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Potential applications and benefits of humanoids in the construction industry: a South African perspective

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Abstract

Purpose – In most developing countries, the delivery of construction project is still characterised by inefficiencies resulting from the use of outdated methods and techniques, which retards project performance. Hence, the call for the implementation of innovative technologies such as humanoids in the execution of construction projects as it has been proven to be very effective in other sectors while improving productivity and quality of work. Consequently, this study looks at how humanoids can be used in the construction industry and what benefits they can bring.

Design/methodology/approach – The study employed a quantitative approach underpinned in post-positivist philosophical view using questionnaire as the instrument for data collection. The target respondents were construction professionals, and purposive sampling was used, while a response rate of 62.5% was gotten. The methods of data analysis were mean item score, standard deviation and one-sample *t*-test.

Findings – The findings revealed that humanoids can be used in progress tracking, auto-documentation and inspection and surveillance of tasks in construction activities. Also, the most important benefits of using humanoids in construction work were found to be shorter delivery times, fewer injuries and more accurate work.

Practical implications – The outcome of the study gives professionals and relevant stakeholders in construction and other interested parties' information about the areas where humanoids can be used and their benefits in construction.

Originality/value – The novelty of this study is that it is a pioneering study in South Africa on humanoids' usage in the construction industry. Also, it expands the existing borderline of the conservation of construction digitalisation for enhanced project execution.

Keywords Applications, Benefits, Humanoids, Construction industry, South Africa

Paper type Research paper

1. Introduction

The construction industry has gained interest in humanoids because of the expanded use of industrial humanoids in manufacturing and the higher projections of greater numbers in the

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future. Construction humanoids are envisioned to enhance working conditions by decreasing injuries on site and elevating productivity (Bock *et al.*, 2012). Humanoids are robots with the features of a human body; their bodies have a head, arms, and legs. Humanoids are designed to carry out activities based on the application inserted in them (Fukaya *et al.*, 2001). Humanoids might need repairs occasionally, but they will never be injured in construction site accidents (Derlukiewicz, 2019). Repetitive motions put stress on the human body that humanoids are immune to. If a key human worker is sidelined by an injury, it can throw off an entire project's schedule (Zhu *et al.*, 2021). On the other hand, autonomous machinery can make the same motion twenty-four hours a day. Humanoids can supplement a workforce with dedicated labour resources, making it easier to adapt to unexpected absences. Humanoids can help perform more severe duties while human labourers are redirected elsewhere, reduce construction time, improve safety on site and produce quality results (Zhu *et al.*, 2021).

The construction industry is a crucial sector of the economy, yet it is plagued by disorganisation, injuries and low productivity (Al-Yami and Sanni-Anibire, 2021; Hossain *et al.*, 2020; Ikuabe *et al.*, 2020a, b). Efficiency in construction seems to have barely increased; instead, it keeps decreasing (Delgado *et al.*, 2019). The ineffectiveness experienced from the deployment of outdated systems for construction project delivery has necessitated the implementation of innovative systems that seek to abate some of the inherent challenges attributed by the construction projects (Atkinson *et al.*, 2022; Ikuabe *et al.*, 2020a, b). Humanoids are probable to correct these imperfections; nonetheless, they still have not been fully introduced and adopted in construction activities (Hossain *et al.*, 2020). Humanoids have proven to be very effective in other sectors while improving productivity and quality of work. Construction humanoids are anticipated to improve working conditions, decrease hazards and improve efficiency (Bock *et al.*, 2012). The emerging difficulties linked with work on-site, such as poor standards and quality, unproductive and insufficient labourers, a lack of safety and lowly working conditions, have paved the way for the possibility of thorough solutions in the industry (Ikuabe *et al.*, 2021; White *et al.*, 2018). One of the solutions is the introduction of humanoids, which has great potential for improving safety, quality and productivity in construction (Mahbub, 2008).

Research on digital technology applications in the South African construction industry has generally focused on the challenges of digital collaboration (Oke *et al.*, 2018; Aghimien *et al.*, 2021); and the adoption of innovative technologies (Aghimien *et al.*, 2018; Ikuabe *et al.*, 2023a, b). The underlying areas of application and benefits of humanoids in the construction industry are still largely unexplored in South Africa. Consequently, this study sets out to empirically evaluate the potential applications and benefits of the usage of humanoids in construction project delivery, with a view to mapping out a roadmap of the espousal of the innovative technology for improved construction execution. The outcome of the study would be immense benefit to construction professionals and other relevant stakeholders in the construction industry as it seeks to significantly contribute to the ongoing conversation of construction digitalisation for improved project delivery.

1.1 Literature review

The fourth industrial revolution (4IR) is constantly changing, and the construction industry needs to accept and use new technologies instead of the old ways of working on sites (Ikuabe *et al.*, 2022). Alade and Windapo (2020) say that the 4IR is a rapid and complete change in the world brought about by mixing technologies. The 4IR includes product design generated by the computer and 3D printing, which creates solid objects by building up successive layers of material. It can also be described as blending advances in artificial intelligence, robotics, the Internet of Things, genetic engineering and other technologies (Xu *et al.*, 2018). Construction companies are always looking for ways to increase productivity while cutting costs

(Aghimien *et al.*, 2021). Unfortunately, productivity has been decreasing because the construction industry still depends on human beings to perform tasks despite automation and business models that are up and running. Ebekozien and Aigbavboa (2021) affirmed that now is the appropriate time to merge these technologies into construction activities because of their potential significance and because technology is rapidly advancing to inscribe unspecified uncertainties possibly.

1.2 Application areas of humanoids in construction activities

1.2.1 Bricklaying. The construction business, which has historically been less automated than many other areas, actively integrates automated and humanoid technologies as they advance (Malakhov *et al.*, 2020). Bricks are one of the oldest building materials, dating to 3500 BC for the first kiln-fired blocks and 7000 BC for the sundried varieties. As a result, bricklayer humanoids are one of the humanoids discovered in construction (Malakhov and Shutin, 2019). Bricklaying is a repetitive and physically exhausting task (Malakhov and Shutin, 2019). Automation has been shown to boost productivity and lower the risk of work disorders in extremely repetitive and physically demanding occupations (Coupe, 2019). Spreading mortar, placing a brick and using a trowel to smooth off any extra mortar are all steps in the classic bricklaying procedure. A design for a man-made device has been created that calls for automated masonry construction on the spot (Mitterberger *et al.*, 2020).

1.2.2 Steel truss assembly. The building of structures autonomously is an appealing application for robots with autonomy. Robots must design an assembly sequence and determine whether intermediate assemblies are stable to create a structure successfully (Komendera and Correll, 2015). The workers reach a fastening location for beam assembly by ascending a tall steel truss structure in the conventional construction method (Cho *et al.*, 2007). The truss is then put together by tightening inserted bolts and nuts with a wrench. Still, instead of using labourers, the robotic steel beam assembly process uses a system to insert bolts, tighten nuts and move to new bolting positions. The three steps of the steel beam assembly process are bolt insertion, primary bolting and complete bolting (Jung *et al.*, 2013).

1.2.3 Welding. Chu *et al.* (2008) explain that steel construction has a lot of welding. A welding robot replaced the human-operated welding process. Contact detection, arc tracking and laser tracking are available in welding robots (Ardiny *et al.*, 2015). A welding torch end-effector is necessary for the robotic arm's automated welding process. A haptic interface that can give the user force feedback upon touch would be beneficial for the system. The operator can use the haptic device to show the robot how to perform the task. The robot can then independently use the newly learnt skill (Brosque *et al.*, 2020). Robotic technology enables precise and speedy outcomes, less reliance on human expertise, improved weld joint quality, reduced waste and increased safety (Saariluoma *et al.*, 2020). The welding humanoids can achieve a high quality of welding, and workers are safe from flying sparks and intense heat (Wang *et al.*, 2020).

1.2.4 Paving. In conventional concrete buildings, efficiency is low (Cobb, 2001). This fact, coupled with the high rates of accidents at construction sites, the poor quality of the products and the inadequate oversight of the project timelines, has prompted academics to create autonomous robots that can do particular tasks (Ma *et al.*, 2021). Such robots are quite helpful for multitasking projects like concrete paving (Zhang *et al.*, 2023).

1.2.5 Inspection and surveillance tasks. Numerous industrial inspection activities require the transportation of sensors or probes to difficult-to-reach locations, such as to take measurements, conduct visual inspections or conduct surveillance (Bryson *et al.*, 2005). In addition to being difficult to access, some of these locations could be dangerous for human inspectors' safety and health. A hypermobile humanoid is needed (Kubandt *et al.*, 2019). The humanoid can fit through small openings, climb up and over tall vertical steps, travel inside and outside of horizontal, vertical or diagonal pipes such as electric conduits or water pipes, climb up and down stairs and pass across wide gaps. It can also traverse rough terrain, such as concrete floors covered in debris or unfinished floors like those found on construction sites (Dickinson *et al.*, 2019).

1.2.6 Material handling. Material handling duties in the construction business need a lot of work (Gambao *et al.*, 2012). Keeping track of the delivery, receipt, storage and movement of building parts throughout the system is a huge logistical challenge (Teizer and Cheng, 2015). The situation is made even more difficult by the lack of space at the construction site and the sporadic requests for the repair of damaged parts and preventative maintenance requirements. Under these circumstances, automation is the only way to manage building materials and components cost-effectively and efficiently (Mustapha *et al.*, 2020). Material handling systems now use a wide range of automation technologies (Heragu *et al.*, 2011).

1.2.7 Progress tracking. Daily site activities in construction projects can experience inefficiencies brought on by a variety of events, such as interruptions and waiting (Sacks *et al.*, 2010). To monitor the progress of construction operations, traditional techniques like work sampling, time studies, activity rating and crew balance charts are helpful (Omar and Nehdi, 2016). These techniques are frequently not affordable for the majority of contractors due to the substantial physical labour requirements (Su and Liu, 2007). When human operators do inspections and assessments, mistakes are bound to happen in the project's development. The manual inspection involves laborious, repeated procedures. All of this raises the likelihood that, over time, the operator becomes more prone to error and may thus provide an incorrect evaluation (Prieto *et al.*, 2020). This task can be carried out by an autonomous robot outfitted with various sensors using an automatic assessment and inspection system, increasing the task's quality and speeding up the process (Sacks *et al.*, 2010).

1.2.8 Auto-documentation. New robotics, automation and digital transformation technologies offer chances to change labour-intensive processes that have existed for a long time. The most important is data collection technologies and procedures that give construction organisations better project visibility by efficiently tracking progress throughout their task locations. The personnel generally charged with creating site documentation using 360° picture capture or laser scanning may find it tedious, error-prone and time-consuming (Ibrahim *et al.*, 2019).

1.2.9 Concrete laying. Concrete construction has high accident rates, and the product quality is sometimes low (Wang *et al.*, 2020). Laying concrete with robots reduces labour expenses, equipment maintenance costs, downtime for construction and clean-up costs. Adopting the concrete-laying robot improves the quality of the finished concrete segment and the safety of the building site (Bryson *et al.*, 2005).

1.3 Benefits of humanoids in construction activities

1.3.1 Enhanced profits. Nik Fatma Arisya *et al.* (2020) indicated that the need for humanoids in the construction industry is important for several reasons, including that it would lead to tangible and intangible benefits. Human resources would need to be replaced with humanoids, which would be expensive in the short term but would produce long-term cost reductions for businesses (Kim *et al.*, 2016). Cost savings will increase, especially because robots will eliminate human mistakes (Alaloul *et al.*, 2022). Dabirian *et al.* (2016) said that relying less on people can also reduce the human resources needed, often 30–50% of a construction project's total cost. This saves money and improves the final product's time performance and quality (Dabirian *et al.*, 2016). Additionally, automation may result in higher productivity and more cost-effective employment (Nik Fatma Arisya *et al.*, 2020). Cost savings, mostly as a result of a reduction in workload per activity and the requirement for scaffolding, security systems and additional transportation equipment, are reduced or eliminated (Kamaruddin, 2012).

1.3.2 Improved security on site. International standards show that most developing and developed countries' construction industries do a terrible job regarding safety and security (Spillane *et al.*, 2011). According to Omran *et al.* (2010), the construction sector is known for having a weak safety culture on a global scale. One of the most important safety issues on construction sites is building flaws caused by poor work. These flaws make sites unsafe and can lead to fatal accidents. So, by making and using machines to do dangerous jobs (Nik Fatma Arisya *et al.*, 2020), automation can improve worker and public safety.

1.3.3 Improved working conditions. The presence of humanoids on the job site enhances the working environment since workers are relieved of uncomfortable work positions, and traditional physical labour is reduced to a minimum (Elattar, 2008). The introduction of humanoids will improve the working environment because it will reduce the amount of traditional manual labour required, relieving workers of uncomfortable work positions while also removing complaints about noise and dust associated with tasks like surface preparation, removal or cleaning (Nik Fatma Arisya *et al.*, 2020).

1.3.4 Increased quality of construction products. In the construction sector, humanoids and automation systems can provide more consistent and accurate quality than professional personnel (Elattar, 2008). The variability of operations carried out by automated and humanised systems is often lower than that of human workers (Hatoum *et al.*, 2020). When reliance on humans is minimised, and humanoids are embraced, problems with subpar workmanship are less likely to occur (Nik Fatma Arisya *et al.*, 2020).

1.3.5 Increased accuracy of tasks. Harstad *et al.* (2015) affirmed that operations can give engineers more control over the project, allowing quicker problem detection and improved work quality and accuracy. Humanoids can replace human labour with more precision because humans are susceptible to weariness, disease and other conditions (Carra *et al.*, 2018). Increased control over the design and construction processes can improve task accuracy because machines can continuously perform in-depth monitoring without impacting their performance, while humans cannot (Nik Fatma Arisya *et al.*, 2020).

1.3.6 Reduced operational cost and wastage. Among the discernible benefits and advancements that will significantly impact the use of humanoids and automation are raising product quality and reducing the number of materials needed to complete projects (Kamaruddin, 2012). Yield will be increased as there will be minimal wastage due to the use of computers to determine the amount of material to be used (Elattar, 2008). The potential of technology to enhance internal organisational processes within the company can result in operational excellence, decrease the time and cost necessary to complete activities in the construction sector and ultimately increase productivity (Hatoum *et al.*, 2020).

1.3.7 Reduced number of injuries. Nik Fatma Arisya *et al.* (2020) believed that humanoids are important for reducing accidents and injuries on the job site. The ability of humanoids to work in hazardous areas for humans reduces workplace accidents (Nik Fatma Arisya *et al.*, 2020). The employment of humanoids prevents slips and falls, falls from heights, electrocution, building collapses and being struck by moving or heavy machinery (Hatoum *et al.*, 2020).

1.3.8 Reduced duration of project delivery. The potential of technology to enhance internal organisational processes within the company can result in operational excellence, decrease the time and cost necessary to complete activities in the construction sector and ultimately increase efficiency (Nik Fatma Arisya *et al.*, 2020). Martinez *et al.* (2008) mentioned that humanoids can accelerate production, remove human limits and reduce operational unpredictability, all of which impact the final product's quality. According to Hatoum *et al.* (2020), productivity increases when the human factor is removed from the equation. This means that projects can be finished faster and in less time.

1.3.9 Boosts efficiency of tasks. The potential of technology to enhance internal organisational processes within the company can result in operational excellence, decrease the time and cost necessary to complete activities in the construction sector and ultimately increase efficiency (Nik Fatma Arisya *et al.*, 2020).

2. Research methodology

The quantitative approach was used for this study. This was chosen since it allows for more data collection in a shorter time (Sukamolson, 2007). Also, this method allows for reaching out to a large population, while also allowing for objectiveness and quantifiability (Tan, 2011). This study evaluated the applicability of variables acquired from earlier studies by employing numerical analysis. As a result, a post-positivist philosophical stance was used. A thorough literature review was done to determine where humanoids could be used and what benefits they might bring to the South African construction industry. Then, five experts with experience in construction technologies were used for a pilot study. This was done with a view to refine the outcome of the variables extracted from the review of literature, while also to review the appropriateness of the research instrument in achieving the aim of the study. Thus, an expert must have at least five years of experience and knowledge of using humanoids. The respondents were asked to comment on the variables, suggest additional variables and rate their likelihood of being included in the study. Similar to the study of Owusu-Manu *et al.* (2022), if at least three respondents agreed on a variable, it was considered for inclusion in the study. After doing this, the study came up with nine areas where humanoids could be used (see Table 1) and nine ways they could help with construction work (see Table 1).

A comprehensive, closed-ended questionnaire was created based on humanoids' potential uses and advantages for construction activities. Each variable was scored on a Likert scale of 1–5, where 1 is strongly disagree and 5 is strongly agree as employed by Enshassi *et al.* (2018). The objective was to accurately pinpoint humanoids' potential uses and advantages for construction activities. The identified application areas and benefits were modelled into a questionnaire using reliable scientific data from prior publications. The research was conducted in Johannesburg, a city in the Gauteng province of South Africa. Johannesburg was selected because of its central location and because there are many construction organisations; finding professionals to take part in the survey would not be a hustle. Members of the target population who met certain practical criteria, such as easy accessibility, geographic proximity, availability at a specific time or a willingness to participate, were included for the purpose of the study through convenience sampling (Etikan *et al.*, 2016). The target population entailed construction professionals in Gauteng province of South Africa, while the sample size was derived using the formular provided by Yamane (1967), thus leading to a sample size of four hundred and eighty-seven.

The questionnaire was administered purposively to eighty architects, construction managers, engineers, site managers, quantity surveyors and construction IT specialists from both the public and private sectors. Purposive sampling was used based on various criteria, including specialist knowledge of the research issue or capacity and willingness to participate in the research (Creswell and Creswell, 2017). The questionnaire was administered through an electronic medium using Google Forms over a period of two months. Out of 80 questionnaires distributed, 50, representing 62.5%, were retrieved and deemed valid for analysis.

The statistical tools employed in the analysis included the mean score ranking and the one-sample *t*-test. The mean score ranking was used to determine the central tendency of the various application areas and the benefits of humanoid adoption in the construction industry. Additionally, a one-sample *t*-test was used to ascertain the statistical significance of the mean values relating to the various application areas and benefits of humanoid adoption in the

	References
Application areas	
Progress tracking	Omar and Nehdi (2016), Su and Liu (2007), Sacks *et al.* (2010), Prieto *et al.* (2020)
Auto-documentation	Ibrahim *et al.* (2019)
Inspection and surveillance	Bryson *et al.* (2005)
Concrete laying	Wang *et al.* (2020), Bryson *et al.* (2005)
Paving	Zhang *et al.* (2023), Ma *et al.* (2021), Cobb (2001)
Material handling	Gambao *et al.* (2012), Teizer and Cheng (2015), Mustapha *et al.* (2020), Heragu *et al.* (2011)
Bricklaying	Malakhov *et al.* (2020), Malakhov and Shutin (2019), Coupe (2019), Mitterberger *et al.* (2020)
Steel truss assembly	Jung *et al.* (2013), Cho *et al.* (2007), Komendera and Correll (2015)
Welding	Wang *et al.* (2020), Saariluoma *et al.* (2020), Brosque *et al.* (2020), Ardiny *et al.* (2015), Chu *et al.* (2008)
Benefits	
Increased quality of construction products	Elattar (2008), Nik Fatma Arisya *et al.* (2020), Hatoum *et al.* (2020)
Improved working conditions	Elattar (2008), Nik Fatma Arisya *et al.* (2020)
Enhanced profits	Nik Fatma Arisya *et al.* (2020), Kim *et al.* (2016), Alaloul *et al.* (2022), Dabirian *et al.* (2016)
Improved security on site	Spillane *et al.* (2011), Omran *et al.* (2010), Nik Fatma Arisya *et al.* (2020)
Reduced duration of project delivery	Martinez *et al.* (2008), Nik Fatma Arisya *et al.* (2020), Hatoum *et al.* (2020)
Reduced number of injuries	Nik Fatma Arisya *et al.* (2020), Hatoum *et al.* (2020)
Increased accuracy of tasks	Harstad *et al.* (2015), Carra *et al.* (2018), Nik Fatma Arisya *et al.* (2020)
Boosts the efficiency of tasks	Nik Fatma Arisya *et al.* (2020)
Reduced operational costs and wastage	Kamaruddin (2012), Elattar (2008), Hatoum *et al.* (2020)

Source(s): Authors' compilation

Table 1. Application areas and benefits of adopting humanoids in the construction industry

construction industry. Furthermore, the reliability and validity of the research instrument was ascertained using the Cronbach's alpha test. An alpha value of 0.824 and 0.911 were given for the potential applications and benefits respectively. Thus, affirming the validity and reliability of the questionnaire as recommended by Tavakol and Dennick (2011), since both alpha values are above the 0.7 threshold. The Statistical Package for Social Sciences, version 23.0, was used to analyse the data.

3. Results and discussion

3.1 Demographic data

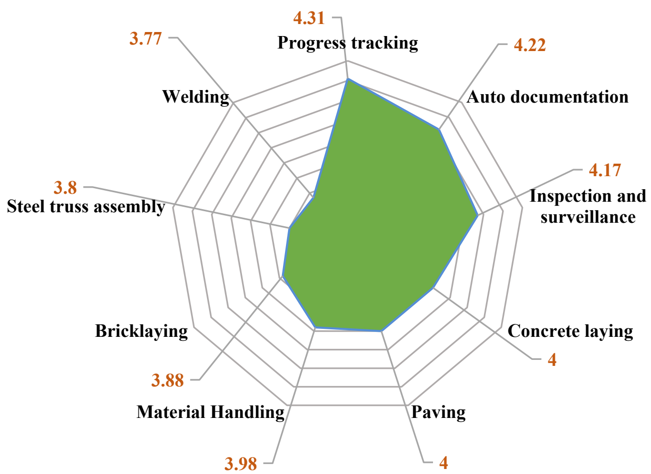
From the analysed data retrieved from the respondents of the study, it is revealed that architects made up 6% of the total number retrieved, construction managers made up 23%, quantity surveyors made up 38%, site managers made up 4%, construction IT specialists comprised 19% and the remaining 10% of the respondents were engineers. Regarding the respondents' educational backgrounds, 32% possessed bachelor's degrees, 54% possessed master's degrees and the remaining 14% had diploma degrees. This suggests that the respondents were well-educated and had the necessary knowledge to partake in the study. In terms of professional experience, 4% of the respondents had one to five years of experience, 12% had six to ten years of experience, 18% had eleven to fifteen years of experience, 28% had sixteen to twenty years of experience and the remaining 38% had over twenty years working experience.

3.2 Application areas of humanoids in construction activities

Respondents were asked to rank from a list gathered from the literature to establish the areas whereby humanoids are commonly used in the construction industry in South Africa. Figure 1 outlines the respondents' extent of agreement with the various application areas was analysed and ranked by their mean scores and respective standard deviations. Table 3 presents the results. Progress tracking ranked first with a mean score value of 4.31 and a standard deviation value of 0.694; auto-documentation ranked second with a mean score value of 4.22 and a standard deviation value of 0.725; inspection and surveillance tasks ranked third with a mean score value of 4.17, and a standard deviation value of 0.771; concrete paving ranked fourth with a mean score value of 4.00, and a standard deviation value of 0.796; paving ranked fifth with a mean score value of 4.00, and a standard deviation value of 0.816; material handling ranked sixth with a mean score value of 3.98 and a standard deviation value of 0.724; bricklaying ranked seventh with a mean score value of 3.88, and a standard deviation value of 0.822; steel truss assembly ranked eighth with a mean score value of 3.80, and a standard deviation value of 0.758; and welding ranked the least with a mean score value of 3.77, and a standard deviation value of 0.742.

To determine the statistical significance of the application areas of humanoids in construction activities, a one-sample *t*-test was used at a 95% confidence level with a *p*-value less than 0.05 and a test value of 3.5. The 95% confidence level interval, according to Aigbavboa *et al.* (2022), estimates the difference between the population mean weight and the test value (3.5). As shown in Table 2, all variables' t-values (test strengths) were positive, meaning their means were much higher than the expected mean of 3.5. As a result, all variables are major areas where humanoids can be used in construction.

The results showed that the survey participants knew how humanoids could be used in the construction industry. In this industry, robots and automation started to be used and do things in the early 1990s. The goal is to improve the workplace's appearance, make it safer and get the most out of how the equipment worked (Elattar, 2008). According to the results, humanoids will benefit more from jobs like progress tracking, auto-documenting, inspection, and surveillance. This was inferred from the outcomes based on the ranking, computed mean item scores, and standard deviation. The findings of the study are in consonance with



Source(s): Authors

Figure 1. Group mean scores of applications areas of humanoids

previous studies which noted that a variety of construction tasks can be carried out by an autonomous robot outfitted with various sensors using an automatic assessment and inspection system, increasing the task's quality and speeding up the process (Sacks *et al.*, 2010). Also affirming the findings of the study, it is noted that personnel generally charged with creating site documentation using 360° picture capture or laser scanning may find it tedious, error-prone, and time-consuming (Ibrahim *et al.*, 2019), consequently giving credence to the application of humanoids for auto-documentation in construction project delivery. Furthermore, it is shown from the outcome of this study that the South African construction industry aligns more with construction progress tracking as one of the major applications of humanoids for construction project delivery. This is in consonance with the study of Omar and Nehdi (2016), which affirms this application in the Canadian construction industry.

3.3 Benefits of humanoids in construction activities

To give credence to why humanoids should be used in construction projects, there was the need to establish if there are any benefits as envisaged. Respondents were thus asked to rank from a list of benefits collated from literature to indicate the significance level using a five-point Likert scale. Mean scores and standard deviations did analyse. The results of the mean scores of the benefits of humanoids are presented in Figure 2. Also, inferring from Table 3, reduced duration of project delivery ranked first with a mean score value of 4.02, and a standard deviation value of 1.097; reduced number of injuries ranked second with a mean score value of 3.98, and a standard deviation value of 1.078; increased accuracy of tasks ranked third with a mean score value of 3.94, and a standard deviation value of 1.096; boosts the efficiency of functions ranked fourth with a mean score value of 3.92, and a standard

Application areas	Mean	Std dev.	Rank	*t*-value (3.5)	Sig. (2-Tailed)
Progress tracking	4.31	0.694	1st	2.727	0.000
Auto-documentation	4.22	0.725	2nd	2.670	0.010
Inspection and surveillance	4.17	0.771	3rd	3.874	0.000
Concrete laying	4.00	0.796	4th	2.571	0.013
Paving	4.00	0.816	5th	2.327	0.023
Material handling	3.98	0.724	6th	2.268	0.027
Bricklaying	3.88	0.822	7th	2.762	0.008
Steel truss assembly	3.80	0.758	8th	2.166	0.034
Welding	3.77	0.742	9th	1.795	0.000

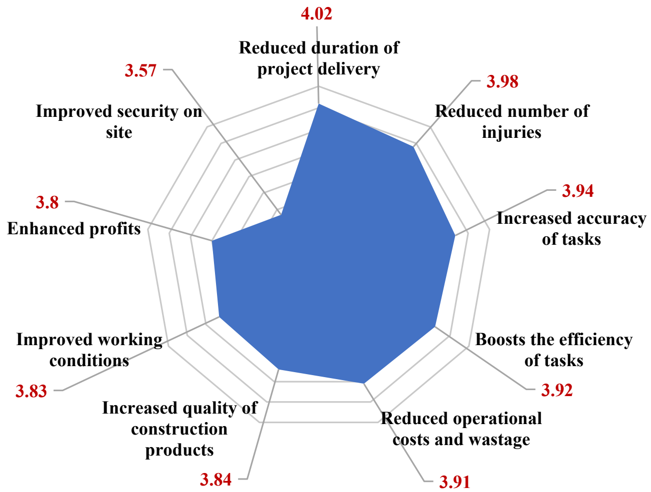
Source(s): Authors' compilation

Table 2. Application areas of humanoids in construction activities

Benefits	Mean	Std dev.	Rank	*t*-value (3.5)	Sig. (2-tailed)
Reduced duration of project delivery	4.02	1.097	1st	6.756	0.000
Reduced number of injuries	3.98	1.078	2nd	7.823	0.000
Increased accuracy of tasks	3.94	1.096	3rd	7.133	0.000
Boosts the efficiency of tasks	3.92	0.986	4th	5.858	0.000
Reduced operational costs and wastage	3.91	1.060	5th	5.755	0.000
Increased quality of construction products	3.84	1.149	6th	6.695	0.000
Improved working conditions	3.83	1.034	7th	7.060	0.000
Enhanced profits	3.80	1.108	8th	5.250	0.000
Improved security on site	3.57	1.208	9th	0.477	0.035

Source(s): Authors' compilation

Table 3. Benefits of humanoids in construction activities



Source(s): Authors

Figure 2.
Group mean scores of benefits of humanoids

deviation value of 0.986; reduced operational costs and wastage ranked fifth with a mean score value of 3.91, and a standard deviation value of 1.060; increased quality of construction products ranked sixth with a mean score value of 3.84, and a standard deviation value of 1.149; improved working conditions ranked seventh with a mean score value of 3.83; and a standard deviation value of 1.034; enhanced profits ranked eighth with a mean score value of 3.80; and a standard deviation value of 1.108; and welding ranked the least with a mean score value of 3.57, and a standard deviation value of 1.208.

Using a confidence level of 95%, a p-value of less than 0.05, and a test value of 3.5, the one-sample t-test was utilised to establish the statistical significance of the benefits further. As indicated in Table 3, all the benefits' t-values (test power) were positive, indicating that their means were significantly above the hypothesised mean value of 3.5. Suggesting that the mean values of these variables do not differ considerably from the proposed mean of 3.5. Therefore, all identified variables are significant benefits of humanoids in construction activities.

The findings agreed with the research conducted by Kim *et al.* (2016) and Nik Fatma Arisya *et al.* (2020). Also, Martinez *et al.* (2008) mentioned that humanoids can accelerate production, remove human limits and reduce operational unpredictability, all of which impact the final product's quality. Furthermore, Hatoum *et al.* (2020) noted that productivity increases when the human factor is removed from the equation. This means that projects can be finished faster and in less time. While the employment of humanoids prevents slips and falls, falls from heights, electrocution, building collapses and being struck by moving or heavy machinery (Hatoum *et al.*, 2020). Since the results, in comparison with the literature, reveal that the respondents are aware of the benefits that can be acquired from adopting humanoids in construction activities, it is of utter importance that time, and resources be invested in educating the various stakeholders in the construction industry about humanoids.

4. Conclusion

This study identified the potential application areas and key benefits of adopting humanoids in the construction industry. Some application areas of humanoids in construction activities are progress tracking, auto-documentation, inspection and surveillance tasks, concrete laying, paving, material handling, bricklaying, steel truss assembly and welding. Additionally, the benefits of humanoids in the construction industry include reduced duration of project delivery, a reduced number of injuries, increased accuracy of tasks, boosted the efficiency of tasks, reduced operational costs and waste, increased quality of construction products, improved working conditions, enhanced profits and improved security on site. This research provides a new perspective on the possible areas and key benefits of adopting humanoids in construction activities. The knowledge gained from this study will help industry professionals and policymakers adopt humanoids in construction activities more effectively.

The findings of this study will stimulate much-needed debate on adopting humanoids in construction projects to take advantage of its related benefits not just to the South African construction industry, but to the world in general. This study will also serve as a source of empirical data to motivate others to conduct further studies on the subject to confirm or otherwise the study's findings. Outcomes of the study's findings provide stakeholders in infrastructure development worldwide with the insight into the benefits of adopting humanoids in projects. Based on the findings, the following recommendations are made: the use of humanoids in construction activities by firms/companies plays a critical role in the firm's success; thus, project managers ought to see the need to embrace humanoids in projects due to the benefits humanoids bring; public awareness of the adoption of humanoids in projects is essential because it leads to improved delivery of projects. Also, top management of construction organisations should prioritise the espousal of humanoids for project delivery, since the potential benefits have been outlined in the findings of this study. Moreover, construction professional bodies should help propagate the adoption of innovative technologies such as humanoids through periodic sensitisation of its members.

Despite the advances in understanding gained through this research, the study had some limitations. Relatively, the sample size was small. Also, the study was limited to the Gauteng province of South Africa. It is recommended that future studies can be conducted in other provinces of the country to give a more robust outcome. Nonetheless, the respondents' level of education and years of experience in industry 4.0 technologies still validate the study's authenticity for future reference. Only South African stakeholders were included in the present study. The research results could differ significantly if carried out in different geographic and economic regions. However, the findings' consistency with the literature further establishes their legitimacy and inspires confidence in them.

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