PLS-SEM assessment of the impediments of robotics and automation deployment for effective construction health and safety

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Abstract

Purpose – The importance of robotics and automation (R&A) in delivering a safe built environment cannot be overemphasised. This is because R&A systems can execute a hazardous job function that the construction workforce may not execute. Based on this knowledge, this study aims to present the

result of an assessment of the impediments to the deployment of R&A for a safe and healthy construction environment.

Design/methodology/approach – This study adopted a post-positivist philosophical stance, using a quantitative research approach and a questionnaire administered to construction professionals in South Africa. The data gathered were analysed using frequency, percentage, mean item score, Kruskal–Wallis *H*-test, exploratory factor analysis and partial least square structural equation modelling (SEM).

Findings – This study revealed that the impediments to the deployment of R&A could be grouped into: industry, technology, human and cost-related factors. However, SEM assessment showed that only the industry, human and cost-related factors would significantly impact attaining specific health and safety-related outcomes.

Practical implications – The findings offer valuable benefits to construction organisations as the careful understanding of the identified impeding factors can help lead to better deployment of R&A and the attainment of its inherent safety benefits.

Originality/value – This study attempts to fill the gap in the shortage of literature exploring the deployment of R&A for a safe construction environment, particularly in developing countries like South Africa, where such studies are non-existent. This paper, therefore, offers a theoretical backdrop for future works on R&A deployment, particularly in developing countries where such a study has not been explored.

Keywords Health, Automation, Construction, Safety, Robotics, South Africa

Paper type Research paper

Introduction

The construction industry has been criticised for its poor delivery of sustainable construction, specifically in relation to health and safety (H&S), which is a key aspect of social sustainability. Everyday, construction workers are put in harm's way by executing jobs that pose the danger of fatal and non-fatal injuries (Cai *et al.*, 2018). Maryania *et al.* (2015) noted that construction is ranked as one of the most dangerous and high accident-risk industries worldwide. With the increased complexity of construction works, the life risk to site workers has increased, and in so doing shortage of construction workers is becoming evident. As such, it is the responsibility of the construction employers or managers to ensure the safety of their working crew, particularly those on site. Oke *et al.* (2018) submitted that for developing countries with an increasing need for construction products to meet society's needs, it is important to adopt innovative approaches that will ensure workers' safety and accident-free projects. To achieve this feat, technological advancements in robotics and automation (R&A) have been proposed (Aghimien *et al.*, 2020; Delgado *et al.*, 2019; Yap *et al.*, 2021).

Past studies have mentioned that the use of R&A proposes a solution to the age-long problem of the construction industry, particularly in terms of time, cost and quality delivery of projects (Bock, 2015). It has also been noted that the technology offers safer delivery of projects and can help cushion the effect of the labour shortage that has affected the industry in recent times (Kamaruddin *et al.*, 2013). The adoption of R&A systems offers the construction industry a way out of the high site accidents rate that has plagued the industry (Yap *et al.*, 2021). These robotic systems are important in off-site production and on-site lifting (Pan and Pan, 2020). To this end, studies on R&A systems in the construction industry of both developed and developing countries have continued to emerge. Some of these studies have explored the implementation (Akinradewo *et al.*, 2018; Struková and Líška, 2013), the barriers to its implementation (Delgado *et al.*, 2019; Oke *et al.*, 2021; Trujillo and Holt, 2020), its overarching impact on the industry (Akinradewo *et al.*, 2021; Cropp, 2021), the trends in R&A advancement (Balaguer and Abderrahim, 2008; Pan and Pan, 2020;

Son *et al.*, 2010) and its adoption for solving specific industry-related issues (Cai *et al.*, 2018; Jung *et al.*, 2013).

In spite of the existence of these studies on R&A in construction, there is a paucity of research on the impediments of R&A adoption to ameliorate H&S in the South African construction industry. This becomes important as the industry in South Africa, like its counterparts in other developing countries, is bedevilled with poor H&S and issues of site accidents is a prevailing occurrence (Aghimien *et al.*, 2018). More so, the industry has been noted as a slow adopter of beneficial digital and physical technologies that could help improve its service delivery (Pärn and Edwards, 2019). Therefore, understanding the deterring factors to the use of R&A for effective H&S is important to the proper adoption of the technology. To this end, this research identified the factors impeding R&A deployment in the construction industry from existing studies. These factors were then empirically tested in the South African context, and their significant impact on specific H&S outcomes was determined. This was done to proffer possible guidelines that will help improve the use of R&A systems. The study provides practical direction for construction organisations seeking to improve their H&S delivery through ubiquitous emerging technologies. The findings should help shape the policies surrounding the use of R&A and its related technologies in these organisations and the South African construction industry at large. Much more, the findings will serve as theoretical background for future studies seeking to explore this area of study, particularly in countries where such research has not been conducted.

Review of literature

Construction site accidents can occur from different forms of activities, and as such, different advancements have been introduced to help deliver these activities safer. For instance, demolition robots have been designed to handle equipment more effectively. As a result, the operator of this machine can be at a safe distance from the debris while carrying out demolition activities. This makes them safer than handheld devices (Ruggiero *et al.*, 2016). Similarly, activities such as continuous bending, lifting of heavy objects, incorrect posture stance and repetitive tasks of a bricklayer may cause them to experience lower back pain. As such, bricklaying robots can substitute a worker for the tedious task and, in the process, reduce the chances of the worker experiencing lower back pain or injury (Adams and Dolan, 2007). Also, Jung *et al.* (2013) submitted that in a robotic beam assembly system, most of the work is performed by a robotic bolting device installed on a cabin that functions as a control station. A graphical user interface system is positioned inside the cabin, and its operator can safely manage the steel beam assembly process. This increases steel beam assembly safety as site workers are not needed to work on high and risky steel beam structures. Instead, the workers will operate the robotic beam assembly system from the safe cabin.

Furthermore, advancement in the form of exoskeletons allows injured or disabled workers to work in construction and lift and transport heavier objects (Mone, 2014). Forklift robots can also help relieve workers from carrying heavy objects or even humans from controlling a forklift to transport the objects (Ruggiero *et al.*, 2016). Also, painters are continuously exposed to hazardous ingredients when painting buildings (Tharshanapriya *et al.*, 2017). For example, paints that contain lead may cause serious health problems to painters and roofers who have been exposed to the toxic solvent for a long period (Santti *et al.*, 2009). Therefore, workers can be moved to safer, less risky positions and allow the robots to work in those harmful environments (Bock and Linner, 2017). Robotic excavation can also be performed using robotic teleoperation. According to Melchiorri (2013), robotic

teleoperation is a system that enables a human operator to interact with objects that are placed at a certain distance. Teleoperated excavators can be used in activities that may pose a danger to humans, such as excavating around buried utilities.

Like every other technology, the adoption of R&A for attaining these aforementioned H&S benefits is challenged by several factors. Several studies have attempted to unearth these factors and categorise them based on their severity for clarity. For instance, in the USA, Trujillo and Holt (2020) categorised the barriers to using robotics into three main groups, namely, cultural, technical and teams' issues. It was noted that while literature has placed focus on the technical aspect of this technology as key deterrents to its usage, the culture at the organisational level and the team needed to handle this technology are key factors to consider. In the Slovak construction industry, Struková and Líška (2013) noted that the high cost of acquiring, maintaining and updating R&A systems and its unavailability in local communities are the major barriers to its adoption. A similar observation was made by Delgado *et al.* (2019) in a study conducted among architecture, engineering and construction specialists in European countries. The high initial capital needed for R&A was rated as the top factor affecting its usage. Huang *et al.* (2021) also noticed the issue of cost deterring the use of R&A in the Chinese construction industry. Mahbub (2012) mentioned that it is expensive to acquire and maintain these R&A systems, which discourages their adoption in Malaysia. This high cost of acquiring technology is a re-occurring problem, particularly in developing countries filled with small and medium enterprises (SMEs) struggling to stay afloat (Hampson *et al.*, 2014; Oke *et al.*, 2018).

Also, Delgado *et al.* (2019) mentioned that lack of government incentives plays a major factor in the slow adoption of R&A. This assertion was based on the fact that government is a major client of the construction industry and, as such, can impact on the use or non-use of certain technologies on public projects. The public sector in countries around the world plays a crucial factor in adopting digital technologies by creating incentives, policies and regulations (Jensson, 2017). More so, it has been stated that because of the "lowest bid" concept adopted in most countries, when contractors decide to adopt innovative approaches to improve H&S on their project, they stand the chance of losing tenders or negotiations to competitors that are less committed to H&S (Smallwood, 2004). Therefore, the contractors are not encouraged to adopt innovative methods and technologies in the quest for safe project delivery (Aghimien *et al.*, 2018). Another issue that creates challenges for adopting R&A is the nature of the construction industry and its activities. The fragmented nature of the industry, the existing construction practices and operations as well as aversion of the industry to change are key issues that have been noted in past studies (Delgado *et al.*, 2019; Trujillo and Holt, 2020; Vähä *et al.*, 2013). Balaguer and Abderrahim (2008) have earlier noted that the unstructured nature of the construction industry makes it difficult to adopt R&A. The fear of changing existing practices that work leads to an aversion to change, which deters the use of beneficial technologies (Oke *et al.*, 2018; Yahya *et al.*, 2019). Dimick (2014) has noted distrust in new technologies in most organisations. This distrust emanates from the fact that change can be challenging for humans. The resultant effect of this distrust is the aversion to change, which is evident at every level of these organisations, from workers to executive decision makers.

The advent of emerging technologies has received significant resistance from construction workers and unions because of the fear of job loss. For an industry that has been dependent on human input for a long time, the fear of robots taking over jobs is a key deterrent to the smooth adoption of these technologies (Aghimien *et al.*, 2021). While studies have noted that the adoption of emerging technologies such as R&A systems will usher in demand for new skill sets and not necessarily take away jobs (Lawrence *et al.*, 2017; Muro *et al.*, 2017), there is still

resistance to change within the construction industry (Aghimien *et al.*, 2021; Akinradewo *et al.*, 2018; Cai *et al.*, 2018; Mahbub, 2012). The fact that the construction industry in most developing countries (South Africa inclusive) is characterised by skill shortage (Windapo and Cattell, 2013) and workers need to be trained and retrained to use these technologies does not help their adoption (Delgado *et al.*, 2019; Kamaruddin *et al.*, 2013). For most technologies to be successfully implemented, organisations will have to get new talent, train the few existing ones or collaborate with other organisations with the required talents (Sacks and Barak, 2010). This can strain these construction organisations' meagre available financial resources, most of whom are SMEs with little financial capabilities (Hampson *et al.*, 2014). Trujillo and Holt (2020) have also noted that the diffusion of existing knowledge and practice with R&A systems can be barriers to their adoption. In most cases, these technologies are either unknown, new or not fully tested in the construction industry. Therefore, poor knowledge and understanding of R&A in the industry and the benefits it proposes for H&S and construction services, in general, can deter its adoption. Other notable issues include the difficulty in using R&A systems (Golizadeh *et al.*, 2019; Mahbub, 2012), lack of mechanical flexibility, fear of robotic failure causing harm to workers (Dimick, 2014; Yang *et al.*, 2018) as well as the fact that there is no evidence of its effectiveness for H&S delivery in the construction industry (Delgado *et al.*, 2019; Lavikka, 2018).

The implementation of R&A promises significant benefits to the construction industry. Yap *et al.* (2021) noted that using technologies such as R&A would lead to easy hazard identification, support safety planning, inspection, monitoring and raise safety awareness. Bahrin *et al.* (2016) also submitted that using R&A for construction work will lead to a safer construction environment as robots will reduce human inputs and associated fatalities. Evidently, the adoption of R&A will lead to better H&S for the construction workforce. Furthermore, wearable devices with embedded sensors can help monitor workers' health issues and detect problems early. Early detection of issues around workers' overworking, stress and subsequent absenteeism allows measures to be implemented before these issues can affect the overall project outcome (Salento, 2017). This, in turn, will increase the productivity of construction workers and overall project success (Kamaruddin *et al.*, 2016). Siderska (2021) has noted that the adoption of R&A by organisations offers a better competitive advantage. Aghimien *et al.* (2019) and Kamaruddin *et al.* (2016) have noted that the introduction of digital and physical technologies offers construction organisations the opportunity to be more competitive and possibly attain a competitive advantage over other organisations that are yet to adopt these technologies. Also, considering the possibility of R&A offering better H&S on construction projects (Ruggiero *et al.*, 2016; Yap *et al.*, 2021), these organisations will be known for their ability to deliver safe projects, thereby increasing their competitiveness.

Based on the various studies reviewed, Table 1 reproduced the impediments to the deployment of R&A in construction. These variables were assessed against the expected outcomes of R&A, leading to better H&S for construction workers, improved workers' productivity, better competitive advantage derived through effective H&S and achieving overall project success.

Research methodology

The study adopted a post-positivist philosophical stance using a quantitative approach to gather data from construction professionals in Gauteng province through a survey technique. A questionnaire was used as the research instrument because of its ability to offer quantifiable data within a short period (Tan, 2011). The choice of conducting the study

Code	Impeding factors	Citations
IMP1	High investment cost	Delgado *et al.* (2019), Manzo *et al.* (2019); Mistri and Rathod (2015); Struková and Líška (2013)
IMP2	High cost of maintenance	Mahbub (2012); Struková and Líška (2013)
IMP3	Lack of government incentives to use R&A for H&S	Delgado *et al.* (2019), Huang *et al.* (2021)
IMP4	Incompatibility with existing construction practices and operations	De Looze *et al.* (2016); Struková and Líška (2013)
IMP5	Fragmented nature of the construction industry	Balaguer and Abderrahim (2008), Chen *et al.* (2018)
IMP6	Aversion to change in the industry	Akshatha *et al.* (2017), Delgado *et al.* (2019); Oke *et al.* (2018), Yahya *et al.* (2019)
IMP7	Poor knowledge and understanding of R&A in the industry	Aghimien *et al.* (2021), Mahbub (2012); Trujillo and Holt (2020)
IMP8	Resistance by workers and unions	Aghimien et al.,(2021); Akinradewo *et al.* (2018), Cai *et al.* (2018); Mahbub (2012)
IMP9	Insufficient skilled personnel	Li and Liu (2019), Oke *et al.* (2018)
IMP10	Need for training or retraining	Delgado *et al.* (2019), Kumar *et al.* (2016); Sacks and Barak (2010); Vähä *et al.* (2013)
IMP11	Fear of robot failure causing harm to workers	Dimick (2014), Yang *et al.* (2018)
IMP12	Difficulty to acquire	Struková and Líška (2013)
IMP13	Difficulty to use	Bock (2015), Golizadeh *et al.* (2019); Huang *et al.* (2021), Mahbub (2012)
IMP14	Product complexity	Huang *et al.* (2021)
IMP15	Unproven effectiveness for R&A for H&S in construction	Delgado *et al.* (2019), Lavikka (2018)

Table 1.
Summary of the impediments of R&A deployment in construction

in Gauteng was premised on the notion that the province has the highest number of construction output, organisations and professionals compared to other provinces (CIDB, 2020; Galal, 2020). The questionnaire was designed in sections and distributed through electronic means to be self-administered by the respondents. The first section of the questionnaire sought answers to the demographic characteristics of the respondents to ascertain their suitability for the study. The second section sought answers to the impediments of R&A deployment within the South African construction industry and the possible impact the use of these systems will have on H&S-related outcomes. This section was assessed on a five-point Likert scale, with one being "very low significance/very low impact" and five being "very high significance/very high impact". The variables measured in this section were gathered from existing related studies and are given in Table 1. For participants to be involved in the study, they must be professionals (architects, engineers, construction managers, quantity surveyors and safety officers) with at least five years of working experience in the South African construction industry and currently actively involved in a project within the province. However, because of the difficulty in getting the exact number of professionals with the set years of experience and practising within the province at the time of the research, a snowball sampling approach was adopted. This is because the sampling approach can significantly increase the sample size of a study because it is based on referral (Heckathorn, 2011). Based on the approach adopted, 134 professionals participated in the study.

Data analysis was done using percentages and frequency on the demographic characteristics of the respondents. In addition, the mean item score $(\overline{X})$ was used to rank the

identified impediments based on their level of significance as rated by the respondents. The premise for ranking these variables was that the variable with the highest $\overline{X}$ is ranked first and all others follow in descending order. Furthermore, because the construction professionals were drawn from different types of organisations (contracting, consulting, government), there is a possibility that they might view the significance of the identified variables differently. Therefore, the Kruskal–Wallis (K–W) *H*-test, which is used to ascertain the significant difference in the view of three or more groups of respondents (Pallant, 2011), was used to ascertain the significant difference in the view of respondents in this study. The K–W test gives a chi-square (χ^2) and a *p*-value. When the *p*-value is >0.05, it implies no significant difference in the perspective of the different groups of respondents.

To further re-group the identified impeding factors into a more manageable sub-scale, exploratory factor analysis (EFA) was adopted. This first-generation multivariate data analysis has been favoured in recent R&A studies (Delgado *et al.*, 2019; Yap *et al.*, 2021; Huang *et al.*, 2021). In conducting EFA, past studies have favoured the use of a sample size of above 150 (Tabachnick and Fidell, 2013). However, it has been noted that as long as a communality of 0.5 and above is attained (as in the case of this current study), researchers need not emphasise the size of the sample (Field, 2009; Preacher and MacCallum, 2002; Tabachnick and Fidell, 2013). Before conducting EFA, the factorability of the data was also tested using Kaiser–Meyer–Olkin (KMO) and the Bartlett test of sphericity (BTS). Ideally, a KMO value ≥ 0.6 and a significant *p*-value < 0.05 for the BTS are needed for the data to be considered factorable. The data for this study met the set thresholds, and EFA was conducted using principal component analysis (PCA) with varimax rotation. PCA was adopted because it can easily identify and reduce a large set of variables into small coherent sub-scales (Tabachnick and Fidell, 2013). These tests were conducted using Statistical Package for Social Sciences version 27. Based on the result from EFA, partial least square structural equation modelling (PLS-SEM) – a second-generation multivariate data analysis – was used using SmartPLS version 3.0. This was done to confirm the variables grouped from EFA and ascertain the structural relationship between these groups and the H&S-related outcomes of R&A deployment. The choice of PLS-SEM was premised on its ability to give a clear view of the cause–effect relationship in a phenomenon irrespective of the distribution of the data (Wong, 2013). Hedaya and Saad (2017) have earlier described PLS-SEM as an extended standardised regression modelling, which is useful in determining how some sets of variables are affected by other variables. The use of PLS-SEM has garnered significant attention in recent studies because of its ability to accommodate small samples in a study (Chin, 1998; Hwang *et al.*, 2010). Unlike the covariance-based SEM (CB-SEM), which needs a large sample size for it to be conducted, the PLS-SEM can be conducted for a sample as low as 50 responses (Benitez *et al.*, 2020; Hair *et al.*, 2019; Hwang *et al.*, 2010; Marcoulides and Saunders, 2006; Wong, 2013). More so, unlike CB-SEM, which is mainly adopted to confirm or reject theories, PLS-SEM is most ideal for developing theories in exploratory research (as in the case of this current study).

Findings and discussion
Demographic characteristics
The demographic characteristics of the respondents revealed that more quantity surveyors and engineers participated in the survey with 32.1% ($f = 43$) and 22.4% ($f = 30$) representation, respectively. This is followed by construction managers (14.9%, $f = 20$) and construction project managers (15.7%, $f = 21$). Architects (8.2%, $f = 11$) and safety officers (6.7%, $f = 9$) had the least representation. Half of the respondents (50%, $f = 67$) have bachelor's degrees, whereas 30.6% ($f = 41$), 15.7% ($f = 21$) and 3.7% ($f = 5$) have a national diploma, master's degree and doctorate,

respectively. These respondents were drawn from contracting (39.6%, $f = 53$), consulting (36.6%, $f = 49$) and government organisations (23.9%, $f = 32$). In terms of years of experience, 56% ($f = 75$) have the minimum threshold of five years, whereas the remaining 44% ($f = 59$) have above five years of working experience. These background results show that the respondents for this study are eligible both in terms of academic background and years of experience to give reasonable answers to the questions under study.

Impediments of robotics and automation deployment for a safe working environment
Table 2 shows the rating of the 15 impeding factors and the K–W test conducted. The K–W test result revealed a disparity in how the respondents rated product complexity (IMP14) as this variable had a significant p-value of 0.044, which is less than the 0.05 threshold. However, there is a consensus in the view of the respondents regarding the significance of the remaining 14 variables, as they all gave a p-value of above 0.05. From the table, it is evident that all the assessed factors impede the adoption of R&A because they all have a $\overline{X}$ of the above-average of 3.0. This implies that careful attention must be given to these identified factors for R&A to be effectively deployed for safer construction in South Africa. Chief of these factors are high investment costs (IMP1, $\overline{X} = 4.10$), aversion to change in the industry (IMP6, $\overline{X} = 4.06$), resistance by workers and unions (IMP8, $\overline{X} = 3.99$), insufficient skilled personnel (IMP9, $\overline{X} = 3.97$), need for training or retraining (IMP10, $\overline{X} = 3.94$) and poor knowledge and understanding of R&A in the industry (IMP7, $\overline{X} = 3.91$).

Exploratory factor analysis. Table 3 shows the result from the KMO and BTS conducted to determine the factorability of the data. KMO gave a value of 0.825, which is above the 0.6 thresholds set for this test. More so, a significant p-value of 0.000 was derived for the BTS. The communalities, which show the relationship of each variable with other variables, gave values ranging from 0.633 to 0.831. Again, these values are above the 0.5 thresholds suggested (Field, 2009; Preacher and MacCallum, 2002; Tabachnick and Fidell, 2013). EFA was conducted using PCA with varimax rotation based on these preliminary estimates. The analyses revealed four principal components with eigenvalues > 1.0 and a total cumulative variance of 75.6%. This implies that the assessed impeding factors account for a large

Impeding factors	$\overline{X}$	Rank	K–W χ^2	p-value
IMP1	4.10	1	1.928	0.381
IMP6	4.06	2	3.002	0.223
IMP8	3.99	3	1.074	0.584
IMP9	3.97	4	1.276	0.528
IMP10	3.94	5	1.350	0.509
IMP7	3.91	6	3.174	0.204
IMP5	3.77	7	3.597	0.166
IMP4	3.72	8	3.397	0.183
IMP2	3.72	8	0.562	0.755
IMP11	3.68	10	1.469	0.480
IMP12	3.60	11	1.771	0.413
IMP15	3.59	12	4.019	0.134
IMP3	3.57	13	5.822	0.054
IMP14	3.55	14	6.230	0.044*
IMP13	3.47	15	2.962	0.227

Notes: *Significant at $p < 0.05$, $\overline{X}$ = Mean item score, K–W = Kruskal–Wallis *H*-test, χ^2 = Chi-square

Table 2.
Ranking of the impediments of R&A deployment for construction H&S

Code	Component 1	2	3	4	Comm.	% var.
IMP6	0.822				0.763	43.5
IMP7	0.808				0.725	
IMP4	0.807				0.734	
IMP5	0.765				0.633	
IMP14		0.865			0.831	15.0
IMP15		0.844			0.781	
IMP13		0.834			0.834	
IMP12		0.635			0.753	
IMP10			0.828		0.809	10.0
IMP9			0.749		0.712	
IMP11			0.718		0.770	
IMP8			0.605		0.694	
IMP1				0.871	0.715	7.1
IMP3				0.768	0.806	
IMP2				0.652	0.706	
KMO	0.825					
BTS						
Approx. χ^2	1,317.92					
df	105					
Sig.	0.000					

Table 3.
EFA principal extraction

amount of the issues deterring the deployment of R&A in the South African construction industry. The remaining 24.4% accounts for other factors not measured in this current study. Further evaluation of the scree plot in Figure 1 confirms the retaining of these four principal components as a clear change in the elbow is evident at the fourth component (Pallant, 2011).

Table 3 also shows that the first principal component accounts for 43.5% of the total variance extracted and has four factors loading on it. These factors are an aversion to
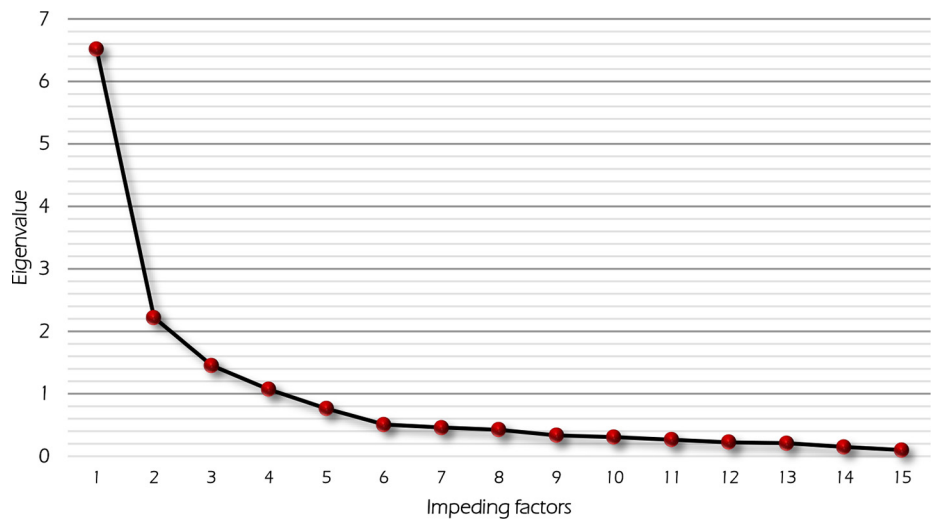

Figure 1.
Scree plot

change in the industry (IMP6), poor knowledge and understanding of R&A in the industry (IMP7), incompatibility with existing construction practices and operations (IMP4) and fragmented nature of the construction industry (IMP5). Based on the latent similarity in these factors, this group was named "industry-related factors". This naming is guided by the suggestions of Williams *et al.* (2010) that the naming of factors must be theoretical, subjective and inductive, following the researchers' judgements in line with the literature. The second component accounts for 15% of the total variance extracted and has four factors loading on it. These factors are product complexity (IMP14), unproven effectiveness for R&A for H&S in construction (IMP15), difficulty to use (IMP13) and difficulty to acquire (IMP12). This component was subsequently named "technology-related factors". The third extracted component accounts for 10% of the total variance extracted and has four variables also loading on it. These variables include the need for training or retraining (IMP10), insufficient skilled personnel (IMP9), fear of robot failure causing harm to workers (IMP11) and resistance by workers and unions (IMP8). The component was named "human-related factors". The last extracted component accounts for 7.1% of the total variance and has a high investment cost (IMP1), lack of government incentives to use R&A for H&S (IMP3) and high cost of maintenance (IMP2) loading on it. This component was subsequently named "cost-related factors".

Reflective measurement model assessment. The first step in the reflective measurement model assessment is to examine the factor loading of the different variables grouped from EFA. Past studies have favoured the use of 0.70 as the cut-off for an acceptable factor as this means that such a variable will explain more than 50% of the variance in the indicator (Hair *et al.*, 2019; Wong, 2013). Table 4 shows that all the assessed impeding factors met this 0.70 cut-off. More so, the four outcome variables, namely, better construction workers H&S (OUT1), improving workers' productivity (OUT2), better competitive advantage derived through effective H&S (OUT3) and overall project success (OUT4) against which these grouped impeding factors were measured, also had a factor loading of above the cut-off.

Construct	Variables	Loading	α	ρA	ρ_c	AVE	VIF
Industry	IMP4	0.836	0.865	0.876	0.908	0.711	1.969
	IMP5	0.832					1.967
	IMP6	0.876					2.507
	IMP7	0.827					2.301
Technology	IMP12	0.834	0.899	0.907	0.930	0.768	2.193
	IMP13	0.913					3.707
	IMP14	0.899					4.219
	IMP15	0.857					3.172
Human	IMP8	0.809	0.841	0.860	0.892	0.674	1.753
	IMP9	0.864					2.187
	IMP10	0.863					2.937
	IMP11	0.743					2.215
Cost	IMP1	0.865	0.768	0.833	0.859	0.671	1.422
	IMP2	0.813					1.666
	IMP3	0.776					1.738
Outcome	OUT1	0.910	0.920	0.924	0.944	0.809	3.830
	OUT2	0.935					4.858
	OUT3	0.939					4.991
	OUT4	0.808					1.916

Table 4.
Summary of the reflective measurement model assessment

The internal consistency of the groups of impeding factors was also tested using Cronbach's alpha (α), Rho coefficient (ρA) and composite reliability (ρ_c) with a cut-off of 0.7 as suggested in past studies (Hair *et al.*, 2019; Henseler *et al.*, 2016; Wong, 2013; Wu *et al.*, 2019). Table 4 revealed that cost-related factors gave the lowest α value of 0.768, ρ_c value of 0.859 and ρA value of 0.833. These derived values are above the cut-off of 0.70 set for all three tests, implying that assessed impeding factors are reliable in measuring their respective groups. Furthermore, the convergent validity of these variables was measured using average variance extracted (AVE). AVE is designed to ensure that measurement variables are free from systematic error of measurement and the ideal cut-off for this test is 0.5 (Fornell and Larcker, 1981; Hair *et al.*, 2019). The result also showed that the variables met this criterion with an AVE of between 0.671 and 0.809.

It is also important to assess the collinearity in the model before determining the structural relationship that exists (Hair *et al.*, 2019). In testing collinearity in PLS-SEM, Henseler *et al.* (2016) suggested checking the variance inflation factor (VIF) values of all predictor constructs. The derived VIF value should be higher than 0.2 and lower than 5.0 for the collinearity issue not to exist (Hair *et al.*, 2019). The VIF column in Table 4 reveals that all the variables were within the acceptable range of below 5.0. This implies that there is no multicollinearity issue with these variables, as such, the structural model assessment can be conducted.

The discriminant validity, which is the extent of empirical distinction of a construct from others in the model, was tested using heterotrait–monotrait (HTMT) with a cut-off of ≤0.85 (Hair *et al.*, 2019; Henseler *et al.*, 2016). It has been suggested that an HTMT value lower than 1 (preferably <0.85) must be achieved for clear discrimination between two factors (Franke and Sarstedt, 2019). However, the result in Table 5 shows that all the grouped impeding factors and the outcome had values below 0.85, implying that each group is unique and the variables measuring them are different.

Model approximate and absolute fit. The approximate fit for the developed model was assessed using standardised root mean square residual (SRMR) as suggested in Henseler *et al.* (2016). While Byrne (2005) suggested that an SRMR of less than 0.05 is considered an acceptable fit, other studies have proven that the SRMR of a complete, correctly specified model can be above this threshold (Henseler *et al.*, 2014). Therefore, an SRMR of 0.08 has, over time, been assumed to be adequate (Bagozzi and Yi, 2012; Henseler *et al.*, 2014). Values of 0.1 for SRMR have also been noted to be acceptable for an approximate fit (Aigbavboa, 2013). For this study, an SRMR of 0.082 was derived and was deemed acceptable. The Bentler–Bonett normed fit index (NFI) was also adopted to determine the model's approximate fit (Henseler *et al.*, 2016). Singh (2009) noted that the value of an acceptable NFI should range from 0.6 to 0.9. The NFI derived for this study was 0.742, and was within the given threshold.

To determine the absolute fit of the model, the out-of-sample prediction procedure was first conducted using PLSpredict (Ringle *et al.*, 2015). This test gives cross-validation, also

Construct	Cost	Human	Industry	Outcome
Cost				
Human	0.503			
Industry	0.575	0.588		
Outcome	0.460	0.478	0.526	
Technology	0.504	0.723	0.423	0.361

Table 5.
Discriminant validity

known as the k-fold, for the outcome variables. The k-value was set at ten and run multiple times, as suggested by Shmueli *et al.* (2019). The analysis gives the root mean squared error (RMSE) for both the PLS and linear regression model (LM). While there is no agreed cut-off for interpreting this analysis in past studies (Hair *et al.*, 2019), Shmueli *et al.* (2019) suggested that the $Q^2_{predict}$ derived for the PLS should be positive as a negative value will imply that the model lacks predictive power. Furthermore, the RMSE derived for the PLS should be compared against the LM using four scenarios, namely, if all the derived PLS values are greater than the LM values, then the model lacks predictive power; if most of the derived PLS values are greater than the LM values, then the model has low predictive power; if few or the same number of the derived PLS values greater than the LM values, then the model has a medium predictive power; and if none of the derived PLS values is greater than the LM values, then the model has high predictive power. Based on the result in Table 6, it is evident that the model has a high predictive power as the derived $Q^2_{predict}$ are positive, and none of the derived PLS RMSE values was greater than the LM values.

Further evaluation of the predictive relevance of the model using the PLS blindfolding process revealed a Q^2 of 0.226. As a rule of thumb, Q^2 values should be greater than 0 for an endogenous construct to depict predictive accuracy (Hair *et al.*, 2019). Using Chin's (1998) submission that Q^2 of 0.02, 0.15 and 0.35 are weak, medium and high, the model is considered to have medium predictive relevance. The predictive power measured using R^2 revealed an acceptable fit of 0.298, following Cohen (1992) submission that R^2 of 0.26, 0.13 and 0.02 are considered acceptable, moderate and weak. Hair *et al.* (2019) have earlier suggested that the acceptable value of R^2 is based on the context of the discipline wherein the model is being applied, and R^2 values of as low as 0.1 have been considered satisfactory in some research fields. Finally, the global criterion of goodness-of-fit (GoF) index, which is the geometric mean of the average communality and the average of R^2, was calculated using equation (1) (Tenenhaus *et al.*, 2005). A GoF below 0.1 is small, 0.25 is moderate and above 0.36 is good (Akter *et al.*, 2011). GoF for this study was calculated as 0.465, which is above the 0.36 cut-off for a good GoF:

$$\text{GoF} = \sqrt{\overline{\text{AVE}} \times \overline{R}^2} \tag{1}$$

$\overline{\text{AVE}} = 0.727$
$R^2 = 0.298$
$\text{GoF} = \sqrt{0.727 \times 0.298} = 0.465$

Considering the diverse acceptable model fits achieved, the level of impact of the grouped factors on the outcomes was assessed. It has been noted that in cases where the researcher intends to generalise from a sample to a population (like in the case of this current study), the path coefficient (β) must be examined (Henseler *et al.*, 2016). Tabachnick and Fidell (2013) have earlier noted that the β is a measure of multiple

| | PLS | | LM | PLS-LM | |
	RMSE	Q^2 predict	RMSE	RMSE	Remark
OUT1	0.890	0.182	0.940	−0.050	*High*
OUT2	0.829	0.229	0.850	−0.021	*High*
OUT3	0.846	0.184	0.901	−0.056	*High*
OUT4	0.877	0.173	0.937	−0.061	*High*

Table 6.
Out-of-sample
prediction

correlation coefficients between the outer model (grouped factors) and the inner model (outcome), and according to Abbasi (2011), the value of β is examined in terms of its sign, its magnitude and its significance. This test was conducted through bootstrapping with 4,999 bootstrap samples. The significance of the β is based on the t-values derived, which should be at least 1.96 for a 95% confidence interval (p-value $<$ 0.05) (Keil, 2000; Wu et al., 2019).

Figure 2 shows that if better workers' H&S, improved workers' productivity, better competitive advantage through safe working approaches and overall project success are to be achieved in the South African construction industry, then careful attention must be given to industry, human and cost-related factors. These three groups were significant, with p-value $<$ 0.05 and t-values of 3.058, 1.992 and 2.137. Furthermore, the figure shows that industry-related factors will have the highest impact as it accounts for about 27.6% ($\beta = 0.276$) of the outcomes measured. Human and cost factors account for 18.1% and 17.4%, respectively. Technology-related factors have no significant relationship with the expected outs as a p-value of 0.550 and t-values of 0.598 was derived. Aside from not being significant, this group also have the least impact of about 4.8% ($\beta = 0.048$).
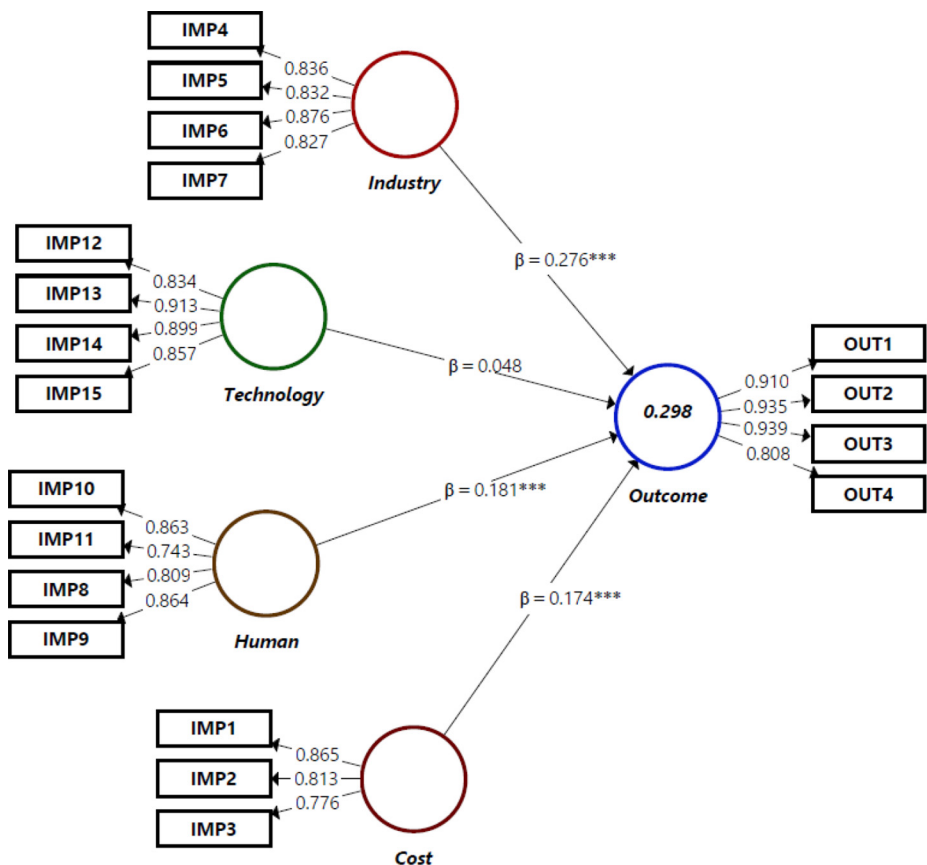

Figure 2.
Partial least square structural equation model

Discussion

The findings revealed that deployment of R&A for safer construction worksites in South Africa is impeded by four major groups of industry, technology, human and cost-related factors. These grouped factors are consistent with existing literature that have grouped the barriers to the use of R&A and related technologies in both developed and developing countries worldwide (Delgado *et al.*, 2019; Huang *et al.*, 2021; Oke *et al.*, 2021; Trujillo and Holt, 2020). However, while Oke *et al.* (2021) submitted that cost and technology-related issues are the major barriers to the use of robotics in the construction industry in Nigeria, this current study found that the barriers exceed these two groups to include industry and human-related factors. More so, it was discovered that only the industry, human and cost factors would significantly affect the attainment of better H&S, improved productivity, competitive advantage and overall project success delivered through improved H&S, as seen in Figure 3. Past studies have emphasised the role of industry-related factors in the adoption of R&A in the construction industry. For instance, Huang *et al.* (2021) noted that factors related to the industry, like its fragmented nature and its conservative nature, play a crucial role in deterring the use of R&A in the Chinese construction industry. Delgado *et al.* (2019) have also noted that the work culture of the construction industry in European countries significantly influences the industry's adoption of technologies. In most cases, a weak innovative culture is evident. In addition, poor knowledge and understanding are also key industry-related issues for construction organisations in the USA (Trujillo and Holt, 2020). The South African construction industry is not an exception to these industry-related issues. While the country has the capability to be technologically advance (Dall'Omo, 2017), its construction industry still struggles with the use of beneficial technologies such as R&A (Aghimien *et al.*, 2019; Akinradewo *et al.*, 2018).

Aside from industry-related issues, human factors in terms of training and retraining, insufficient skilled personnel, fear of robot failure causing harm to workers and resistance by workers and unions are also significant to deploying R&A for safe construction. Evidently, the proper implementation of R&A requires human input to drive and monitor these technologies. However, the need to train and retrain workers on using these technologies might discourage organisations from adopting them (Delgado *et al.*, 2019;
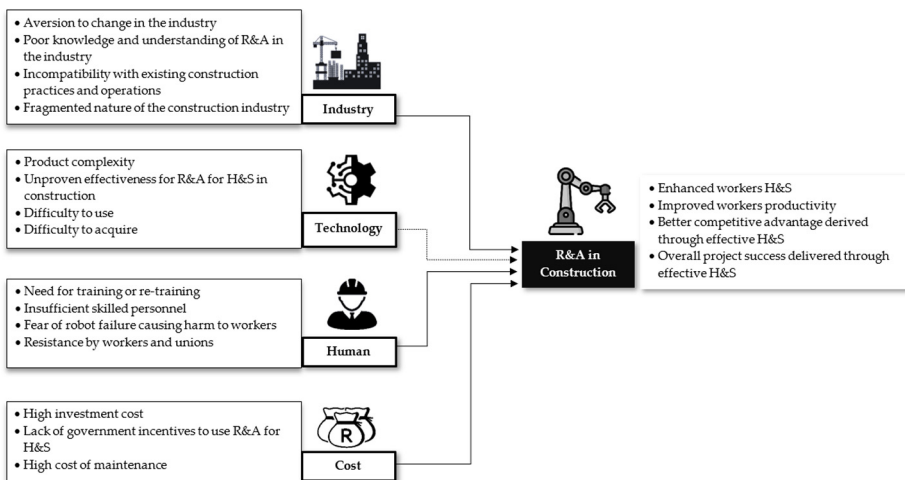
Figure 3.
Summary of the impeding factors to R&A deployment for safe construction

Kamaruddin *et al.*, 2013). In the case of South Africa, the construction industry is littered with SMEs who find it difficult to fund construction works without upfront payment from clients (Construction Industry Development Board, 2020). Using their limited resources to train workers on the use of emerging technologies might discourage the adoption of such technology. Furthermore, the South African construction industry has been characterised by skills shortage (Windapo and Cattell, 2013), which significantly affects technology usage in the country (Oke *et al.*, 2018). The fear of the available workforce losing their jobs to robots has led to the resistance to technological advancement that has been noticed in the country (Aghimien *et al.*, 2021; Mzekandaba and Pazvakav, 2018). Aghimien *et al.* (2021) have earlier warned that the introduction of technologies that can be seen as a threat to workers' job security must be carefully planned and introduced strategically and systemically to avoid resistance.

Studies have continued to emphasise the impact of cost on the adoption of R&A systems in Slovakia (Struková and Líška, 2013), China (Huang *et al.*, 2021), Malaysia (Mahbub, 2012; Yahya *et al.*, 2019), Nigeria (Oke *et al.*, 2021) and parts of Europe (Delgado *et al.*, 2019). The cost of investing in R&A is high (Rahman and Omar, 2006), which SMEs in the construction industry might find difficult to afford. The government and financial institutes can assist in giving soft loans that will help construction organisations in South Africa acquire these R&A systems without the burden of cost weighing heavily on them. The government can also support adjusting the cost of importation to assist organisations in acquiring these technologies because they are scarce locally. Samari *et al.* (2012) hinted that the government need to come to the aid of construction organisations through incentives that will promote the use of R&A on public projects and attain proper H&S in the process.

Implication of findings

The findings of this study imply that certain industry, human and cost-related factors play a significant role in the improvement of H&S within the construction industry. The findings have also revealed that these three groups of factors will also significantly improve productivity, competitive advantage and overall project success if given adequate consideration. However, past studies have shown that the South African construction industry, like its counterpart worldwide, has been slow in adopting technologies. This slow adoption has been attributed to a lack of knowledge among industry practitioners and the industry's unwillingness to change old practices (Aghimien *et al.*, 2021). Therefore, the current structure and culture of the industry in the country is not supporting the use of beneficial technologies such as R&A. If any improvement is to be visible, particularly concerning how the industry delivers its project to specific H&S requirements through the use of R&A, there must be a drastic change in the embrace and use of technologies in the industry as a whole.

Also, the findings from this study imply that the holistic use of R&A for effective H&S in the South African construction industry cannot be actualised if the people expected to use these technologies are not sensitised to understand the benefits inherent in the use of these technologies. More so, the use of these technologies will not be effective if there are no well-trained individuals to manage them. Thus, construction organisations in the country need to create avenues for their staff to be trained and retrained on the use of R&A and expected safety guidelines needed for effective project delivery. Through this training, the fear of workers regarding "robots taking over their jobs" can be alienated and the resistance to using these technologies can be eliminated. H&S regulators can also play a crucial part in ensuring that favourable regulations that require organisations to use machines for dangerous works rather than humans are put in place and are followed correctly. More so,

these H&S regulators hold the duty to ensure that organisations do not just replace workers with machines but can re-skill and optimise the potential of their workforce to carry out safe jobs on site.

Conclusion

Based on construction professionals' perspective, the study concludes that the actualisation of enhanced H&S, workers' productivity, better competitive advantage derived through effective H&S and overall project success derived using R&A cannot be achieved if issues relating to the industry, human and cost are not addressed. These three groups had the highest significant impact on the aforementioned H&S-related outcomes. Evidently, with the current wave of technological advancement, it is no longer about whether technology should be adopted but how it should be adopted to improve the construction industry's service delivery. To this end, this study shows that if construction organisations are to improve their project delivery and ensure the safety of their workers through the successful deployment of R&A, factors relating to the nature of the industry, the workforce and cost must be given thorough considerations. Practically, the findings can help shape construction organisations' technology adoption policies, particularly as it relates to R&A. More so, the study shows the impact of the government on the deployment of R&A. The government can champion this course through the provision of incentive policies for construction organisations to be able to adopt these systems in the quest for a safe working environment. Professional bodies also must sensitise their members regarding the importance of adopting R&A systems rather than resisting their adoption. The study also offers a theoretical platform for future studies seeking to explore this area of research, particularly in countries where such a study has not been conducted.

While this study contributes to the existing body of knowledge, care must be taken in generalising its findings as certain constraints limited the study. For instance, this study was conducted in one province. Although Gauteng houses the majority of the construction organisations and projects in the country, noteworthy contributions might also be derived from exploring other provinces in the country, and their findings can be used to compare those of this current study. Also, further studies are recommended in countries where such research is absent. Other target populations, such as construction organisation owners and policymakers, different from those adopted in this current study, can be used to get a wider view of the topic. In terms of the methodology used, future studies can adopt other approaches like the mixed method to gain further insights into the study. Also, this study explored the impediments of R&A deployment for effective H&S-related outcomes using PLS-SEM. Future studies can explore the use of other multivariate data analyses such as CB-SEM and multiple regression to test this relationship.

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