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Robotic Technologies and Automation in Construction: A Systematic Review

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Abstract

The global construction industry is experiencing a high rate of disruption arising from the deployment of emerging robotic technologies and process automation. This study investigates research trends in robotic technologies and automation in the construction industry. Using topic-specific keywords to organise and summarise pertinent studies, the study undertook a systematic literature review and meta-analysis of robotic technologies and automation in construction. A systematic search of the databases of Scopus, Web of Science, and Dimensions was conducted, with a total of 9,515 journal articles retrieved from them. Based on inclusion and exclusion criteria, a total of 51 research papers met the parameters for meta-analysis and systematic review. Data relating to the research papers' demography and to robotic technologies as well as automation in construction were mined, with a quantitative meta-analysis performed on them. The results show a spread of research efforts across Europe, Asia and America, with an increase in research output between 2019 and 2023. The results further show that construction gantry systems, bricklaying robots and 3D concrete printers are the most studied robotic technologies and automation processes in the sector. The study concludes that there is still a paucity of research on robotic technologies and automation in construction. The study therefore recommends further research on robotic technologies and automation in construction, especially with regard to their appropriate application and deployment in construction projects across Africa.

Keywords: Automation; Building; Construction; Efficiency; Robot; Technology

1.0 Introduction

Robotics and automation are cutting-edge technologies that are revolutionising the construction industry (Oke et al., 2019). With huge advantages ranging from improved effectiveness to safety and cost savings, modern disruptive technologies are gradually replacing traditional construction processes (Smith, 2019). While these emerging technologies hold immense promise for the construction industry, their level of adoption remains unsatisfactorily low, especially in Africa with its huge infrastructural challenges (Aghimien et al., 2020).

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For example, the national housing deficit in Nigeria was estimated to be 17 million as of August 2012 (Okunola, 2022), while that of South Africa was close to three million units (Sobantu et al., 2019). These housing shortages are among the most acute globally, with both countries harbouring the largest number of residents living in substandard housing and slums (Ebekozien et al., 2023). These statistics suggest a huge housing market teeming with business opportunities for the building construction sector in both countries. The deficit in Nigeria has been further increased by the incessant collapse of buildings. Between December 2012 and December 2022, 271 building collapses were recorded in Nigeria with over 531 fatalities (Ajayi, 2022).

Previous researchers (Umo et al., 2018; Windapo & Rotimi, 2012) identified the causes of building collapse to include the use of substandard materials, the presence of structural defects and compromise at various stages of the building production process. These problems suggest the need for reviewing the current building production processes. The emergence of robots and process automation, with their potential for significantly reduced human involvement, may be the much needed solution to the myriad of problems confronting the building construction sector in Nigeria and the rest of Africa.

No doubt, the adoption of disruptive technologies such as robotics and automation has improved production processes, especially in the manufacturing, production and management domains (Hajare & Gajbhiye, 2022; Lakkala et al., 2023; Ryan et al., 2022). What remains concerning, however, is the low level of adoption of evolving technologies in the production process for buildings, as well as the inadequacy of literature on enhancing the building production process through the use of robotic technologies and automation. Therefore, this study seeks to cover this gap with a systematic investigation of the trends and patterns of robotics and automation technology that are used in the construction industry. The specific foci of this study are to:

(i) identify the most commonly adopted types of robotics and automation in the construction industry;
(ii) determine the significance of deploying robotics and automation in the construction industry.

2.0 Methodology

The meta-analysis and systematic review approaches were adopted for the study, since they are appropriate research designs for synthesising existing scientific information, reducing bias in the selection and inclusion of studies, appraising the quality of included studies, validating the conclusions of primary studies, and identifying areas for future research in a particular research area (Anane et al., 2023). The Scopus, Web of Science, and Dimensions databases were considered for data mining for this study based on their reputation for credibility (Martín-Martín et al., 2021). A total of nine thousand, five hundred and fifteen (9,515) papers were retrieved from the three databases.

Furthermore, the study examines trends and patterns of robotics and automation technology in construction; therefore, the studies selected were those focusing on the use of automation and robotic technologies in construction. Studies were eligible for inclusion in the review if they presented empirical data on robotics and (or) any form of construction automation. The systematic review included research studies published from 2012 to 2023 that were written in English and clearly described their methodology. Papers in consideration were excluded if the focus was not related to robotics and (or) automation in construction, while papers were included if they presented empirical data in their analysis. Each of the papers was subjected to quality assessment using the criteria presented in Table 1.

Table 1: Criteria for paper inclusion for the study

Criteria	Standard
Research	Is the paper based on research?
Aim	Was the aim of the research clear?
Method	Was the research methodology used appropriate?
Data analysis	Was the data analysis sufficiently rigorous?
Findings	Are the findings clearly stated?
Acceptance	Can I accept these findings as true?
Value	Can I apply these findings to my own work?

Only papers meeting the criteria in Table 1 were considered for inclusion in the study.

Figure 1 shows the flow diagram for selecting articles for the study based on the predefined extraction criteria for the study.

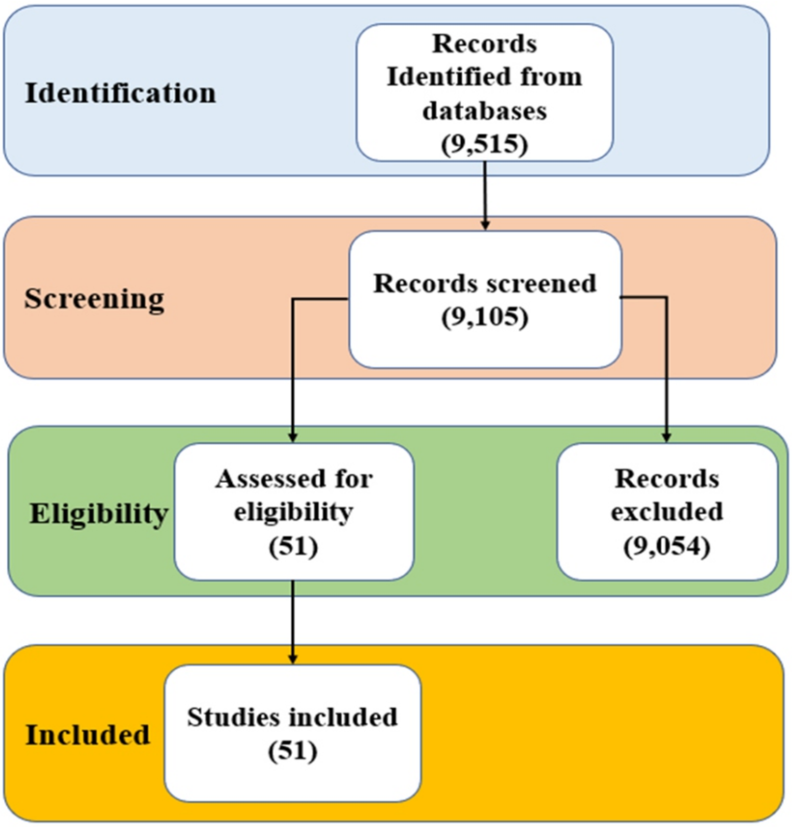

Figure 1: Flow diagram for selection of articles for the study

Figure 1 shows that only 51 of the initial 9,515 database-retrieved paper met the inclusion criteria for meta-analysis and systematic review. For the systematic review, data was extracted from each of the included papers. The relevant information included the paper title, the year of publication, the source name, the findings, and the conclusion of the paper. Each of the papers was analysed based on the following themes: (i) type of robot and (or) automation system; (ii) impact on construction; (iii) robotic system design; (iv) critical hardware; and (v) purpose of robot and (or) automation system.

3.0 Results

3.1 Publishing Year

Figure 2 shows the distribution of selected studies based on publication year.

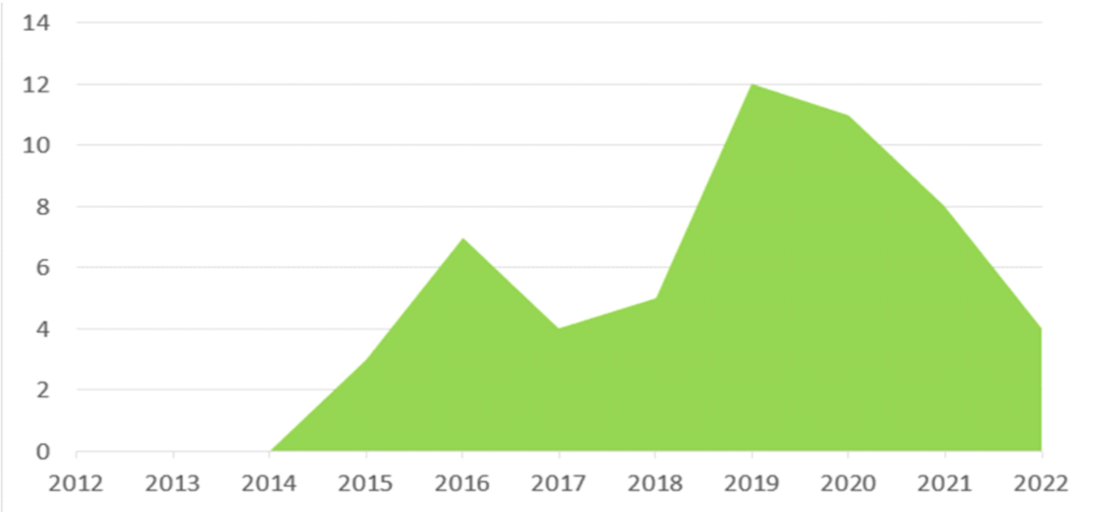

Figure 2: Publication distribution over the period 2012-2022

The sequential year-by-year paper distribution in Figure 2 shows growing interest in research on the related subject-matter of robots and automation in construction. The number of papers grew from 19 papers in the first half of the decade, i.e. between 2012 and 2018, while the period from 2018 to 2022 accounted for the most published papers, with a total of 32 papers. The results indicate an increase in the number of publications during the last five years, thus showing that automation systems and robotics for concrete building construction is a growing area of research interest.

3.2 Publishing Houses

Figure 3 shows the paper distribution based on the database in which the papers were published.

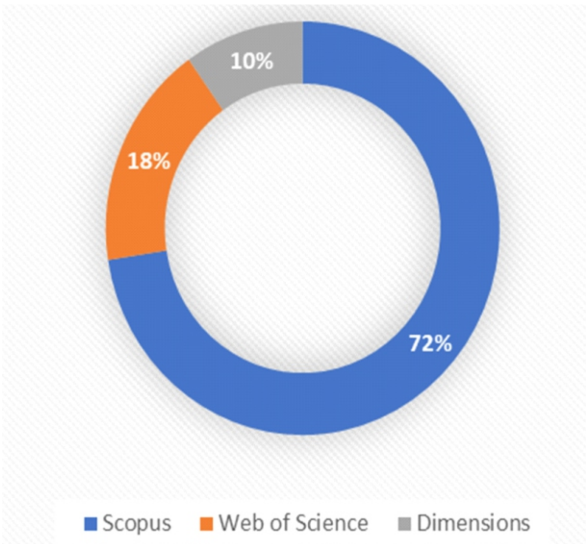

Figure 3: Publication distribution based on publishing database

From the analysis of the publishing databases in Figure 5, it can be seen that Elsevier's Scopus publishing has the highest number, at 72%, of published papers on the subject of investigation, followed by Web of Science at 18% and Dimension at 10%.

3.3 Publications Based on Countries and Continents

The distribution of the papers based on the country of origin of publication is presented in Figure 4.

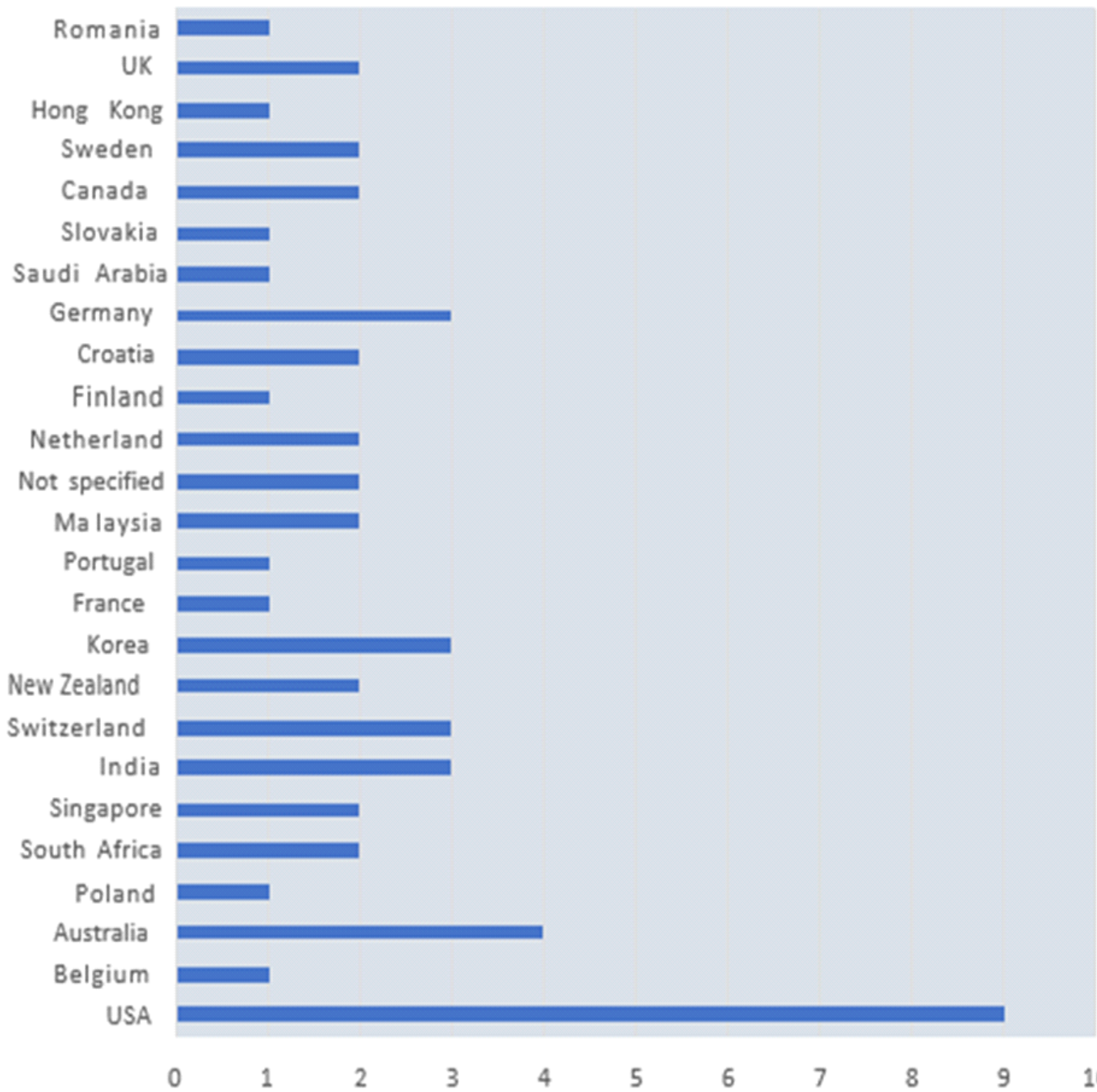

Figure 4: Paper distribution based on country of publication

Figure 4 shows the geographical distribution of the papers. The analysis shows that the majority of the papers were published in the USA (f = 9) and Australia (f = 5). Furthermore, the analysis was aggregated based on the continent of publication and the results are presented in Figure 5.

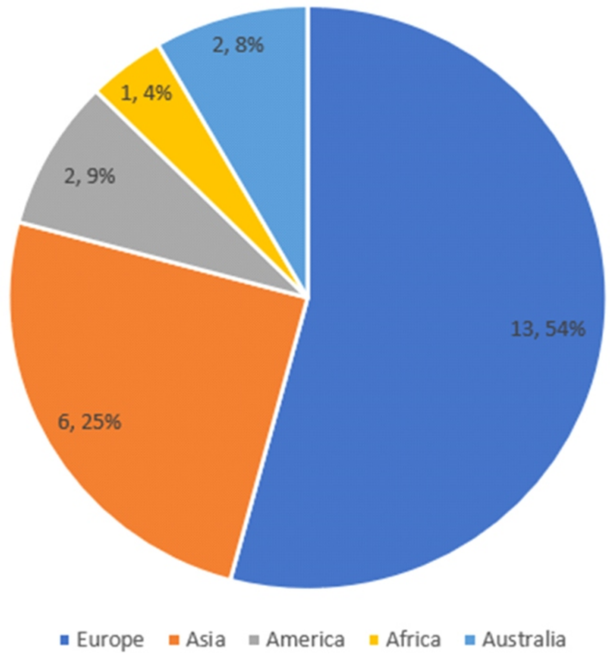

Figure 5: Paper distribution based on continent of publication

The result in Figure 5 reveals that Europe has the highest publication output, at 54%, followed by Asia at 25%, while Africa had the least publication output of 4% only.

3.4 Publications Classification Based on Research Focus

The papers were categorised based on the research focus of automation, robotics or a combination of both. The result of the analysis is presented in Figure 6.

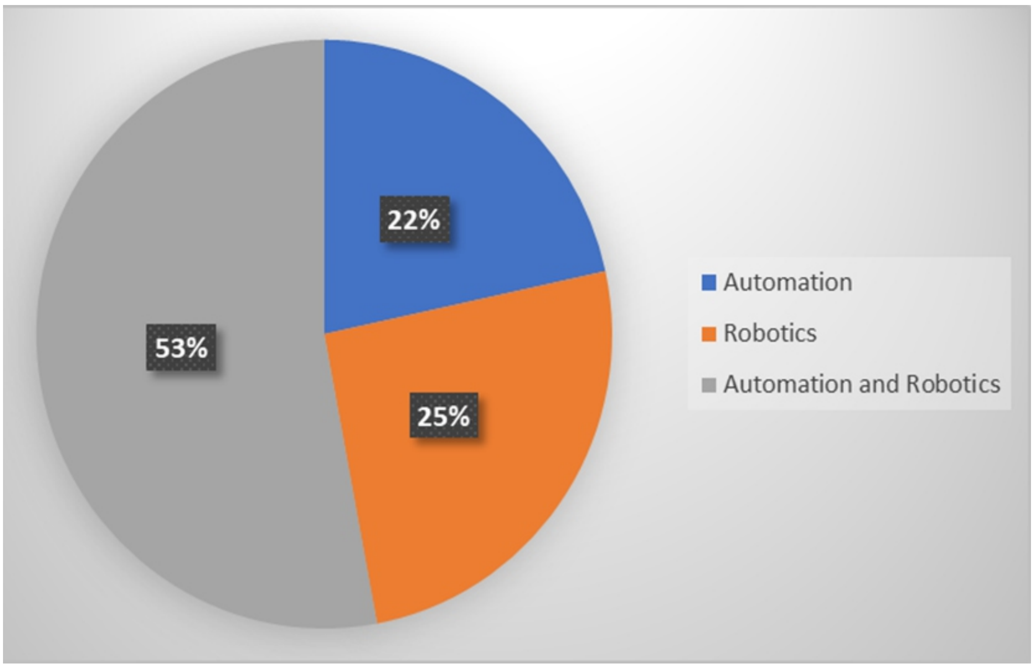

Figure 6: Paper distribution based on research focus

As Figure 6 shows, 53% of the papers focused on both automation and application of robotics in construction, while 22% focused only on automation and 25% focused only on robotics.

3.5 Types of Robots and Automation

The papers were analysed to identify the various types of construction robots and automation processes that they focused on, with the results presented in Figure 7.

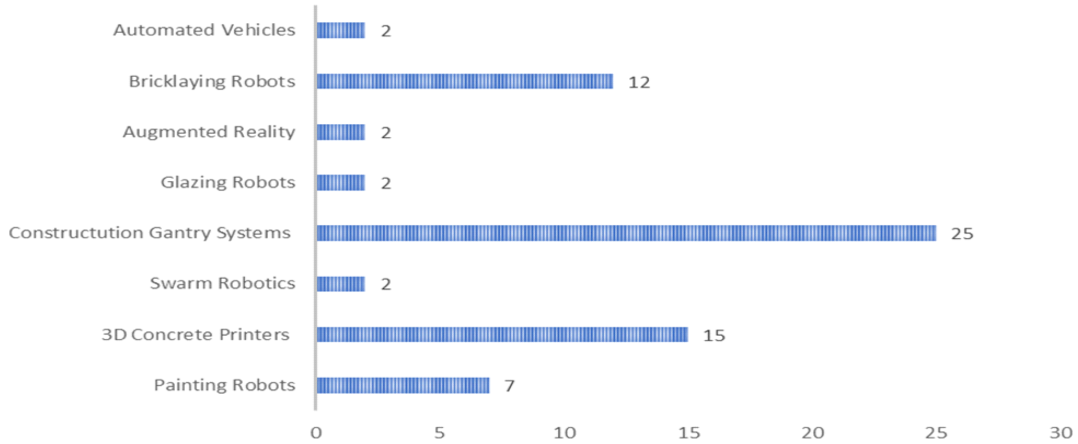

Figure 7: Paper distribution-based types of discussed robots and automation

Figure 7 shows that most of the researched robotic and automation system technologies were found to address construction gantry systems, which are applicable in industrialised pre-fabricated, assembled onsite works and design works. However, the most specific type of robot discussed by the papers is the 3D concrete printer (a truly beneficial technology that is widely used in construction, especially with respect to construction speed and mass production of buildings). It is worth noting that concrete-printed buildings have been gaining attention in recent times. Furthermore, the results shows that research focusing on bricklaying robots and painting robots is equally gaining momentum.

3.6 Significance of Robots and Automation in Construction

Submissions on the significance of robots and automation in construction were extracted from the papers and the results of the analysis are presented in Figure 8.

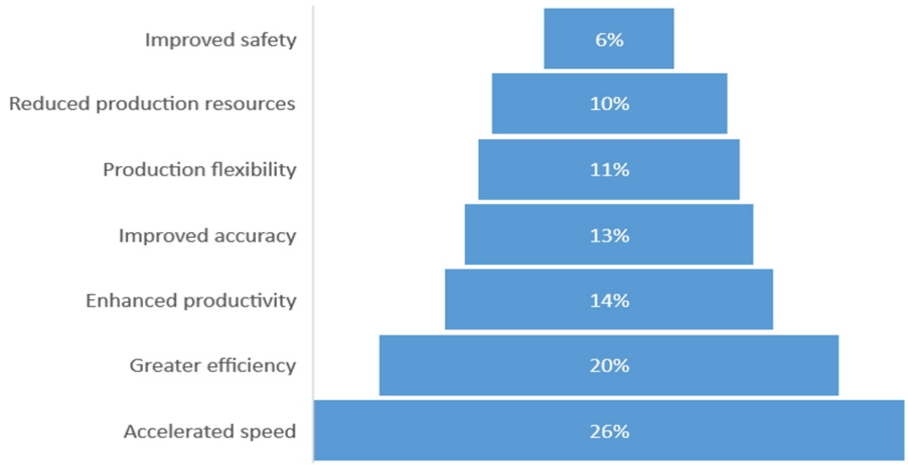

Figure 8: Significance of robots and automation in construction

As Figure 8 shows, a total of 26% of the articles identified accelerated speed of construction as the most significant driver for using robots and automation in construction. This was closely followed by the need for greater efficiency and enhanced productivity (at 20% and 14% representations respectively).

4.0 Discussion

At present, research on robotic technologies and automation in construction is mostly being undertaken in Europe and Asia and the bulk of the research focuses on construction gantry systems, 3D concrete printing and bricklaying robots. Commonly described as gantry cranes or overhead gantries, construction gantry systems have long been essential to the construction industry (Craveiro et al., 2019). The traditional gantry systems were made up of steel beams and cables that could be moved manually or with the help of crude mechanical equipment(Kristombu Baduge et al., 2021; Wang et al., 2023; Yi et al., 2019). Although they were effective and safe, they were not without their flaws.

However, there have been considerable advancements as a result of the development of construction gantry systems, especially with respect to enhancing load capacity, automation and robotics integration, and operational safety. Construction gantry systems have advanced significantly over time, changing from simple mechanical frameworks to sophisticated, highly automated systems (Douin et al., 2022; Kareem & Michael, 2022; Prasad et al., 2023). The effectiveness, safety and sustainability of buildings have all been significantly impacted by these developments (Lakshmanan et al., 2023). The use of gantry systems in contemporary construction is more crucial than ever as projects become bigger and more complicated (Aghimien et al., 2020). There can be no doubt that the capabilities of construction gantry systems will grow as technology advances, leading to further advancement in the construction sector.

Over the years, the construction sector has experienced notable developments, one of which is the three-dimensional printing of concrete. This innovative technology is changing how buildings are constructed by providing affordable, sustainable and effective solutions (Oke et al., 2019). Using automated equipment, 3D concrete printing, commonly described as Additive Manufacturing (AM) in the construction industry, produces three-dimensional objects by layering concrete. Similar to conventional 3D printing, but done on a much bigger scale, this technique requires precisely depositing material layer by layer. Computer-aided design (CAD) models are frequently used in the process to direct the printer's movements and ensure precise fabrication(Bademosi & Issa, 2021; Smith, 2019). Three-dimensional concrete printing offers cost efficiency, speed, design flexibility, safety and improved sustainability through optimisation of materials.

In Europe and Asia, the use of bricklaying robots for construction has been gaining momentum (Liu & Jebelli, 2021; Smith, 2019). It is important to note that traditional bricklaying is a labour- and time-intensive procedure that requires trained masons to painstakingly lay each brick (Wos et al., 2021). However, this time-honoured tradition is fast giving way to bricklaying robots that can work quickly and precisely, as they are outfitted with cutting-edge robotics, automation and computer vision technologies(Malakhov et al., 2021). As technology continues to advance, bricklaying robots will be more affordable and accessible, paving the way for their widespread use in the construction industry (Smith, 2019).

Bricklaying robots have the potential to revolutionise the way buildings are constructed because they offer greater efficiency, precision and safety in the rapidly advancing construction industry. Robots work tirelessly, as well as with precision and consistency, thus making them a major innovation in the construction industry.

5.0 Conclusion

Based on findings from the research it may be concluded that the most investigated aspects of robotic technologies and automation in the construction industry are gantry systems, bricklaying robots and 3D concrete printers. Research on robotic technologies and automation in construction is still minimal, however, especially across the African continent. At present, the continents of America, Australia and Europe are at the forefront of research in robotic technologies and automation in construction, with an upsurge in research output in robotic technologies and automation in the last five years.

As already noted, robotic technologies and automation have the potential to significantly impact the construction industry, especially in terms of speed, efficiency, productivity and accuracy. It is apparent that the deployment of robotics and automation in construction can be further facilitated by middleware applications that improve communication between established and emerging technologies while serving as the interminable link for connecting old infrastructure and antiquated systems to create a cohesive environment.

Therefore, more research efforts on robotic technologies and automation in construction should be encouraged, especially with respect to their application and deployment for construction projects across Africa. Such studies may be funded by both the government and private-sector stakeholders in the construction industry.

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