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Revolutionising high-rise building construction: the role of robotics in South Africa's construction industry

Ntebo Ngcobo[1] and Opeoluwa Akinradewo[2]

[1&2]Department of Civil Engineering Technology, Faculty of Engineering and the Built Environment, University of Johannesburg, Johannesburg, South Africa

Email: ntebon@uj.ac.za; opeakinradewo@gmail.com

ABSTRACT

With the increased demand for high-rise buildings in urban areas, the construction industry is experiencing more accidents caused by workers carrying out construction at heights. Robotic technology has been adopted in the manufacturing industry over the years, which has reduced factory accidents. Therefore, this study explores the impact of robotics in constructing high-rise buildings in South Africa, focusing on productivity, safety, efficiency, and project management. The research investigates how robotics can revolutionise the industry by employing a quantitative research methodology, which involves surveys from professionals in the construction sector. The findings reveal significant benefits of robotics in enhancing productivity, reducing accidents, and improving construction quality. The study also identifies challenges such as high costs and lack of skilled labour for robotics operations. The exploration extends to robotics' influence on project timelines, cost management, and environmental sustainability. The implications of these findings are significant for stakeholders in the construction industry, suggesting a need for investment in research and development, training, and policy formulation to support the adoption of robotics. This research contributes to understanding the potential of robotics in transforming high-rise construction, particularly in emerging economies.

Keywords: Efficiency, High-Rise Building, Productivity, Robotics, Safety

1. INTRODUCTION

Globally, the building sector has a rich historical record of being widely recognised as one of the most accident-plagued industries (Guo et al., 2020; Ikuabe et al., 2021). As the demand for high-rise construction projects has grown, there has been a corresponding increase in accidents and fatalities during construction. Furthermore, the construction of high-rise buildings necessitates a substantial workforce to meet project deadlines and effectively manage the intricacies of such constructions. An elevated risk of occupational injuries has accompanied the substantial presence of labourers in high-rise construction projects. As documented by Gambatese et al. (2008), the building sector in the United States is notably hazardous, surpassing other industries in terms of injury rates. Each year witnesses a regrettable tally of individuals sustaining injuries, incurring damages, and even losing their lives as a result of accidents on construction sites. This predicament continues to persist in both industrialised and emerging nations, adversely impacting the construction industry (Cheng et al., 2020; Wang et al., 2019).

According to Cheng et al. (2020), the International Labour Organization has estimated that, on a global scale, 2.78 million individuals succumb to occupational accidents annually, with the construction sector accounting for one-sixth of these fatalities. South Africa's construction industry also grapples with the inherent dangers associated with on-site accidents (Aghimien et al., 2022; Ikuabe et al., 2021). Safety concerns within the construction industry have long preoccupied practitioners and researchers (Gambatese et al., 2008). Despite concerted efforts to mitigate construction, site calamities have persisted as an enduring issue. It is imperative to acknowledge that South Africa's building sector is not exempt from the perils posed by on-site accidents (Ikuabe et al., 2021).

As a result, new methodologies must be implemented to improve the safety of people working in the building sector and enhance the effectiveness of the construction industry productivity. Introducing or increasing high-rise building construction robotics can solve the specified problems (Lim et al., 2012; Sakin and Kiroglu, 2017; Fonseca, 2018). If robotics replaces the labour force, injuries during construction will be avoided or minimised, the construction industry's productivity will improve, and errors will be minimised as machines are more efficient and effective than humans (Petrillo et al., 2018). Several elements can influence the usage of robotics in a country. Previous studies have identified problems such as high expenses, inexperienced labour, and a paucity of funding for research and experimental development, according to Cai et al. (2019). The inadequate funding for research and innovation has been identified as the primary reason for the robotics adoption gap (Aghimien et al., 2018). According to Fadhi and Tan (2001), Chilipunde (2010), and Aghimien et al. (2019), the construction sector in developing countries seldom supports research and development, which has had a considerable influence on the industry's success, especially in terms of adopting innovative technology.

Much study has been done in recent decades to underline the need to use robotics and automatic machinery in the construction industry. Despite countless research studies and several systems and technology developments, the sector is still in its infancy, and there needs to be more implementation of robotics and automation, which trails behind other sectors (Cai et al., 2019). The failure to capitalise on the inherent benefits of digitalisation has tremendously impacted the sector, especially in underdeveloped countries where the construction sector has yet to undergo considerable transformation (Akinradewo et al., 2021). In various parts of the world, robotics used during high-rise construction are limited (Agarwal et al., 2016; Aghimien et al., 2022; Castagnino., 2016; Osunsanmi et al., 2018; Cai et al., 2019). Based on this adoption issue, assessing the influence of robotics utilisation in the construction industry is critical. Therefore, this study aims to evaluate how robotics usage influences high-rise building construction in South Africa to enable corporations, contractors, the government, and other construction industry participants to become more aware of the benefits robotics offer.

2. ROBOTICS IN HIGH-RISE BUILDINGS

The building industry is a profitable venture closely connected to economic growth. Numerous studies have highlighted the building sector's valuable input to the success of the national economy (Akinradewo et al., 2021). Construction is the nation's second-largest industry after agriculture. It severely affects the nation's economy and employs many people. The building industry is a significant economic sector that employs many individuals and adds to the GDP of nations worldwide, including South Africa (Mathonsi and Thwala, 2012; CIDB, 2017). However, many clients in the industry would like to be more satisfied with the end product's standards and level of service provided. The process's labour-intensive (Agapiou et al., 1995) and the sector's clear challenges in accepting modern innovations, notably information technology (IT) (Akinradewo et al., 2021), are some potential causes that might be linked to these.

Robotics have revolutionised high-rise building construction, addressing labour shortages and construction difficulties. Automation and robotics technology significantly aid earth and foundation work, superstructure erection, and façade installation (Cai et al., 2018). These technologies facilitate ground and base operations, enhancing efficiency and safety in construction processes (Akinradewo et al., 2021). Robotic systems are instrumental in maintaining high-rise buildings, particularly in inspecting and cleaning external walls (Tso and Feng, 2003). These systems use advanced sensors for contamination measurement and evaluation, thereby improving the efficiency of cleaning, coating, and inspection processes (Kang et al., 2011). Multi-robot systems minimise human labour and enhance process efficiency, making the maintenance of high-rise building façades more economically feasible (Lee et al., 2015).

Robotics in high-rise buildings also enables bespoke design elements, liberating architectural designs from the constraints of serial production and standardisation (Budig et al., 2014). This flexibility allows for more creative and customised building designs. Using robotic systems in construction increases quality, productivity, and safety. Replacing human labourers with robots in tasks like steel beam assembly enhances these aspects significantly (Chu et al., 2013). Similarly, construction robot technology is recognised for its efficiency and safety, increasing productivity in high-rise building construction (Joo et al., 2007). Innovative applications include humanoid robots designed for fire extinguishing and rescue operations in high-rise buildings, using protocols like HARMS (Wagoner et al., 2015). The RiSE robot, a hexapedal robot capable of climbing vertical surfaces without suction or magnets, represents another specialised application (Spenko et al., 2008).

Robotic technologies extend to logistics in high-rise construction. A study on a robotic lift capable of autonomous operations at night highlights the potential for improving efficiency in construction logistics and addressing space constraints (Cho et al., 2009). Furthermore, a robotic tower-crane system can improve productivity by 9.9%-50% compared to traditional cranes, addressing safety and efficiency issues (Lee et al., 2009). Robotic technologies for on-site construction include additive manufacturing, automated installation systems, and robotic bricklaying, among others (Gharbia et al., 2020). These technologies are reshaping the way high-rise buildings are constructed. Robotic technologies for on-site construction include additive manufacturing, automated installation systems, and robotic bricklaying, among others (Gharbia et al., 2020). These technologies are reshaping the way high-rise buildings are constructed.

Research has shown that various challenges hamper the adoption of robotics in the construction industry. These include insufficient technological knowledge (Boya et al., 2022), excessive implementation cost and worker skilling (Oke et al., 2018), data security issues (Zeng et al., 2012), data exchange issues (Eastman et al., 2011), resistance and fear of new technologies (Boya et al., 2022). According to Fadhil and Tan (2001), Chilipunde (2010), and Aghimien et al. (2019), the construction sector in developing countries seldom supports Research and development, which has hampered the sector's progress, notably in terms of implementing the latest technology. The lack of well-trained technology workers (Akinradewo et al., 2021) and insufficient funding for research and advancement (Aghimien et al., 2018) are two important concerns limiting the exploitation and appropriation of technological advancements in construction.

However, studies have also shown that 3D printing and autonomous robots promise lower costs of labour and supplies, fewer workplace accidents and deaths, more production of end products, and even new employment possibilities development (Lim et al., 2012; Sakin and Kiroglu, 2017; Fonseca 2018). According to Akinradewo et al. (2021), autonomous robots' operations alongside traditional building systems can increase employment diversity and create fresh roles for workers in the building sector. The fundamental nature of digital technologies enables effective projects that are executed on schedule and under budget (Boya et al., 2022). According to Vaduva-Sahhanoglu et al. (2016), robots used in the building sector may enhance construction effectiveness, stakeholder contentment, environmental preservation, and durability.

3. RESEARCH METHODOLOGY

This research project adopted a post-positivist philosophical standpoint, aiming to investigate the impact of using robotics in constructing high-rise buildings in South Africa through collecting empirical evidence. This philosophical orientation guided the selection of a quantitative research approach, which involved administering a questionnaire survey. The quantitative methodology employed here entailed a structured survey using questionnaires. In this study, the questionnaire design was informed by a thorough review of the existing literature on the influence of robotics in high-rise building construction. The rationale behind employing a questionnaire was its capability to efficiently collect data from a diverse range of respondents within a relatively brief timeframe. This method has been widely utilised in numerous construction-related research endeavours. Respondents were asked to assess their level of agreement or disagreement with various variables using a 5-point Likert scale during the survey. Given the statistical nature of this research study, the target population was drawn from the Gauteng Province of South Africa. This location was chosen due to its prominence as a major business hub in the country and the concentration of construction projects within this region.

A purposive sampling technique, specifically heterogeneous sampling, was employed to ensure a representative sample. The selected professionals included Quantity Surveyors, Architects, Engineers, Construction Managers, and Project Managers. Two hundred questionnaires were distributed, with 153 returned, resulting in a notable return rate of 76.5%. Subsequently, data analysis was conducted, using tables and charts to draw statistical conclusions. Microsoft Excel and the Statistical Package for Social Science (SPSS) software were employed for the data analysis. Key statistical measures such as percentages, frequencies, mean item scores, and exploratory factor analysis were utilised to derive insights from the collected data. Percentages and frequencies were employed to scrutinise the demographic information of the survey respondents, while mean item scores facilitated the ranking of variables based on respondents' feedback. Exploratory factor analysis (EFA), a statistical tool for data reduction, was employed to explore the underlying theoretical structure of the variables and elucidate the relationships between respondents and each variable. To ascertain the reliability and validity of the research instrument, Cronbach's alpha was employed, yielding a favourable alpha value of 0.839. This result underscores the trustworthiness of the data gathered through the questionnaire survey.

4. FINDINGS

4.1 Demographics of respondents

Based on the retrieved data, results showed that 19.0% of respondents have a diploma, 39.7% have a bachelor's degree, 5.2% have a PhD, 20.7% have an honour's degree, and 13.8% have a master's degree. Furthermore, the data revealed that 8.6% of the respondents were architects, 51.7% were engineers, 17.2% were quantity surveyors, 12.1% were construction and project managers, and 10.3% were architects. Also, 39.66% of the respondents work for consulting firms, 37.93% work for the government, and 22.42% work as contractors. Furthermore, the result demonstrates that most respondents (43.1%) worked for 1-5 years, followed by those who worked for less than a year (32.8%). Those who worked for 6-10 years account for 13.8%; those who worked for 11-15 years account for 5.2%; and those who worked for 16-20 years account for 1.7%. Finally, most respondents (41.4%) have completed seven or more projects, which enhances the usefulness of the survey results by showing that most respondents are knowledgeable about the industry. 22.4% of participants completed 1-2 projects, 17.2% completed 3-4 projects, 8.6% completed 56 projects, and 10.3% completed no projects.

4.2 Descriptive Analysis Results

Table 1 shows the ranking of the influence of robotics utilisation in high-rise construction projects. Respondents ranked variables on a five-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree). From Table 1, 'High productivity' had the highest mean item score (MIS) of 4.60 and the standard deviation (SD) of 0.647. 'Enhancing organisations' service delivery' was ranked second, with MIS of 4.53 and SD of 0.627, while the 'reduction of workplace accidents' was ranked third, with MIS of 4.50 and SD of 0.707. 'Lower labour and material cost' was ranked eleventh with MIS of 3.78 and SD of 1.325, while 'environmental preservation' ranked twelfth with MIS of 3.74 and SD of 1,208. Finally, 'project completed within budget' was ranked last with MIS of 3.60 and SD of 1.337. Standard deviation values above 1.00 indicated that the respondents have diverging opinions about the ranking of each variable, such as Development of new job possibilities and improved durability.

Table 1: Descriptive Analysis Result

Influence of Robotics in High-rise Building Construction	MIS	SD	Ranking
High productivity	4.60	0.647	1
Enhancing organisations' service delivery	4.53	0.627	2
Reduction of workplace accidents	4.50	0.707	3
Improved accuracy	4.36	0.667	4
Projects completed within schedule	4.31	0.777	5
Improved efficiency	4.31	0.863	5
Establishment of new roles for construction employees	4.24	0.865	7
Improved stakeholder satisfaction	4.12	0.993	8
Development of new job possibilities	4.09	1.064	9
Improved durability	3.91	1.274	10
Lower labour and material costs	3.78	1.325	11
Environmental preservation	3.74	1.208	12
Projects completed within budget	3.60	1.337	13

4.3 Exploratory Factor Analysis Result

After completing the descriptive analysis, examining the 13 identified variables also encompassed an Exploratory Factor Analysis (EFA). EFA serves the purpose of unveiling underlying correlation patterns within the dataset. Before executing the EFA, a preliminary assessment of data suitability was conducted by examining Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity values. The KMO statistic gauges the adequacy of value distribution for EFA. In this study, the KMO value was determined to be 0.834, surpassing the acceptable threshold of 0.6. Simultaneously, Bartlett's test of sphericity yielded a value of 0.000, indicating a significant statistical relationship among the variables (Pallant, 2007). This result signifies that the variables are suitable for factor analysis. Furthermore, the total variance, as presented in Table 2, was examined in accordance with Kaiser's criterion eigenvalues. Only eigenvalues above 1.0 were considered for further analysis. As a result, three components met this criterion, collectively explaining a cumulative percentage of 76.211 of the variances observed in the variables.

The direct oblimin rotation was employed for the EFA rotation as there was a correlation between the 13 variables. The results of the percentage of variance, communalities extraction and pattern matrix are presented in Table 2, showing the three-component classifications of the variables based on their inter-relationships.

Table 2: Factors Affecting the Implementation of robotics Classifications

Influence of Robotics in High-rise Building Construction	Communalities Extraction	% of variance	Components		
			1	2	3
High productivity	0.661	57.273	0.909		
Reduction of workplace accidents	0.777		0.841		
Improved accuracy	0.711		0.732		
Projects completed within schedule	0.588		0.676		
Improved efficiency	0.678		0.604		
Lower labour and material costs	0.466		0.511		
Establishment of new roles for construction employees	0.518	9.530		0.820	
Development of new job possibilities	0.702			0.787	
Enhancing organisations' service delivery	0.766	9.408			0.941
Improved stakeholder satisfaction	0.704				0.901
Improved durability	0.787				0.746
Environmental preservation	0.641				0.708
Projects completed within budget	0.700				0.638
KMO Value	0.834				
Bartlett's test of sphericity	0.000				

From Table 2 above, the EFA results showed that three-factor clusters were obtained. The clusters are discussed below:

Cluster one – Operational Efficiency and Cost Management. A total of six factors were loaded onto this cluster, and they are 'High productivity' (90.9%); 'Reduction of workplace accidents' (84.1%); 'Improved accuracy' (73.2%); 'Projects completed within schedule' (67.6%); and 'Improved efficiency' (60.4%).

Cluster two – Innovation and Workforce Transformation. Two factors loaded onto this cluster: ' Establishment of new roles for construction employees' (82.0%); and 'Development of new job possibilities' (78.7%).

Cluster three – Sustainability and Stakeholder Satisfaction. This cluster has five factors loaded onto it, which include 'Enhancing organisations' service delivery' (94.1%); 'Improved stakeholder satisfaction' (90.1%); 'Improved durability' (74.6%); 'Environmental preservation' (70.8%); and 'Projects completed within budget' (63.8%).

5. DISCUSSION OF FINDINGS

From the findings of the data analysis carried out, it was evident from the descriptive analysis that respondents think that robotics technology plays a pivotal role in revolutionising various aspects of high-rise construction, yielding a multitude of benefits. One of the foremost advantages is the significant enhancement of productivity. Integrating automated systems, encompassing robotised cranes and finishing robots, promises to augment productivity levels, simultaneously reducing the industry's reliance on manual labour. Doing so contributes to higher productivity and elevates safety standards and overall construction quality, as corroborated by Akinradewo et al. (2021). Furthermore, robotics addresses labour shortages and mitigates safety risks, further bolstering overall productivity, as Cai et al. (2019) indicated.

In addition to heightened productivity, robotics technology profoundly impacts organisations' service delivery within the construction domain. The deployment of robotic building maintenance systems, employing multiple robots, is a notable example. Such systems minimise human labour involvement, enhancing process efficiency and economic viability. As highlighted by Lee, Kang, and Han (2012), this innovation paves the way for a more streamlined and cost-effective approach to building maintenance. Moreover, integrating robotics in fabrication introduces bespoke design elements, effectively liberating high-rise construction from the constraints of serial production, as elucidated by Budig, Lim, and Petrovic (2014).

Robotic adoption further contributes to the reduction of workplace accidents in construction. By substituting human labour in perilous conditions, robotics systems help create a safer working environment, as evidenced by Kim et al. (2009). These automated systems extend their safety benefits to high-rise building façade maintenance, where they improve maintenance efficiency and substantially reduce the occurrence of accidents, as detailed in the research by Kim and Seo (2017).

The quest for precision and accuracy in construction processes finds an ally in robotics. Robotics technologies, including mark robots and survey total stations, introduce precision crucial in tasks such as foundation marking. Inoue, Doi, and Omoto (2011) assert that deploying these technologies significantly enhances accuracy while streamlining operations. Moreover, fully integrated sensing and control systems enable mobile robotic construction, further ensuring high precision, as Gawel et al. (2019) affirmed.

Robotic technologies have the potential to streamline construction workflows, thereby influencing project schedules. Gharbia et al. (2020) suggest that robotics can reduce project schedules by optimising various construction processes. These innovations also impact task sequencing, which affects project scheduling, as highlighted in the research by Beauchat et al. (2022). Efficiency in high-rise construction receives a considerable boost through the integration of robotics. Lee et al. (2007) emphasised the role of robotics in increasing efficiency while mitigating labour shortages. Additionally, automation and robotics technologies in high-rise building construction are expected to alleviate labour shortages and address construction challenges, according to Cai et al. (2018). The introduction of robotics in construction leads to the establishment of new roles within the industry. García de Soto et al. (2018) point out that these technologies give rise to digital fabrication managers, programmers, and technicians positions. This role expansion aligns with the broader trend of automation and robotics technology in high-rise construction, creating new opportunities and reshaping the employment landscape, as noted by Cai et al. (2018).

The adoption of robotics in high-rise building construction catalyses improved stakeholder satisfaction. By enhancing construction quality, productivity, and safety, robotics contribute to a more satisfactory overall construction experience, as Chu et al. (2013) suggested. Robotic fabrication in high-rise construction also has the potential to produce structurally differentiated and material-efficient buildings, further contributing to stakeholder satisfaction, as indicated by Hack et al. (2013). Lastly, integrating robotics in construction has a positive effect on developing new job possibilities. García de Soto et al. (2019) highlight the creation of new job opportunities, particularly in managerial and operational roles, due to robotics adoption. Automation and robotics in high-rise building construction not only help resolve labour shortages but also open up avenues for diverse career paths, in line with the findings of Cai et al. (2019).

In addition to these advantages, automation and robotics in high-rise building construction contribute to improved durability. By enhancing productivity, working conditions, and safety standards, these technologies play a pivotal role in increasing high-rise buildings' overall durability, as Cai et al. (2019) emphasised. Incorporating robotic systems in construction leads to elevated levels of quality and safety, further reinforcing the long-term durability of high-rise structures, as corroborated by Chu et al. (2013).

6. CONCLUSION AND RECOMMENDATION

This study on the influence of robotics in the construction of high-rise buildings in South Africa highlights several key findings and implications. Using robotics in this sector has demonstrated significant potential in enhancing productivity, safety, efficiency, and overall quality of construction projects in developed countries. The opinion of the respondents corroborated this adopted for the study. It was gathered from the findings that robotics technology addresses labour shortages and safety concern and introduces innovative approaches to design and construction processes.

Given these findings, the following recommendations are proposed:

Enhanced Integration of Robotics: It is crucial for stakeholders in the South African construction industry, including corporations, contractors, and the government, to invest in and integrate robotics technology actively. This will help mitigate risks associated with manual labour and improve overall construction efficiency.

Investment in Research and Development: The construction sector, particularly in developing countries, should prioritise funding and support for research and development in robotics and automation. This will aid in bridging the current technological gap and foster innovation.

Training and Skill Development: As robotics technology evolves, there is a need to upskill the workforce to adapt to new roles and challenges. Initiatives should be taken to train robotics operation and maintenance personnel, ensuring a smooth transition and integration of these technologies.

Environmental Sustainability: Emphasise the role of robotics in promoting environmental sustainability in construction. Robotic technologies can lead to more efficient use of materials and reduced waste, contributing to eco-friendly construction practices.

Based on the findings of this study, the adoption of robotics in high-rise building construction presents a transformative opportunity for the South African construction industry. Robotics can significantly contribute to safer, more efficient, and innovative construction practices through strategic investment, collaboration, and policy support. A notable limitation of this study is its regional focus on South Africa, which may not fully represent the global context of robotics in construction. Hence, a further study can be carried out in other provinces of South Africa.

REFERENCES

Agapiou, A., Price, A. D. F. and McCaffer, R. (1995) Planning future construction skill requirements: Understanding labour resource issues. Construction Management and Economics, 12, 413-422.

Agarwal, R., Chandrasekaran, S., and Sridhar, M. (2016). Imagining construction's digital future. McKinsey and Company, 24(06).

Aghimien, D., Aigbavboa, C., and Oke, A. (2019). A Review of the Application of Data Mining for Sustainable Construction in Nigeria. Energy Procedia, 158, 3240-3245

Aghimien, D., Aigbavboa, C., Oke, A., and Koloko, N. (2018). Digitalisation in construction industry: Construction professionals perspective. In Proceedings of the Fourth Australasia and South-East Asia Structural Engineering and Construction Conference, Brisbane, Australia (pp. 3-5).

Aghimien, D., Ikuabe, M., Aghimien L.M., Aigbavboa, C.O., Ngcobo, N. Yankah, J.E. (2022). PLS-Sem assessment of the impediments of Robotics and Automation Deployment for Effective Construction Health and Safety, Journal of Facilities Management. DOI: 10.1108/JFM-04-2022-0037

Akinradewo, O., Oke, A., Aigbavboa, C., and Molau, M. (2021). Assessment of the level of awareness of robotics and construction automation in South African. In Collaboration and Integration in Construction, Engineering, Management and Technology: Proceedings of the 11th International Conference on Construction in the 21st Century, London 2019, pp. 129-132.

Beauchat, T., Blazejewski, E., Hu, Y., Leicht, R. M., and Suanico, C. (2021). Construction Activity Dependency and Sequencing Analysis for Robotic Construction Methods Based on Graph Analysis. In Computing in Civil Engineering 2021, 596-603.

Boya, A., Akinradewo, O., Aigbavboa, C., Ebekozien, A., and Ramabodu, M. (2022). Bottlenecks to the Implementation of Automation and Robotics in the Construction Industry. In International Conference on Computing in Civil and Building Engineering, 139-149.

Budig, M., Lim, J., and Petrovic, R. (2014). Integrating robotic fabrication in the design process. Architectural Design, 84(3), 22-43.

Cai, S., Ma, Z., Skibniewski, M., Guo, J., and Yun, L. (2018). Application of automation and robotics technology in high-rise building construction: An overview. In ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction, Vol. 35, pp. 1-8

Cai, S., Ma, Z., Skibniewski, M.J. and Bao, S. (2019). Construction automation and robotics for high-rise buildings over the past decades: A comprehensive review. Advanced Engineering Informatics, 42, p.109.

Cheng, M.-Y., Kusoemo, D. and Gosno, R.A. (2020). Text mining-based construction site accident classification using hybrid supervised machine learning. Automation in Construction, 118, p.103265.

Chilipunde, R.L. (2010). Constraints and Challenges Faced by Small, Medium and Micro Enterprise Contractors in Malawi. A treatise submitted to the Faculty of Engineering, the Built Environment and Information Technology, Nelson Mandela Metropolitan University, School of the Built Environment.

Chu, B., Jung, K., Lim, M. T., and Hong, D. (2013). Robot-based construction automation: An application to steel beam assembly (Part I). Automation in construction, 32, 46-61.

CIDB (2017). "Construction quality in South Africa, a client perspective," Retrieved on 13th September 2017 from https://bizconnect.standardbank.co.za/sectornews/construction/swot-analysis-of-the-construction-sector-in-South-Africa.

Dall'Omo, S. (2017). Driving African development through smarter technology. African Digitalisation Maturity Report, p.1-45.

Development Bureau. (2018). Construction 2.0-Time to change, Hong Kong. https://www.hkc2.HK/en

Fadhil, M. D., and Tan, F. H. (2001). Developing World Class Construction Companies in Singapore. Construction Management and Economics. 19(6), 591-599.

Fonseca, L.M. (2018). Industry 4.0 and the digital society: concepts, dimensions and envisioned benefits. Proceedings of the International Conference on Business Excellence, [online] 12(1), pp.386-397.

Gambatese, J.A., Behm, M. and Rajendran, S. (2008). Design's role in construction accident causality and prevention: Perspectives from an expert panel. Safety Science, 46(4), pp.675-691.

Garcia de Soto, B., Agusti-Juan, I., Joss, S. and Hunhevicz, J. (2019). Implications of Construction 4.0 to the workforce and organisational structures. International Journal of Construction Management, pp.1 -13.

Gawel, A., Blum, H., Pankert, J., Krämer, K., Bartolomei, L., Ercan, S., ... and Sandy, T. (2019, November). A fully-integrated sensing and control system for high-accuracy mobile robotic building construction. In 2019 IEEE/RSJ international conference on intelligent robots and systems (IROS), pp. 2300-2307

Gharbia, M., Chang-Richards, A., Lu, Y., Zhong, R. Y., and Li, H. (2020). Robotic technologies for on-site building construction: A systematic review. Journal of Building Engineering, 32, 101584.

Guo, S., Zhou, X., Tang, B. and Gong, P. (2020). Exploring the behavioural risk chains of accidents using complex network theory in the construction industry. Physica A: Statistical Mechanics and its Applications, 560, p.125

Ikuabe, M., Aghimien, D., Aigbavboa, C., Oke, A., and Thwala, W. (2021). Site Accidents in the South African Construction Industry: Cleaning the Augean Stables. In Advances in Human Factors, Business Management and Leadership: Proceedings of the AHFE 2021 Virtual Conferences on Human Factors, Business Management and Society, and Human Factors in Management and Leadership, July 25-29, 2021, USA, pp. 92-99.

Inoue, F., Doi, S., and Omoto, E. (2011). Development of high accuracy position making system applying mark robot in construction site. In SICE Annual Conference 2011, pp. 2413-2414.

Joo, H., Son, C., Kim, K., Kim, K., and Kim, J. (2007). A study on the advantages on high-rise building construction which the application of construction robots take. In 2007 International Conference on Control, Automation and Systems, pp. 1933-1936.

Kang, M. S., Lee, S., Chun, B., Shin, K., Traver, A. E., and Han, C. S. (2011, December). Window contamination detection method for the robotic building maintenance system. In International Symposium on Automation and Robotics in Construction. Vol. 28, No. 1, pp. 1432-1433.

Kim, D. W., An, S. H., Cho, H., Jeong, J. W., Lee, B. H., Doh, N. L., and Kang, K. I. (2009). Development of conceptual model of construction factory for automated construction. Building and Environment, 44(8), 1634-1642.

Lee, G., Kim, H. H., Lee, C. J., Ham, S. I., Yun, S. H., Cho, H., ... and Kim, K. (2009). A laser-technology-based lifting-path tracking system for a robotic tower crane. Automation in Construction, 18(7), 865-874.

Lee, S., Kang, M. S., and Han, C. S. (2012). Sensor based motion planning and estimation of high-rise building façade maintenance robot. International Journal of Precision Engineering and Manufacturing, 13, 2127-2134.

Lee, S., and Moon, J. I. (2015). Case studies on glazing robot technology on construction sites. In ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction, Vol. 32, p. 1.

Lim, s., Buswell, R.A., Le, T.T., Austin, S.A., Gibb, A.G., Thorpe, T. (2012). Developments in construction-scale additive manufacturing processes. Automation. 262-268, https://doi.org/10.1016/j.autcon.2011.06.010.

Mathonsi, M. D. and Thwala, W. D. (2012). Factors influencing the selection of procurement systems in the South African construction industry. African Journal of Business Management Vol. 6(10), pp. 3583-3594.

Oke, A. E., Aghimien, D. O., Aigbavboa, C. O., and Koloko N. (2018). Challenges of Digital Collaboration in The South African Construction Industry. Proceedings of the International Conference on Industrial Engineering and Operations Management Bandung, Indonesia, March 68, p. 2472 - 2482

Osunsanmi, T. O., Aigbavboa, C. O., and Oke, A. E. (2018) Construction 4.0: The Future of South Africa Construction Industry, World Academy of Science, Engineering and Technology International Journal of Civil and Environmental Engineering, 12, (3), 206-212.

Pallant, J. (2011). SPSS Survival Manual, 4th Edition, Allen and Unwin, Australia.

Petrillo, A., De Felice, F., Cioffi, R., and Zomparelli, F., (2018). Fourth Industrial Revolution: Current Practices, Challenges, and Opportunities. University of Napoli "Parthenope" Centro Direzionale, Napoli (NA), Italy. Pp. 2-20.

Sakin, M., Kiroglu, Y.C. (2017). 3D Printing of Buildings: Construction of the Sustainable Houses of the Future by BIM. Energy Procedia. 134, 702-711.

Secolsky, C. (1987). On the direct measurement of face validity: A comment on Nevo. Journal of Educational Measurement, 24(1): pp. 82-83.

Spenko, M. J., Haynes, G. C., Saunders, J. A., Cutkosky, M. R., Rizzi, A. A., Full, R. J., and Koditschek, D. E. (2008). Biologically inspired climbing with a hexapedal robot. Journal of field robotics, 25(4-5), 223-242.

Tso, S. K., and Feng, T. O. N. G. (2003, September). Robot assisted wall inspection for improved maintenance of high-rise buildings. In 20th International Symposium on Automation and Robotics in Construction, pp. 449-455.

Vaduva-Sahhanoglu, A., Calbureanu-Popescu, M.X. and Smid, S. (2016). Automated and robotic construction-a solution for the social challenges of the construction sector. Revista de stiinte politice, Vol. 50, 1-11.

Wada, K., Nakagawa, K., Tanaka, T., Hashimoto, M., and Suzuki, T. (2014). Concept of module carrier robot for smart variable space. In 2014 10th France-Japan/8th Europe-Asia Congress on Mecatronics (MECATRONICS2014-Tokyo), pp. 19-22.

Wagoner, A., Jagadish, A., Matson, E. T., EunSeop, L., Nah, Y., Tae, K. K., ... and Joeng, J. E. (2015, February). Humanoid robots rescuing humans and extinguishing fires for Cooperative Fire Security System using HARMS. In 2015 6th International Conference on Automation, Robotics and Applications (ICARA), pp. 411-415.

Wang, C., Loo, S.C., Yap, J.B.H. and Abdul-Rahman, H. (2019). Novel Capability-Based Risk Assessment Calculator for Construction Contractors Venturing Overseas. Journal of Construction Engineering and Management, 145(10), p.401

Zeng, Y., Wang, L., Deng, X., Cao, X. and Khundker N., (2012). Secure collaboration in global design and supply chain environment: Problem analysis and literature review, Computers in Industry, 63, 545-556.