Rangarirai Muvungani

Mr Rangarirai Muvungani, Namibia University of Science and Technology, Windhoek, Namibia. ROR: https://ror.org/03gg1ey66, Email: rmuvungani@nust.na, ORCID: https://orcid.org/0000-0002-9424-8423

Iceman Mahohoma

Mr Iceman Mahohoma, National University of Science and Technology, Bulawayo, Zimbabwe. ROR: https://ror.org/02kesvt12, Email: icemahohoma@gmail.com, ORCID: https://orcid.org/0009-0001-9737-5049

Tinoapei Dhliwayo

Dr Tinoapei Dhliwayo, Namibia University of Science and Technology, Windhoek, Namibia. ROR: https://ror.org/03gg1ey66, Email: tdhliwayo@nust.na, ORCID: https://orcid.org/0000-0001-5925-8397

Ringisai Abigail Dhliwayo

Dr Ringisai Abigail Dhliwayo, Namibia University of Science and Technology, Windhoek, Namibia. ROR: https://ror.org/03gg1ey66, Email: rdhliwayo@nust.na, ORCID: https://orcid.org/0000-0003-0922-0221

ISSN: 1023-0564 • e-ISSN: 2415-0487

Received: September 2025
Peer reviewed and revised: November 2025
Published: December 2025

KEYWORDS: accidents and fatalities, construction industry, Geographical Information Systems, GIS, safety management, Zimbabwe

HOW TO CITE: Muvungani, R., Mahohoma, I., Dhliwayo, T. & Dhliwayo, R.A. 2025. Key barriers to GIS adoption for safety management in the Zimbabwean construction industry. *Acta Structilia*, 32(2), pp. 97-135.

Published by the UFS
http://journals.ufs.ac.za/index.php/as

KEY BARRIERS TO GIS ADOPTION FOR SAFETY MANAGEMENT IN THE ZIMBABWEAN CONSTRUCTION INDUSTRY

RESEARCH ARTICLE[1]

https://doi.org/10.38140/as.v32i2.9884

ABSTRACT

Following years of hyperinflation, Zimbabwe's construction industry has grown rapidly since 2017, often without adequate safety measures, resulting in increased injuries and fatalities. Geographic Information Systems (GIS) have globally transformed safety management in construction, yet their adoption in Zimbabwe remains limited. While existing literature highlights general barriers to advanced technology uptake in developing countries, specific impediments to GIS adoption in Zimbabwe are underexplored. This study investigates the key barriers to GIS implementation for safety management in Zimbabwe's construction sector. A mixed-methods approach was employed, combining quantitative data from 86 professionals, including project managers, engineers, architects, and safety officers, via a web-based survey, with qualitative insights from 12 in-depth interviews. Quantitative data were analysed using descriptive and inferential statistics, particularly principal factor analysis, while qualitative data were examined thematically. Four major barrier components emerged, namely industry fragmentation and resource constraints; standardisation, legal, and user preference issues; management-related challenges, and technological complexity and security concerns. The study recommends

1 DECLARATION: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

government intervention through supportive legal frameworks, infrastructure development, and financial incentives to promote GIS adoption. In addition, awareness campaigns via workshops and conferences are essential to support professional engagement. Given the moderate sample size, findings are indicative rather than generalisable but offer valuable insights for enhancing construction safety through GIS in Zimbabwe.

ABSTRAK

Na jare van hiperinflasie het Zimbabwe se konstruksiebedryf sedert 2017 vinnig gegroei, dikwels sonder voldoende veiligheidsmaatreëls, wat gelei het tot meer beserings en sterftes. Geografiese Inligtingstelsels (GIS) het wêreldwyd die bestuur van veiligheid in konstruksie verander, maar die aanvaarding daarvan in Zimbabwe bly beperk. Terwyl bestaande literatuur algemene hindernisse vir gevorderde tegnologie-aanvaarding in ontwikkelende lande beklemtoon, is die spesifieke belemmerings vir GIS-aanvaarding in Zimbabwe onvoldoende ondersoek. Hierdie studie ondersoek die belangrikste hindernisse vir GIS-implementering vir veiligheidsbestuur in Zimbabwe se konstruksiesektor. ‘n Gemengde metodologie is gebruik, wat kwantitatiewe data van 86 professionele persone, insluitend projekbestuurders, ingenieurs, argitekte en veiligheidsamptenare, deur ’n aanlyn-opname, gekombineer met kwalitatiewe insigte uit 12 diepte-onderhoude. Kwantitatiewe data is ontleed met behulp van beskrywende en inferensiële statistiek, veral hoofkomponentontleding, terwyl kwalitatiewe data tematies ontleed is. Vier groot komponenthindernisse het na vore gekom, naamlik bedryffragmentasie en hulpbronbeperkings; standardisering, wettige en gebruikervoorkeurkwessies, bestuursverwante uitdagings, en tegnologiese kompleksiteit en sekuriteitskwessies. Die studie beveel regeringsintervensie aan deur ondersteunende wetlike raamwerke, infrastruktuurontwikkeling en finansiële aansporings om GIS-aanvaarding te bevorder. Daarbenewens is bewustheidveldtogte deur werksessies en konferensies noodsaaklik om professionele betrokkenheid te ondersteun. Gegewe die gematigde steekproefgrootte, is die bevindings aanduidend eerder as veralgemeenend, maar bied waardevolle insigte vir die verbetering van konstruksieveiligheid deur GIS in Zimbabwe.

1. INTRODUCTION

In many developing countries, construction sites continue to exhibit weak safety standards, largely due to the slow adoption of advanced tools such as Geographic Information Systems (GIS) for effective safety management. Despite the proliferation of GIS in safety management worldwide, extant literature shows that the lagging in GIS adoption in the construction industry within most of the developing countries (Yap, Skitmore & Talebian, 2022; Aranda, De Waegemaeker & Van de Weghe, 2023; Rashid & Haron, 2024) has contributed to higher accidents and fatalities on construction sites compared to other industries (Kang, Wu, Liao & Wang, 2020), making the hazardous construction working environments worrisome.

The slow adoption of GIS in most of the developing countries is attributed to a myriad of factors, including high procurement and installation costs (Dhedheya, Dube & Sanders, 2023; Karakhan & Alsaffar, 2019), complexity and interoperability issues (Rashid & Haron, 2024; Aranda *et al.*, 2023), regulatory challenges (Mohiuddin *et al.*, 2023; Yap *et al.*, 2022), digital ineptness (Karimazondo, 2020), and management-related challenges (Letshaba & Ndlovu, 2024).

The plethora of challenges has led to the emergence of several theories that attempt to conceptualise the phenomenon. Often, more than one theoretical lens is needed for a holistic understanding of the challenges involved in technological adoption (Taherdoost, 2018). Theories such as the Diffusion of Innovation (DOI), Technology-Organisation-Environment (TOE) framework, and Technology Acceptance Model (TAM) explain how technology such as GIS is adopted and spread in each social context (Yuen *et al.*, 2021; Dhedheya *et al.*, 2023).

In Zimbabwe, the circumstances surrounding the slow adoption of GIS remain underexplored, with a few studies (Karimazondo, 2020) pointing to the lack of digital skills to integrate GIS in safety management. Muzurura (2019) note that most of the construction workers and practitioners in Zimbabwe lack GIS knowledge, resulting in its low adoption within this context. This is further exacerbated by institutional barriers such as the lack of government policies promoting GIS integration, insufficient funding, and absence of digital transformation strategies in construction safety (Dhedheya *et al.*, 2023). In support, Mateko (2024) mentions eleven leading causes of Zimbabwe's low digital technological advancement as including macroeconomic factors, poor infrastructure, irregular power supply across the country, political upheaval which limits foreign direct investment, high internet costs, information asymmetry, and complex tax regime structures. Despite the availability of generic national ICT and construction policies, there are no dedicated frameworks promoting GIS integration in safety management in Zimbabwe's construction sector. This policy vacuity and infrastructural gap contribute to the continued underutilisation of GIS for improving site safety.

Using GIS provides important benefits such as helping to predict and manage accidents and reducing hazards, especially during geotechnical surveys near existing structures (Kanchana & Faney, 2016). Considering the shortcomings of traditional approaches commonly used to manage safety on construction sites, the failure to embrace GIS in the construction industry deprives firms and practitioners from managing project safety effectively (Muzurura, 2019). For instance, although most of the developing countries put in place legal frameworks for occupational health and safety (OHS) management, accidents and fatalities recur, thereby raising questions as to the efficacy of existing safety management practices. In the absence of advanced tools such as GIS, predicting new risks in the construction industry is extremely challenging (Mupedza, 2022).

The construction industry, particularly in developing countries such as Zimbabwe, shows high levels of non-compliance with safety management standards (Chigara & Moyo, 2023), compromising site safety. Integrating GIS into safety management can help proactively prevent accidents and fatalities in Zimbabwe through rapid identification of hazardous environments and early prediction of accidents, as experienced in some developed countries such as the United Kingdom (Manase *et al.*, 2011), culminating in safer working environments, improved productivity, and increased profitability.

GIS has proven to be an effective technology for safety management across various industries. For instance, Kumar and Bansal (2016) investigated the use of GIS for selecting safe sites in hilly regions and reported that safe site selection is key to ensuring the safety of both construction workers and future tenants, confirming that GIS can effectively assist engineers and architects during design. This is further supported by Kanchana and Faney (2016), who found that GIS can help workers create file diagrams to identify construction sites prone to accidents. Similarly, Sarasanty (2020) notes that GIS can function as an alert system for hazard identification when combined with sensing technologies on a construction site. In addition, Akindele *et al.* (2023) observe that GIS can be used for sustainable construction safety monitoring to prevent accidents, by ensuring compliance with safety protocols.

GIS technologies have existed since the early 1960s. However, evidence suggests that their adoption remains relatively low across many sectors (Ye, Brown & Harding, 2013). While the diffusion of innovation theory may partly explain this trend, it is also clear that the implementation of GIS technologies is associated with numerous challenges. Several studies have examined the barriers to GIS adoption (Akindele *et al.*, 2023; Aranda, *et al.*, 2023; Antah *et al.*, 2022), highlighting that these barriers evolve as GIS technologies develop. Supporting this view, Aranda *et al.* (2023) note a fundamental shift in the state of Geographic Information (GI) Science in 2005, marked by the release of API products such as OpenStreetMap, Google Earth, and Google Maps. These free and open-source platforms supported a surge in participatory mapping, which, in turn, introduced a new set of challenges for GIS implementation at that time.

Although numerous studies have explored GIS applications in construction, its use in enhancing safety operations on construction sites remains underexplored. Notably, most positive advancements in the GIS domain have occurred in developed countries (Dhedheya *et al.*, 2023), leaving developing countries such as Zimbabwe, characterised by infrastructure limitations, economic instability, and varying levels of technology adoption, with significant research limitations. Mateko (2024) observe that Zimbabwe faces substantial economic and social burdens, due to workplace injuries. Shabani *et al.* (2023) posit that these accidents or injuries are not only limited to the construction industry but are a common phenomenon across industries in Zimbabwe.

According to Matare and Gondo (2018), Zimbabwe recorded 116 accidents and 1,400 injuries in 2003. However, in 2013, the number of injuries increased to 5,666 (Matare & Gondo, 2018), leading to the increasing call to proffer appropriate measures to eliminate or mitigate these accidents and injuries within the construction industry. It is noteworthy to highlight that statistics across various industries in Zimbabwe show that 20,641 serious injuries and 400 deaths were experienced between 2009 and 2013 (Mkungunugwa *et al.*, 2022), with the construction industry taking the lead. In its annual report, NSSA (2018) claimed that the construction sector's incident rate exceeds the national all-sector average. For example, the recent Mbudzi Interchange crane collapse, which resulted in the death of a construction worker (Mosia, 2025), demonstrates the poor safety performance in the country's construction industry, highlighting the urgent need for research.

In this context, studies investigating the impediments to GIS adoption for enhancing safety in construction operations are both critical and limited. While some impediments might be universal, others are context specific. To date, there is scant evidence of such research having been conducted in Zimbabwe, leaving policymakers and industry practitioners with limited locally relevant insights to address these challenges. This study, therefore, aims to identify the key barriers impeding the use of GIS technology in managing safety operations within Zimbabwe's construction industry.

2. LITERATURE REVIEW

Despite the importance of GIS in enhancing safety operations in the construction industry, its adoption is impeded by various factors. As explained by Yap *et al.* (2022), the most common impediments of GIS adoption include high cost, fragmented nature of the industry, complexity of projects, and high-risk levels of construction projects. This is supported by Kache and Seuring (2017) who point out that GIS necessitates substantial resources, which include funding and the hiring of skilled professionals to operate the system effectively. In Zimbabwe, implementing GIS in safety management remains challenging, due to the lack of infrastructure and digital capacity (Muzurura, 2019; Mateko, 2024). During the period 2015 to 2025, Zimbabwe experienced frequent power outages and poor internet connectivity challenges, making it costly to implement GIS technology, as well as posing interoperability challenges.

2.1 Theoretical frameworks

The study was underpinned by the theoretical lenses of Diffusion of Innovation (DOI) (Rogers, 1983), Technology-Organisation-Environment (TOE) framework (DePietro, 1990) and Technology Acceptance Model

(TAM) (Davis, 1989). DOI explains how new innovations such as GIS are adopted in each context at a particular time, by categorising adopters into five distinct groups, namely innovators, early adopters, early majority, late majority, and laggards (Taherdoost, 2018). On the other hand, TOE framework suggests that the adoption of technology such as GIS is influenced by three distinct contexts, namely technological, organisational, and environmental contexts (Dhedheya *et al.*, 2023). According to DePietro (1990), technological context entails both the existing and the new technologies relevant to the organisation, while organisational context encompasses the formal and informal linking structures, communication processes, the size of the organisation, and the number of slack resources available in the organisation. In addition, the environmental context involves industry characteristics and market structure, technology support infrastructure, and government regulations. While TOE emphasises the context of the innovation, TAM explains the process of new technology adoption, emphasising the user's subjective attitude and use behaviour of new technology such as GIS (Yuen *et al*., 2021). According to Davis (1989), the two exogenous variables of TAM, namely perceived usefulness (PU) and perceived ease of use (PEOU), pose a significant influence on the user's behavioural intention (BI) to adopt a novel technology such as GIS. Through the highlighted theoretical lenses, the study examined several factors limiting the adoption of emerging and transformative technologies such as GIS in safety management within the Zimbabwean context.

2.2 High cost

One of the major impediments to GIS adoption is the excessive costs incurred during procurement, installation, hiring of the relevant workforce, training of the existing and new workforce, and maintenance of the GIS system (Ye *et al*., 2013). In a recent study, Dhedheya *et al.* (2023) acknowledge that the high costs associated with the procurement, installation, and maintenance of GIS, which most of the construction companies in Zimbabwe cannot afford, is one of the constraints hindering GIS adoption. The authors note that the training of employees on novel technologies such as GIS is not only expensive but time consuming, coupled with employee retention problems. Furthermore, the volatility of the macroeconomic environment in Zimbabwe makes it difficult for the stakeholders in the construction sector to embrace GIS, even though there is a high interest to improve site safety. This is consistent with Aghimien, Ngcobo and Aigbavboa (2022), who found that the adoption of digital technology in South Africa is impeded by the high cost of training employees to become proficient in GIS, since it is a complex technology. Due to the costs involved, a plethora of studies highlight that most companies are reluctant to adopt such innovative technologies since they are sceptical about the potential benefits to be accrued from such investments (Alzighaibi, Mohammadian & Talukder, 2016). To improve safety management, Karakhan *et al.* (2021) posit that it is imperative for any company aiming to implement safety technology to make substantial investments in both personnel and the appropriate technology across all levels within the organisation.

2.3 Complexity and interoperability issues

A plethora of studies (Aranda *et al.*, 2023; Rashid & Haron, 2024) underscore that most of the construction professionals find it daunting to use GIS, due to its complexity. GIS demands high level of knowledge and technical skills to gather 3D spatial data, visualise it, and analyse the data. Rashid and Haron (2024) note that GIS is a complicated technology to non-expert users. They further argue that efforts by some companies to train their workers still yielded marginal improvement in OHS performance. In an earlier study, Iyengar (1998) discovered that GIS technology faces interoperability issues, when attempting to use it in conjunction with other technologies. In this case, Iyengar (1998) argues that the user needs to have a fundamental understanding of the difference between GIS and other technologies for successful integration. However, studies such as Kumar and Bansal (2016), which aimed to develop models that combined GIS with other systems for safety management on construction sites such as Building Information Modelling (BIM), IoT, 3D rendering among other industry 4.0 technologies, concluded that GIS has, in some instances, interoperability issues. Consequently, the vast majority of companies have limited capabilities for automatic GIS data analysis, which limits their ability to use GIS. Hence, this is a significant barrier especially for organisations whose capacity is limited (Aranda *et al.*, 2023). In addition, the adoption of new technologies requires time-consuming efforts to ensure a smooth integration and compatibility with the company's new and existing equipment, machinery, other technologies, network systems, and data from IoT (Bakar *et al.*, 2014). This complicates the integration of GIS into the existing company's methods of operating business. Although there is a dearth of literature explaining the severity of complexity and interoperability issues in Zimbabwe, this factor cannot be ignored within the context, considering the challenges raised by Dhedheya *et al.* (2023) such as the lack of GIS infrastructure, lack of digital proficiency among personnel in the construction sector, regulatory hurdles, and poor internet connectivity, particularly in remote areas. In the absence of GIS infrastructure, GIS knowledge, relevant regulatory frameworks to guide GIS implementation and unreliable internet connectivity, integrating GIS technology into other existing technologies used to manage site safety in Zimbabwe would be daunting, resulting in interoperability challenges.

2.4 Cyber-security risks

Research shows that the use of GIS comes with various security-related challenges that can discourage its adoption (Ye *et al.*, 2013; Rashid & Haron, 2024). Rashid and Haron (2024) express the sensitivity of sharing GIS data across servers, arguing that it is prone to severe cyber-attacks which can affect the owner. This is further supported by Ye *et al.* (2013) who claim that GIS poses some serious security concerns, as it involves tagging workers to track their location and movements, which is an infringement on their privacy. These sentiments radiate with Göçmen and Ventura (2010) who report that GIS adoption comes with cyber-security risks which make company data susceptible to hacking and malware attacks. This is due to the absence of a system within the construction industry that can detect cyber-security threats, thus rendering this a very critical challenge (Mantha & De Soto, 2019). In that sense, construction companies need to devise strategies to handle cyber-security risks involved with GIS usage. According to Chingoriwo (2022), Zimbabwe is not spared from cyberspace threat, due to weak cybersecurity legislation, poor security of ICT assets, poor internet connectivity, and infrastructure. With the everchanging cyberspace landscape, Zimbabwe is likely to be confronted with cyber-security risks which impede its efforts to adopt GIS in safety management.

2.5 Management-related challenges

Management-related challenges can subsequently hinder the adoption of GIS for safety operations in the construction industry (Manase *et al.*, 2011). As highlighted by Faiz, Le and Masli (2024), adopting technology is a pivotal decision that requires collaborative action and, if top management does not cooperate effectively, then it becomes potentially difficult to come up with an effective digital strategy to implement new and existing technologies. The vast majority of companies do not have existing systems within their organisations that are capable of processing and handling real-time spatial data (Aranda *et al.*, 2023), a shortfall which stifles the use of GIS, since the technology requires efficient and advanced knowledge management processes that are able to integrate with IoT and other web systems. By implication, management represents the pinnacle of technology adoption, as all decisions and resources originate from them; hence, an organisation might need to deal with various in-house issues first to promote the GIS adoption process. Like other developing countries, Zimbabwe grapples with management-related challenges in the quest to adopt new technologies such as GIS. This challenge is partly attributed to the fact that most of the construction companies are owned by people who are technologically inept (Karimazondo, 2020) and reluctant to embrace innovation such as GIS to improve safety management, and partly linked to the inflexibility of the vast majority of organisations to shift from traditional approaches to novel technologies that are considered complex and expensive to procure, implement, and maintain. Due to this organisational culture within the Zimbabwean context, less funds are invested in technology and employees are seldom trained on emerging technologies (Dhedheya *et al.*, 2023), leading to slow adoption of such technologies in the country.

2.6 Fragmented industry

The construction industry poses numerous limitations towards the effective adoption of GIS for safety operations that need to be addressed at both macro and micro levels to create a conducive environment for technology adoption (Alaloul *et al.*, 2020; Senna *et al.*, 2022). Alaloul *et al.* (2020) assert that the construction industry has a fragmented set-up, which is, in most instances, project-based and not conducive to technology integration, since effective implementation of GIS requires robust organisational frameworks that encourage participation from all members. As argued by Senna *et al.* (2022), GIS adoption is constrained by unstandardised processes which characterise the construction industry in most of the developing countries, where the lack of production of equipment and componentry that is complementary persists, such that the process of retrofitting and integrating smart technologies in the construction industry becomes less expensive and complex. An earlier study by Iyengar (1998) reveals the importance of having identical GIS systems in easing the process of sharing and analysing data across industries and regions. Similarly, in Zimbabwe, Karimazondo (2020) points to the need for a coordinated approach in the implementation of GIS in the industry, citing the lack of clear frameworks at both central and local government levels. Currently, the construction processes in Zimbabwe follow a traditional approach, where the construction phase is separated from the design phase, creating challenges in coordinating GIS implementation among different parties working on a project. To improve the gap, a standardised platform is essential for synchrony among parties involved in a project. For instance, the integration of GIS into safety management requires synchrony among their operating systems. Considering the widely recorded barriers to GIS adoption worldwide, Table 1 summarises several impediments that were gleaned from the literature.

Table 1: Summary of impediments of GIS adoption in the construction industry

Category	*Code*	*Barrier*	*Sources*
Economic	A1	High capital requirement in GIS implementation	Alaoul *et al.* (2020); Nnaji & Karakhan (2020); Matt, Modrák & Zsifkovits (2020)
	A2	Lack of infrastructure	Raj (2019); Kiraz *et al.* (2020); Xu *et al.* (2018)
	A3	Very low profit margins in the industry	Fantini *et al.* (2020); Chan, Darko & Ameyaw (2017)
	A4	Unclear benefits and gains	Demirkesen & Tezel (2021); Woodhead *et al.* (2018); Berlak *et al.* (2020); Luthra & Mangla (2018)
Technology	B1	Need for retrofitting implementation processes	Senna *et al.* (2022); Tsai & Yau (2014); Nnaji &Karakhan (2020)
	B2	Lack of coherent integration and interoperability capabilities	Kumar & Bansal (2016); Petimani *et al.* (2019)
	B3	Incompatibility of the technology with current practices and operations of a company	Tsai & Yau (2014); Yahya, *et al.* (2019)
	B4	Complex data processing	Khudzari *et al.* (2023); Flatt *et al.* (2016); Alinshipe, Ikuabe & Aigbvaboa (2022)
Security	C1	Risk of security breaches	Mantha & deSoto (2019); Oesterreich & Teuteberg (2016); Edirisinghe (2019); Maskuriy *et al.* (2019)
	C2	Privacy of workers' personal data is not guaranteed	Lee & Lee (2015); Kamble *et al.* (2018)
Management	D1	Inadequate knowledge management systems and data handling systems	Letshaba & Ndlovu (2024)
	D2	Ineffective digital strategy	Faiz, *et al*. (2024); Oesterreich & Teuteberg (2016)
	D3	Lack of investment in research and development	Sydow (2019); Hatoum & Nassereddine (2024)
	D4	Failure through displacement of old workers	Nnaji & Karakhan (2020); Bademosi & Issa (2021)
Regulatory	E1	Hardly any or no government support	Mohiuddin *et al.* (2023); Demirkesen & Tezel (2021)
	E2	Lack of guidance from relevant institutions	Pedone & Mezgar (2018); Pradhananga *et al.* (2021); Nnaji & Karakhan (2020)
	E3	Absence of legal and contractual assurance	Osunsanmi *et al.* (2021; Dermirkesen & Tezel (2021)
	E4	Lack of stringent safety rules	Yap, Skitmore & Talebian (2022); Okpala et al, (2019) and Nnaji & Karakhan (2020)

Category	*Code*	*Barrier*	*Sources*
Sociocultural	F1	Resistance to change	Chan et al (2019), Hemström et al (2017) and Haupt (2016)
	F2	Poor construction industry safety culture	Yap *et al.* (2022; Dodge Data and Analytics (2017)
	F3	Weak innovation culture	Nnaji & Karakhan (2020); Oni (2013); Yap *et al.* (2022)
	F4	Different client-to-contractor preferences on technology integration	Yap *et al.* (2019); Shen & Marks (2016); Nnaji & Karakhan (2020)
Industry	G1	Lack of collaboration and coordination among firms	Gamil & Rahman (2019); Egwim (2024)
	G2	Fragmented industry	Elmualim & Gilder (2014); Chowdhury *et al.* (2019)
	G3	Shortage of standardisation efforts	RICS, 2020; Dermirkesen & Tezel (2021)
Knowledge	H1	Lack of awareness	Sepasgozar (2021); Babatunde & Ekundayo (2023); Sabongi (2023); Karimazondo (2020)
	H2	Lack of digital skills	Mateko (2024); Karimazondo (2020); Dhedheya *et al.* (2023)

Summarily, several studies have been carried out on the barriers to the adoption of GIS in various industries. A study by Antah *et al*. (2022) on the factors influencing the use of geospatial technology depicted that lack of knowledge, shortage of financial resources, lack of experience, lack of training, difficulties in data-sharing management, lack of institutional support, and poor communication among firms are some of the critical hindrances to the adoption of GIS. Göçmen and Ventura (2010) conducted a study on the barriers to the use of GIS in planning, in which they highlight the underutilisation of GIS as a planning tool in various industries. They also highlight that lack of training, shortage of funding, and data-management issues are among the most significant impediments to the adoption of GIS in most of the sectors of an economy. Rashid and Haron (2024) conducted a study on the use of GIS as a project management tool in the Malaysian construction industry and discussed the impeding factors to GIS adoption. This study concluded that the most significant barriers to the adoption of GIS include a lack of expertise, a shortage of funding, a lack of awareness, the complexity of GIS, and lack of data-security assurance. Ye *et al.* (2024) also conducted a study, in which they explored the barriers and opportunities for underexploited GIS applications. Their study also concurred that the issue of cost, lack of awareness, shortage of required software, inadequate data sources, lack of computer skills, and complexity are among the hindrances to the adoption of GIS in most of the economic sectors. Leeonis *et al.* (2024) conducted a study on the challenges of using GIS in management of flash floods in Malaysia and deduced that lack of equipment, limited access, and excessive costs form significant barriers to GIS adoption. Alzigaibi *et al.* (2016) also carried out a study on the factors affecting adoption of GIS in the public sector in Saudi Arabia and mentioned that training, incentives, and managerial support are critical measures for promoting the adoption of GIS. From the literature review it can be noted that studies have been done on hindrances to adoption of the GIS from a general perspective. However, not much has been aligned to the construction industry, and more specifically, on safety management. This study, therefore, aims to identify the most influential factors impeding the adoption of GIS for enhancing safety operations on construction sites in Zimbabwe. It is envisaged that the study's findings will provide industry practitioners with a clear understanding of the key barriers, enabling them to develop targeted strategies to promote GIS adoption and improve safety management on construction sites, ultimately saving lives. Furthermore, the findings can inform policy formulation, guide interventions that support the uptake of GIS, and enhance overall safety performance in the construction industry.

3. METHODOLOGY

3.1 Research design

The study adopted an explanatory sequential mixed-methods approach, where questionnaires were first used to collect quantitative data and later complemented by qualitative interviews (Creswell & Poth, 2018). The questionnaire included a single construct comprising 26 Likert-scale items derived from existing literature on the perceived barriers to GIS adoption. Descriptive statistical analysis was applied to rank responses and identify key barriers (Finch, 2022), while inferential analysis through principal component analysis (PCA) was employed to reduce the 26 measured items into a smaller set of core factors impeding GIS adoption in safety management in Zimbabwe. As noted by Rossoni, Engelbert and Bellegard (2016), PCA assists in extracting key factors, by summarising data into a manageable number of components based on the highest eigenvalues. To complement the quantitative findings, semi-structured interviews were conducted *tabula rasa* with selected professionals to explore their perceptions of contextual barriers to GIS adoption in safety management. A qualitative approach, enabling participants to express and clarify their thoughts with minimal restriction (Mohajan, 2018), was adopted to identify context-specific variables relevant to the Zimbabwean setting (Creswell, 2013; Grbich, 2013). The interview data were analysed thematically, involving the systematic development of codes and themes (Creswell & Poth, 2018). The mixed-methods design facilitated triangulation of the findings, enhancing the study's validity, given that GIS adoption in safety management remains at an emergent phase of development in Zimbabwe, despite its established application in other developed and developing contexts (Flick, 2019). This approach aligns with Dhedheya *et al.* (2023), who employed methodological triangulation – combining quantitative and qualitative designs – to formulate a framework for GIS adoption in service delivery.

3.2 Population, sampling, and response

The study focused on Harare and Bulawayo, where 90% of registered contractor organisations are based (Construction Industry Federation of Zimbabwe [CIFOZ], 2023-2024). It included CIFOZ category A (75) and B (20) contracting firms, 105 engineering firms registered with the Zimbabwe Association of Consulting Engineers (ZACE), and 51 architectural firms registered with the Institute of Architects in Zimbabwe (IAZ), giving a total population of 251 organisations. While GIS is mainly used by engineers and surveyors, Monsur and Islam (2014) note its growing use among landscape architects, and Bilous *et al*. (2021) emphasise integrating GIS with tools such as AutoCAD and Google SketchUp to optimise spatial design. Given their GIS expertise and role in ensuring safe working environments in Zimbabwe, architects were included in this study. They often act as principal agents on building projects, coordinating technical and administrative tasks, and conducting site inspections with Safety, Health, and Environment (SHE) officers, contractors, and engineers to ensure compliance with safety regulations.

CIFOZ category A and B firms were selected for their size and financial capacity to adopt GIS. Using stratified random sampling, 152 firms were chosen to participate (Kothari, 2019), which closely aligns with Krejcie and Morgan's (1970) recommendation of 155 for a population of 260. A total of 86 valid responses were received, resulting in a 57% response rate, which was considered acceptable for survey research (Babbie, 2014) and is higher than comparable studies in Zimbabwe at 29.6% (Chigara & Moyo, 2023). Although the response rate is modest, the respondents' experience, designation, and qualifications support the credibility of the findings, while generalisation beyond this population should be approached cautiously.

To complement the survey, twelve interviews were conducted with purposively sampled professionals with expertise in GIS and safety management, reaching data saturation by the tenth participant, was consistent with Creswell and Poth (2018).

Table 2: Survey response rate

Respondent category	*Population*	*Sample*	*Responses received*	*%*
Contractors (Category A) (CIFOZ 2024)	75	45	27	18
Contractors (Category B) (CIFOZ 2024)	20	12	13	9
Engineering firms civil/structural (ZACE 2024)	105	64	35	23
Architects' firms (IAZ 2024)	51	31	11	7
Total	251	152	86	57

3.3 Data collection

A questionnaire survey and interviews were employed in the study. For collecting quantitative data, the web-based questionnaire consisted of two sections, with the first section enquiring demographic information of the respondents such as gender, experience, educational levels, position in the organisation, and the representative bodies with which they are registered. The second section required the respondents to rate the significance of 26 barriers to GIS adoption in enhancing safety operations in the Zimbabwean construction industry, using a scale of 1 = Not significant, 2 = Less significant, 3 = Moderately significant, 4 = Significant, and 5 = Very significant. Likert scale was used because it provides a convenient way to measure unobservable constructs (Jebb, Ng & Tay, 2021). The 26 barriers identified in the questionnaire were adopted from a synthesis of previous studies on GIS adoption in construction and safety management (Yap *et al*., 2022; Aghimien *et al*., 2022; Akindele *et al*., 2023) and piloted to a few selected construction professionals in Zimbabwe. Cronbach's *alpha* (α) was computed to assess the internal consistency of the survey items (α = 0.95), confirming high reliability, as asserted by Nunnally and Bernstein (1994) who point out that *alpha* greater than 0.7 is acceptable. The questionnaires were distributed via emails to respondents who are involved in designing and ensuring safety management on construction sites. The initial data collection was done in 2024, and supplementary data collection was done in 2025.

Face-to-face interviews were conducted with key informants, using a semi-structured interview guide that had both close- and open-ended questions. Close-ended questions sought to probe participants' demographic information, including designation, educational qualification, and work experience, with the aim of selecting participants most likely to yield appropriate and useful information that aligns with the objective of the study. Open-ended questions assessed one construct, with the main question asking the interviewees on what they perceived as the key barriers to GIS adoption in safety management in the Zimbabwean construction industry. The responses to the main question triggered three follow-up questions that sought to understand the reasons behind the reluctance of the vast majority of contractors and practitioners to adopt GIS, despite its potential to create safe environments, the failure by construction companies and consultant firms to upskill their employees, despite the proliferation of advanced technology such as GIS in other economic sectors, and the role that government should play to promote the adoption of novel technologies in safety management for improved construction working environments in Zimbabwe. These were preferred so that more information can be obtained in great depth (Kothari, 2019).

3.4 Data analysis

The researchers used SPSS version 22 in this study to aid the data-analysis process (Field, 2009). A Cronbach *alpha* test was carried out, first, to test the reliability of the collected data. This is a measure of the internal consistency of a test or scale and is numerically treated between 0 and 1 (Tavakol & Dennick, 2011). The results were then analysed, using descriptive statistics including frequency percentages, mean score computations, and standard deviations. The results were further substantiated with a factor analysis. The mean score was used to rank the responses regarding the significance of the impediments, as opined by Omer, Rahman and Almutairi (2022). The standard deviation was calculated to assess the average variability within the data set and to measure how far on average each value deviates from the mean, with the lesser standard deviation being ranked higher (Bhandari, 2020). For analyses purposes, the range of interpreting the 5-point Likert scale mean score was: >1.00 ≤ 1.79 (not significant), >1.80 ≤ 2.59 (less significant), >2.60 ≤ 3.39 (moderate), >3.40 ≤ 4.19 (significant), and >4.20≤ 5.00 (very significant).

Factor analysis was used to categorise barriers of GIS adoption for safety management enhancement on construction sites. It is a technique used to resolve a large set of measured variables in terms of relatively few categories (Kothari & Garg, 2019). The Kaiser-Meyer-Olkin (KMO) test was used to test the suitability of factor analysis, varying from 0 to 1, with values close to 1 being considered better (Kothari & Garg, 2019). The study used Bartlett's Test of Sphericity, which is a statistical test for overall significance of the correlation within a correlation matrix, and whose significance value must be less than 0.05, signifying a suitable multivariate acceptable data for factor analysis (Field, 2014). Factor extraction, which encompasses determining the least number of factors that can be used to best represent the interrelationship among the set of variables (Shresta, 2021), was done, using principal component analysis (PCA) with varimax rotation. The choice was due to its advantage of maximising variance for each factor (Yong &

Pearce 2013), only considering those with eigenvalues greater than 1. The extracted components were named after their contributing barriers.

For the interview data analysis, data were transcribed, cleaned, coded, and analysed, using thematic analysis. Since qualitative approach augmented quantitative data, both deductive and inductive coding were employed, as previously adopted by Azungah., (2018). Deductive coding involved predetermined categories which emerged from quantitative data, while inductive coding entailed the generation of codes *tabula rasa*, that is, without predetermined codes, as highlighted by Bazeley (2013) and Grbich (2013).

4. RESULTS

4.1 Demographics of participants

The profile of respondents for quantitative data and key informants is summarised in Table 3. Table 3 shows that a diverse population was consulted, with engineers and project managers constituting the majority (58%), due to their direct involvement in GIS technology. Academically, the vast majority of the respondents were holders of master's degrees (47%), with 40% holding bachelor's degrees. Most of the respondents (73%) across the population categories had six or more years' work experience. Pertaining to qualitative data, Table 3 shows that the interviewees held various education levels and work experiences. Of the twelve purposefully selected participants, 8 (67%) possessed bachelor's degrees, while 4 (33%) held a master's degree. The participants' high educational qualifications, together with their extensive work experience, enabled them to provide relevant and in-depth information on GIS technology in the safety management of construction sites in Zimbabwe, thereby enhancing the validity of the study's data.

Table 3: Participant profile

Survey participants				*Interviewees*	
Demographic	*Category*	*F (n=86)*	*%*	*F (n=12)*	*%*
Position	Project manager	15	17	2	17
	Contracts manager	7	8		
	Site manager	11	13		
	Safety manager	7	8	3	25
	Engineer	35	41	4	33
	Architect	11	13	3	25

Survey participants				*Interviewees*	
Demographic	*Category*	*F (n=86)*	*%*	*F (n=12)*	*%*
Education	Diploma	7	8		
	Degree	34	40	8	67
	Masters	40	47	4	33
	Post Grad	5	6		
Experience (years)	0-5	23	27		
	6-10	35	40	4	33
	11-15	22	26	8	67
	16-20	4	5		
	Above 20	2	2		
Nature of construction projects involved in	Both	54	62.7		
	Building	20	23.3		
	Civil	12	14		
Company Category (CIFOZ)	Category A	27	31		
	Category B	13	15		

4.2 Descriptive analysis

As shown in Table 4, respondents rated 26 barriers to GIS adoption in construction safety management, with an overall composite score of 3.53, indicating that these barriers are moderately to highly significant. The highest-ranked barriers were high capital requirements (MS = 4.15) and hardly any or no government support (MS = 4.12), highlighting financial constraints and limited institutional backing as the most critical obstacles.

Table 4: Ranking of GIS barriers

Code	*Barrier* *Cronbach Alpha = 0.95*	*N*	*Std. deviation*	*Mean (MS)*	*Rank*
A1	High capital requirement in GIS implementation	86	1.15	4.15	1
E1	Hardly any or no government support	86	1.17	4.12	2
H1	Lack of awareness	86	1.15	4.05	3
A2	Lack of Infrastructure	86	1.27	3.92	4
F1	Poor construction industry safety culture	86	1.29	3.88	5
G2	Fragmented industry	86	1.21	3.80	6
H2	Lack of digital skills	86	1.11	3.76	7
F1	Resistance to change	86	1.29	3.69	8
B4	Complex data processing	86	1.22	3.65	9

Code	*Barrier* *Cronbach Alpha = 0.95*	*N*	*Std. deviation*	*Mean (MS)*	*Rank*
E4	Lack of stringent safety rules	86	1.19	3.62	10
F3	Weak innovation culture	86	1.19	3.52	11
G1	Lack of collaboration among firms	86	1.06	3.48	12
D1	Inadequate knowledge management systems and data handling systems	86	1.10	3.41	13
C1	Risk of security reaches	86	1.16	3.40	14
A4	Unclear benefits and gains	86	1.06	3.40	16
D3	Lack of investment in research and development	86	1.15	3.40	15
D2	Ineffective digital strategy	86	1.03	3.37	17
B3	Incompatibility of the technology with the current practices and operations of a company	86	1.06	3.36	18
E2	Lack of guidance from relevant institutions	86	1.04	3.36	19
A3	Very low profit margins in the industry	86	1.11	3.301	20
C1	Privacy of workers' personal data not guaranteed	86	1.15	3.30	21
B1	Need for retrofitting the implementation process	86	1.04	3.21	22
B2	Lack of coherent integration and interoperability capabilities	86	1.11	3.21	23
F4	Different client-to-contractor preferences on technology integration	86	0.96	3.14	24
G3	Shortage of standardisation efforts	86	1.10	3.14	25
E3	Absence of legal and contractual assurance	86	1.18	3.08	26
	Composite score			3.53	

High capital requirement (MS = 4.15; SD = 1.15) was rated one of the top barriers to GIS adoption for safe operations in the Zimbabwean construction industry. GIS implementation, including all the ancillary requirements, largely depends on the availability of capital, and this explains the prominence of this barrier. This is in line with a study by Yap *et al*. (2022) on the barriers to safety technology adoption in the construction industry, where high cost was ranked the most influential barrier to the adoption of safety technologies in the construction industry. In addition, You *et al*. (2018) maintain that employing a new technology to enhance workers' safety comes with very prohibitive costs. Consequently, the vast majority of construction companies end up relying more on the traditional paper-based approach in carrying out their safety management to safeguard their finances and profit levels in place of adopting GIS. Kamaruddin, Mohammad and Mahbub (2016) point to the need of a substantial budget for technology implementation and ongoing maintenance needs. Most of the contractors are reluctant to invest such significant amounts, as the issue of investigating into safety-related issues on sites can erode their profits. Interviewee 1's sentiments confirm the questionnaire finding:

> Subscription costs are high, especially for GIS systems like Arc GIS and GIS is somewhat complicated to use especially for us who do not have the required technical skills [Interviewee 1: Engineer].

The above view was common among all the twelve interviewees, with Interviewee 8 rating high cost as the predominant challenge to GIS adoption in Zimbabwe compared to other factors:

> I think above all, the issue of costs is the major challenge and we cannot talk of knowledge because once someone decides to implement GIS it means they already have the technical know-how of doing it [Interviewee 8: Engineer].

Hardly any or no government support (MS = 4.12; SD = 1.17) was also identified as a key barrier to GIS adoption. GIS adoption succeeds once the government, as the guardian of operations within jurisdictions, embraces the initiative. The interviewees also highlighted the significance of government support in increasing the uptake of GIS on construction sites:

> I think the government can also step in to help by providing companies with subsidies, tax breaks, etc, to lower the costs of acquiring these technologies (GIS) [Interviewee 5: Engineer].

Hence, the survey and interviewee findings confirm the importance of government support in GIS successful adoption. This finding supports the assertions of Yap *et al*. (2021), which identified insufficient government support and the absence of government incentives as barriers to adopting safety technologies in the construction sector. Hassan and Grobbelaar (2023) emphasise that government support can facilitate technological adoption and boost the confidence of potential users.

Lack of awareness (MS = 4.05; SD = 1.15) and lack of infrastructure (MS = 3.92; SD = 1.27) also emerged as critical barriers. Lack of infrastructure is an impediment experienced more dominantly in developing countries, possibly due to outdated infrastructure and poor telecommunication services. This was echoed in the interviews, where subjects reiterated their limited use of GIS as being attributed to poor infrastructure provision. This is supported by Cholo and Agumba (2023), who report that poor infrastructure is a significant impediment, restricting developing countries from fully digitalising their industries:

> Some of these technologies we really want to use them but with the current economic conditions and our level of infrastructure, we find it much better to stick to our traditional ways of doing business to stay afloat. This is because we have tried various technologies like BIM, for

> instance, and had to suspend it since we started to have profitability issues and now GIS is also at the risk of being dropped [Interviewee 4].

Fragmented construction industry (MS = 3.80; SD = 1.21) and poor construction industry safety culture (MS = 3.88; SD = 1.29) were also among the highly ranked barriers. These findings align with Tam, Toan and Phong (2024), who argue that fragmentation in the construction sector creates coordination challenges that limit technology adoption, and with Demirkesen and Tezel (2021), who note that subcontractor involvement complicates technology integration. Interview data also reflected this view:

> As for me I think we tend to overlook the issue of the structure of our construction industry because somewhere somehow, it's difficult to convince someone from another department or another trade to adopt or implement a technology when they think their side of operation has its own methods of conducting business [Interviewee 1: Engineer].

Lack of digital skills (MS = 3.76; SD = 1.11) was perceived as a major impediment to adoption. Firms find it difficult to implement GIS in the absence of necessary skills to operate the system. This corroborates the findings of Mago and Chigara (2023), who also identified lack of digital skills as a central barrier to the adoption of technological tools. Digital skills are a critical component if a company intends to adopt or implement GIS. Muvungani, Gore and Dzimiri (2023) highlighted that this is one of the major barriers within the construction industry. Interviews further confirmed this:

> Our Company does not provide means for us to get digital skills. I have been using simple things like Excel and HIRAs since I came to this company, and whenever they intend to do things that require GIS, they hire some guys [Interviewee 2: Safety manager].

> We still find the GIS systems a bit complex, and we still need to learn. I think I need to take a short course to learn more skills because I find it difficult to fully operate GIS on my own [Interviewee 3: Engineer].

Likewise, Interviewee 10 noted that most of the practitioners are curious to adopt GIS, but their curiosity is hindered by the lack of knowledge and skills to implement GIS.

> … people in the construction industry are very curious about how they can use GIS. So the curiosity is there but the level of understanding as how do we plug in the GIS system and we even tried to apply it at the Mpilo project which is a big site where we ended up manually measuring and setting out areas for car parks etc we did not have the skilled person to capture us information we needed in real time using GIS [Interviewee 10: Architect].

Besides these, several other barriers received moderately high ratings, and these include resistance to change (MS = 3.69; SD = 1.29), complex data-processing (MS = 3.65; SD = 1.22), lack of stringent safety rules (MS =

3.62; SD = 1.19), weak innovation culture (MS = 3.52; SD = 1.19), lack of collaboration among firms (MS = 3.48; SD = 1.06), inadequate knowledge-management systems and data handling (MS = 3.41; SD = 1.10), risk of security breaches (MS = 3.40; SD = 1.16), and lack of investment in research and development (MS = 3.40; SD = 1.15). Data insecurity and lack of privacy have been a deterring factor in the use of some digital technologies in construction (Aghimien *et al.*, 2022).

At the lower end, incompatibility of the technology with the current practices and operations of a company (MS = 3.36; SD = 1.06), lack of guidance from relevant institutions (MS = 3.36; SD = 1.04), very low profit margins in the industry (MS = 3.30; SD = 1.11), privacy of workers' personal data not guaranteed (MS = 3.30; SD = 1.15), and the need for retrofitting the implementation process (MS = 3.21; SD = 1.04) were reported as relevant but less critical barriers. Retrofit implementation is a significant impediment, as it necessitates both financial and human resources to develop organisational systems that are compatible with the adoption of GIS (Nnaji & Karakhan, 2020; Aranda *et al.*, 2023). When retrofitting company assets such as equipment, high financial costs are usually incurred, and construction firms tend to eliminate such responsibilities, by maintaining the traditional methods of conducting their day-to-day operations.

The least significant impediments identified were different client-contractor preferences (MS = 3.14; SD = 0.96) and the absence of legal and contractual assurance (MS = 3.08; SD = 1.18). Shen and Marks (2016) argue that differing preferences by contractors and clients on technology usage is a very significant challenge to technology adoption. Unity of preferences between contractors and clients is crucial for effective technology integration into construction sites operations. The low rating of the barriers could be due to the several perceptions that people of different generations have on GIS adoption. Although less prominent, these barriers remain relevant in shaping perceptions of GIS adoption across different generational and organisational contexts, as different generations do not agree when it comes to technology (McGowan, 2024; Calvo-Porral & Pesqueira-Sanchez, 2019). Hence, every fragment has different needs and levels of technological readiness, making it challenging to implement uniform solutions, which somewhat affects the level of diffusion of GIS.

4.3 Inferential analysis

4.3.1 Principal component analysis

The 26 barriers to GIS adoption for safety enhancement on construction sites were subjected to PCA to reduce the data into key factors based on the highest eigenvalues. The data were suitable for factor analysis, as indicated by a KMO value of 0.866, exceeding the recommended minimum of 0.7, and a highly significant Bartlett's test of sphericity ($\chi^2 = 1287.969$, df = 231, $p < 0.001$) (see Table 5). The outputs of the factor analysis are presented in Tables 6 and 7.

Table 5: KMO and Bartlett's test of GIS barriers

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin measure of sampling adequacy		.866
Bartlett's Test of Sphericity	Approx. *Chi*-Square	1287.969
	Df	231
	Sig.	<.001

Table 6: Pattern matrix on barriers to GIS adoption towards safety management

Barrier	*Component*				
	1	*2*	*3*	*4*	*5*
F1 Poor construction industry safety culture	.800	.388	.054	.070	.177
G2 Fragmented industry	.787	.151	.063	.215	.153
H1 Lack of awareness	.750	.132	.384	-.021	.187
A1 High capital requirement in GIS implementation	.736	-.091	.188	.326	.009
E4 Lack of stringent safety rules	.735	.417	.172	.066	.066
E1 Hardly any or no government support	.723	.151	.358	.190	.217
A2 Lack of infrastructure	.704	.055	.341	.173	.255
B4 Complex data processing	.492	.212	.140	.444	.399
G3 Shortage of standardisation efforts	.138	.864	.171	.075	.128
E4 Different client-to-contractor preferences on technology integration	.101	.764	.202	.008	-.003
E3 Absence of legal and contractual assurance	.115	.763	.080	.171	.292
A4 Unclear benefits and gains	.397	.536	.250	.246	.225
F3 Weak innovation culture	.430	.501	.448	.346	-.005
D2 Ineffective digital strategy	.155	.474	.441	.238	.387
G1 Lack of collaboration among firms	.359	.175	.734	.115	.187
D3 Lack of investment in research and development	.160	.213	.641	.149	.474
A3 Very low profit margins in the industry	.254	.238	.629	.278	-.005
D1 Inadequate knowledge of management systems and data handling systems	.130	.261	.426	.417	.054
F1 Resistance to change	.402	.455	.524	.205	-.113
B1 Need for retrofitting the implementation process	.055	.067	.138	.735	.224

Barrier	*Component*				
	1	*2*	*3*	*4*	*5*
B2 Lack of coherent integration and interoperability capabilities	.069	.309	.325	.650	.111
C1 Risk of security breaches	.367	-.054	.137	.613	.074
H2 Lack of digital skills	.578	.170	.068	.603	.028
E2 Lack of guidance from relevant institutions	.203	.398	.346	.420	.371
B3 Incompatibility of the technology with the current practices and operations of a company	.217	.170	.192	.130	.740
C1 Privacy of workers' personal data not guaranteed	.386	.147	-.103	.439	.571
Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser Normalization. Rotation converged in 6 iterations.					

Table 6 presents the pattern matrix showing the factor loadings of all 26 barriers following the initial PCA extraction without suppressing coefficients, revealing five components. After applying a factor suppression threshold of 0.5, four components were retained (Table 7), while two barriers were excluded due to loadings below 0.5 (Inadequate knowledge of management systems and data handling; Ineffective digital strategy) and two were removed for cross-loading on multiple factors (Lack of digital skills and Lack of coherent integration and interoperability capabilities). Using the eigenvalue >1 criterion, 22 sub-factors were extracted across four components, which were named according to their constituting barriers.

Table 7 shows the rotated factor matrix after Varimax rotation, with the four key components identified as Industry fragmentation and resource barriers; Standardisation, legal, and preference barriers; Management-related barriers, and Technological complexity and security barriers. These components accounted for 66.89% of the cumulative variance, with eigenvalues ranging from 10.676 to 1.135, and the rotation converging in six iterations. The extracted factors provide a structured understanding of the most significant barriers to GIS adoption for safety management in the Zimbabwean construction industry and form the basis for further discussion.

Table 7: Rotated factor matrix for key barriers to GIS adoption

Barrier	*Component*			
	1 Industry fragmentation, and resource barriers	*2 Standardisation, legal, and preference barriers*	*3 Management-related barriers*	*4 Technological complexity and security barriers*
F2 Poor construction industry safety culture	0.792			
G2 Fragmented industry	0.791			
H1 Lack of awareness	0.748			
E4 Lack of stringent safety rules	0.744			
A1 High capital requirement in GIS implementation	0.723			
A2 Lack of infrastructure	0.721			
E1 Hardly any or no government support	0.720			
G3 Shortage of standardisation efforts		0.853		
E3 Absence of legal and contractual assurance		0.781		
F4 Different client-to-contractor preferences on technology integration		0.744		
A4 Unclear benefits and gains		0.537		
G1 Lack of collaboration among firms			0.735	
A3 Very low profit margins in the industry			0.708	
F1 Resistance to change			0.637	
F3 Weak innovation culture			0.581	
D3 Lack of investment in research and development			0.564	
C3 Privacy of workers' personal data not guaranteed				0.752
B1 Need for retrofitting the implementation process				0.674
B4 Complex data processing				0.600
B3 Incompatibility of the technology with the current practices and operations of a company				0.569
E2 Lack of guidance from relevant institutions				0.534
C1 Risk of security breaches				0.507

Barrier	*Component*			
	1 Industry fragmentation, and resource barriers	*2 Standardisation, legal, and preference barriers*	*3 Management-related barriers*	*4 Technological complexity and security barriers*
Eigenvalue	10.676	2.118	1.454	1.135
Proportion of variance (%)	46.419	9.210	6.322	4.935
Cumulative variance (%)	46.419	55.629	61.952	66.886
Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser Normalization. Rotation converged in 6 iterations.				

Component 1: Industry fragmentation and resource barriers

The first component, industry fragmentation and resource barriers, had an eigenvalue of 10.676, accounting for 46.416% of the variance. Seven variables loaded onto this factor, namely fragmented industry, poor construction industry safety culture, lack of awareness, lack of stringent safety rules, high capital requirements in GIS implementation, lack of infrastructure, and hardly any or no government support. Most of these factors reflect the fragmented nature of the construction industry. As noted by Alaloul *et al.* (2020), the sector is largely project-based, which hinders technology integration, as effective GIS implementation requires robust organisational structures encouraging full participation. Government support is crucial for technological adoption through policies, incentives, and subsidies. The limited governmental backing in Zimbabwe exacerbates resource-related barriers such as high capital requirements. This aligns with Munongo and Pooe (2022), who highlighted that the vast majority of technologies require significant financial investment to streamline construction processes compared to conventional methods. The current economic challenges in Zimbabwe, including the aftermath of COVID-19 and persistent hyperinflation, further reinforce the prominence of these barriers. The strong loadings of high capital requirements and lack of government support suggest that technological interventions cannot succeed without addressing macro-level institutional and economic constraints, highlighting the need for policy interventions, financial incentives, and industry coordination.

Component 2: Standardisation, legal, and preference barriers

The second component, standardisation, legal, and preference barriers, had an eigenvalue of 2.118, explaining 9.2% of the variance, with four variables loading, namely shortage of standardisation efforts, absence of legal and contractual assurance, differing client-contractor preferences on technology integration, as well as unclear benefits and gains. Standardisation is critical to ensure interoperability and effective data integration for spatial analysis, facilitating coordination between project parties (Karimazondo, 2020). Legal and contractual frameworks enhance investor confidence in technology (Heever, 2019), yet their absence in Zimbabwe, compounded by evolving global legislation on digital technologies (Aghimien *et al*., 2022), limits adoption. Divergent client-contractor preferences and unclear benefits further reinforce hesitancy. This component highlights that governance and interoperability issues are meaningful obstacles, suggesting that harmonised industry standards and clearer legal frameworks are needed to reduce perceived risks for firms.

Component 3: Management-related barriers

The third component, management-related barriers, had an eigenvalue of 1.454, explaining 6.3% of the variance. Five variables loaded, namely lack of collaboration among firms, very low profit margins, resistance to change, weak innovation culture, and lack of investment in research and development. These factors are inherently linked to management practices. As observed by Alzighaibi *et al.* (2016), management support significantly influences employee acceptance of innovation. Technology adoption requires collaborative decision-making; without top management engagement, it is difficult to develop and execute effective digital strategies (Faiz, Le & Masli, 2024). Low profit margins, resistance to change, and weak innovation culture indicate that proactive leadership and strategic vision are essential for effective GIS integration, aligning with technology adoption models emphasizing managerial support and organisational readiness.

Component 4: Technological complexity and security barriers

The fourth component, technological complexity and security barriers, had an eigenvalue of 1.135, accounting for 4.9% of the variance. Six variables loaded, namely privacy of workers' personal data not guaranteed, need for retrofitting implementation processes, complex data processing, incompatibility of technology with current practices, lack of guidance from relevant institutions, and risk of security breaches. The first three factors reflect GIS complexity issues, as adopting new technologies requires integration with existing equipment, network systems, and IoT data (Liu *et al*., 2025). Retrofitting, which demands substantial financial and human resources, is a major impediment (Nnaji & Karakhan, 2020; Aranda *et al.*, 2023). While GIS is a powerful tool for project management, its complexity remains a challenge (Rashid & Haron, 2024). Data security and privacy concerns add another layer of difficulty, as these technologies are inherently vulnerable to breaches (Aghimien *et al*., 2022; Rashid & Haron, 2024), with

GIS unable to fully guarantee data protection (Stanik & Kiedrwickz, 2021). This component underscores that technical sophistication and operational integration are significant hurdles, reinforcing the need for training, systems integration, and cybersecurity measures to ensure effective GIS implementation in daily operations.

5. DISCUSSION

This study examined the barriers to GIS adoption for safety management in Zimbabwe's construction industry. A total of 26 barriers, adapted from international studies and validated through a pilot study with Zimbabwean professionals, were identified. These findings align with the Diffusion of Innovation theory, which suggests that socio-economic and institutional conditions influence technology adoption. They also correspond with the TOE framework, which posits that technological, organisational, and environmental contexts shape technology adoption (Dhedheya *et al.*, 2023). Furthermore, the study supports the TAM, which asserts that perceived usefulness (PU) and perceived ease of use (PEOU) drive technology adoption (Yuen *et al.*, 2021).

Descriptive analysis revealed nine significant barriers, the most prominent being high capital requirements, lack of government support, limited awareness, inadequate infrastructure, and insufficient digital skills. The high cost of GIS implementation, identified as a major barrier in developing countries (Alaoul *et al.*, 2020; Nnaji & Karakhan, 2020; Matt, Modrák & Zsifkovits, 2020), is compounded by limited government support – both financial and legislative (Mohiuddin *et al.*, 2023). The findings highlight the crucial role of government in facilitating technology uptake, as the absence of support contributes to low adoption and high accident rates on construction sites.

Other barriers include awareness gaps, skills shortages, and digital transformation deficits, aligning with previous research (Osunsanmi *et al.*, 2021; Demirkesen & Tezel, 2021). Without adequate training and digital skills, firms struggle to integrate GIS effectively. While 16 other factors were rated as moderate barriers, their significance varies by context. For instance, interoperability, weak safety regulations, and poor collaboration were moderate in Zimbabwe, but considered critical elsewhere (Kumar & Bansal, 2016; Petimani *et al.*, 2019), underscoring the importance of contextualising GIS adoption barriers.

Inferential analysis revealed four key components, namely Industry fragmentation and resource constraints; Standardisation, legal, and preference barriers; Management-related barriers, and Technological complexity and security issues. The first component, Industry

Fragmentation and Resource Constraints, includes high capital costs, lack of government support, fragmented industry, lack of awareness, and inadequate infrastructure, reflecting Zimbabwe's economic challenges. As Muzurura (2019) notes, low investment confidence hinders technological advancement. Zimbabwe must harmonise systems, promote GIS awareness, and invest in infrastructure to improve adoption. These efforts should be supported by government policies, including reliable power supply, political will, and infrastructure development (Mateko, 2024).

The second component, Standardisation, Legal, and Preference Barriers, points to the absence of standardised processes for GIS implementation in Zimbabwe. This is in line with Senna *et al.* (2022), who argue that GIS adoption is hindered by unstandardised processes in many developing countries.

Management-related barriers include lack of collaboration, resistance to change, weak innovation culture, and limited investment in R&D. These findings are consistent with studies by Karimazondo (2020) and Dhedheya *et al.* (2023), who identify organisational culture, digital skills shortages, and resistance to change as key barriers. Firms must collaborate to pool resources, expertise, and infrastructure, while supporting a technology-oriented culture to capitalise on GIS benefits.

Finally, technological complexity and security concerns were identified as significant barriers. Limited infrastructure, digital expertise, and unreliable power supply make GIS integration challenging. Furthermore, GIS' reliance on complex, often inaccessible data limits adoption. These findings align with Kumar & Bansal (2016) as well as Petimani *et al.* (2019), who report interoperability issues. Cybersecurity concerns, also raised in this study, resonate with global challenges (Rashid & Haron, 2024). Although Zimbabwe has a Data Protection Act, a stronger legal framework is needed to ensure data security and promote GIS adoption (Chingoriwo, 2022).

This study makes theoretical and practical contributions. Theoretically, it enriches the literature on GIS adoption in construction safety in the Global South. Practically, it highlights the need for contractors, engineers, and architects to develop proficiency in advanced technologies such as GIS to improve safety outcomes. Training programmes, workshops, and professional development initiatives could bridge the technological knowledge gap, enhance safety cultures, and reduce accidents.

The findings also have important policy implications. To facilitate GIS adoption, the government must develop national guidelines, provide financial incentives (*e.g.*, subsidies or tax rebates), and address industry fragmentation. The NSSA, as the statutory body overseeing occupational safety, could leverage these findings to promote GIS adoption through campaigns and regulatory measures, thereby reducing workplace hazards.

Finally, GIS adoption in construction safety aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDG 3 (Good health and well-being) and SDG 8 (Decent work and economic growth). This study offers valuable insights not only for Zimbabwe, but also for other developing countries facing similar barriers to technological adoption.

6. CONCLUSION

Despite the existence of established occupational health and safety (OHS) frameworks, accidents and fatalities continue to affect Zimbabwe's construction industry, highlighting the urgent need for the integration of advanced safety technologies such as GIS. While GIS adoption has been widespread in many developing countries, its uptake in Zimbabwe remains limited. This study set out to identify the key barriers to GIS adoption in safety management within the Zimbabwean context.

Descriptive statistical analysis revealed several prominent barriers to GIS adoption, including high implementation costs, limited government support, lack of awareness, inadequate infrastructure, and digital skills shortages. Inferential statistical analysis, through principal component analysis (PCA), further identified four key components hindering GIS adoption in safety management in Zimbabwe: Industry fragmentation and resource barriers; Standardisation, legal, and preference barriers; Management-related barriers, and Technological complexity and security barriers.

In light of these findings, the study makes several recommendations:

- Addressing industry fragmentation and resource barriers. The fragmented nature of the Zimbabwean construction industry, compounded by resource constraints, hampers the widespread adoption of GIS. It is critical for industry players to collaborate more effectively, pooling financial resources, expertise, and infrastructure. Government intervention is also crucial, particularly through financial incentives and infrastructure development, to address these fragmentation issues and reduce the high costs of GIS implementation.
- Overcoming standardisation, legal, and preference barriers. GIS adoption is constrained by the lack of standardised processes and regulatory frameworks. The study recommends that the government develop clear guidelines and regulations that promote GIS adoption in construction safety. This could include establishing industry standards, providing legislative support, and offering tax incentives or subsidies for firms investing in GIS technologies.

- Mitigating management-related barriers. Management-related challenges such as resistance to change, lack of collaboration, and insufficient investment in research and development must be addressed to support a culture of technological innovation. Construction firms should prioritise collaboration, with both large and small companies working together to enhance resources and share knowledge. In addition, supporting a culture of innovation and providing support for ongoing research and development will be key in overcoming these organisational barriers.
- Reducing technological complexity and security barriers. Technological complexity, coupled with concerns over data security, presents a significant challenge to GIS adoption. To address these barriers, targeted digital skills training is essential to improve the capacity of construction stakeholders in effectively using GIS technologies. Furthermore, it is vital to enhance infrastructure, including reliable power supply and internet access. Addressing cybersecurity concerns through improved legal frameworks and data-protection measures is also critical to ensuring safe data-sharing and integration of GIS technologies.

While these recommendations provide a pathway to overcoming the barriers to GIS adoption in Zimbabwe, the study's limitations such as its small sample size and focus on large contractors may limit the generalisability of the findings. Future research could include a more diverse range of firms, including smaller contractors and clients, to offer a more comprehensive perspective. Cross-country comparative studies on GIS adoption in construction safety would also provide valuable insights into how these challenges can be addressed in similar contexts across the Global South.

In conclusion, addressing the four key barriers identified in this study – industry fragmentation, legal and standardisation issues, management-related challenges, and technological complexity – will be essential for improving GIS adoption in Zimbabwe's construction industry. By supporting industry collaboration, strengthening regulatory frameworks, investing in professional development, and improving technological infrastructure, Zimbabwe can leverage GIS to improve construction safety. These efforts will contribute to broader global objectives, particularly SDG 3 (Good Health and Well-Being) and SDG 8 (Decent Work and Economic Growth), demonstrating the potential of GIS to improve safety outcomes and support sustainable development in developing countries.

ACKNOWLEDGMENTS/FUNDING

This research is self-funded. The authors acknowledge the contribution of the reviewers and editorial team.

REFERENCES

Aghimien, D., Ngcobo, N. & Aigbavboa, D. 2022. Barriers to digital technology deployment in value management practice. *Buildings*, 12(6), article 731. https://doi.org/10.3390/buildings12060731

Akindele, O., Ajayi, S. Oyegoke, A., Alaka, H. & Omotayo, T. 2023. Application of Geographic Information System (GIS) in construction: A systematic review. *Smart and Sustainable Built Environment*, 12(3), pp. 145-170. https://doi.org/10.1108/SSBE-03-2023-0012

Alaloul, W., Ismail, A., Ammad, S. & Saad, S. 2020. Health and safety for infrastructure projects: Adaptation and barriers. *International Journal of Construction Management*, 20(4), pp. 356-372. https://doi.org/10.1080/15623599.2020.1712203

Alzighaibi, A., Mohammadian, M. & Talukder, M. 2016. Factors affecting the adoption of GIS systems in the public sector in Saudi Arabia and their impact on organizational performance. *Journal of Geographic Information System*, 8(3), pp. 396-411. https://doi.org/10.4236/jgis.2016.83034

Antah, F., Khoiry, M., Maulud, K. & Ibrahim, A. 2022. Factors influencing the use of geospatial technology with LiDAR for road design: Case of Malaysia. *Sustainability*, 14(15), article 8977. https://doi.org/10.3390/su14158977

Aranda, N., De Waegemaeker, J. & Van de Weghe, N. 2023. The evolution of public participation GIS (PPGIS) barriers in spatial planning practice. *Environment and Planning B: Urban Analytics and City Science*, 50(5), pp. 1120-1138. https://doi.org/10.1177/23998083231104562

Azungah, T. 2018. Qualitative research: deductive and inductive approaches to data analysis. *Qualitative Research Journal*, 18(4), pp. 383-400. https://doi.org/10.1108/QRJ-D-18-00035

Babbie, E. 2014. *The basics of social research.* 6th edition. Wadsworth, Cengage Learning.

Bakar, A., Kimaro, H., Sultan, A. & Hamiar, S. 2014. Adoption of open-source geographic information system solution for health sector in Zanzibar, Tanzania. *Health Informatics Journal*, 20(3), pp. 183-196. https://doi.org/10.1177/1460458214522223

Bademosi, F. & Issa, R. 2021. Factors influencing adoption and integration of construction robotics and automation technology in the US. *Journal of construction engineering and management*, 147(8), article 04021075. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002103

Bazeley, P. 2013. *Qualitative data analysis: Practical strategies*. London: SAGE Publications.

Berlak, J., Hafner, S. & Kuppelwieser, V. 2020. Digitalization’s impacts on productivity: a model-based approach and evaluation in Germany’s building construction industry. *PP&*C 32 (4), pp. 335-345. https://doi.org/10.1080/09537287.2020.1740815

Bhandari, P. 2020. How to calculate standard deviation (Guide): Calculator and example. scribbr.com [Accessed: 12 September 2025].

Bilous, L., Samoilenko, V., Shyshchenko, P. & Havrylenko, O. 2021. GIS in landscape architecture and design. *Geoinformatics. European Association of Geoscientists & Engineers,* (1), pp. 1-7. https://doi.org/10.3997/2214-4609.20215521034

Calvo-Porral, C. & Pesqueira-Sanchez, R. 2019. Generational differences in technology behaviour: Comparing millennials and generation X. *Journal of Knowledge Management*, 23(6), pp. 1235-253. https://doi.org/10.1108/K-09-2019-0598

Chan, A., Darko, A. & Meyaw, E. 2017. Strategies for promoting green building technologies adoption in the construction industry - An international study. *Sustainability*, 9, article 969. https://doi.org/10.3390/su9060969

Chigara, B. & Moyo, T. 2023. The impact of COVID-19 on the construction sector in Zimbabwe. *African Journal of Construction Economics*, 18(2), pp. 45-59. https://doi.org/10.21315/jcdc-03-21-0052

Chipato, E., Chigara, B. & Smallwood, J. 2019. Health and safety practices in Zimbabwean construction industry. *Safety Science*, 120, pp. 531-541. https://doi.org/10.1016/j.ssci.2019.07.012

Chingoriwo, T. 2022. Cybersecurity challenges and needs in the context of digital development in Zimbabwe. *British Journal of Multidisciplinary and Advanced Studies: Engineering and Technology*, 3(2), pp. 77-104. https://doi.org/10.37745/bjmas.2022.0046

Chowdhury, M., Quaddus, M. & Agarwal, R., 2019. Supply chain resilience for performance: role of relational practices and network complexities. *Supply Chain Management: An International Journal*, 24(5), pp. 659-676. https://doi.org/10.1108/SCM-09-2018-0332

Cholo, K. & Agumba, J. 2023. Exploring the factors hindering the use of project management processes in delivering RDP houses in Tshwane. *African Journal of Built Environment Research*, 14(1), pp. 101-118.

CIFOZ (Construction Industry Federation of Zimbabwe). 2023-2024 member downloads cifoz.co.za.[Accessed: 2 February 2924].

Creswell, J. 2013. *Qualitative inquiry and research design: Choosing among five approaches*. 3rd edition. Thousand Oaks, CA: Sage Publications.

Creswell, J. & Poth, C. 2018. *Qualitative inquiry and research design: Choosing among five approaches*. Thousand Oaks, CA: Sage Publications.

Davis, F. 1989. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), pp. 319-340. https://doi.org/10.2307/249008

Demirkesen, S. & Tezel, A. 2021. Investigating major challenges for Industry 4.0 adoption among construction companies. *Engineering, Construction and Architectural Management*, 28(4), pp. 1021-1045. https://doi.org/10.1108/ECAM-12-2020-1059

DePietro, R., Wiarda, E., & Fleischer, M. 1990. The context for change: Organization, technology and environment. In: Tornatzky, L. (Ed.). *The processes of technological innovation*. Lexington Books, pp. 151-175.

Dhedheya, I., Dube, S. & Sanders, I. 2023. A framework for the adoption of Geographic Information Systems (GIS) in service delivery: A case study of Harare City Council, Zimbabwe. *International Journal of Construction Management*, 23(7), pp. 2045-2060. https://doi.org/10.1080/15623599.2023.2216784

Dodge Data and Analytics. 2017. Safety management in the construction industry 2017 (Smart Market Report). cpwr.com [Accessed: 4 June 2024].

Egwim. C., Alaka, H., Demir, E., Balogun, H. & Olu-Ajayi, R. *et al*. 2024. Artificial intelligence in the construction industry: A systematic review of the entire construction value chain lifecycle. *Energies*,17(1), article 182. https://doi.org/10.3390/en17010182

Elmualim, A. & Gilder, J. 2014. BIM: innovation in design management, influence and challenges of implementation. *Architectural Engineering and design management*, 10(3-4), pp.183-199. https://doi.org/10.1080/17452007.2013.821399

Faiz, F., Le, V. & Masli, E. 2024. Determinants of digital technology adoption in innovative SMEs. *Journal of Innovation & Knowledge*, 9(4), article 100610. https://doi.org/10.1016/j.jik.2024.100610

Field, A. 2009. *Discovering statistics using SPSS*. 3rd edition. London: Sage Publications.

Finch, H. 2022. An introduction to the analysis of ranked response data. *Practical Assessment, Research and Evaluation*, 27(1), article 7. https://doi.org/10.7275/tgkh-qk47

Flatt, H., Schriegel, S., Jasperneite, J., Trsek, H. & Adamczyk, H. 2016. Analysis of the Cyber-Security of industry 4.0 technologies based on RAMI 4.0 and identification of requirements. In: *IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA)*. IEEE, pp. 1-4. https://doi.org/10.1109/ETFA.2016.7733634

Flick, U. 2019. *Doing triangulation and mixed methods*. Thousand Oaks, CA: Sage Publications. https://doi.org/10.4135/9781529716634

Gamil, Y. & Rahman. I. 2019. Awareness and challenges of building information modelling (BIM) implementation in the Yemen construction industry. *Journal of Engineering, Design and Technology*, 17(5) pp. 1077-1084. https://doi.org/10.1108/JEDT-03-2019-0063

Göçmen, Z. & Ventura, S. 2010. Barriers to GIS use in planning. *Journal of the American Planning Association*, 76(2), pp. 172-183. https://doi.org/10.1080/01944360903585060

Grbich, C. 2013. Foreword: Depth psychological research methods. *International Journal of Multiple Research Approaches*, 7(3), pp. 286-286. https://doi.org/10.5172/mra.2013.7.3.286

Hassan, F. & Grobbelaar, S. 2023. Adoption of engineered wood products in the building construction industry – A conceptual model. *Construction Innovation*, 23(4), pp. 521-540. https://doi.org/10.1108/CI-05-2023-0078

Hatoum, M. & Nassereddine, H. 2024. Determining decision-making factors for technology adoption in the construction industry. In: *Industry 4.0 Transformation Towards Industry 5.0 Paradigm-Challenges, Opportunities and Practices*. IntechOpen.

Heever, B. 2019. Construction mafia derailing projects, causing engineers to flee. asaqs.co.za [Accessed: 12 September 2025].

Iyengar, J. 1998. Application of geographical information systems. *Journal of International Information Management*, 7(2), article 9. https://scholarworks.lib.csusb.edu/jiim/vol7/iss2/9

Jebb, A., Ng, V. & Tay, L. 2021. A review of key likert scale development advances: 1995–2019. *Frontiers in Psychology,* 12, article 637547. https://doi.org/10.3389/fpsyg.2021.637547

Kache, F. & Seuring, S. 2017. Challenges and opportunities of digital information at the intersection of big data analytics and supply chain management. *International Journal of Operations and Production Management*, 37(1), pp. 10-36. https://doi.org/10.1108/IJOPM-02-2015-0078

Kamaruddin, S., Mohammad, M. & Mahbub, R. 2016. Barriers and impact of mechanisation and automation in construction to achieve better quality products. *Journal of Construction Engineering and Management*, 142(6), article 04016022.

Kamble, S., Gunasekaran, A. & Sharma, R. 2018. Analysis of the driving and dependence power of barriers to adopt industry 4.0 in Indian manufacturing industry. *Computers in Industry*, 101, pp. 107-119. https://doi.org/10.1016/j.compind.2018.06.004

Kanchana, S. & Faney, J. 2016. Study of safety management by using GIS in Coimbatore. *International Journal of Safety and Security Engineering*, 6(3), pp. 213-220.

Karimazondo. N. 2020. Exploring the status of geospatial skills within local authorities in Zimbabwe. *International Journal of Scientific Research in Computer Science and Engineering*, 8(2), pp. 32-38.

Kang, L., Wu, C., Liao, X. & Wang, B. 2020. Safety performance and technology heterogeneity in China’s provincial construction industry. *Safety Science*, 124, article 104589. https://doi.org/10.1016/j.ssci.2019.09.005

Karakhan, A. & Alsaffar, O. 2019. Technology’s role in safety management. *Professional Safety Journal of the American Society of Safety Professionals*, 64(3), pp. 43-45.

Karakhan, A., Xu, Y., Nnaji, C. & Alsaffar, O. 2019. Technology alternatives for workplace safety risk mitigation in construction: Exploratory study. In: Hartmann, T. (Ed.). *Advances in informatics and computing in civil and construction engineering*. Cham, Switzerland: Springer International Publishing, pp. 823-829. https://doi.org/10.1007/978-3-030-00220-6_99

Kiraz, A., Canpolat, O., Ozkurt, C. & Tas-kın, H. 2020. Analysis of the factors affecting the Industry 4.0 tendency with the structural equation model and an application. *Computers & Industrial Engineering*, 150, article 106911. https://doi.org/10.1016/j.cie.2020.106911

Kothari, C. 2019. *Research methodology: Methods and techniques*. 4th edition. New Delhi: New Age International Publishers.

Kothari, C. & Garg, G. 2019. *Research methodology: Methods and techniques*. 4th edition. New Delhi: New Age International Publishers.

Khudzari, F., Rahman. R., Ayer, S. & Tarmizi-Harun, A. 2023. Critical factors influencing construction technology adoption: A multivariate analysis: *AIP Conference Proceedings*, 2688(1), article 030020*. https://doi.org/10.1063/5.0111810*

Krejcie, R. & Morgan, D. 1970. Determining sample size for research activities. *Educational and Psychological Measurement*, 30(3), pp. 607-610. https://doi.org/10.1177/001316447003000308

Kumar, S. & Bansal, V. 2016. A GIS-based methodology for safe site selection of a building in a hilly region. *Journal of Construction Engineering and Management*, 142(9), article 04016055. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001184

Lee, J., Kim, K., Lee, S. & Shin, D. 2015. Can autonomous vehicles be safe and trustworthy? Effects of appearance and autonomy of unmanned driving systems. *International Journal of Human-Computer Interaction*, 31(10), pp. 682-691. https://doi.org/10.1080/10447318.2015.1070547

Leeonis, A., Ahmed, M., Moktar, M., Lim, C. & Halder, B. 2024. Challenges of using Geographic Information System (GIS) in managing flash floods in Shah Alam, Malaysia. *Sustainability*, 16(17), pp. 7528. https://doi.org/10.3390/su16177528

Letshaba, R. & Ndlovu, N. 2024. Evaluating knowledge management in skills development providers. *South African Journal of Information Management*, 26(1), article 1865. https://doi.org/10.4102/sajim.v26i1.1865

Liu, X., Antwi-Afari, M., Li, J., Zhang, Y. & Manu, P. 2025. GIS complexity issues, as adopting new technologies requires integration with existing equipment, network systems, and IoT data. *Automation in Construction*, 174, article 106149. https://doi.org/10.1016/j.autcon.2025.106149

Luthra, S. & Mangla, S. 2018. Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. *Process safety and environmental protection*, 117, pp.168-179. https://doi.org/10.1016/j.psep.2018.04.018

Mago, H. & Chigara, B. 2023. Barriers to adopting Property Technology (PropTech) in residential property valuation practice in South Africa. *Journal of Property Valuation and Investment*, 41(2), pp. 123-140.

Manase, D., Heesom, D., Oloke, D. & Proverbs, D. 2011. GIS analytical approach for exploiting construction health and safety information. *Journal of Information Technology in Construction*, 16, pp. 335-349

Mantha, B. & de Soto, B. 2019. Cyber security challenges and vulnerability assessment in the construction industry. In: *Proceedings of the Creative Construction Conference*, 29 June, pp. 1-12. https://doi.org/10.3311/CC2019-005

Matare, Z. & Gondo, K. 2018. Workplace accidents and diseases affecting informal construction workers in Ruvimbo and Rujeko suburbs of Chinhoyi, Zimbabwe. *IOSR Journal of Humanities and Social Science (IOSR-JHSS)*, 23(9), pp. 15-20. https://doi.org/10.9790/0837-2309081520

Mateko, F. 2024. Digital technologies and economic development in Zimbabwe. *Development*, 67(1), pp. 85-90. https://doi.org/10.1057/s41301-024-00400-y

Matt, D., Modrák, V. & Zsifkovits, H. 2020. *Implementing Industry 4.0 in SMEs*. Palgrave Macmillan Cham. https://doi.org/10.1007/978-3-030-70516-9

McGowan, E. 2024. Millennials vs baby boomers: Who is less secure. Norton.com [Accessed: 12 September 2025].

Mkungunugwa, T., Owili, P., Muula, A. & Kuo, H. 2022. Implementation determinants of Zimbabwe National Occupational Safety and Health Policy in Willowvale industrial area, Zimbabwe. *International Journal of Environmental Research and Public Health,* 19, article 1424. https://doi.org/10.3390/ijerph19031424

Mohajan, H. 2018. Qualitative research methodology in social sciences and related subjects. *Journal of Economic Development, Environment and People*, 7(1), pp. 23-48. https://doi.org/10.26458/jedep.v7i1.571

Mohiuddin, M., Reza, M., Jayashree, S., Al-Azad, S. & Ed-dafali, S. 2023. The Role of Governments in Driving Industry 4.0 Adoption in Emerging Countries. *Journal of Global Information Management*, 31(1), https://doi.org/10.4018/JGIM.323439

Monsur, M. & Islam, Z. 2014. GIS for architects: Exploring the potentials of incorporating GIS in architecture curriculum. ARCC Conference Repository. https://doi.org/10.17831/rep:arcc%y250

Moore, S. 2020. RICS professional education and training for quantity surveyors and the extent to which it is relevant in the current UK built environment market. Unpublished PhD dissertation. University of Salford, United Kingdom.

Mosia, T. 2025. Tragic crane collapse. centralnews.co.za [Accessed: 12 September 2025].

Munongo, S. & Pooe, D. 2022. Small and medium enterprises' adoption of 4IR technologies for supply chain resilience during the COVID-19 pandemic. *Journal of Transport and Supply Chain Management*, 16, article 747. https://doi.org/10.4102/jtscm.v16i0.747

Mupedza, L. 2022. Managing novel risks in construction projects: A Zimbabwean construction industry case study of risk management during the COVID-19 pandemic. *International Journal of Construction Project Management*, 14(2), pp. 67-85.

Muvungani, R., Gore, A. & Dzimiri, T. 2023. Challenges affecting the adoption of Industry 4.0 technologies in enhancing construction project delivery in Zimbabwe. *Journal of Engineering, Design and Technology*, 21(5), pp. 1012-1030.

Muzurura, J. 2019. Foreign direct investment in Zimbabwe: The role of uncertainty, exports, cost of capital, corruption and market size. *The Economics and Finance Letters*, 6(1), pp. 9-24. https://doi.org/10.18488/journal.29.2019.61.9.24

Nnaji, C. & Karakhan, A. 2020. Technologies for safety and health management in construction: Current use, implementation benefits and limitations and adoption barriers. *Journal of Building Engineering*, 30, article 101249. https://doi.org/10.1016/j.jobe.2020.101249

NSSA (National Social Security Authority). 2018. Annual Statistical Report nssa.org [Accessed: 12 September 2025]

Nunnally, J. & Bernstein, I. 1994. *Psychometric theory*. 3rd edition. New York, NY: McGraw-Hill.

Oesterreich. T. & Teuteberg, F. 2016. Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry*, 83, pp. 121-139. https://doi.org/10.1016/j.compind.2016.09.006

Omer, M., Rahman, R. & Almutairi, S. 2022. Strategies for enhancing construction waste recycling: A usability analysis. *Sustainability*, 14(10), article 5907. https://doi.org/10.3390/su14105907

Osunsanmi, T., Aigbavboa, C., Thwala, W. & Molusiwa, R. 2021. Modelling Construction 4.0 as a vaccine for ensuring construction supply chain resilience amid COVID-19 pandemic. *Journal of Engineering, Design and Technology*, 20(1), pp. 132-158. https://doi.org/10.1108/JEDT-07-2021-0384

Pedone, G. & Mezg´ar, I. 2018. Model similarity evidence and interoperability affinity in cloud-ready Industry 4.0 technologies. *Computers in Industry*, 100, pp. 278-286. https://doi.org/10.1016/j.compind.2018.05.003

Petimani, V., Awati, V. & Rashmi, J. 2019. Monitoring the Construction Project by 4D Application of GIS. *International Journal of Recent Technology and Engineering*, 8(2), pp. 2994-2999. https://doi.org/10.35940/ijrte.B2718.078219

Pradhananga, P., ElZomor, M. & Santi-Kasabdji, G. 2021. Identifying the challenges to adopting robotics in the US construction industry. *Journal of Construction Engineering and Management*, 147(5), article 05021003. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002007

Raj, A., Dwivedi, G., Sharma, A., de Sousa Jabbour, A. & Rajak. S. 2019. Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective. *International Journal of Production Economics*, article 14. https://doi.org/10.1016/j.ijpe.2019.107546

Rashid, F. & Haron, R. 2024. Understanding the conceptual of Geographical Information System (GIS) for project management in Malaysian construction industry. *Research in Management and Technology Bulletin*, 5(1), pp. 109-124. https://doi.org/10.30880/rmtb.2024.05.01.109

Rogers, E. 1983. *Diffusion of innovations*. 3rd edition. Free Press.

Rossoni, L., Engelbert, R. & Bellegard, N. 2016. Normal science and its tools: Reviewing the effects of exploratory factor analysis in management. *Revista de Administração*, 51(2), pp. 198-211. https://doi.org/10.5700/rausp1234

Sarasanty, D. 2020. Safety hazards identification of construction site layout based on Geographic Information System (GIS). *International Journal on Advanced Science Engineering Information Technology*, 10(5), pp. 1772-1780. https://doi.org/10.18517/ijaseit.10.5.12822

Senna, P., Ferreira, L., Barros, A., Roca, J. & Magalhaes, V. 2022. Prioritizing barriers for adopting of Industry 4.0 technologies. *Computers and Industrial Engineering*, 169, article 108428. https://doi.org/10.1016/j.cie.2022.108428

Shabani, T., Jerie, S. & Shabani, T. 2023. The effectiveness of total loss control approach in accident prevention in industries in Zimbabwe. *Life Cycle Reliability and Safety Engineering*, 12, pp. 93-10. https://doi.org/10.1007/s41872-023-00222-w

Shen, X. & Marks, E. 2016. Near-miss information visualization tool in BIM for construction safety. *Journal of Construction Engineering and Management*, 142(4), article 04015100. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001100

Shrestha, N. 2021. Factor analysis as a tool for survey analysis. *American Journal of Applied Mathematics and Statistics*, 9, pp. 4-11. https://doi.org/10.12691/ajams-9-1-2

Stanik, J. & Kiedrowicz, M. 2021. Organisational security system as a determinant of enhancing security culture of GIS. *GIS Odyssey Journal*, 1. https://doi.org/10.57599/gisoj.2021.1.1.91

Sydow, J. 2019. The inter-firm network as partial organization. In: *Organization outside organizations: The abundance of partial organization in social life.* Cambridge University Press, pp. 191-211. https://doi.org/10.1017/9781108604994.009

Tam, N., Toan, N. & Phong, V. 2024. Investigating potential barriers to construction digitalization in emerging economies: A study in Vietnam. *Journal of Construction in Developing Countries*, 29(1), article 100226. https://doi.org/10.1016/j.jjimei.2024.100226

Tavakol, M. & Dennick, R. 2011. Making sense of Cronbach's alpha. *International Journal of Medical Education*, 2, pp. 53-55. https://doi.org/10.5116/ijme.4dfb.8dfd

Taherdoost, H. 2018. A review of technology acceptance and adoption models and theories. *Procedia Manufacturing*, 22, pp. 960-967. https://doi.org/10.1016/j.promfg.2018.03.137

Tsai, M. & Yau, N. 2014. Enhancing spatial information for relief work during nuclear accidents. In: *Ubiquitous Information Technologies and Applications: CUTE 2013*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 237-243. https://doi.org/10.1007/978-3-642-41671-2_31

Woodhead, R., Stephenson, P. & Morrey, D. 2018. Digital construction: From point solutions to IoT ecosystem. *Automation in construction*, 93, pp.35-46. https://doi.org/10.1016/j.autcon.2018.05.004

Xu, L., Xu, E. & Li, L. 2018. Industry 4.0: state of the art and future trends. *International journal of production research*, 56(8), pp. 2941-2962. https://doi.org/10.1080/00207543.2018.1444806

Yahya, M., Hui, Y., Yassin, A., Omar, R., Anak-Robin, R. & Kasim, N. 2019. The challenges of the implementation of construction robotics technologies in the construction. In: *MATEC Web of Conferences*, 266, article 05012. EDP Sciences. https://doi.org/10.1051/matecconf/201926605012

Yap, J., Chow, I. & Shavarebi, K. 2019. Criticality of construction industry problems in developing countries. *Journal of Management in Engineering*, 35(5). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000709

Yap, J., Skitmore, M. & Talebian, N. 2022. Barriers to the adoption of new safety technologies in construction: A developing country context. *Safety Science*, 149, article 105641. https://doi.org/10.1016/j.ssci.2022.105641

Ye, H., Brown, M. & Harding, J. 2013. For all: Exploring the barriers and opportunities for underexploited GIS applications. *Computers, Environment and Urban Systems*, 41, pp. 132-145. https://doi.org/10.1016/j.compenvurbsys.2013.04.001

Yong, A. & Pearce, S. 2013. A beginner's guide to factor analysis: Focusing on exploratory factor analysis. *The Quantitative Methods of Psychology*, 9(2), pp. 79-94. https://doi.org/10.20982/tqmp.09.2.p079

You, S., Kim, J., Lee, S., Kamat, V. & Robert, L. 2018. Enhancing perceived safety in human-robot collaborative construction using immersive virtual environments. *Automation in Construction*, 96, pp. 161-170. https://doi.org/10.1016/j.autcon.2018.09.008

Yuen, K., Cai, L., Qi, G. & Wang, X. 2021. Factors influencing autonomous vehicle adoption: An application of the technology acceptance model and innovation diffusion theory. *Technology Analysis and Strategic Management*, 33 (5), pp. 505-519. https://doi.org/10.1080/09537325.2020.1826423