the same operation over and over.

According to Jingyi & Shanshan, (2020), a robot is an electromechanical device which is guided by computer or microcontroller and electronic programming. Robots are flexible in that they can easily change their function in order to meet the demands of the manufacturer or the client. In doing so, robots essentially perform three tasks, as they “sense” by drawing on environmental stimuli, then “think” by using pre- set algorithms for planning and finally “act”, using the robots’ end-effector (e.g. a clamp or welding torch) to pick up and place an object or weld two objects together (Laurent, 2013). Robots require both software and hardware for its function.

Robotics is all about computerizing machinery to perform certain functions (Kumar et al, 2008). Construction Robotics is a replacement for labour and reduces the demand for skilled labour in the construction field. It is mostly adopted because of the demands for simplifying work, and work can be repeated over and over again. Moreover, due to the large amount of work in construction, this technology can increase productivity at a lower cost because it substitutes high labour (Opeoluwa, 2018). Construction robotics are designed to mitigate identified problems encountered in construction.

Dario, (2019) identified three (3) main reasons / drivers for the use of robots instead of humans to do something: **speed, precision and safety.** Safety is relevant where the activity to be performed has an intrinsic danger for the life of the human being normally performing it. Precision is required where accurate measurement is very essential. However, speed is the major driver that truly made a difference for the vast widespread use of robots. Such speed reduces the cost of production.Robots have mostly been used since they were first invented over the last fifty (50) years in industrial manufacturing (Forge & Blackman, 2010). However, according to International Federation of Robotics statistics (IFRS, 2021), despite promises of an industrial revolution as a result of the emergence of this technology, the best known uses of robotics in manufacturing is in the automotive industry. The first applications of robotic technologies to the construction industry were designed in Japan during the 70’s, in order to improve the quality of prefabricated elements for modular residential buildings. Since then, robots started spreading in the construction industry, slowly moving from factories to actual construction sites (Saidi, Bock, & Georgoulas, 2016).

When applying the concept of robotics to construction industry, one important caveat has to be made: the robotization of the industry that produce building materials or prefabricated parts of building (off – site) is very different from the robotization of the construction activities themselves (on – site). The first type is largely occurring already. This is evidenced in more bricks, blocks and concrete being produced, safer sawing of timber elements and more accurate dimensions of glass or metal cuts. However, on – site operations are much less prone to be changed for many reasons, but mostly because of safety, speed and precision are not needed to the extent robots can guarantee (Dario, 2019).

2.2. Robot Requirements for Construction Tasks

Rajkumar, (2017) identified four major requirements for robots in construction task:

- It should work in hazardous situations to replace men from fatalities.
- It should work in foul weather, darkness, hazardous areas without problems of motivation and administration leading to financial benefits.
- It should be designed to maximize benefits in number of application areas.
- It should be autonomous, mobile and cognitive.

2.3 Types of Robotics in the Construction Industry

a) Pre- fabrication Robotics

In the pre-fabrication there is 100% of robotics and construction automation which are more accurate in measuring batching, thereby avoiding wastage in concrete production. Robotics are being widely used in the pre-fabrication of components such as pre-cast concrete, prefabrication of masonry and prefabrication of steel. This can bring about good quality of products, high level of monitoring and supervision by worker is simplified. Moreover, the workplace is highly controlled to suit the situation of component hence quality can be achieved to optimum level (Kamaruddin, 2013)

b) Robotic Drones

Another emerging robotic technology is that of robotic drones. Drones are unmanned robots that are controlled remotely by human interface and are used to accomplish various tasks. They are very versatile as these robots can be small or large, fast or slow. There are four main types of drones that are directly applicable to construction practices: Contour crafting, transportation, surveying, and monitoring drone. **Contour crafting** drones merge drones and 3D printing technology to create a flying 3D printer. **Transportation drones** has the ability to lift heavy payloads and deliver them to a high location. The benefits of this technology is that they can attain high locations very easily whereas it could take a human worker a long time to deliver materials to the same high location and in some cases practically impossible for human. **Surveying drones** are used to get still images, 360 panoramas, and aerial shots of a construction site.A surveying drone is capable of analyzing weaknesses in a bridge when partnered with software imaging technology (Drelich, 2015).**Monitoring drones** are used to act as security at a construction site. They can be used as security for the construction site but also can be used to monitor the site to determine who is there and how long they have been there using facial recognition. The advantages of this technology are similar to that of the surveying drones in that they can attain high locations.

c) 3D printing Robot

This technology can fundamentally change the way we construct buildings. Where normal construction takes a few months, construction by 3D printing robots can print a structure in a day or two. There is little to no waste created, as the robot applies the exact amount of material needed for the structure.3D printing and contour crafting robots require the placement of a rig which can be very demanding. 3D printers aim to be highly mobile when setup is complete. While it may take some time to set up the apparatus, the 3D printer aims to save significant time in the build period of the structure (Kamaruddin, 2013).

d) Bricklaying Robotics

Bricklaying robots are being used in the construction field to perform a task consecutively and efficiently by laying bricks for buildings, roads, walls, etc. Bricklaying robots come in a few sizes. Industrial robotics arms are able to do repetitive task efficiently.Many bricklaying robots utilize industrial robotics arms to do repetitive tasks including bricklaying or stacking. Other bricklaying robots can lay a masonry pathway using a conveyor belt or a coupled pattern arrangement system.Bricklaying robots can assemble the masonry structure of the building, while the workers operate the robot or perform support task (such as mixing the cement or bonding agent). They can also make elaborate masonry structures that could not be created with traditional methods. (Forge & Blackman, 2010).

e) Welding Robots

These robots can be used on steel structures and particularly on the docking stations of ports. They are able to make precise welds and maneuver in hard to reach locations. There are two areas where this robot can be used in, one being the construction of skyscrapers. Welding robots are used to weld steel beams together. Another use in construction are concrete slabs. Before the concrete can be poured, riggings must be placed in and welded. Because of the maze of riggings, a welder is at a large risk of getting hurt, but a welding robot could take the place of a worker and prevent injury (Jung, Chu, & Hong, 2013).

f) Forklift robot

Forklift robots have a main goal of transporting heavy or generally large objects from one point to another. They aim to alleviate the need for a human to carry these objects, or have a human control a forklift to transport the goods. They are able to accomplish this through vision tracking and map localization. In construction, it is very common for many materials and supplies to be heavy and or burdensome for workers. Having a forklift robot would alleviate this burden (Bogue, 2018).

g) Steel-Beam Positioning Robot

Steel-Beam erection work is one of the most dangerous tasks on the construction to be robotized. Steel -Beam positioning manipulator lifts two or three steel beams and sets them in the correct position by teleportation. While setting beams, the manipulator grasps the top of the columns and there is no need to be lifted by a tower crane. This means that the tower crane can be used for the other jobs while the manipulator is working (Bogue, 2018)

h) Ceiling-Panel Positioning Robot

Ceiling construction for office buildings, hostels and other commercial buildings is accomplished by using plaster-board panels, which are made of plaster and covered with paper. A typical midsize office building, for example, with eight floors and 5,000 sqm requires 400 panels for each door. The procedure for ceiling construction requires temporary scaffolding to be erected over the floor and then cleared away for next procedure. The workers must raise heavy, large panels over their heads for placement against the hanging ceiling flat bars. Repetition of this work over a long period of time exhausts workers (Forge, & Blackman, 2010).

i) Roadwork robots

Roadwork robots are primarily focused upon repainting and repaving roadways. The primary reason for this is to do small patch jobs to avoid the highway clutter and traffic jams (Laurent, 2013).

j) Fire Proofing Spray Robot

Rock wool spray work for fireproofing steel structural members is a hazardous construction job. The robot was developed to provide a safer work environment for spray workers. While spraying, the robot moves parallel to a steel beam at a constant distance measured with a pair of ultrasonic sensors (Forge & Blackman, 2010).

k) The Wall spraying robot

This robot replaces the high-altitude operations in traditional buildings, greatly improving the safety, with 4 to 6 times of the traditional work efficiency.Wall-Finishing Robot is an automatic spray-painting system for the high-rise residential buildings. Conventional painting work has resulted in accidents when objects fall from high scaffolding. This robot is developed to decrease such accidents and to realize uniform spray quality using robot. Moving along the handrail on the wall, the robot extends its multi axis arm. A spray nozzle moves up and down on the end member of the arm. The arm avoids obstacles, such as pipes located along the wall and moves its spray nozzle (Saidi, Bock, & Georgoulas, 2016).

l) floor tile robot

This robot can accurately grasp and place floor tiles with a robotic arm to ensure the flatness of the floor tiles and the gap between the floor tiles, which consequently reduce the hollow rate of the floor tiles (Melenbrink, Werfel & Menges, 2020).

m) **The floor cleaning robot**

This robot can clean floor stones, debris and dust on the construction site in a dusty environment, and automatically empty the trash can. The cleaning rate is 90%, and the construction efficiency is more than twice of manual operation. (Melenbrink et al, 2020).

n) Demolition Robots

Demolition robots are primarily used for tearing down building walls and other various structures. Demolition is an important part of construction, specifically in the renovation field. The primary benefits of demolition robots are that they are much more effective than handheld equipment. They also allow the operator to stand away from the debris and contaminants, making them safer than handheld devices.There are three distinct types of demolition robots that are available or being developed: multi-tooled, hydro-powered, and eco-friendly. Multi-tooled demolition robots allow for multiple types of tools to be placed at the end of a robotic arm on the demolition. Hydro-powered demolition robots use high pressured water jets to disintegrate walls and beams with ease.The eco- friendly demolition robots turn the waste product into recyclable aggregate (Laurent, 2013)

o) Exoskeletons Robots

The robotic exoskeletal suits work with humans to enhance a task or ability the human body lacks. Intelligent suits are meant to increase the strength of the average user, endurance, speed, agility, etc. Its major benefit is that it allows for injured or disabled workers to work in construction. Also it allows workers to lift and transport heavier objects than ever before (nLink, 2018)

p) Humanoid Robot – 5P

This robot can be used in large buildings such as the construction sites, shipyards and aircraft facilities. It is a 182cm, 101kg humanoid robot with 37 degrees of freedom in the body: two on the neck, three on the waist, eight on the arms, six on the legs, and two on the hands. Except for hands, this represents the freest freedom of movement in the human robot prototype (HRP) series. HRP-5P, constructed with HRP series, adopts new hardware technology. In order to imitate the human body motion, in the absence of human freedom, the researchers ensured a wider range of joint movement in the hip and waist area (where multiple joints are concentrated). In this series, it has unparalleled physical capabilities. Its robot intelligence includes environmental measurement and object recognition, facilitated with whole-body motion planning and control, task description and execution management, and highly reliable systematic technology. The intelligence of the shell in this body has enabled autonomous plasterboard installation by robots, and HRP-5P can be used on construction sites. Using HRP-5P as a development platform, with the cooperation of industry and academia, it is expected to accelerate research and development, enabling the practical application of humanoid robots in construction sites and the assembly of large structures such as aircraft and ships. HRP-5P joint torque and speed doubled on average, using a high-output motor, adding cooling to the drive mechanism, and adopting a joint drive system with some joints with multiple motors. Therefore, the robot can perform tasks involving heavy loads, such as lifting gypsum boards from a stack. Each arm of HRP-5P extends horizontally and weighs 2.9kg. HRP-5P uses a head-mounted sensor, and the robot continuously obtains 3D measurements of the surrounding environment (frequency 0.3 Hz). Even if the field of view is blocked by objects used at work, the stored and updated measurement results allow the execution of a walking plan while carrying a panel or correcting walking when the foot is slippery. HRP-5P can learn convolutional neural networks involving the use of a newly constructed object image database. The robot can detect 10 types of 2D object areas, even under low-contrast backgrounds or dim lights, with a high accuracy of 90% or more. By arranging a virtual test environment, setting up a virtual test environment for robot intelligence in the Choreonoid robot simulator, and monitoring the software regression for 24 hours, a highly reliable robot system can be constructed and the quality of large-scale software can be maintained (AIST, 2018)

2.4 Opportunities for Adopting Robotics in Nigerian Construction Industry

The use of construction automation and robotics will definitely increase productivity of the construction project (Everett & Saito, 1994). Opeoluwa, (2018) opined that robotics in construction has shown a great advantage in the construction industry for execution of different types of work in construction in terms of increasing production, cost reduction, resolving labour issue and delivering project on time. In the same vein, Bogue, (2018) identified the following as opportunities for adopting robotics in construction: increased safety, increased productivity, improved quality, better reliability and accuracy, faster and more consistent than humans.

However, this research summarizes the opportunities for adopting robotics in construction industry as follows: improved quality of the construction product, enhanced supervision, cost effectiveness, improved safety and accident reduction, optimized working environment, promote standardization and refinement of construction operation, reduce the workload of operators, increase productivity and efficiency, increased speed of construction, enhanced constructability and buildability, better reliability and accuracy,

2.5 Barriers for Adopting Robotics in Nigerian Construction Industry

Bogue, (2018) identified the following as limitations for adopting Robotics in construction: high initial cost, unstructured work environment, maintenance and repair cost, and potential loss of jobs due to automation. While Trujillo & Holt (2020) categorized the barriers to the implementation of automation and robotics technologies into three main categories: culture, technical and teams. However, this research categorizes the main factors hindering the adoption of robotic technologies in the construction industry into seven (7) categories for easy assessment. These are:

- **Environment / Site Related Barriers**

The inherently unstructured nature of construction sites prevents straightforward integration of robotic technologies already used in factories. Every building can be considered as being unique due to the many differences that apply to its shape, materials, components used and locations. This variability in construction sites requires robotics that can learn and adapt fast in changing environments. This means that robotics to be deployed in the construction industry must be useable in different construction projects or sites and tested thoroughly to convince construction contractors to use them.

- **Human related barriers**

Warzawki (1991) mentioned that the full adaptation of construction automation and robotics is dependent on human. James, Wong, & Chan, (2006) stated that Construction industry plays a significant role in the employment of workers in the country. Therefore, workers fear unemployment with the adoption of robotics in the construction industry, hence it becomes the barriers for automation because if robots are the future construction technology, it means there will be job loss. The use of robotics will replace skilled labour, and those workers that are affected will be required to change trade in which they specialize in. For example, bricklayers will change to specialize in carpentry because robots that can lay bricks are introduced, so substitution for bricklayer will be expected. Unskilled labour will be left with shortage of work.

- **Economic / Finance related barriers**

The benefits of innovative solutions in the construction industry are indisputable. However, the initial costs required to invest in such innovative solutions like robotics are usually very high. The maintenance requirements of such solutions also need to be considered. According to Mahbub (2012) the resistance in the implementation of robotics and construction automation involves high initial cost and maintenance cost. This may be unaffordable for the vast majority of subcontractors and small firms that make up the bulk of the Nigerian construction industry. Therefore, it is important for firms to determine the cost savings and return on investment of such technologies to determine whether to invest or not. High initial cost,maintenance and repair cost is a great factor to consider before embracing robotics. Because of this high cost, contractors still prefer the use of traditional method of constructing.

- **Government and ethics related barriers**

The negligence of the public sector / government towards career development in the field of automation and robotics, lack of industrial partnership with academic excellence in the areas of research and funding and lack of government support to the startups whose innovative abilities towards mechanization and automation have been quashed by insensitive politically inclined roles played by the government are all government related barriers towards the adoption of robotics. Winfield & Jirotka (2017) further elucidated that establishing and maintaining public trust in innovative technologies is dependent on an inclusive, transparent and agile governance. This is a crucial issue that is of great importance to the society at large. The competences of innovative technologies while promising great outputs, could also be dangerous if not properly regulated by the government. The essence of the regulation is to safe guard the construction company and construction workers where such innovations are being used.

- **Cultural related barriers**

In construction, traditionally known ways of doing things are favoured above the new but untrusted technologies promising to deliver great rewards (Babic & Rebolj, 2016). Skeptical Attitude of the main stakeholders involved in construction (construction companies, clients and regulatory bodies) are characterized by a strong tendency to stick to well consolidated practices rather than to innovate and adopt novel technologies. This means that the construction industry is slow to adopt innovative technologies. This is because little mistakes in construction processes often lead to huge quality, cost and time implications, with a roll-over effect to the overall project plan (time, cost, supply chain and logistics, procurement, etc.). Thus, construction industry especially in Nigeria has a high resistance to change, which is a great barrier in adopting robotics.

- **Technical related barriers**

Construction sites are mostly remote and lacking power, telecommunications and internet connectivity (Winfield & Jirotka, 2017). Sometimes, even construction activities lead to interruptions in power and internet connectivity. This poses a serious problem in the use of innovative tools on construction sites whose operation relies mostly on good internet connectivity and power supply e.g. robots, site monitoring systems, etc (Winfield & Jirotka 2017). Forexample, sensors and actuators communicate information that needs to be computed in real-time during construction. It is pertinent to look for ways to solve this problem efficiently and effectively.

Also, there is a global shortage of robotic engineers with the requisite skills to spearhead serious developments across industries (Oyedele & Jaiyeoba, 2015). It is quite difficult to get robotic engineers with experience in the construction sector to build custom solutions targeted at solving the many problems in the industry.

Robotics can be complex which makes it difficult to be understood by people because it involves integration of information technology. Robotics operators need to undergo training to be familiar with the new technology and to avoid being eliminated in the construction industry (Kamaruddin, Mohammad, & Mahbub, 2016). Sadique & Mahesh (2016) further elaborates the barriers to implementation of robots and automation as expensive to update as technology release new automation and adopting new technology to suit the task because not all the construction processes are the same.

- **Market / Material related barriers**

For every construction site, there are numerous materials to control for the execution of a project. The nature and forms of such materials varies, thus there is no uniformity. This makes it difficult to create a multi-purpose robotics, rather each robot is streamline to perform a particular function. Also, construction industry is characterized with complexity of the supply chain and variety of markets. The number of different stakeholders and the fragmentation of the supply chain entails a strong inertia towards innovation due to extremely varying interests and needs. Different Markets (regional markets) have intrinsic differences in regulations, cost of materials, cost of workforce, quality requirements for products, etc.) that imply different requirements and restrictions.

3.0 Research Methodology

This research survey was conducted by employing both quantitative and qualitative methods. The primary data were obtained through a well-structured and simplified questionnaire distributed to fifty (50) construction professionals in the South-East region of Nigeria. These professionals include: Architects, Builders, Quantity Surveyors, Project Managers, Civil Engineers and structural engineers. Out of the fifty questionnaire distributed, forty-eight were returned fully completed which represents 96% of the survey sample. The secondary data were obtained through extensive literature review mostly from journal publications, internet source, text books and articles.

3.1 Method of Data Analysis

Data for this research were analyzed using the descriptive statistics. This helped in describing, summarizing and organizing data in a sequence. The factors of barriers and opportunities for adopting robotics in construction were assessed through the questionnaire on a five (5) point likert scale and using Weighted Mean and Relative importance index (RII) for their analysis. The five likert scale is rated as follows: strongly disagree = 1, disagree = 2, neutral = 3, agree = 4, strongly agree = 5. The computing formula are as follows:

i. Weighted mean (X) = $\mathbf{\Sigma}f$x / $\mathbf{\Sigma}f$ Where: x = points on the Likert's scale (1, 2, 3, 4 & 5) and f = frequency of respondents' choice of each point on the scale.

ii. RII = Mean / K. where K is the maximum point on the likert scale (5).

Rule for rating of factors: The item with the highest RII is ranked first and so on. Interpretation of RII value is as follows: if RII < 0.60 then item assessed has low rating. If 0.60 ≤ RII <0.80, item assessed has high rating and if RII ≥ 0.80, item assessed has very high rating.

4.0 Data Analysis

4.1 Analysis of primary data from questionnaire

The primary data obtained from the forty-eight (48) respondents to the questionnaire were analyzed and presented in the tables below:

Table 1: Analysis of Opportunities for Adoption of Robotics in Nigerian ConstructionIndustry

S/n	Opportunities for Adoption of Robotics in Construction	1	2	3	4	5	$\Sigma f x$	Σf	Mean	RII	Rank
1	Improved quality	0	0	0	21	27	219	48	4.56	0.91	5th
2	Cost effectiveness	3	5	7	13	20	186	48	3.88	0.78	8th
3	Improved safety	0	0	0	15	33	225	48	4.69	0.94	3rd
4	Optimized working environment	1	0	5	12	30	214	48	4.46	0.89	6th
5	Promote standardization of operation	0	0	2	14	32	222	48	4.63	0.93	4th
6	Increased productivity	0	0	0	5	43	235	48	4.90	0.98	1st
7	Increased speed	0	1	2	4	41	229	48	4.77	0.95	2nd
8	Enhanced constructability	2	6	8	15	17	183	48	3.81	0.76	9th
9	Better reliability and accuracy	0	1	3	7	37	224	48	4.67	0.93	4th
10	Enhanced supervision	1	4	6	14	23	198	48	4.13	0.83	7th
11	Reduced workload on operators	0	0	2	8	38	228	48	4.75	0.95	2nd

Field Study (February, 2022)

Table 2: Analysis of Barriers for adoption of Robotics in Nigerian Construction Industry

S/n	Barriers to Adoption of Robotics in Construction	1	2	3	4	5	$\Sigma f x$	Σf	Mean	RII	Rank
1	Site related barrier	0	0	3	12	33	222	48	4.63	0.93	2nd
2	Human related barrier	0	2	1	4	41	228	48	4.75	0.95	1st
3	Material/Market related barrier	5	7	6	8	22	179	48	3.73	0.75	5th
4	Finance related barrier	0	2	5	6	35	218	48	4.54	0.91	3rd
5	Government related barrier	4	6	18	8	12	162	48	3.38	0.68	6th
6	Technical related barrier	2	6	4	19	17	187	48	3.90	0.78	4th
7	Cultural related barrier	7	15	12	6	8	137	48	2.85	0.57	7th

Field Study (February, 2022)

4.3 Discussion of Findings

Analysis and ranking of opportunities for adopting robotics displayed in table 1 above revealed that nine of the indices have RII> 0.8 and are rated very high. These factors ranked accordingly are as follows: increased productivity (0.98 –1st), increased speed and reduced workload on operators (0.95 – 2nd), improved safety (0.94- 3rd), promote standardization and better reliability & accuracy (0.93 - 4th), improved quality (0.91 – 5th), optimized work environment (0.89 – 6th) while enhanced supervision (0.83 – 7th).However, two of the indices have 0.6<RII<0.8 and are rated high. These are: cost effectiveness (0.78 – 8th) and enhanced constructability (0.76 – 9th). None of the assessed indices has a low or very low rating. This is a pointer that all the indices addressed in this research are potential benefits for adopting robotics in Nigeria Construction Industry.

The analysis and ranking of barriers to the adoption of robotics in Nigerian construction industry in table 2 above revealed that three of the factors have RII > 0.8 and are therefore rated very high. These factors ranked accordingly are: human related barriers, site / environment related barriers, and finance related barriers. Human related barriers ranking first indicates that construction workers are unwilling to adopt robotics for fear of losing their jobs. This is very critical particularly in Nigeria where the level of unemployment is very high. Also, the skill and knowledge needed to operate such robots are not inculcated to the construction professional in Nigeria. Site related barriers ranking second clearly supports the view of other authors that construction site is very rough, unstructured and unorganized with so many uncertainties. Thus, integrating robots into such an environment will be very difficult unlike the control environment of manufacturing industry. Finance related barriers ranking third shows that cost of initial purchase, maintenance and repair of robots are very high. Not all construction companies can afford it and even when they succeed in purchasing it, to recover the expenses may end up pushing the overall project cost up beyond the budget. Other factors such as Technical related barrier, material / market related barrier and government / ethics related barriers have 0.6<RII<0.8 and are rated high. This reveals that these factors are also strong but not to be compared with other three factors initially discussed.

However, only cultural related barrier has RII<0.6 and is therefore rated low. This implies that cultural related issue is not a strong barrier to the adoption of robotics in Nigerian construction industry.

5.0 Summary

Construction work usually takes place in a disorganized environment hosting many types and areas of danger.Current trends in skyscraper towers, with accompanying escalations in labour costs and difficulty in hiring suitable workers, inevitably raises the need to adopt various robotic technologies in the construction industry. This research identified fifteen (15) types of robots applicable for construction works. This innovative move has lots of advantages which this research has assessed and ranked accordingly. These are: increased productivity, increased speed and reduced workload on operators, improved safety, promote standardization and better reliability & accuracy, improved quality, optimized work environment, enhanced supervision, cost effectiveness and enhanced constructability. Above all, there are limitations and barriers for adopting robotic technologies in construction which this study has also assessed and ranked accordingly. These are: human related, site/environment related, finance related, technical related, material / market related, government / ethics related and cultural related barriers.

5.1 Recommendation

Knowing fully well that robotics is faced with high cost of implementation, government of Nigeria should get involved in assisting the construction users with incentives to promote the use of such innovative technology in construction. The government needs to assist the contractors by paying incentives to reduce cost of such machinery and as well provide loan at a lower interest rate to construction robotics user. Training and education of construction professional should be given a priority. Workers need to be retrained to upgrade their skills in order to be able to operate the robots. The curriculum for training construction professionals should incorporate robotics and innovative technologies. This will help produce graduates that are knowledgeable in robotics applications. Lastly, the private and public sectors, and tertiary institutions in Nigeria should embark on research and commercial projects to study and produce automated machines for local construction processes.

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