Cape Peninsula University of Technology

Exploring Barriers and Strategies for the Adoption of Industry X.0 Technologies in Civil Engineering Consulting Firms in South Africa

by

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DECLARATION

I, Resego Thabiso Matlakala, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

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ABSTRACT

Industry X.0 technologies—spanning Building Information Modelling (BIM), Geographic Information Systems (GIS), drones, Internet of Things (IoT), artificial intelligence and digital twins—promise measurable gains in delivery certainty, coordination and lifecycle performance for civil-engineering consulting. Yet adoption in South Africa has been uneven, shaped by resource constraints, skills gaps and interoperability challenges. This study investigates the current state of adoption, quantifies realised benefits, ranks barriers, and identifies practical strategies to accelerate integration in South African civil-engineering consulting firms. A cross-sectional, mixed-methods design was employed using an online questionnaire with closed Likert-type items and optional open-ended responses to capture both prevalence and practitioner commentary. Data were analysed using descriptive statistics for frequencies, proportions and mean barrier scores, complemented by thematic coding of free-text responses to surface implementation insights.

Results indicate that perceived benefits are concentrated in efficiency/productivity (73.9%) and accuracy/error-reduction (71.6%), with collaboration (50.0%), cost savings (46.6%) and sustainability (36.4%) also frequently reported. Among firms that had adopted one or more Industry X.0 tools, nearly one-third observed high improvements (>21%), while roughly half reported moderate gains (6–20%), and a minority noted low or no measurable improvement—consistent with tools being in early pilot phases. Ranked barriers show a clear hierarchy: cost (mean≈3.58/5) and technical skills (≈3.50/5) dominate, followed by insufficient training (≈3.40/5), resistance to change (≈3.33/5) and workflow/interoperability challenges (≈3.13/5). Practical levers preferred by respondents include in-house workshops (≈59%), online courses/certifications (≈55%) and on-site demonstrations (≈46%), alongside policy ideas such as BIM-informed procurement and fiscal incentives. Technology-specific signals point to strong momentum in GIS/BIM, expanding drone use (with a substantial share relying on outsourced flight services), and growing interest in IoT and digital twins as data standards mature. The study concludes that benefits materialise most reliably when tools move from isolated pilots into disciplined workflows supported by people development and data-integration practices. It recommends a cyclical framework—rapid diagnostics; parallel tracks for financing, skills and technical integration; threshold-based pilots; and scale-up through internal knowledge-sharing—to convert pilots into institutionalised capability. These findings offer an evidence-based roadmap for firms, professional bodies and public clients seeking to close the gap between innovation and routine practice in the South African context.

Keywords: Industry X.0 Adoption, Civil Engineering Consulting, Digital Transformation Barriers, BIM–GIS Integration, Technology Implementation Framework

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GLOSSARY

Terms/Acronyms/Abbreviations	**Definition/Explanation**
Industry X.0 Technologies	A set of digital innovations, including automation, AI, IoT, and smart data systems, aimed at transforming engineering and industrial sectors.
Building Information Modelling (BIM)	A digital representation of physical and functional characteristics of a facility, used for planning, designing, managing, and operating infrastructure.
Internet of Things (IoT)	A network of connected devices that collect and share data, used in engineering to monitor structural health, automate systems, and improve efficiency.
Digital Twin	A virtual model of a physical asset that uses real-time data to simulate, predict, and optimize performance.
3D Printing (Additive Manufacturing)	The process of creating three-dimensional objects layer by layer from digital models, often used in construction for rapid prototyping and prefabrication.
Geographic Information Systems (GIS)	A technology that captures, stores, analyses, and presents spatial or geographic data to support decision-making in engineering projects.
Unmanned Aerial Vehicles (UAVs)/Drones	Remote-controlled aircraft used for surveying, mapping, and real-time site monitoring in construction and engineering.
Artificial Intelligence (AI) in Civil Engineering	The application of machine learning and data-driven decision-making to optimize structural design, safety, and project efficiency.
Cyber-Physical Systems (CPS)	Integrated systems where physical engineering components interact with digital systems to enable automation and predictive maintenance.
Stakeholder Engagement	The process of involving relevant parties, such as engineers, clients, and regulators, in decision-making throughout a project lifecycle.

CHAPTER ONE: INTRODUCTION

1.1 Background

South Africa continues to execute civil engineering project delivery through traditional methods that include manual paper-based systems and minimal technological adoption and cautious acceptance of new approaches (WASET, 2023). The sector maintains its reliance on established project planning and design and execution methods which Oluwafemi *et al.* (2021) has documented in their research. Manual procedures control all documentation tasks and design drafting and stakeholder communication which results in inefficient processes and mistakes according to Tanga *et al.* (2021).

South African consulting firms have not widely adopted Industry X.0 technologies that include Building Information Modelling (BIM), Internet of Things (IoT), 3D printing, AI and digital twins despite their proven ability to boost efficiency and lifecycle management and enhance accuracy (Khudzari *et al.*, 2021). The slow adoption rate of these technologies exists even though worldwide studies demonstrate their positive effects on some of the different project's speed and results.

Multiple barriers prevent organizations from adopting new technologies. Civil engineering professionals in South Africa lack knowledge about Industry X.0 tool advantages which creates resistance because of traditional practices and insufficient digital competency (Adebiyi *et al.*, 2024). The high expenses of implementation create additional problems especially for smaller companies because training employees who might leave after skill development represents financial dangers (Li *et al.*, 2024). The shortage of systematic training programs for professional skill development presents an additional difficulty (Tanga *et al.*, 2021) and regulatory inertia which leads to slow policy updates and inadequate digital infrastructure that restricts large-scale implementation (van Wyk, Kajimo-Shakantu & Opawole, 2021). Civil engineering projects encounter adoption obstacles due to client-side limitations, particularly from local municipalities and state-owned enterprises, which often do not include the use of advanced technologies—such as BIM or IoT—as part of their project requirements. This lack of demand from major clients reduces the incentive for consulting firms to invest in or adopt these technologies, thereby slowing market-driven innovation.

A survey conducted by van Wyk, Kajimo-Shakantu and Opawole (2021) found that many civil engineers are unaware of the full range of emerging construction technologies, indicating a significant gap in knowledge and willingness to explore new methods. Additionally, biased procurement practices based on past experiences rather than objective evaluations of technological benefits further hinder progress (Laryea, 2019). These issues not only affect the efficiency and accuracy of project delivery but also weaken South African firms' competitiveness in the global market.

Despite these challenges, there is growing recognition of the need for digital transformation in the South African civil engineering sector. Global case studies show that countries leading in Industry X.0 adoption have implemented strategic policies, training programs, and financial incentives to facilitate the transition (Sepasgozar & Davis, 2018). However, South Africa lacks a structured framework to guide the widespread integration of these technologies.

This research moves beyond identifying barriers—it seeks to develop practical, solution-oriented strategies to bridge the gap between technological potential and real-world implementation. By examining successful adoption models, civil engineering practitioner's recommendations, and structured implementation plans. This study aims to provide actionable strategies for South African civil engineering firms to overcome adoption challenges and fully harness Industry X.0 technologies for enhanced project delivery, improved collaboration, and greater long-term sustainability.

Civil engineering consulting firms in South Africa have constantly been seeking to improve efficiency and accuracy by leveraging the tools available, this is evident in the use of Computer Aided Design software compared to the old way of producing drawings through drawings on paper. Firms typically deliver planning, design, contract administration, and asset management services within a highly regulated and cost-sensitive environment. Projects are frequently delivered under public-sector procurement constraints, with uneven client digital readiness and varying levels of in-house capability across small, medium and large consultancies. This context shapes how new digital tools are selected and used to fuel productivity, funded, governed, and sustained—therefore influencing both the barriers to Industry X.0 adoption and the feasibility of implementation strategies.

1.2 Problem statement

The adoption of Industry X.0 technologies including Building Information Modelling (BIM), Artificial intelligence, Internet of Things (IoT), 3D Printing, and Digital Twins by civil engineering consulting firms in South Africa is hampered by numerous challenges. Although these technologies have the potential to enhance efficiency, accuracy, and sustainability in project delivery, their adoption has been slow due to factors like low awareness, resistance to change, high implementation costs, low levels of training, and regulatory issues (Khudzari *et al.*, 2021; Adebiyi *et al.*, 2024).

Although many of the predictable barriers to Industry X.0 adoption are general challenges that are encountered during any technological or regime shift or change, such as resistance to changing established practices, skills gaps, and costs of implementation (Geels, 2002), this research goes beyond generic obstacles to identify targeted solutions for South Africa's civil engineering sector. This study aims to develop practical implementation frameworks that address both general transition barriers and region-specific constraints by focusing on the intersection of these universal adoption challenges with local contextual factors.

1.3 Research questions

- What are the key Industry X.0 technologies relevant to civil engineering consulting firms in South Africa?
- What is the current level of awareness and adoption of these technologies in the civil engineering field?
- What are the current barriers to the adoption of Industry X.0 technologies in project delivery processes in South Africa, and
- What practical implementation framework can South African civil engineering consulting firms apply to overcome the identified barriers and accelerate Industry X.0 adoption?

1.4 Hypotheses

- Awareness and routine use of Industry X.0 technologies in South African civil engineering consulting is generally low, with adoption concentrated in mature tools that have been tried and tested (e.g., BIM and GIS).
- High implementation cost and shortages of technical skills/training are perceived as the dominant barriers across firm sizes.
- Firms with higher adoption maturity report higher perceived improvements in efficiency and accuracy.

1.5 Aim

This research aims to explore the barriers and strategies for the adoption of Industry X.0 technologies within civil engineering consulting firms in South Africa.

1.6 Objectives

- To identify the relevant Industry X.0 technologies applicable to civil engineering consulting firms in South Africa.
- To assess the current level of awareness and adoption of these technologies in the South African civil engineering sector.
- To identify the key barriers hindering the adoption of Industry X.0 technologies in project delivery processes and
- To develop a practical, evidence-based implementation framework that addresses the identified barriers and guides staged adoption in South African civil engineering consulting firms.

1.7 Significance of the study

Implementation of Industry X.0 technologies in civil engineering consulting firms is likely to improve project delivery, reduce errors, and increase sustainability. Nevertheless, the South African civil engineering sector is faced with several challenges that hinder the uptake of the Industry X.0 technologies including resistance to change, low level of awareness, and financial constraints. It is therefore important that these challenges are addressed to ensure that the industry is well positioned to compete in the market in the face of globalization.

This study is significant to both academic research and industry practice as it offers an empirical understanding of the barriers and opportunities of Industry X.0 technologies. The study will be particularly useful for consulting engineers, policymakers, and technology suppliers who seek to influence the digital transformation of the sector. In addition, the research will present practical approaches that can be used to support the uptake of new technologies in order to enhance project delivery and operational efficiency in civil engineering firms.

In addition to the industry, the study has wider societal implications by encouraging the development of sustainable infrastructure, rational use of resources, and integration of engineering disciplines. The adoption strategies that will be uncovered through this research could also serve as a model for other companies facing similar technological integration challenges.

1.8 Structure of the research thesis

This research thesis is structured in five chapters which examine different fundamental elements of the research process. The first chapter of this work presents an introduction to the study by combining background information about the problem with research questions and objectives and study significance.

The second chapter of this study reviews existing literature about Industry X.0 technologies and their implementation in civil engineering together with obstacles to integration and worldwide case studies. The research examines theoretical and conceptual knowledge that supports this investigation.

In Chapter 3, the research design together with data collection methods and sampling strategies and analytical techniques receive explanation in this chapter to answer the research questions. This chapter and other university-submitted documentation present ethical concerns along with study boundaries.

The main data collection for this research will include a standardized questionnaire distributed to South African civil engineering consulting professionals. Chapter 4 of the final mini dissertation will present the analysis of this data. The analysis will identify patterns and themes about the awareness, adoption, and implementation challenges of Industry X.0 technologies which will be compared with findings from relevant literature to place the results in both local and global contexts. The last chapter provides a summary of research findings and discusses their implications for industry and policy before offering recommendations for future research and implementation strategies. The chapter presents solutions together with implementation strategies that businesses can use to adopt these technologies successfully.

The thesis includes a references section which lists all sources used in addition to appendices that contain supplementary materials including survey questionnaires.

CHAPTER TWO: LITERATURE REVIEW

This chapter synthesises prior research on Industry X.0 adoption in the built environment, focusing on reported applications, benefits, and barriers across relevant technologies. The review consolidates evidence on organisational, financial, skills, and integration constraints, and highlights gaps relating to South African civil engineering consulting firms—particularly the limited local benchmarking of multi-technology awareness/adoption, barrier severity ranking, and practical implementation guidance grounded in local constraints.

The civil engineering discipline, just like other industries depends on receiving ongoing development through technological innovations that both boost delivery efficiency and project sustainability (Adwan & Al-Soufi, 2016). The civil engineering consulting firms in South Africa face rising project complexity and have to tender at discounted fees, to still be competitive and improve design times or increase efficiency the industry demands the implementation of Industry X.0 technologies. The technologies of artificial intelligence and 3D printing alongside Internet of Things devices and digital twins demonstrate strong potential to boost efficiency and project success rates, different industry sectors display varying degrees of technological integration which creates a substantial obstacle for achieving peak project delivery results (Khudzari *et al.*, 2021).

This study examines how Industry X.0 tools affect every stage of infrastructure projects - covering planning methods and upkeep after building - in civil engineering consultancies across South Africa. It looks at present adoption rates, combining digital solutions, advantages in design and build stages along with lasting gains in managing assets over time while cutting expenses. Findings aim to clarify ways these technologies improve daily engineering tasks, especially under local conditions (Sepasgozar & Davis, 2018).

The adoption of Industry X.0 tools in civil engineering consultancies faces hurdles due to steep startup expenses, insufficient staff preparation, interruptions in daily operations, along with limited awareness of the benefits - barriers often seen during transitions, whether tech-driven or policy-based (Geels, 2002). Resistance to transformation persists across many companies, complicating integration of novel solutions into existing workflows (Opoku *et al.*, 2023). Certain experts argue that skill-building programs could be introduced while forming alliances with vendors so insights and effective methods can flow more easily (Chudikova & Faltejsek, 2019). Civil engineering firms based in South Africa experience significant difficulty when implementing Industry X.0 technologies because different firms adopt these technologies at varying rates which creates delivery inefficiencies. A thorough assessment must be conducted to determine which factors such as infrastructure capabilities, expertise levels and regulatory environments affect technology integration within these firms (Khudzari *et al.*, 2021).

The civil engineering field must adopt tailored technologies to meet South Africa's unique demands for successful use. Establishing project goals alongside clear operational traits - shaped by region and industry - is essential (Sepasgozar & Davis, 2018). The use of technology requires clear plans that link training efforts with collaboration among specialists along with ways to measure results through performance indicators (Reyes *et al.*, 2020). These methods allow companies to show the value of spending on Industry X.0 tools while making sure projects are fully executed.

Civil engineering in South Africa may improve significantly through use of Industry X.0 technologies. Findings here indicate that consultancy practices need technological updates - enabling them to perform more effectively whilst keeping pace with rivals. However, advancement depends on addressing known barriers, as well as fostering an environment supportive of innovation and change (Igwe *et al*, 2020).

The chosen Industry X.0 tools covered here - such as BIM, GIS, UAVs, IoT, 3D printing, robotics, AI, and digital twins - are included since evidence shows real-world use; these are now spreading across civil engineering fields globally. Despite different levels of maturity, each offers measurable improvements in areas like project execution, operational speed, oversight processes, or environmental performance. What's more, many have already worked well in countries facing development hurdles comparable to South Africa's, particularly where physical infrastructure is limited or funding is tight. Given rising access through open platforms or modular setups, combined with strong potential to tackle key barriers within local consultancy practice, they represent logical targets for deeper investigation.

2.1 Adoption of UAV technology in civil engineering consulting firms

Civil engineering consulting in South Africa could realise meaningful performance improvements through Industry X.0 technologies, particularly in productivity, accuracy, coordination, and asset oversight. However, the extent of these gains is not automatic and depends on whether firms can overcome documented adoption barriers and sustain organisational conditions that support innovation and change (Igwe et al., 2020).

This study focuses on a set of Industry X.0 tools—BIM, GIS, UAVs, IoT, 3D printing, robotics, AI, and digital twins—because the literature demonstrates their real-world application in civil engineering and the built environment, with increasing diffusion across multiple contexts. Although these technologies vary in maturity, prior studies report measurable improvements in project execution, monitoring, decision support, and environmental performance. Evidence from developing-country contexts further suggests that benefits can be realised even under infrastructure and funding constraints, provided that implementation is structured and supported through appropriate skills development, resourcing, and process integration. These characteristics make the selected tools appropriate for deeper investigation in relation to South African consulting practice.

Figure 1: Engineer using a drone on a construction site (Sky360 Aerial, 2023).

While UAVs offer potential value in construction monitoring and site inspection, the literature also reports several constraints that shape adoption in practice. In the South African construction context, barriers commonly include limited operator training and organisational capability, high initial procurement and maintenance costs, and uncertainty about return on investment—particularly where UAV use remains pilot-based. Regulatory requirements and variability in enforcement can further delay or prevent routine integration into site workflows. In addition, limited awareness of operational benefits and concerns about workforce displacement may contribute to reluctance and slower acceptance of UAV-enabled methods (Ikuabe et al., 2022).

Prior studies consistently identify training and capability as recurring constraints for UAV implementation and highlight that organisational readiness and regulatory compliance are often decisive during the transition from interest to routine use. However, there remains limited empirical clarity on how South African civil engineering consulting firms prioritise UAV adoption relative to other Industry X.0 tools, and how firms weigh UAV-specific barriers (skills, cost, regulation, and organisational acceptance) against broader digital transformation constraints. This study addresses that gap by examining awareness, adoption levels, perceived barriers, and preferred interventions across technologies, including UAVs.

The use of UAVs in civil engineering practices holds great promise, improving construction monitoring and project delivery, reducing risk, and enhancing efficiency. Civil engineering sector can better leverage the advantages of UAV technology by removing educational, financial, and cultural impediments to technology uptake.

2.2 Conceptualization and implementation of digital twins in civil engineering

Digital twins link physical assets with dynamic virtual models that can be updated using operational data streams, enabling monitoring, simulation, and decision support across the asset lifecycle. In built-environment applications, digital twins are commonly positioned as an extension of BIM-enabled information environments, supporting improved representation accuracy and more integrated lifecycle decision-making (Adebiyi et al., 2024).

The integration of sensor data—including Internet of Things (IoT) devices and computer-vision outputs—enables digital twins to support more responsive operational control and efficiency across project phases.

Digital twins are typically defined as virtual representations of real-world assets, systems, or processes that are continuously or periodically updated using data from the physical counterpart (Fuller et al., 2020). This capability allows practitioners to test scenarios, identify emerging risks, and evaluate interventions in a virtual environment before applying changes to the physical system, thereby reducing operational disruption and avoiding unnecessary real-world risk (Fuller et al., 2020).

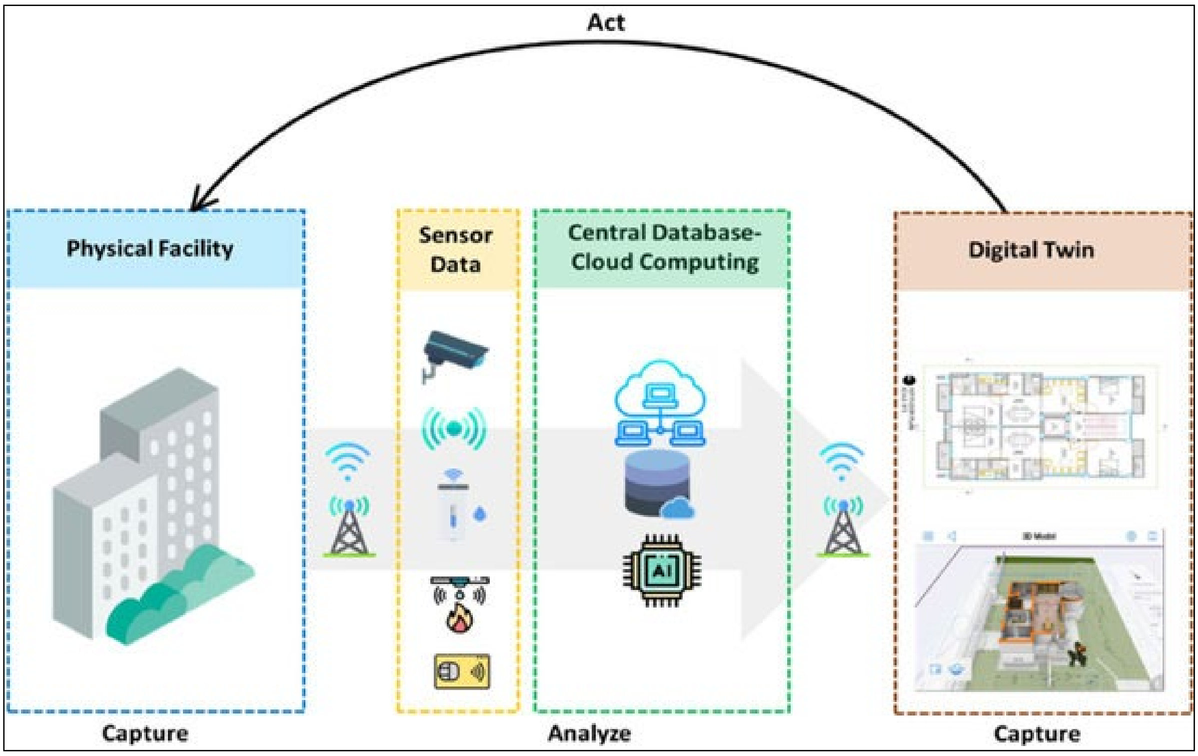


Figure 2: Framework for the implementation of Digital Twin in construction (El Jazzar, Piskernik and Nassereddine, 2020)

The literature reports digital twin applications across multiple phases of civil engineering projects:

- Design phase: Integration with BIM can strengthen visualisation, coordination, and risk-informed planning, supporting improved forecasting and decision quality (Adebiyi et al., 2024).
- Construction phase: Real-time data integration can support more responsive site decision-making, with potential improvements in scheduling, coordination, and resource allocation (Adebiyi et al., 2024).
- Operations phase: Continuous monitoring and predictive maintenance capabilities may extend asset service life by identifying deterioration trends and enabling earlier intervention (Adebiyi et al., 2024).

Despite these reported benefits, adoption is constrained by the complexity and scale of construction and infrastructure systems, the challenge of progressively developing models from early design through operations, and the need for interoperable information flows across project stages and toolchains (Adebiyi et al., 2024; Opoku et al., 2023). These constraints indicate that successful implementation depends not only on technical capability, but also on organisational readiness, governance, and integration approaches that support consistent data management across lifecycle phases.).

2.3 3D printing in civil engineering: enhancing project delivery through advanced technology

3D printing, also known as additive manufacturing (AM), is described in the literature as a construction method where three-dimensional forms are produced layer-by-layer from digital models. In civil engineering applications, this can involve materials such as concrete, plastics, or composite mixtures, which allows geometries that may be difficult to achieve using conventional construction methods. Kruger (2019) notes that 3D printing can support rapid prototyping and accuracy for design development tasks, particularly in architectural contexts.

A commonly reported application of 3D printing in civil engineering is the fabrication of components with complex shapes, including architectural elements and forms that require high dimensional precision. Studies also discuss its use in housing and building components, where potential advantages include reduced material waste and lower labour intensity for certain construction stages, depending on the printing approach and project conditions (McCoy & Yegagneh, 2021).

Existing evidence indicates that 3D printing is being explored in both industrial environments and research settings, with attention given to material efficiency and potential reductions in construction waste. NAIOP (2021) reports that additive manufacturing may shorten certain build activities and can influence cost outcomes, although performance depends on factors such as equipment costs, supply chain availability, required skills, and the suitability of the technology to the specific project type.

Overall, the literature frames 3D printing as an emerging construction technology with growing capability and interest, but with adoption shaped by practical constraints, readiness levels, and the fit between project requirements and the technology's current maturity.

2.4 Geographic information systems (GIS) in civil engineering

The management of spatial data in civil engineering is changing fast thanks to Geographic Information Systems (GIS). These tools combine hardware, software, and geographic info - not just store it but show it clearly. Engineers use them to explore connections and trends by viewing and testing datasets side by side. In practice, GIS enables engineers to compare datasets, identify spatial relationships, and explore trends that inform planning and design decisions. Prior studies report that GIS can improve precision and reduce manual effort across applications such as environmental assessment, route planning, and urban development (Perera et al., 2021).

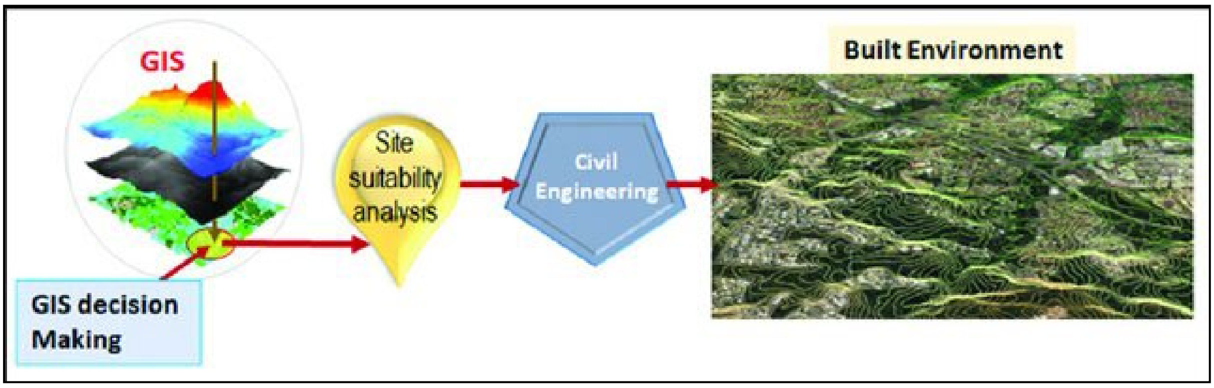


Figure 3: The link between GIS and civil engineering (Perera *et al*, 2021)

The civil engineering field experiences a transformation through GIS technology which delivers complex site selection capabilities together with environmental conservation and resource management tools. Urban planning benefits from GIS by integrating zoning information with traffic flow data and utility information and land use data which produces a comprehensive view that enables better decision making in the concept and design stages (Harahap et al., 2024). Studies confirm that GIS serves as a fundamental application in transportation engineering to create efficient road networks which cause minimal disruption to the environment. The geospatial technology is believed to serve as a vital component for flood risk assessment because it creates models that track water movement across landscapes and forecast vulnerable locations during storms which enables better mitigation strategies (Zhu *et al.*, 2018).

The use of GIS in civil engineering brings many benefits, yet comes with several challenges. A major issue arises when connecting GIS to CAD and BIM platforms, since both play key roles in planning and managing projects. Incompatibility among these systems often leads to inconsistent data outcomes and longer completion times - Zhu *et al.* (2018) point this out clearly. Ongoing training combined with agreed technical guidelines could help improve system interoperability. Smaller firms, or underdeveloped areas, may struggle to use GIS due to expense and technical demands. Civil engineering requires focused funding, cooperation between government and industry, also shared tech efforts - to overcome hurdles preventing GIS integration (Harahap *et al.*, 2024; Zhu *et al.*, 2018).

The current state of civil engineering relies heavily on Geographic Information Systems because these tools deliver advanced spatial analysis capabilities for making decisions. The strategic use of GIS technology will become essential for improving project results and environmental sustainability of construction activities as infrastructure complexity keeps rising. Future GIS development must prioritize creating user-friendly interfaces and integration functions to increase its adoption throughout all civil engineering applications.

2.5 Artificial intelligence in civil engineering

The development of artificial intelligence (AI) drives major changes throughout civil engineering practice because it optimizes materials and constructs buildings while handling administrative work. The implementation represents a technological advancement which produces improved project operations and strengthens construction outcomes (Govindaraju *et al.*, 2024).

By studying large amounts of data, AI forecasts material performance to improve building methods. Because of this, constructions can be long-lasting while also supporting sustainability goals. Using environmental impact assessments, artificial intelligence adjusts concrete parts and blends - ensuring they meet strength needs. These improvements rely on smart analysis rather than guesswork (Rabehi *et al.*, 2023).

The use of AI in robots, drones, or self-driving vehicles handles tasks from site scanning to moving materials or putting parts together - this increases efficiency while reducing errors and improving safety (Lagaros & Plevries, 2022).

A machine learning tool uses data patterns to check building conditions - predicting damage before it happens. So, repairs are planned early, cutting expenses while improving protection levels over time (Bhuva & Damdoo, 2023).Civil engineering faces multiple barriers during AI adoption including system integration difficulties and substantial initial expenses and traditional practice-related cultural resistance. Continuous professional development combined with industrial changes towards compatible infrastructure and acceptance of industry change will solve these barriers. The management of ethical concerns regarding data privacy and algorithmic bias requires strict standards and ethical guidelines according to Govindaraju *et al.* (2024).

The administrative functions within civil engineering show considerable enhancement with the utilization of AI technology beyond its applications within engineering. The integration of applications with AI technology ensures automation within report writing and management of emails, while checking document validity to comply with industrial standard formats. The efficiency thus achieved is imperative within project communication, with time being reduced and document validity ensured within large-scale projects (Rabehi *et al.*, 2023). The future of civil engineering is closely tied to advances in AI. As AI evolves, so will its impact on the discipline - enabling smarter solutions that align more effectively with global demands. These shifts are turning traditional approaches into ones that prioritize accuracy , efficiency, and environmental responsibility (Lagaros & Plevris, 2022).

2.6 Internet of things in civil engineering

In civil engineering, IoT systems are starting to reshape routine tasks. Where sensors go into structures or sit at job locations, data flows nonstop to analysis tools - so crews can follow how buildings behave, notice shifts in surroundings, while also tracking where key machinery is moving. Such linked networks lead to faster oversight responses; these setups usually boost both worksite protection and productivity (Budimirov *et al.*, 2022).

A major advantage shows up in monitoring structural condition. If sensors are placed on bridges or buildings, data flows directly to engineers - offering real-time performance instead of delayed check-ups. This visibility helps catch damage sooner, so fixes tend to be smaller while extending the overall life of the infrastructure (Mishra *et al.*, 2024).

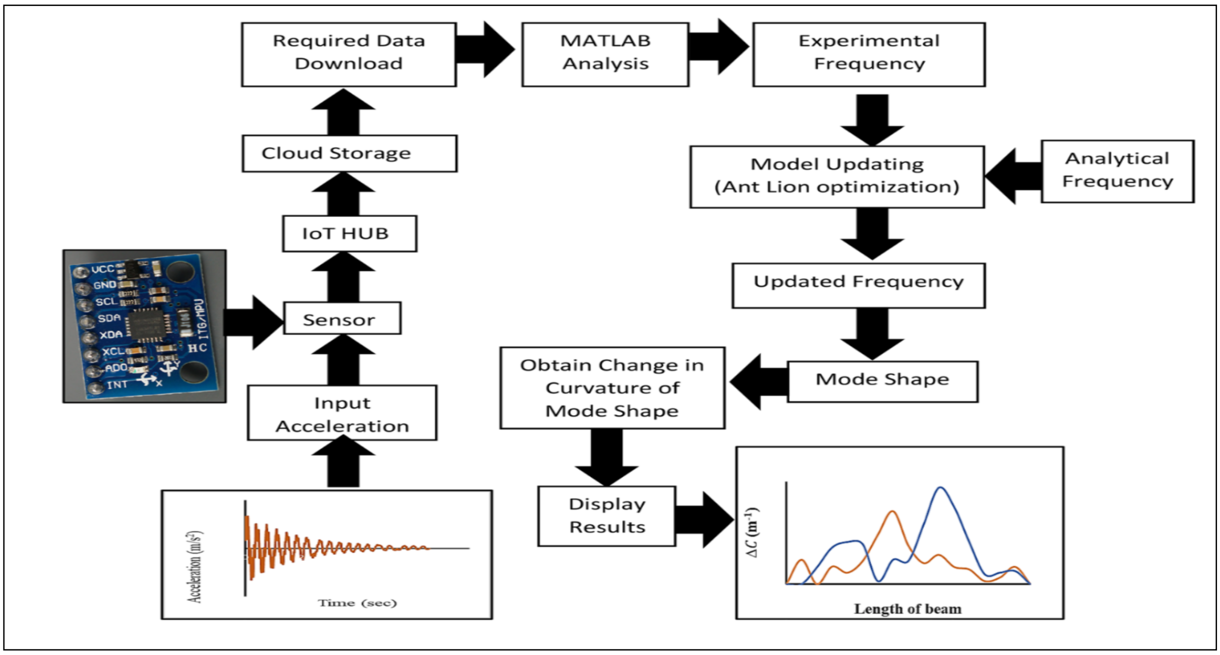


Figure 4: Comprehensive IoT environment: A proposed methodology for experimentation on two laboratory-scale civil engineering structures (Mishra *et al*, 2024)

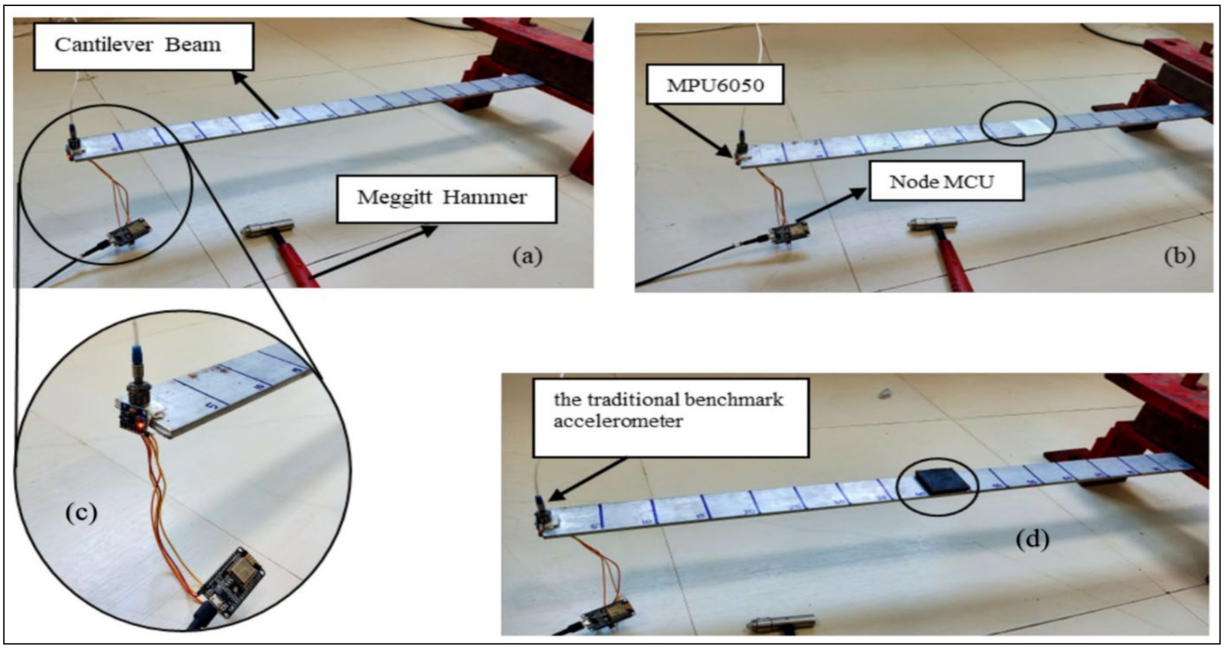


Figure 5 Comprehensive IoT environment: A proposed methodology for experimentation on two laboratory-scale civil engineering structures (Mishra *et al*, 2024)

In civil engineering, Internet of Things (IoT) systems are increasingly reported as influencing routine monitoring and site-control tasks. Where sensors are embedded in structures or deployed across project sites, continuous data streams can be transmitted to analytical platforms, allowing teams to observe structural behaviour, detect changes in environmental conditions, and track the status or movement of key equipment. The literature suggests that these connected networks can support faster oversight and response, with potential implications for site safety and operational efficiency (Budimirov et al., 2022).

A commonly cited application is structural condition monitoring. When sensors are installed on bridges or buildings, performance data can be received by engineers in near real time, reducing reliance on periodic inspections alone. This increased visibility may support earlier identification of deterioration, potentially enabling smaller interventions and contributing to improved asset life-cycle management (Mishra et al., 2024). However, studies also describe practical constraints to implementation, including cybersecurity risks, high data volumes requiring appropriate IT infrastructure, and the need to maintain sensor reliability, calibration, and data quality. These factors imply that effective adoption depends on data governance procedures and suitable technical capacity. Mishra et al. (2024) reported that relatively low-cost IoT sensors performed effectively in small-scale laboratory monitoring contexts, producing results comparable to conventional approaches at reduced cost. Budimirov et al. (2022) also discussed IoT-enabled networks in geodesy and related civil engineering applications, noting that real-time data exchange and automated processing can shorten decision cycles compared to more manual, traditional workflows.

Overall, the literature positions IoT as a developing capability in civil engineering that supports continuous monitoring and more data-driven maintenance and control, while highlighting that adoption and scaling depend on integration readiness, information security, and the skills required to manage sensor-based systems effectively.

2.7 In the NAIOP publication

The NAIOP Research Foundation, linked to a North American group focused on commercial property development, conducts key studies on changes and new ideas in constructed spaces. While its main interest lies in U.S. and Canadian markets, its findings matter worldwide - especially because it highlights tech advances, eco-friendly design, or better ways to manage projects; these same topics affect civil engineering in South Africa. A report by McCoy and Yeganeh (2021) outlines four game-changing tools reshaping building methods: off-site modular assembly, location-based digital systems, smart wearable gear, and BIM software. This segment examines each one, considering how they might work within local conditions across South Africa.

The civil engineering consultancy sector boosts performance and project outcomes by using modern construction tools. According to McCoy & Yegapeh (2021), as highlighted in NAIOP's report, key innovations include off-site modular building methods, digital mapping systems, on-body sensor devices, besides BIM platforms. Each and every one of these tech approaches brings unique advantages when applied to infrastructure projects across South Africa.

The modular method allows quicker assembly, cutting labour needs through streamlined processes. This approach works well in areas needing repeated layouts - such as clinics, disaster response units, or shops. For our South Africa's building industry, it offers faster results with lower spending and shorter timelines.

Geospatial tech relies on tools like GPS, along with remote sensing, to improve how sites are assessed and risks spotted during projects. When linked with BIM platforms, these systems support smarter planning - key for handling South Africa's varied terrain and challenging environments.

The use of wearables (tech like smartwatches or sensors) on building sites boosts safety while lifting work efficiency - through smart helmets, support suits, or tag tracking to monitor well-being, ease physical strain, and sharpen site awareness. Such tools show strong promise for strengthening protection measures where the industry in South Africa aims to make gains.

Building Information Modelling (BIM): BIM enables digital representations of physical and functional attributes of places which improves coordination between different stages of a project through better communication. The system provides enhanced capabilities for project management together with clash detection and cost estimation. BIM provides South African civil engineering companies with an efficient system to manage their resources while creating detailed visualizations that lead to better project decisions.

These tech tools are changing how building work is done in the industry and juxtaposed to traditional methods - helping teams connect more smoothly, run operations faster, and keep workers safer. Such cases show the field actively using new ideas to fix persistent problems. Firms in South Africa’s civil engineering space can deliver projects more effectively by embracing such advances, staying competitive as technology shifts around them.

2.8 Digital transformation in South Africa’s construction industry

The South African construction sector is reaching a turning point - digital tools could drive meaningful shifts. While BIM, IoT, and digital twins show promise, uptake stays low due to practical barriers. Implementation still lags behind expectations even though benefits are acknowledged across the field. Financial hurdles play a role; startup expenses scare off many firms. Gains in early stages seem uncertain, which weakens motivation. Workers often resist new systems, fearing job impacts or skill mismatches. These challenges overlap, creating complex roadblocks rooted in cost, clarity, and culture (Agarwal *et al.*, 2016; Taylor and Smith, 2000).

This section distinguishes between South Africa-based evidence and international studies used as comparative context; international sources are referenced to frame broader patterns, while South Africa-based studies are used to support local claims. International studies report that digital technologies could provide multiple useful applications for the construction sector in South Africa.

- Project Management Efficiency which means the combination of BIM and IoT systems enables real-time project monitoring which produces cost savings and shorter project durations.
- From a Risk Management perspective Digital twins and advanced analytics enable the prediction of structural problems and maintenance requirements which leads to better project safety and sustainability outcomes (Delgado *et al.*, 2019).

- When we think about labour and resource optimization, the implementation of robotics systems together with automation methods enables better resource distribution which leads to substantial reductions in waste production and labour expenses (Aghimien *et al.*, 2021).

Local digital technology implementation for the construction industry could come with multiple obstacles to overcome as reported by multiple international studies:

- Financial Constraints are a problem since many firms avoid technological investments because the high initial costs do not produce clear immediate financial returns.
- Resistance from a cultural perspective, Workers strongly believe that technological advancements will replace human jobs which creates opposition from the workforce (Mzekandaba and Pazvakav, 2018).
- Data Security Risks, the growing number of connected systems creates greater possibilities for data breaches and cyber-attacks which require organizations to establish strong cybersecurity protocols to defend their sensitive information (Pärn and Edwards, 2019).

The industry maintains a strong potential for digital transformation despite existing obstacles to adoption. According to reports and online articles, business leaders recognize digital technology's impact but express their unpreparedness for transition which demonstrates the necessity of educational programs to train the workforce for upcoming technological requirements (Accenture, 2019.).

2.9 Conclusion: Literature synthesis and research gap

Across Industry X.0 technologies, the literature reports potential gains in productivity, accuracy, coordination, and lifecycle decision-making, but also recurring constraints: high initial costs, limited digital skills, inadequate training pathways, organisational resistance, and interoperability challenges. South Africa-based evidence indicates uneven digital maturity, suggesting benefits are not realised without structured implementation support.

Despite growing global literature on individual technologies, limited empirical evidence exists that (i) benchmarks multi-technology awareness and adoption within South African civil engineering consulting firms, (ii) ranks barriers by perceived severity across firm sizes/experience levels, and (iii) synthesises these findings into a practical, locally grounded implementation framework. This study addresses these gaps through its survey analyses and framework synthesis.

CHAPTER THREE: RESEARCH METHODOLOGY

This study adopted a mixed-methods research design, which combined both quantitative and qualitative approaches to explore the barriers and strategies for the adoption of Industry X.0 technologies in civil engineering consulting firms in South Africa.

The quantitative approach included the use of a pre-developed survey that was administered to civil engineering professionals in consulting firms across South Africa. This method allowed for the collection of numerical data that was analysed statistically to identify trends, correlations, and the extent of Industry X.0 adoption. The survey's structured format provided uniformity in responses, which allowed for effective comparison between different subgroups, including firm size and geographic location.

The qualitative approach included open-ended questions with participating professionals to gain deeper insights into the perceptions, experiences, and challenges associated with adopting Industry X.0 technologies. Unlike structured surveys, open-ended questions enabled respondents to elaborate on their responses, providing rich contextual information that might not have been captured through quantitative methods alone.

This mixed-methods approach was justified because it allowed for a more comprehensive understanding of the research problem. While the quantitative component provided measurable trends and adoption patterns, the qualitative component offered explanatory depth, which helped to interpret the underlying reasons behind these trends. This approach enhanced the validity and reliability of the findings by ensuring that the research captured both broad statistical insights and nuanced industry perspectives.

Table 1: Objective–Method alignment

Objective	Data source (instrument items)	Analysis	Output
Objective 1: Identify the relevant Industry X.0 technologies applicable to South African civil engineering consulting firms	Survey items listing Industry X.0 technologies (e.g., BIM, GIS, UAVs/drones, IoT, AI, robotics/automation, digital twins, 3D printing), including items where respondents indicate awareness and current use; any open-ended item allowing respondents to mention additional technologies	Descriptive statistics: frequencies/percentages for awareness and use per technology; grouping into maturity tiers based on distribution patterns (e.g., established vs emerging vs aspirational); synthesis of any additional technologies from open-ended responses	Final set of technologies for the study; ranked/clustered technology list and maturity-tier classification (e.g., Established/Emerging/Aspirational) to frame subsequent analysis

Objective 2: Assess the level of awareness and adoption of Industry X.0 technologies among South African civil engineering consulting firms	Likert-scale items measuring awareness and adoption/use per technology (including frequency of use where available); respondent profile items (firm size, role/job category, years of experience) for subgroup comparisons	Descriptive stats (mean/median, % in high agreement categories if Likert); cross-tabulations by firm size/role/experience; optional association tests (e.g., chi-square for categorical comparisons) if you are reporting statistical significance	Technology adoption profile for the sector; adoption levels by technology and subgroup; charts/tables showing where adoption is concentrated and where it is low
Objective 3: Identify and rank the key barriers to adoption of Industry X.0 technologies	Barrier Likert-scale items (e.g., high costs, lack of technical skills, insufficient training programmes, resistance to change, workflow incompatibility, etc.); any open-ended question where respondents add barriers	Compute mean/weighted average barrier scores and rank barriers; compare barrier ratings by subgroups (firm size/experience/role); thematic coding of open-ended barrier statements to confirm/extend the barrier list	Barrier hierarchy (ranked list) with supporting statistics; subgroup insights (which barriers are most severe for which firms); consolidated barrier themes for interpretation
Objective 4: Develop a practical implementation framework to address the barriers and guide adoption	Items capturing preferred adoption strategies (e.g., workshops, online courses, demonstrations, partnerships), policy/industry recommendations (e.g., funding, BIM mandates, incentives), and open-ended recommendations; inputs from Objective 1–3 findings (adoption tiers + barrier ranking)	Synthesis method: map top barriers → preferred interventions → staged actions; thematic analysis of open-ended recommendations; triangulation between quantitative preferences and qualitative themes; convert synthesis into framework components, steps, and decision gates	Evidence-informed Industry X.0 adoption framework (diagram + explanation), including barrier-to-intervention mapping, implementation steps, adoption thresholds/decision gates, and guidance on scaling/institutionalising adoption

3.1 Population

The research focused on civil engineers employed in consulting firms throughout South Africa. The sampling was based primarily on the number of firms rather than the number of individual respondents. While the sampling frame aimed to ensure firm-level representation, individual responses were collected and analysed independently. This was because respondents from the same firm might hold different views, shaped by their roles, levels of experience, and exposure to Industry X.0 technologies. Such differences provided additional depth to the analysis by capturing a broader range of perspectives within firms.

The study required a minimum of 60 responding firms to generate significant and reliable findings. This threshold was determined using Cochran's formula (Cochran, 1977) for analysing finite population data. The population frame consisted of 580 consulting firms registered with Consulting Engineers South Africa (CESA, 2023). Using a 95% confidence level (Z = 1.96), maximum variability (p = 0.5), and a 10% margin of error (e = 0.1), the initial sample size was calculated as:

$$n_0 = \frac{Z^2 \times p \times q}{e^2} = \frac{1.96^2 \times 0.5 \times 0.5}{(0.1)^2} \approx 96\ (Cochran, 1977)$$

Applying the finite population correction (Bartlett *et al.*, 2001):

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{N}} = \frac{96}{1 + \frac{96 - 1}{580}} = \approx 83\ (Bartlett\ et\ al., 2001)$$

Although the statistical calculation indicated that 83 firms would be ideal, practical constraints—including anticipated low response rates and resource limitations—necessitated a lower minimum target.

As noted by Saunders *et al.* (2019), organisational survey response rates in developing economies often range between 20 % and 40 % due to time constraints and survey fatigue. For this mini-dissertation, completed as part of a course-based master's programme, it was therefore considered appropriate to set a lower limit of 60 respondents. While the questionnaire was distributed to professionals via their respective firms, there was no guarantee that each firm would provide a response. This threshold also aligned with thematic saturation principles for mixed-methods studies, which suggest that meaningful patterns can often be identified with responses from 50–60 participants or cases (Guest *et al.*, 2006).

The target population included civil engineering professionals at all levels. This encompassed senior decision-makers involved in project planning, design, construction, and maintenance, as well as junior engineers with direct, hands-on experience using value-creation tools. Including both groups was considered essential for assessing awareness levels, identifying adoption barriers, and proposing practical strategies for integrating Industry X.0 technologies into civil engineering practice.

3.2 Sample

The study employed stratified random sampling. The population of civil engineers was divided into subgroups (strata) according to relevant characteristics such as firm size (small, medium, large) and geographic location (urban and rural areas).

Respondents were then selected randomly from each stratum and received a link to participate in the survey. This approach ensured that each subgroup was adequately represented. It also enhanced the representativeness of the sample and captured the diversity of perspectives regarding Industry X.0 technologies, thereby increasing the reliability and generalisability of the study's findings.

3.3 Sample frame

The sample frame was constructed using databases and membership lists from professional bodies such as the South African Institution of Civil Engineering (SAICE) and Consulting Engineers South Africa (CESA), supplemented by other relevant industry sources. All civil engineers working in consulting firms were considered eligible to participate, thereby enabling the study to capture a wide and representative sample of the profession.

3.4 Sampling methods

Survey invitations were distributed via email to selected individuals within each stratum, in accordance with the stratified sampling method described in Section 3.2.

The sampling method incorporated voluntary participation, as recipients could choose whether to complete the questionnaire or decline. This approach combined methodological rigour with practical feasibility. After data collection, responses were analysed within the predefined strata, which distinguished between firm sizes and geographic regions, to identify patterns and variations in perspectives regarding Industry X.0 technologies.

3.5 Firm size:

- Small,
- medium, and
- large firms,

as different firm sizes often face unique challenges and resource constraints in adopting Industry X.0 technologies.

3.6 Specialization:

Participants represented various civil engineering disciplines (e.g., structural, geotechnical, environmental), as different disciplines could experience distinct barriers and opportunities in technology adoption.

3.7 Geographic location:

The adoption of new technologies in South Africa was expected to vary between urban and rural areas, as regional factors such as infrastructure access and local policies created differences in implementation.

A wide range of civil engineers from the specified groups received survey invitations via email through professional bodies, industry directories, and company contacts. The initial contact list was organised according to the stratified criteria, allowing respondents to choose whether to participate. This process resulted in a response pool that represented the diversity of the civil engineering community in South Africa.

The study aimed to gather a minimum of 60 voluntary responses to achieve statistically meaningful results. This minimum threshold was established to ensure adequate representation for each subgroup. The analysis of voluntary responses focused on subgroup comparisons between different firm sizes, specialisations, and geographic locations. This design allowed for a structured investigation of how these variables influenced Industry X.0 technology adoption.

3.8 Data collection methods

The main data collection tool was an online survey administered via Google Forms. This platform was chosen because it offered extensive reach, low cost, and straightforward data collection for both quantitative and qualitative information. The survey consisted of six distinct sections:

- Demographics and Firm Profile – This section collected participants' demographic information, including job title, experience level, firm size, and geographic region, to enable subgroup analysis.
- Knowledge of Industry X.0 Technologies – Participants' understanding of Industry X.0 technologies was assessed through Likert-scale items, focusing on areas such as

Building Information Modelling (BIM), Geographic Information Systems (GIS), drones, the Internet of Things (IoT), 3D printing, robotics, and digital twins.

- Barriers to Adoption – Multiple-choice and Likert-scale questions were used to identify perceived obstacles to adoption and to assess their level of importance.
- Adoption Strategies – This section allowed participants to select and rank potential solutions, as well as provide open-ended feedback on feasible approaches to implementation.
- Expected Advantages – Both quantitative measures (anticipated benefits) and qualitative responses (observed improvements from prior adoption experiences) were collected to evaluate the expected advantages of Industry X.0 technologies.
- Final Comments and Recommendations – An open-ended section invited participants to share additional thoughts, recommendations, or insights relevant to the study.

3.9 Data collection instruments

The survey instrument includes both closed-ended questions for statistical analysis and open-ended questions to gather qualitative insights (See APPENDIX A: QUESTIONNAIRE). The survey structure maintains uniformity in responses through its structure yet enables participants to share detailed thoughts about Industry X.0 adoption.

The research design of the questionnaire follows the research objectives to gather useful data about awareness levels and adoption barriers and potential strategies for Industry X.0 technology integration in civil engineering consulting firms in South Africa.

3.10 Data analysis

The built-in analytical tools of Google Forms will analyse quantitative data by producing automatic descriptive statistics about response distributions and averages and correlations. The analysis enables direct identification of patterns and essential elements affecting technology adoption. The qualitative data will undergo thematic coding to identify major themes which will provide valuable insights. The combination of qualitative analysis with Google Forms' automated features provides a detailed understanding of the data through efficient analysis.

3.11 Ethical considerations

The survey form includes an introductory statement which explains the research purpose to participants while requiring a consent checkbox for voluntary participation. The Google Forms secure encrypted system will collect data while responses will be anonymized before analysis. The raw data will be accessible only to authorized personnel. The research will follow CPUT ethical guidelines to protect participant rights and privacy from start to finish.

3.12 Data reliability and validity

The questionnaire's reliability will be assessed through pilot testing and the use of statistical measures (e.g., Cronbach's alpha) to ensure internal consistency.

Content validity will be ensured by consulting industry experts and academic advisors during the design phase. The construct validity will be examined via factor analysis during data analysis.

3.13 Limitations and delimitations

The study has some limitations which include response bias, non-response and the difficulty of reaching some subgroups within the civil engineering sector. The study is limited to consulting firms and therefore the results cannot be generalised to other sectors.

Delimitations: The study is limited to civil engineering consulting firms in South Africa and the adoption of Industry X.0 technology. This focused scope helps to ensure that the research is addressing solutions that are relevant to the chosen sector.

3.14 Expected outcomes:

According to the expected results of this study, it is hypothesized that there will be a low level of awareness and a low level of usage of Industry X.0 technologies by civil engineers in South Africa. It is anticipated that most engineers will be quite unfamiliar with technologies like BIM, IoT, 3D Printing and digital twins which are typical of the industry that has not yet fully embraced digital transformation. It is expected that the data will indicate that despite the fact that these technologies have the potential of improving efficiency, reducing costs and enhancing project delivery, their practical application is still low in consulting engineering firms. This indicates that although Industry X.0 technologies are acknowledged as beneficial, there are still systemic issues that limit their uptake.

It is likely to be found that one of the major impediments to the uptake of these technologies is the barriers that hinder their adoption. These could be considered as including cost of implementation, lack of technical skills, resistance to change, and insufficient training programs. It is expected that the small consulting firms will be faced with financial challenges that will make it difficult to embrace technology, while the large firms will have challenges related to change management and legacy systems that will hinder digital integration. Engineers may also argue that current policies and regulatory frameworks do not encourage or support the adoption of Industry X.0 technologies which can be attributed to the slow pace of their uptake.

Another result that is expected to be obtained is the evaluation of the proposed strategies to overcome these barriers. Engineers will assess the practicality of the recommended interventions including training programs, incentives, and a phased approach from the questionnaire responses. It is expected that specific training programmes will be considered as an essential measure in the creation of the required skills, and financial incentives in the form of tax incentives or subsidies will be regarded as useful in decreasing the cost for firms. The engineers' opinions will also offer further ideas that may have been overlooked in the initial study, thus improving the study's recommendations.

The study is set to end with the design of a specific adoption framework for South African consulting engineering firms. This framework will present a plan for the short-, medium- and long-term implementation of Industry X.0 technologies so that firms at various levels of technological development can easily identify and implement relevant and applicable measures for adoption. Furthermore, policy recommendations will be made to enhance the digital transformation of the industry and will include recommendations for both the private sector and the regulatory bodies on how to promote the change.

In general, it is believed that this study will underscore the necessity for consulting engineering firms in South Africa to adopt a more technological approach. The results will probably reveal that unless interventions are put in place, the industry will be left behind in terms of global developments that may affect competition, efficiency and sustainability. This research will validate the strategies through direct industry feedback, and will, therefore, provide practical and implementable recommendations for firms on how to effectively incorporate Industry X.0 technologies in their operations.

3.15 Contribution of this research:

The research adds value to academic knowledge and industry practices and policy formulation and societal development by providing empirical evidence and practical suggestions on the adoption of Industry X.0 technologies in South African civil engineering consulting firms. This study aims to enhance the industry's technology-driven, competitive and sustainable nature through a systematic assessment of technology awareness, adoption barriers and feasible strategies.

3.16 Societal contributions

The results of this research have implications for the promotion of sustainable and resilient infrastructure development in the society. The study facilitates the adoption of advanced construction technologies that support environmentally friendly practices, improved resource management and waste reduction. The integration of Industry X.0 technologies can result in better-designed, safer and more durable infrastructure which will benefit urban development, public safety and long-term economic growth.

This research will catalyse the digital transformation of the South African civil engineering sector by providing practical, industry-validated strategies for overcoming adoption barriers. The study will contribute to a more innovative, efficient and sustainable future for civil engineering in South Africa by addressing the needs of academia, industry, policymakers and society.

This research aims to bridge the gap between barriers to adopting Industry X.0 technologies in civil engineering and the practical, actionable strategies needed for effective integration in South African consulting firms. The study will provide a nuanced understanding of the unique challenges faced by civil engineers in South Africa by verifying the consensus on these barriers through a stratified sampling approach and collecting data via a comprehensive questionnaire.

The research design, which encompasses preliminary research, systematic data collection, rigorous data analysis, and iterative strategy development, is structured to ensure that the final recommendations are both evidence-based and directly applicable to industry practices. The outcomes are expected to not only inform the academic community but also guide industry practitioners and policymakers toward a more digitally integrated future.

This study will contribute significantly to the ongoing digital transformation within the civil engineering sector by offering practical solutions that enhance project efficiency, reduce costs, and improve competitiveness in a rapidly evolving global market. Future follow-up studies will further refine these strategies, ensuring their continued relevance and effectiveness as technology advances.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction to survey results

This chapter outlines the results obtained from a comprehensive survey aimed at assessing the obstacles and approaches for the integrating Industry X.0 technologies in South African civil engineering consulting firms. The survey sought to capture both qualitative and quantitative information across five primary areas: (1) industry awareness and adoption of Industry X.0 technologies, (2) implementation challenges, (3) strategies to overcome challenges, (4) perceived value and realized value, and (5) policy and industry recommendations Level initiatives to foster support.

The survey was conducted using Google Forms, which were shared with employees across different hierarchical levels in South African civil engineering consulting firms. The sample population was built from engineers, technicians, technologists, and management staff who were part of project delivery units and were active in the technology-related decision-making processes. The survey was organized into five sections capturing specific thematic areas and utilized the Likert scale as well as multiple-choice and open-ended questions.

During the duration of the survey, responses peaked at 90. These responses went beyond the predetermined figure of 60 participants, which was derived using Cochran’s formula meant for finite population sampling and based on principles concerning thematic saturation within mixed-methods research.

Slightly more than half of the respondents had more than 5 years of working experience in the civil engineering domain.

To ensure the results explicitly address the study objectives, the findings are presented in an objective-driven structure. Objective 1 is addressed by identifying and classifying the Industry X.0 technologies reported by respondents (technology set and maturity tiers). Objective 2 is addressed by the awareness and adoption results for each technology, including subgroup comparisons where applicable. Objective 3 is addressed through the ranked barrier results (mean scores and ordering) and any supporting qualitative barrier themes. Objective 4 is addressed through the preferred strategies, additional recommendations, and policy/industry initiatives, which are synthesised to inform the implementation framework presented in Chapter 5.

4.2 Respondent demographics

The chart in the next page represents the respondent demographics based on their current job titles, derived from 90 responses. The largest group, 78.9%, consists of

Engineer/Technician/Technologist. Other notable job titles include Civil Engineering Project Managers at 8.9%, with the remaining 12.2% distributed across various roles such as Technical Specialists, a Business Owner, Academic, Directors, an Operations Director, a Supply Chain Manager, a Graduate Trainees, Town Planner Managers, and a Researcher. This distribution highlights a predominantly Engineer/Technician/Technologist-heavy sample, with a diverse mix of other professional roles who also shared their input.

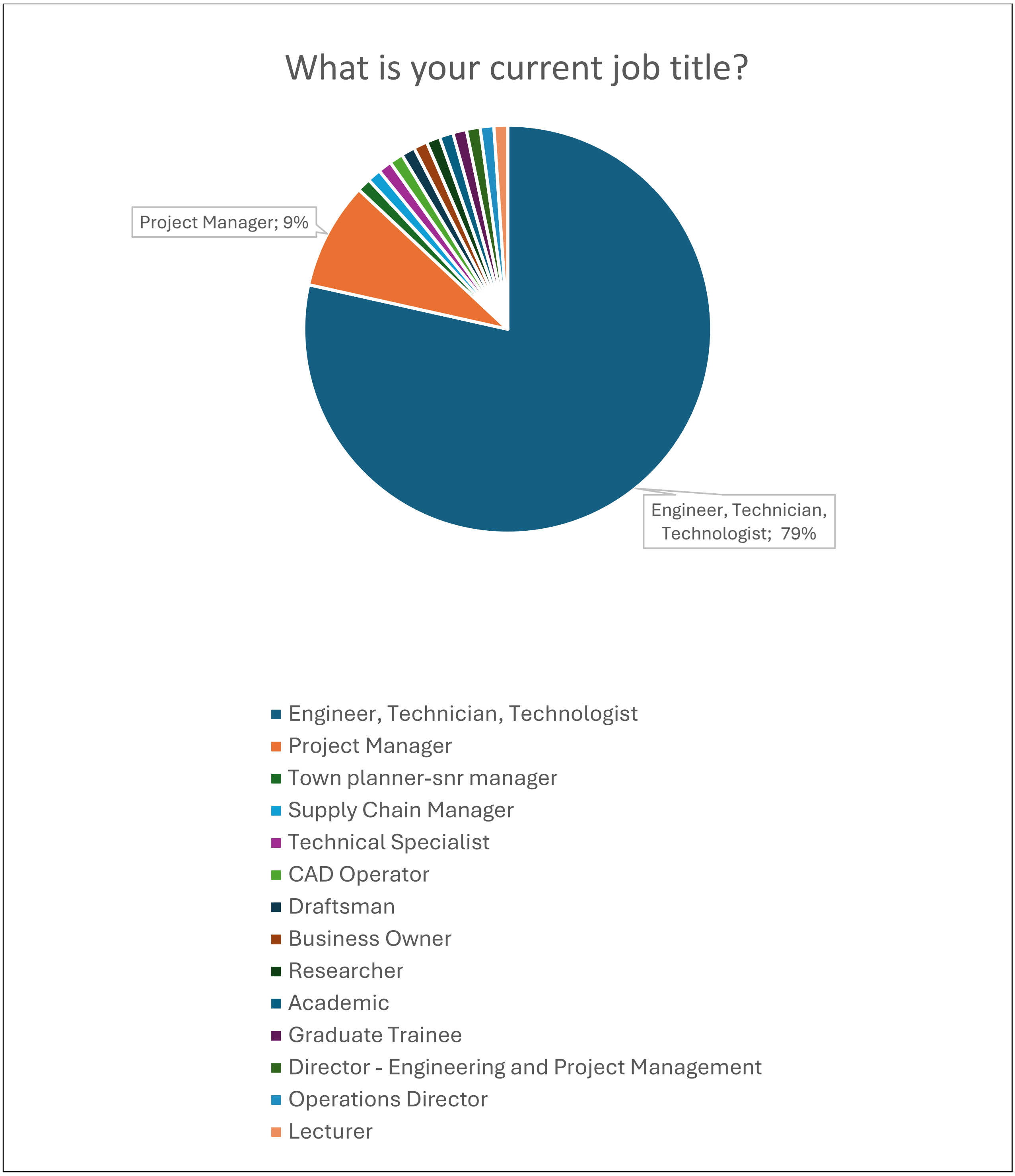


Figure 6: Distribution of Respondent Job Titles in South African Civil Engineering Consulting Firms

These respondents are well-suited to achieve the study's results due to their strong representation of technical and engineering expertise, particularly among

Engineer/Technician/Technologists, who likely possess hands-on knowledge and experience relevant to the study's focus and work with value creation tools such as Civil 3D etc. The inclusion of Civil Engineering Project Managers and other specialized roles such as Technical Specialists and Directors adds valuable insights into project management, operational strategies, and industry applications, enriching the data so that it also gives us a view of the more senior and seasoned personnel who can add insights into company vision and so forth. Additionally, the diverse mix of professionals, including Academics and Researchers, ensures a blend of theoretical and practical perspectives, enhancing the study's depth and credibility in delivering meaningful outcomes and also allows us to understand how the academia views adoption in Civil engineering consulting firms.

4.3 Job titles and experience levels

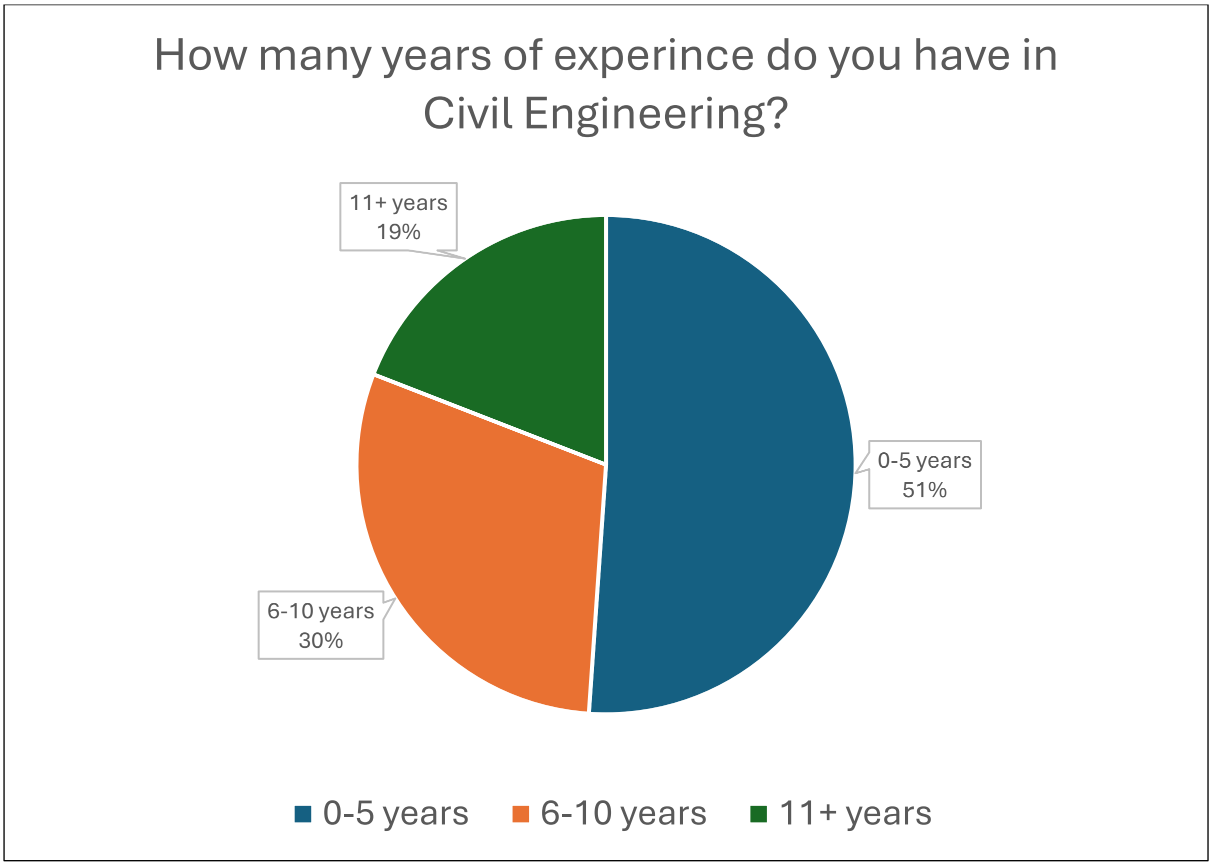


Figure 7: Professional Experience Levels of Survey Respondents in Civil Engineering

Figure 7 illustrates the distribution of experience levels in civil engineering among 90 respondents, revealing a diverse sample that spans early-career engineers to senior industry veterans. The largest group, 51.1%, has 0-5 years of experience, likely familiar with Industry X.0 concepts like IoT and AI from academic training, providing insight into which tools are practically used versus those that remain theoretical. Mid-level professionals with 6-10 years of experience make up 30% of the sample, often acting as change champions or gatekeepers in their organizations, offering transitional perspectives on technologies taught in university but not yet mainstream in practice. The remaining 18.9% with over 10 years of experience include senior engineers, project managers, and directors who have witnessed multiple technology waves—such as CAD evolving into BIM and the integration of IoT—capturing the challenges of change management by comparing past transitions (e.g., AutoCAD to Revit) to current shifts (e.g., adopting digital twins) and identifying successful or failed approaches.

4.4 Firm sizes and geographic distribution

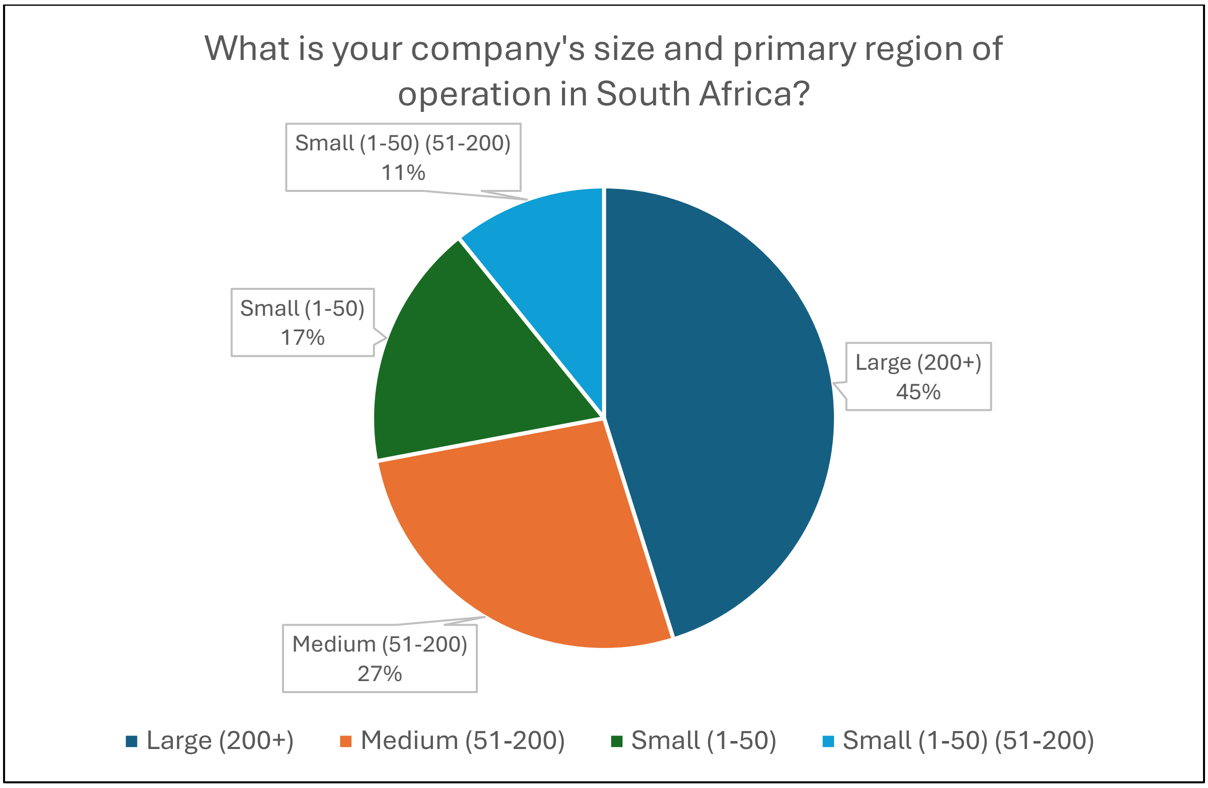


Figure 8: Company Size and Regional Distribution of Participating Firms

The chart provides insight into company size and primary region of operation in South Africa, based on 89 responses, highlighting a diverse business landscape in the civil engineering sector. The largest group, 46.1%, consists of large companies with 200+ employees, which often have dedicated IT or innovation units and substantial training budgets, which may have enabled them to pilot comprehensive tools like a full BIM environment (Mtya and Windapo, 2019). This is followed by 25.8% from medium-sized companies (51-200 employees), typically with one or two internal champions for digital initiatives but operating under tighter budgetary constraints (Adekunle *et al.*, 2023). Small firms with 1-50 employees account for 16.9%, where technology adoption often hinges on clear return on investment or direct client demand. An additional 11.2% of respondents selected the “Small (1-50) (51–200 employees)” category, this was a mistake on the Google Forms that was detected and fixed after distributing the forms and confused about 10 respondents. In fact, this category, which appears to duplicate the medium-sized classification; for analytical purposes, these responses have been merged with the 51-200 bracket, bringing the total for medium-sized firms to 37%. This distribution across firm sizes is essential, as it allows comparison of barriers and strategies: large firms may focus on aligning departments and managing change, while medium and small consultancies are often more sensitive to upfront capital costs, licensing fees, and lost billable hours during training.

4.5 Which region is your office based?

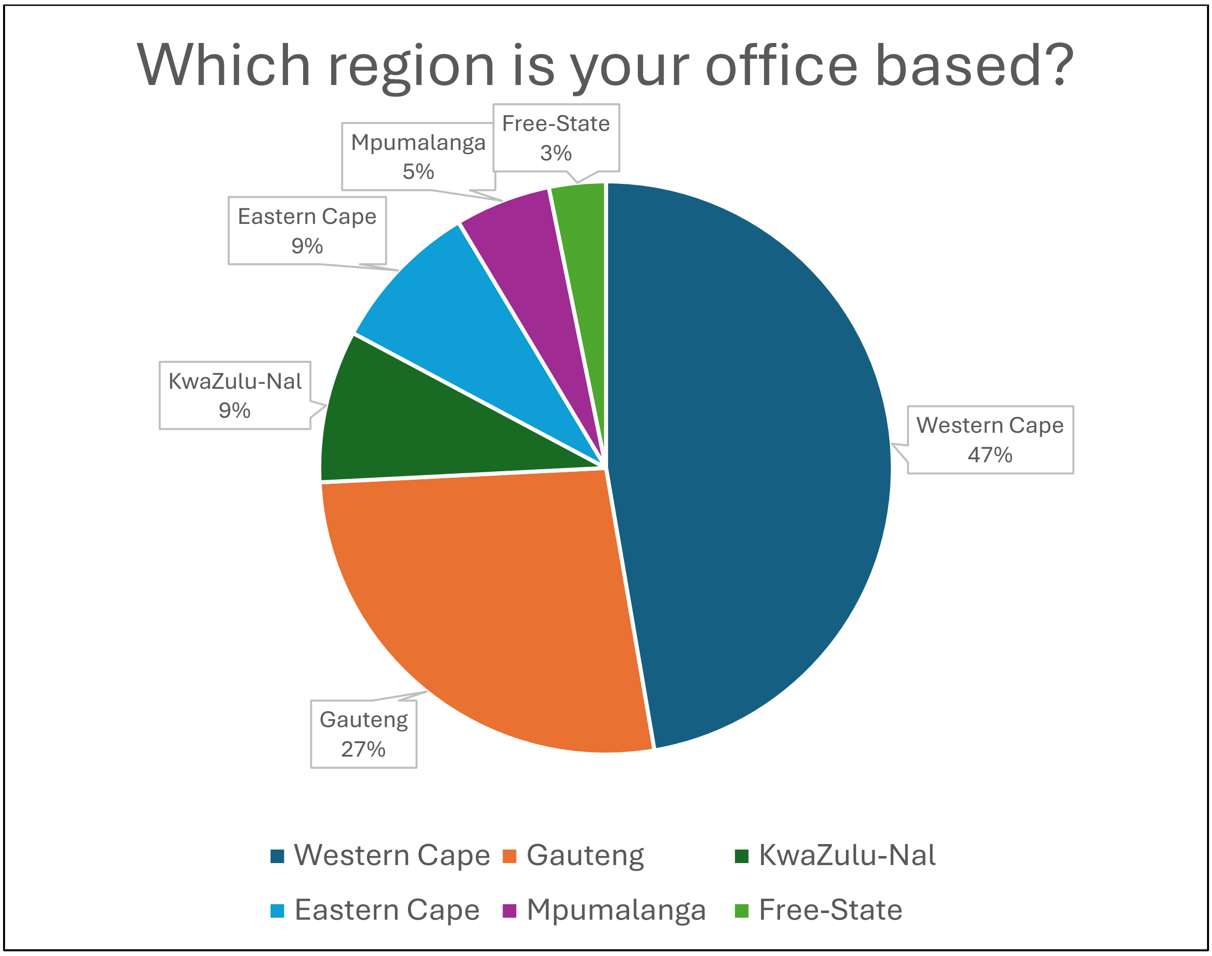


Figure 9: Provincial Representation of Civil Engineering Consulting Respondents

The researcher is based in the Western Cape, so it is unsurprising that nearly half of the respondents—47.2%—operate there, as the professional network has naturally been strongest in Cape Town over the course of the researcher's career. Among the remaining 89 valid responses, the other provinces were represented as follows: Gauteng (27.0%), Eastern Cape (9.0%), KwaZulu-Natal (6.7%), Mpumalanga (5.6%), Free State (3.4%), and Northern

Cape, Limpopo, and North West each at approximately 1.0%. Western Cape and Gauteng together account for over 70% of consulting firm respondents in this questionnaire. However, the survey was distributed widely and completed on a voluntary basis, meaning that the geographic spread does not necessarily reflect each region's actual rate of Industry X.0 adoption. Nonetheless, including perspectives from all nine provinces ensures a more comprehensive analysis in the sections to follow.

4.6 Awareness and adoption levels of industry x.0 technologies

Respondents rated their familiarity and use of seven key Industry X.0 technologies—Building Information Modelling (BIM), Geographic Information Systems (GIS), Drones (UAVs), Internet of Things (IoT), 3D Printing, Robotics & Automation, and Digital Twins—on a five-point Likert scale, where 1 signifies "Not at all familiar/useful" and 5 signifies "Highly familiar/well adopted." Each subsection below summarizes the bar-chart distributions and provides an interpretation of what these figures imply for the South African civil engineering consulting sector.

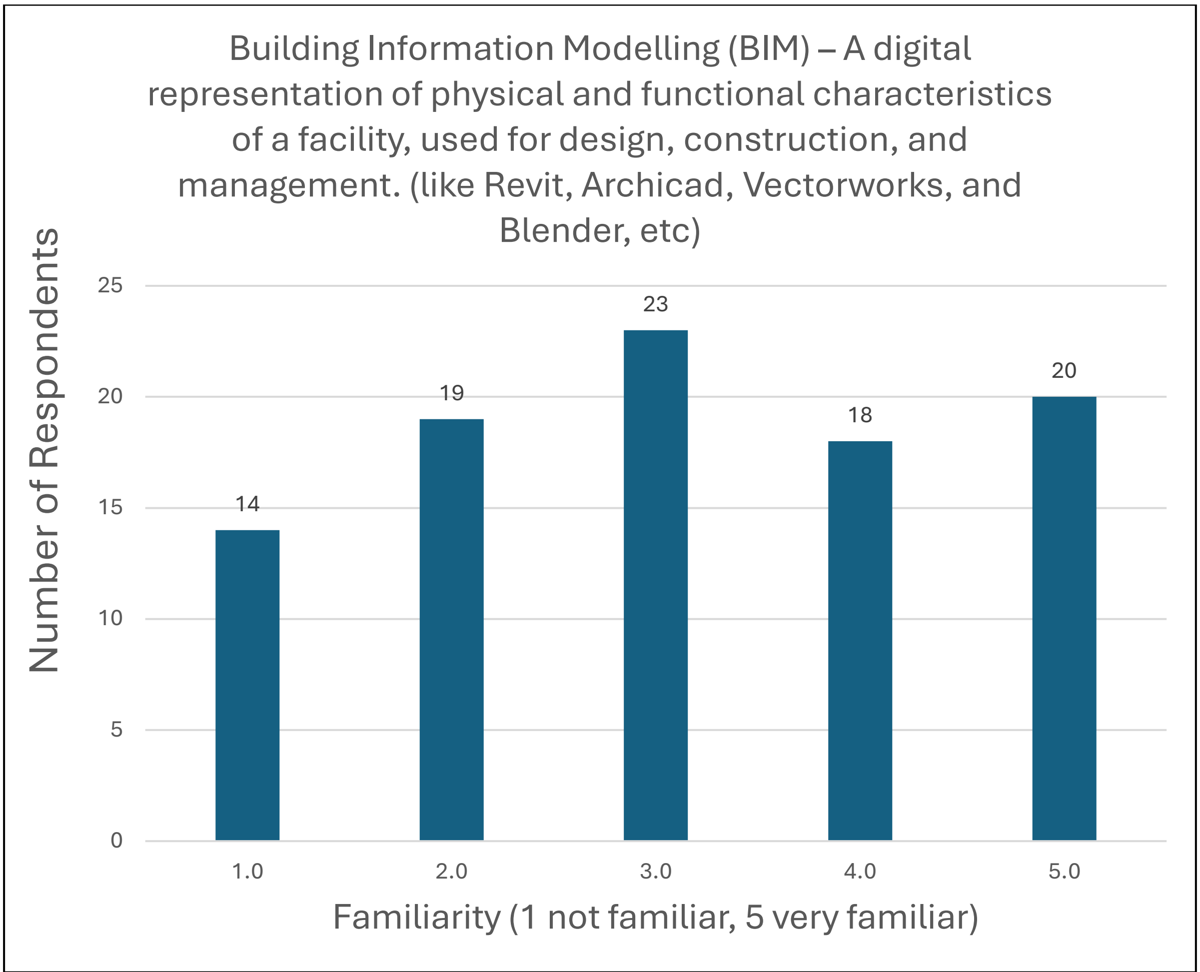


Figure 10: Respondent Familiarity and Adoption of Building Information Modelling (BIM)

Approximately 64.4 % of participants scored BIM at 3, 4, or 5, indicating moderate to strong familiarity and use. This confirms that BIM has become a well-known tool in South African consulting practices—likely driven by a decade's worth of software training programs, client requirements (especially for larger infrastructure projects), and published best-practice guidelines.

Nonetheless, the 35.6 % who rated BIM at 1 or 2 suggest that one in three consulting professionals either has little exposure to BIM or does not use it regularly. In particular, smaller firms or those serving clients who do not mandate BIM appear to lag behind, keeping BIM adoption from being truly universal.

In essence, the data indicate that BIM is firmly established in many larger consultancies but remains a growth opportunity among mid- and small-sized firms that have not yet integrated it into their standard workflows.

A cross-tabulation of BIM familiarity across firm size, experience, region, and current role shows clear patterns of adoption and opportunity. Large consultancies (200 + staff) report the strongest uptake, averaging a score of 3.50 with 52.50 % rating themselves 4–5, while medium firms (51–200) sit at 2.82 (33.33 % high) and small practices (1–50) at 2.86 (28.57 %). By tenure, mid-career engineers (6–10 years) lead slightly with 3.19 mean (44.44 % high), followed by both early-career (0–5 years, 3.12, 39.53 %) and senior professionals (11+ years, 3.12, 41.18 %). Regionally, Gauteng and Mpumalanga shine (means 3.62 and 3.60, high-rating 58.33 % and 60.00 %), whereas KwaZulu-Nal and Free-State trail at 2.71/14.29 % and 2.67/33.33 %. Finally, by role, Graduate Trainees and Academics top out at perfect high ratings (mean 5.00/4.00), Engineer/Technologist groups average 3.19 with 42.03 % high use, and Project Managers are lower at 2.38 (25.00 %). These insights point to prime targets for BIM upskilling—especially within medium-sized firms, certain provinces, and among project managers—to drive more universal adoption.

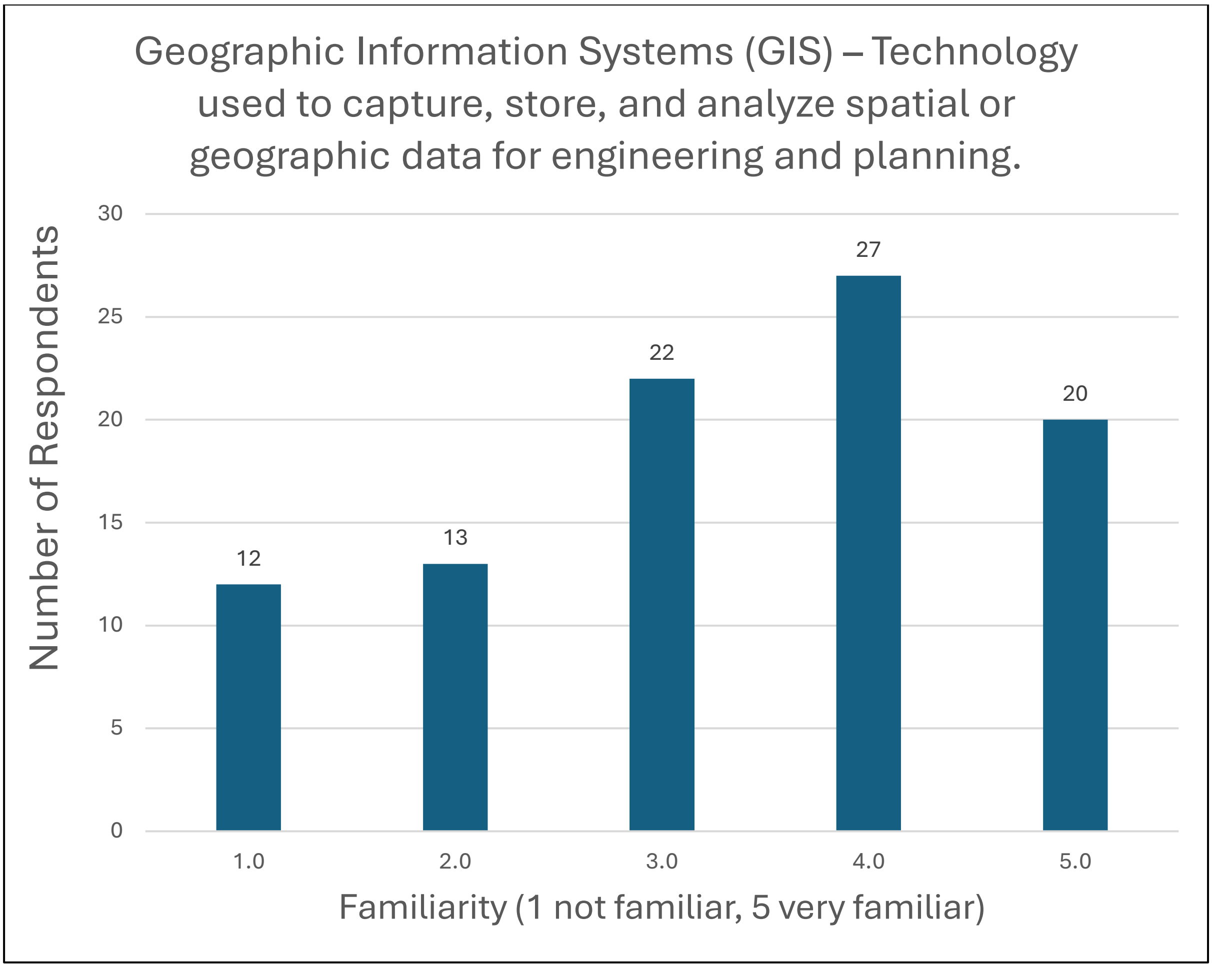


Figure 11: Familiarity and Adoption of Geographic Information Systems (GIS) Among Respondents

Approximately 73.3 % of respondents rated their GIS familiarity at 3 or higher, with half (50.0 %) assigning top scores of 4 or 5. Only 26.6 % remain at the 1–2 (“not familiar” to “slightly familiar”) end of the scale, demonstrating that GIS is firmly embedded in most firms’ workflows. The strong mid-to-high ratings reflect the technology’s critical role in tasks such as site analysis, flood modeling, and infrastructure planning—functions that are increasingly mandated by municipal and government tenders. The 23.3 % of respondents at a neutral rating of 3 represent an opportunity for targeted upskilling: by investing in advanced GIS training (e.g., 3D spatial analytics, cloud-based geodatabases) and fostering data-sharing platforms, consultancies can convert these “on-the-fence” users into full adopters and further enhance project delivery efficiency.

This entrenched adoption of GIS aligns with findings by Perera *et al* (2021), who highlight GIS as an essential tool for civil engineering education and practice, particularly in developing contexts. Zhu *et al.* (2018) demonstrate how GIS integration enhances flood risk modelling and environmental assessments, while Harahap *et al.* (2024) emphasize the benefits of cloud-based geodatabases and advanced spatial analytics for infrastructure planning. Moreover, Laryea (2019) notes that many South African government tenders now explicitly require GIS deliverables, solidifying its status as a baseline competency for consulting firms.

A cross-tabulation of GIS familiarity by company size, experience, region, and role shows where adoption is strongest and where targeted upskilling could pay off. Large firms (200+ staff) lead with a mean score of 3.70 and 65.00 % rating themselves 4–5, followed by small practices (1–50 staff) at 3.21 (35.71 %) and medium consultancies (51–200) at 3.06 (42.42 %). By tenure, mid-career engineers (6–10 years) are most familiar (3.67, 59.26 %), with senior professionals (11+ years) close behind (3.59, 58.82 %), and early-career practitioners (0–5 years) at 3.12 (44.19 %). Regionally, KwaZulu-Nal firms report the highest uptake (4.00, 71.43 %), followed by Gauteng (3.62, 58.33 %), Eastern Cape (3.50, 50.00 %), Mpumalanga (3.40, 40.00 %), Western Cape (3.15, 47.50 %), and Free-State (2.67, 33.33 %). Among roles, Engineer/Technologist respondents (n = 69) average 3.33 with 49.28 % high ratings, Project Managers (n = 8) 3.12 (50.00 %), and specialist roles—Academics, Graduate Trainees, Directors, Researchers, Supply Chain Managers, and Technical Specialists—often hit 4.00–5.00 (100 % high), though with low counts. These patterns suggest focusing GIS training in medium-sized firms, early-career engineers, and lower-adoption provinces to drive universal competence.

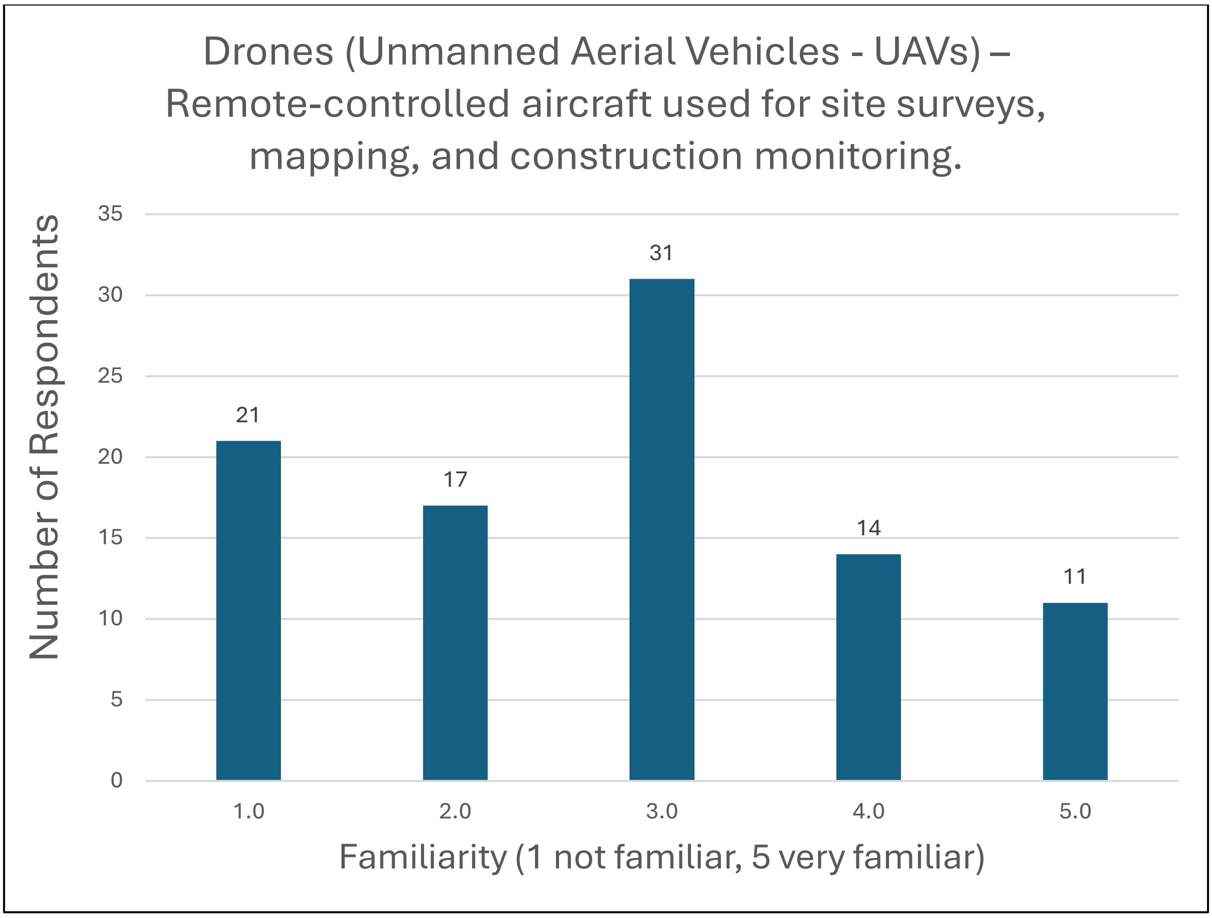


Figure 12: Use and Awareness of Unmanned Aerial Vehicles (Drones) in Civil Engineering Firms

The distribution for drones shows that only 26.7 % of respondents rate their familiarity or use at 4–5, while 38.9 % fall at 1–2 and the plurality (34.4 %) select a neutral 3. In concrete terms, 22.2 % report virtually no engagement (rating 1) and just 11.1 % consider UAVs highly adopted (rating 5). This pattern suggests that, although many firms recognise the theoretical value of drones for rapid site surveying and volumetric analyses, actual implementation remains limited. Barriers commonly cited in the literature include the upfront capital cost of drone hardware, regulatory hurdles around flight permissions, and the need for specialized operator training (Ikuabe *et al.* 2022; Aghimien *et al.* 2021). Where drones are deployed—typically in larger consultancies or specialised surveying teams—projects benefit from centimetre-level topographic accuracy and faster progress monitoring (Ikuabe *et al.* 2022). To bridge the current adoption gap, respondents—and prior studies—recommend subsidised pilot programmes, simplified civil-aviation approvals, and collaborative training partnerships between firms and certified drone-training providers (Mishra *et al.* 2024).

A cross-tabulation of drone (UAV) familiarity by company size, years of experience, region, and current job title highlights where uptake is strongest and where targeted interventions could accelerate adoption. Small firms (1–50 staff) report a mean familiarity score of 2.53 with 20.00 % rating themselves 4–5, mid-sized consultancies (51–200 staff) lead slightly at 2.91 (30.30 %), and large firms (200+ staff) sit at 2.78 (26.83 %). By experience, senior professionals (11+ years) show the highest adoption (3.29, 41.18 %), followed by mid-career engineers (6–10 years) at 3.00 (29.63 %) and early-career practitioners (0–5 years) at 2.45 (20.45 %). Regionally, Mpumalanga stands out with 4.00 mean and 80.00 % high-ratings, Gauteng follows at 3.17 (45.83 %), while Western Cape (2.62, 17.50 %), KwaZulu-Natal (2.57, 14.29 %), Eastern Cape (2.50, 12.50 %), and Free-State (1.67, 0.00 %) lag. Among roles, Engineer/Technologist respondents (n = 69) average 2.80 with 26.09 % high ratings, Project Managers (n = 8) 2.25 (12.5(Familiarity (1 not familiar, 5 very familiar) mics and Business Owners remain low or have no high ratings. These findings suggest prioritizing subsidized pilot programs, streamlined approvals, and specialized training—particularly in smaller firms, among newer engineers, in under-adopting regions, and for core practitioner roles—to bridge the UAV implementation gap.

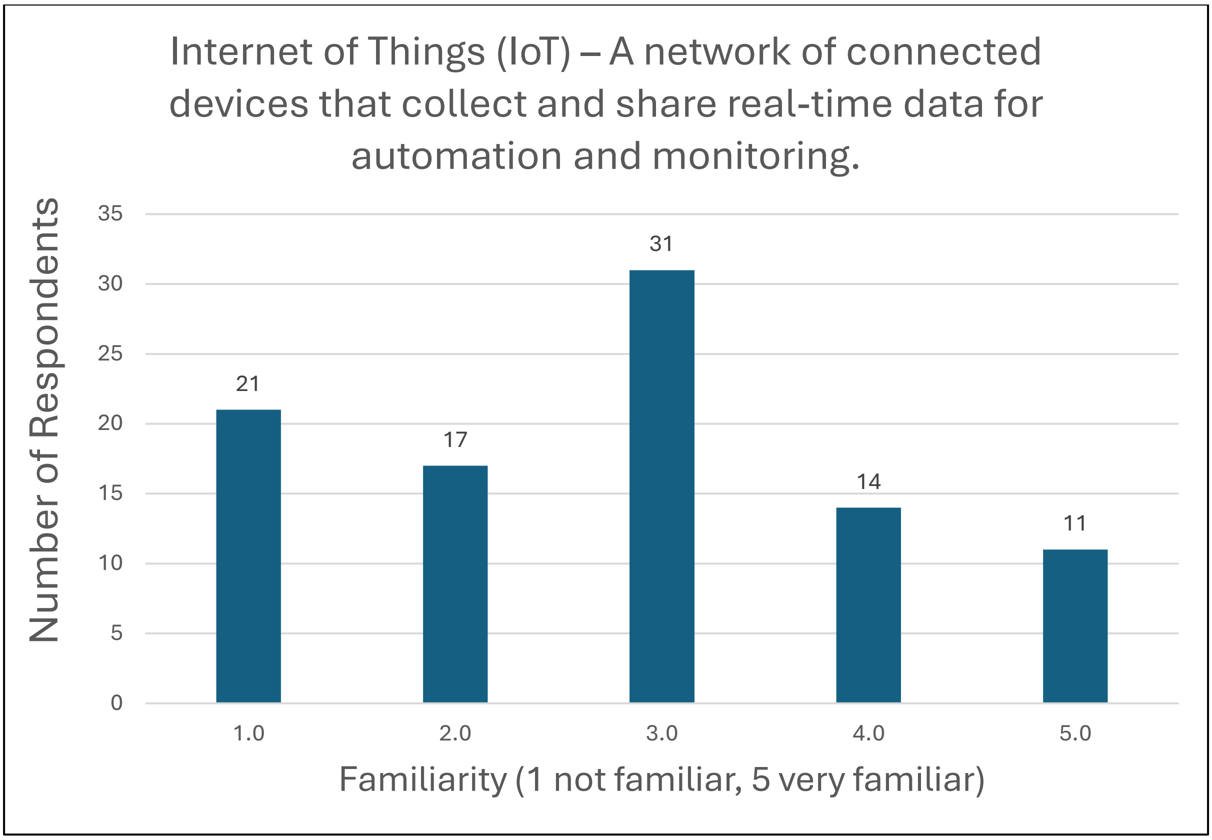


Figure 13: Familiarity and Adoption Levels of Internet of Things (IoT) in Civil Engineering

The IoT familiarity and adoption distribution is markedly bipolar: 47.8 % of respondents rate their use at 1–2 (25 at “1” and 18 at “2”), indicating minimal awareness or deployment, while 33.3 % rate it at 4–5 (21 at “4” and 9 at “5”), reflecting a committed early-adopter segment. The remaining 18.9 % sit at a neutral “3,” suggesting pilots or exploratory use. This pattern underscores that IoT remains at an emerging stage in South African consulting: a third of firms have implemented sensor networks for structural health monitoring and environmental data capture, but nearly half have yet to integrate real-time connectivity into their workflows. Common barriers—high sensor and platform costs, data-management uncertainty, and a dearth of in-house expertise—echo findings by Budimirov *et al.* (2022) and Mishra *et al.* (2024). To accelerate adoption, respondents and the literature recommend subsidised demonstration projects that showcase clear ROI (e.g., reductions in unplanned maintenance), streamlined vendor-partner training schemes, and shared data-infrastructure hubs to lower entry costs (Mishra *et al.* 2024; Budimirov *et al.* 2022).

A cross-tabulation of IoT adoption across firm size, experience, operating region, and current job role reveals distinct patterns. Small consultancies (1–50 staff) lead with an average familiarity score of 3.07 and 46.67% rating themselves 4–5, followed by large firms (200+ staff) at 2.95 mean and 43.90%, while medium-sized firms (51–200 staff) trail at 2.21 mean and only 15.15% high-ratings. By tenure, senior engineers (11+ years) report the highest mean (3.29) and 41.18% high use, mid-career professionals (6–10 years) average 3.00 with 29.63%, and early-career practitioners (0–5 years) come in at 2.43 mean and 19.57%. Regionally, Mpumalanga–based firms show the strongest uptake (3.80 mean, 60.00% high), followed by KwaZulu-Natal (3.43, 42.86%) and Gauteng (3.17, 50.00%), while Western Cape (2.31, 21.43%), Eastern Cape (2.12, 25.00%) and Free-State (2.00, 33.33%) lag behind. Finally, by job title, Operations Directors and Supply Chain Managers (both n = 1) report perfect familiarity (mean 5.00, 100.00%), Academics and Business Owners similarly score 4.00 (100.00%), Engineer/Technician/Technologists (n = 71) average 2.72 with 32.39% high-ratings, and Project Managers (n = 8) average 1.62 with 12.50%.

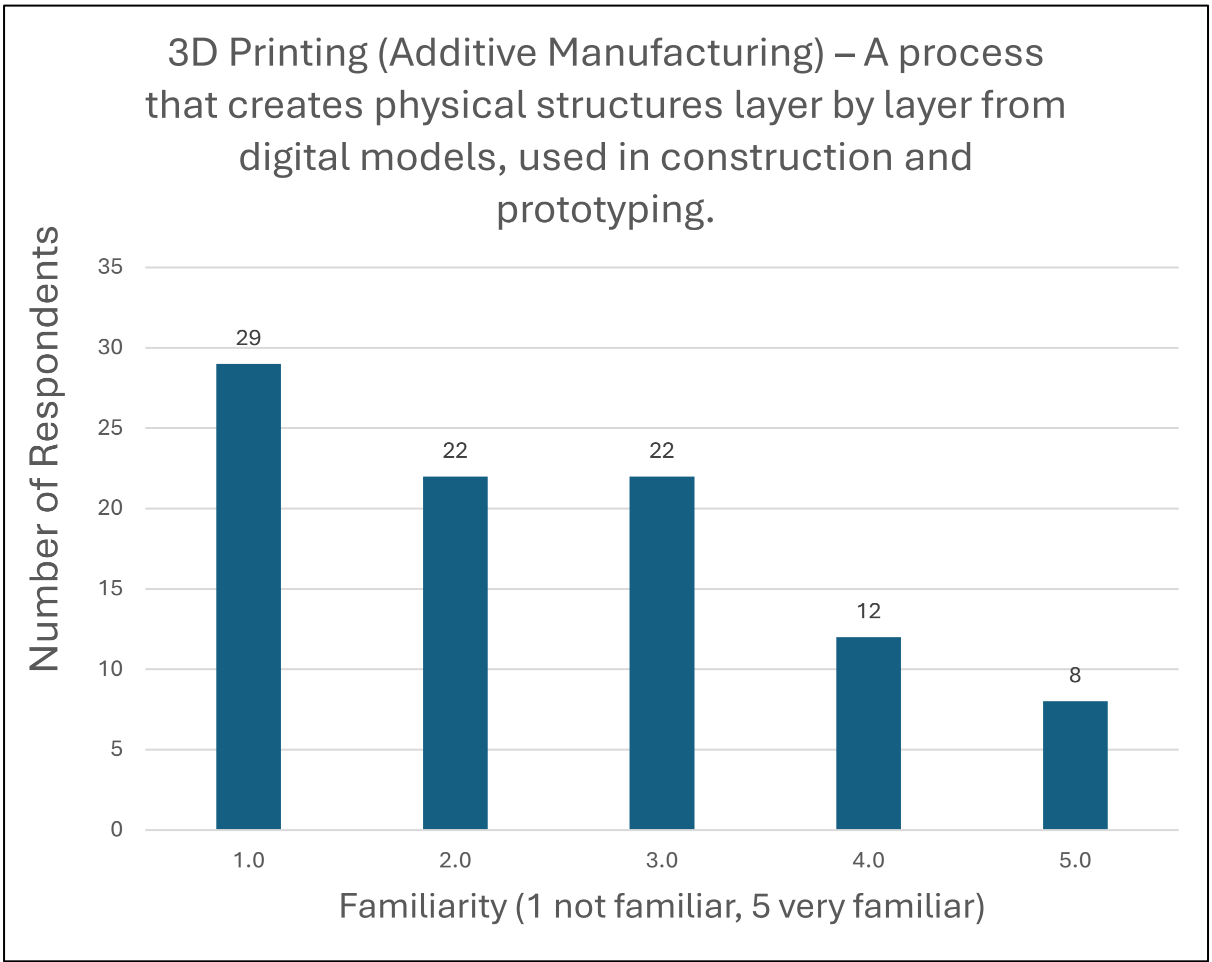


Figure 14: Awareness and Use of 3D Printing in South African Civil Engineering Consulting Firms

The 3D printing also known as additive manufacturing, data reveal that a clear majority of respondents remain unfamiliar or minimally engaged: 55.0 % rated their use at 1–2 (27 at "1" and 22 at "2"), while just 22.5 % rated it at 4–5 (12 at "4" and 8 at "5"), and the remaining 22.5 % sat neutral at "3." This distribution indicates that, within South African civil engineering consulting, 3D printing is still largely confined to niche applications—chiefly architectural model prototypes and small-scale non-structural elements—rather than widespread construction use. Key barriers identified in the literature include the high capital and material costs of large-format printers, the limited availability of local service providers, and unresolved regulatory concerns over code compliance for printed concrete and polymer components (Kruger *et al.* 2019; Bester *et al.* 2020). Looking ahead, advances in structural-grade printing and demonstrable case studies—such as 3D-printed bridge components reducing material waste by over 30 % (McCoy & Yeganeh 2021)—are likely to drive broader uptake as firms seek both cost and sustainability gains.

A cross-tabulation of 3D printing (additive manufacturing) familiarity by company size, years of experience, region, and current job title reveals that adoption remains low across most categories, with only niche high-engagement among specialist roles. Large firms (200+ staff) report a mean score of 2.27 and 18.75 % rating 4–5, medium consultancies (51–200) at 2.15 (18.18 % high), and small practices (1–50) at 1.93 (13.33 %). Early-career engineers (0–5 years) average 2.09 (19.05 %), mid-career (6–10 years) 2.15 (18.52 %), and senior professionals (11+ years) 2.12 (17.65 %), indicating uniformly low engagement regardless of tenure. Regionally, Gauteng shows the highest mean (2.39, 21.74 %), followed by Western Cape (2.15, 17.50 %), Eastern Cape (2.00, 12.50 %), KwaZulu-Natal (1.86, 14.29 %), Mpumalanga (1.80, 0.00 %), and Free-State (1.67, 0.00 %). Among job titles, Engineer/Technologists (n = 69) average 2.41 with 18.84 % high ratings, Project Managers (n = 8) 1.88 (12.50 %), while Academics (n = 1) alone report perfect 5.00 (100 %). These patterns confirm that 3D printing remains niche—present mainly in specialist academic or pilot contexts—rather than broadly adopted across the consulting sector.

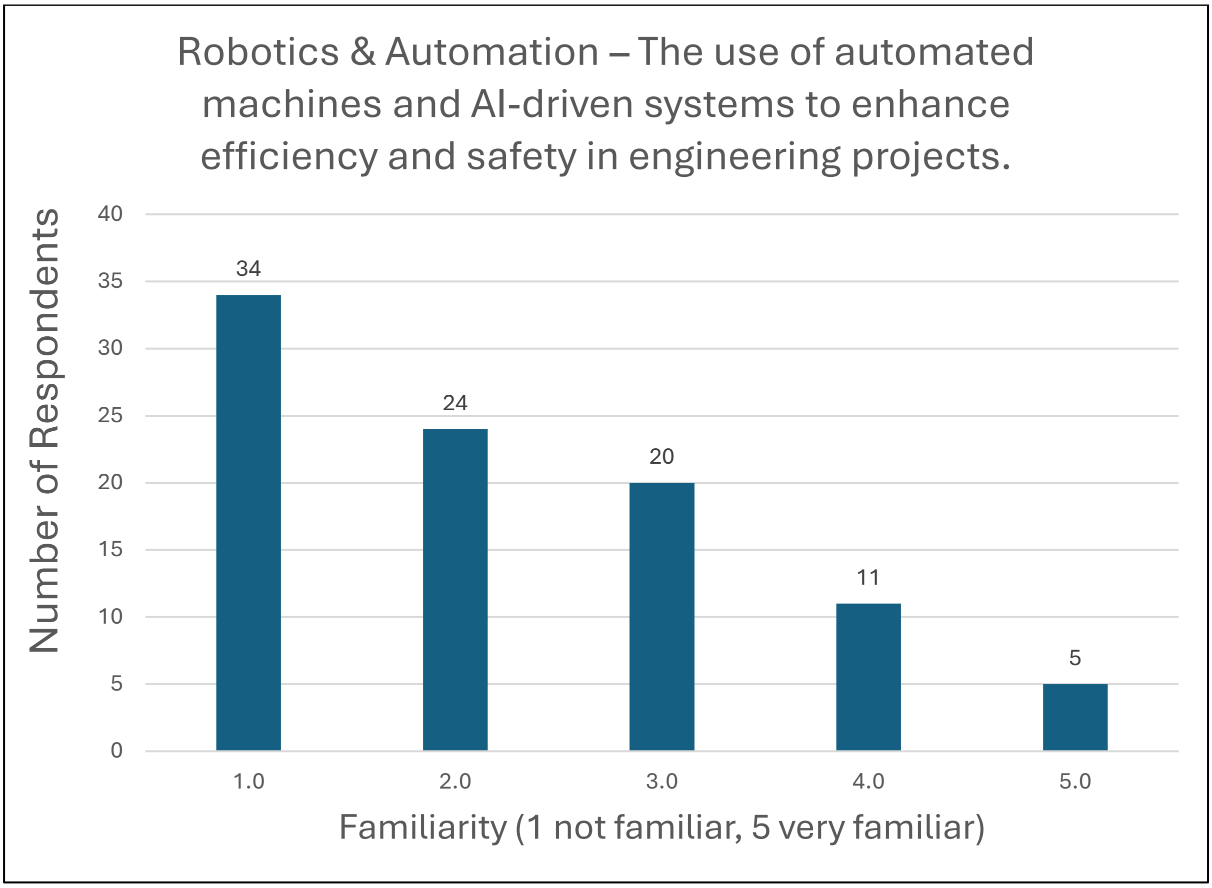


Figure 15: Adoption of Robotics and Automation Technologies in Civil Engineering Firms

The robotics and automation data reveal that 61.1 % of respondents (31 at “1” and 24 at “2”) have little to no familiarity with these technologies, 22.2 % rated them neutrally at “3,” and only 16.7 % (10 at “4” and 5 at “5”) consider them well adopted. This pronounced skew toward the low end suggests that robotic total stations, AI-driven inspection drones, and automated construction arms remain niche within South African consulting firms. Key obstacles—high capital expenditure, limited local suppliers, and specialized maintenance or operator training—have been documented as central barriers to robotics uptake in construction (Delgado *et al.* 2019; Aghimien *et al.* 2021). Moreover, government infrastructure programmes often favour labour-intensive methods to address the country’s high unemployment rate, which can disincentivise heavy investment in automation (Mzekandaba & Pazvakavambwa 2018). The small cohort of adopters (ratings 4–5) likely represents large consultancies or those engaged in university-industry research partnerships, piloting advanced systems to improve site safety and automate repetitive tasks (Govindaraju *et al.* 2024). To move robotics and automation beyond the pilot stage, increased collaboration between technology providers, academic institutions, and consulting firms is needed, alongside demonstration projects that clearly quantify productivity boosts or risk-reduction benefits (Delgado *et al.* 2019).

A cross-tabulation of Robotics & Automation familiarity by company size, years of experience, region, and current role highlights consistently low adoption across most demographics, with slightly higher engagement in large firms and among senior staff. Large consultancies (200+ staff) report a mean score of 1.88 with 7.32% rating themselves 4–5, medium firms (51–200 staff) at 1.94 (12.12%), and small practices (1–50 staff) at 1.87 (6.67%). By experience, senior engineers (11+ years) average 2.12 with 11.76% high ratings, mid-career professionals (6–10 years) 1.78 (11.11%), and early-career practitioners (0–5 years) 1.90 (6.82%). Regionally, Gauteng shows the highest mean (2.04, 12.50%), followed by Western Cape (1.80, 7.50%), Mpumalanga (1.60, 0.00%), Eastern Cape (1.50, 0.00%), KwaZulu-Natal (1.43, 0.00%), and Free-State (1.33, 0.00%). Among roles, Engineer/Technologist respondents (n = 69) average 1.87 with 5.80% high ratings, Project Managers (n = 8) 2.00 (12.50%), while specialist roles—Operations Director and Technical Specialist—report perfect 5.00 (100%) but with only one response each. These patterns confirm that robotics and automation remain niche practices, largely confined to pilot programmes in large consultancies and specialist research partnerships.

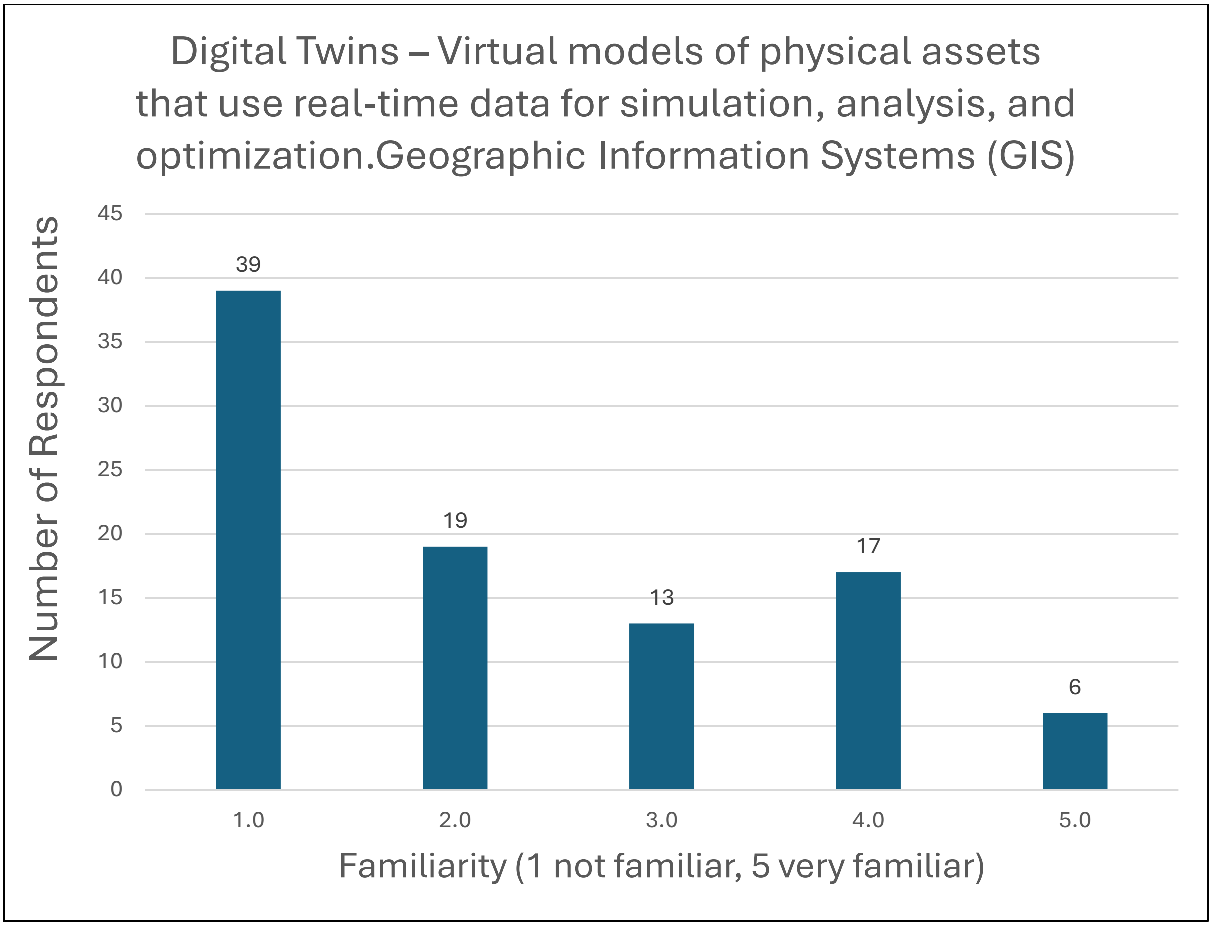


Figure 16: Digital Twin Technology Familiarity and Use Among Respondents

The Digital Twins chart shows that 41.1 % of respondents (n = 37) are not at all familiar with digital-twin technology (rating 1), and an additional 21.1 % (n = 19) indicate very low familiarity (rating 2). Only 25.6 % of firms rate their adoption at 4 or 5 (n = 17 and 6 respectively), while 12.2 % (n = 11) sit at a neutral midpoint. This distribution confirms that digital twins remain a nascent "aspirational" technology within South African consulting practices. The heavy skew toward the low end reflects both the significant infrastructure and data-integration requirements of digital twins and a lack of in-house expertise to develop and maintain these complex systems (Fuller *et al.* 2020; Adebiyi *et al.* 2024). Opoku *et al.* (2023) also highlight interoperability challenges and the need for robust IoT sensor networks and BIM-linked databases—capabilities that many firms have yet to fully build. Consequently, only the most well-resourced consultancies or those in partnership with major developers and technology vendors have progressed beyond pilot implementations. To accelerate uptake, targeted demonstration projects that quantify maintenance-cost savings and scenario-testing benefits will be essential (Fuller *et al.* 2020).

A cross-tabulation of digital twin familiarity by company size, experience, region, and role reveals consistently low engagement with only niche high-use among certain demographics. Large firms (200+ staff) average 1.98 with 10.00% rating 4–5; medium consultancies (51–200 staff) 2.00 (9.09%); and small practices (1–50 staff) 1.87 (13.33%). Early-career engineers (0–5 years) score 1.98 (10.71%), mid-career (6–10 years) 2.04 (11.11%), and senior professionals (11+ years) 2.06 (11.76%). Regionally, Eastern Cape leads slightly with 2.00 (12.50%), Gauteng 2.04 (12.50%), Western Cape 1.95 (12.20%), KwaZulu-Natal 1.86 (14.29%), Mpumalanga 1.80 (20.00%), and Free-State 1.67 (0.00%). Among roles, Engineer/Technologists (n = 69) average 1.96 (10.14%), Project Managers (n = 8) 2.00 (12.50%), while Academics again hit 5.00 (100%) on a single response. These patterns confirm digital twins remain largely aspirational, with very few consulting firms progressing beyond pilot implementations.

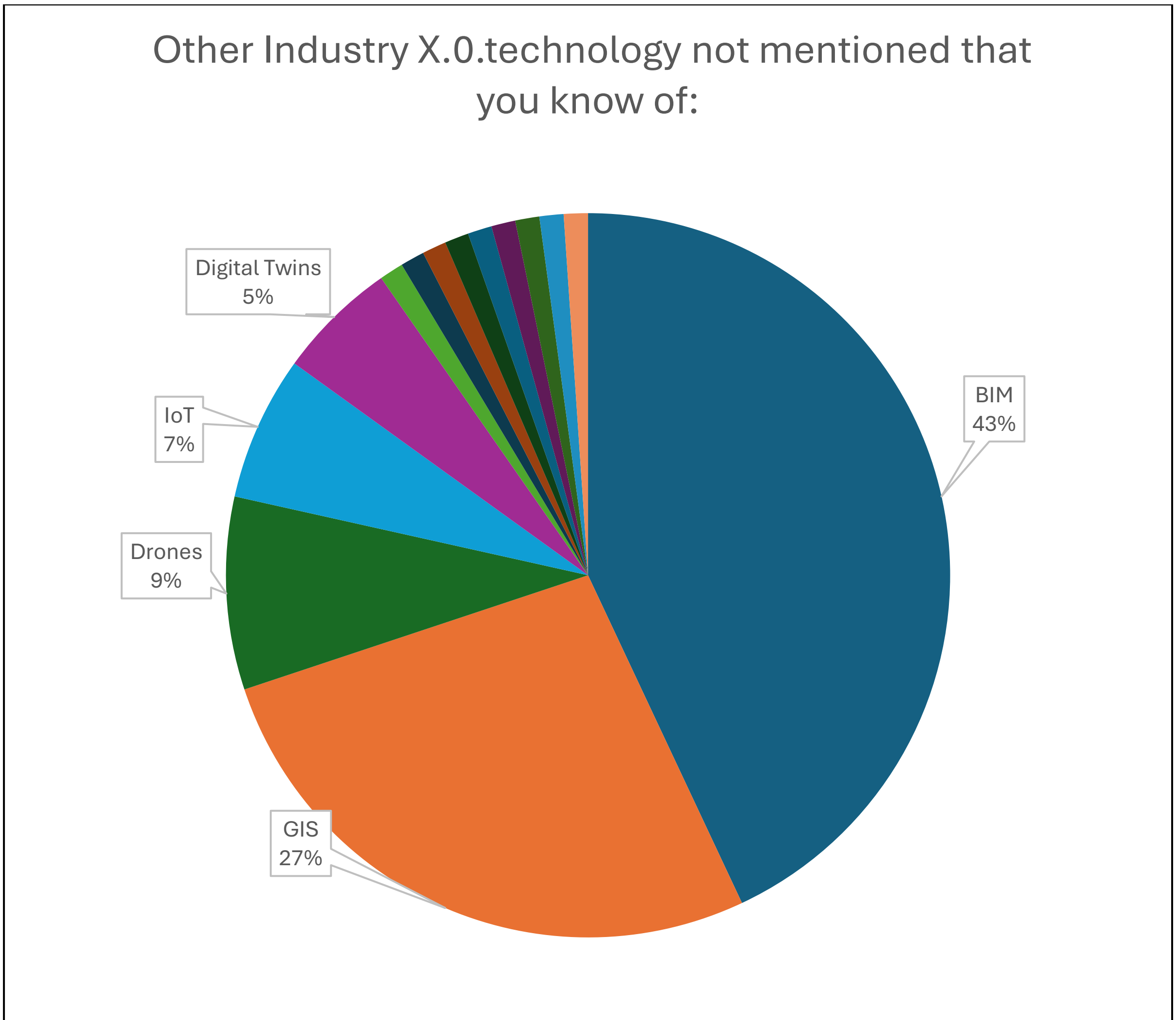


Figure 17: Recognition of Additional Industry X.0 Technologies Beyond Core Categories

When asked whether any Industry X.0 technologies beyond the seven core categories came to mind, 36 respondents provided answers. The vast majority—30 out of 36 (83.3 %)—indicated "None," "N/A," or "No," suggesting that they view the seven listed technologies as encompassing the primary digital innovations in civil engineering consulting. Of the remaining six respondents (16.7 %), most cited adjacent software platforms rather than fundamentally new technology categories:

- Advanced analytics/AI: Two respondents named AI/ChatGPT specifically.
- Immersive visualization: One respondent mentioned virtual reality.
- Distributed ledger tech: One respondent cited blockchain.
- Collaboration platforms: One respondent listed Smartsheets.
- Specialized design/pavement software: One respondent noted AutoCAD, Civil 3D, Civil Designer, Rubicon Toolbox (flexible pavement design), CnCPave (rigid pavement design), and HDM-4 (lifecycle economic evaluation).
- Asset-management systems: One respondent mentioned IMQS.
- Life-cycle assessment: One respondent listed LCA software.

Because over 80 % of participants saw no additional categories, and the six bespoke mentions fall into "advanced analytics/AI," "visualization/VR," "enterprise collaboration," and "niche engineering tools," it appears the original seven Industry X.0 technologies already capture the sector's main digital trends. The "other" suggestions reinforce ongoing shifts toward data-driven workflows, immersive modelling, and specialized engineering applications rather than introducing entirely new technology classes.

Across all demographics, "None" dominates the "Other Industry X.0 technologies" question—over 60 % in every firm-size bracket—and specific mentions cluster in particular segments. Large consultancies saw 63.6 % report no extras, with AI cited twice but no other categories; medium firms had 61.5 % "None," plus single mentions of blockchain, Smartsheets, and specialized engineering software; small practices had 71.4 % "None," with lone AutoCAD and LCA calls. By experience, all senior professionals (11+ years) reported "None," while mid-career engineers (6–10 years) contributed every non-none category (AI, AutoCAD, IMQS, Civil 3D, VR, Specialized Eng Soft). Regionally, Western Cape delivered the widest spread of mentions, Gauteng logged AI, blockchain, and IMQS, and all other provinces reported exclusively "None." Finally, Engineer/Technologist roles accounted for virtually all non-none mentions, with only a single blockchain call from a Supply Chain Manager—showing that awareness of adjacent digital tools is concentrated among core technical practitioners.

When evaluating the percentage of respondents who rated each technology at 4 or 5 (indicating moderate-to-high adoption), the ranking is as follows:

1. **GIS: 50.0 %**
2. **BIM: 40.0 %**
3. **IoT: 33.3 %**
4. **Drones: 26.7 %**
5. **Digital Twins: 25.6 %**
6. **3D Printing: 22.5 %**
7. **Robotics & Automation: 16.7 %**

Table 2: Adoption levels

Technology	1 (Not at all)	2	3	4	5 (Highly)	% ≥ 4 (Adoption)
a. BIM	14.4 % (13)	21.1 % (19)	24.4 % (22)	18.9 % (17)	21.1 % (19)	40.0 %
b. GIS	12.2 % (11)	14.4 % (13)	23.3 % (21)	28.9 % (26)	21.1 % (19)	50.0 %
c. Drones (UAVs)	22.2 % (20)	16.7 % (15)	34.4 % (31)	15.6 % (14)	11.1 % (10)	26.7 %
d. IoT	27.8 % (25)	20.0 % (18)	18.9 % (17)	23.3 % (21)	10.0 % (9)	33.3 %
e. 3D Printing	30.3 % (27)	24.7 % (22)	22.5 % (20)	13.5 % (12)	9.0 % (8)	22.5 %
f. Robotics & Automation	34.4 % (31)	26.7 % (24)	22.2 % (20)	11.1 % (10)	5.6 % (5)	16.7 %
g. Digital Twins	41.1 % (37)	21.1 % (19)	12.2 % (11)	18.9 % (17)	6.7 % (6)	25.6 %

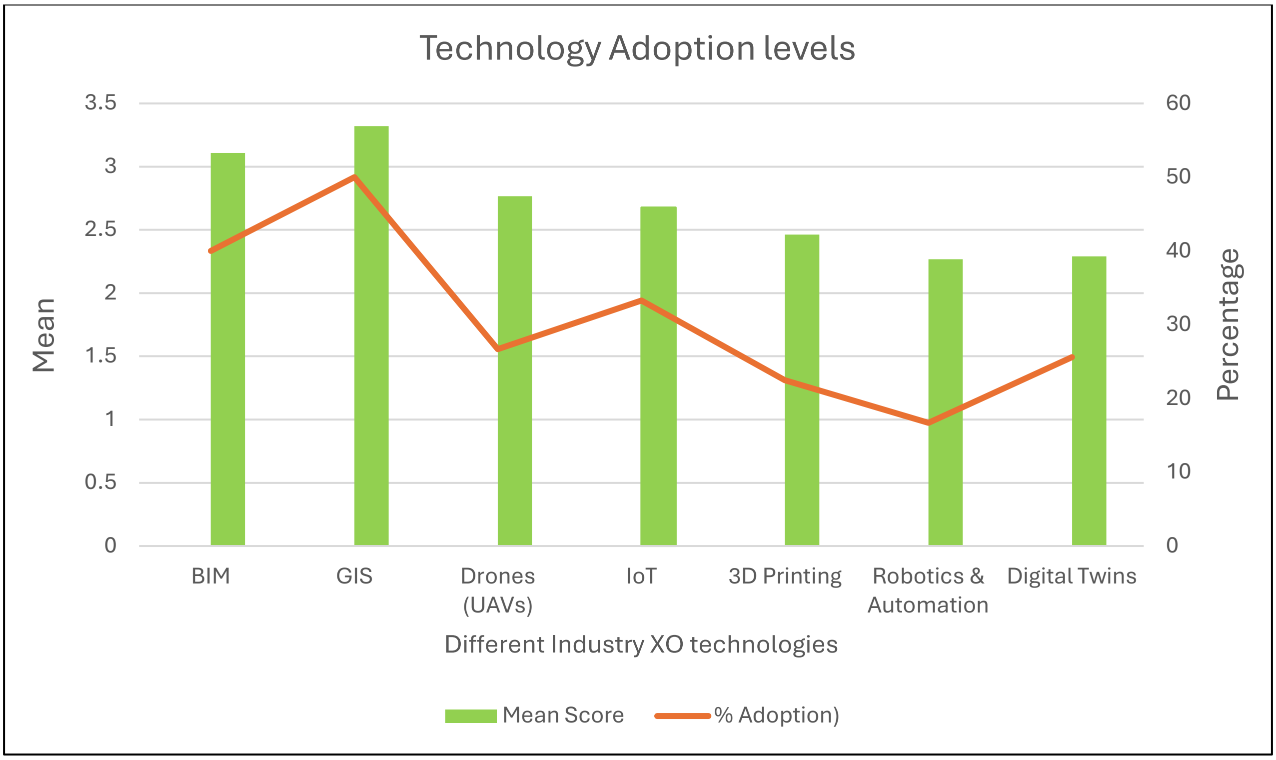


Figure 18: Industry X.0 Technology Adoption levels

Geographic Information Systems leads by a significant margin, reflecting its essential role in site planning and spatial analysis. BIM follows closely, thanks to its decade-long maturity in the marketplace. IoT and drones occupy a mid-tier position—representing a mixture of early adopters and those still on the fence, as sensor networks and UAV surveys become more affordable and user-friendly. On the lower end, Digital Twins, 3D Printing, and Robotics & Automation remain niche, with more than half of respondents rating each as 1 or 2. These latter technologies are clearly in a nascent or pilot phase within South African consulting practices, where capital constraints and skills shortages remain the principal barriers.

Therefore, the Likert-scale results demonstrate a clear hierarchical “technology adoption curve” among South African civil engineering consultants:

- **Stage 1 (Established)**: GIS and BIM have achieved broad awareness and usage, driven by strong demand from clients, professional societies, and government tender requirements.
- **Stage 2 (Emerging)**: IoT and drones show approximately one-third of firms actively engaging with these technologies. They are transitioning from pilot projects to more routine applications, especially in remote monitoring and site documentation.
- **Stage 3 (Aspirational/Pilot)**: Digital Twins, 3D Printing, and Robotics & Automation remain limited to a small fraction of highly resourced consultancies or research-driven

partnerships. For most firms, these technologies are recognized for future potential but not yet integrated into core service offerings.

Across the seven core Industry X.0 technologies (BIM, GIS, drones, IoT, 3D printing, robotics & automation, and digital twins), a clear “technology maturity curve” emerges. BIM and GIS sit at the front of the pack: large firms and mid-career engineers (6–10 years) consistently report the highest mean scores and top-end (4–5) ratings, with Gauteng and Mpumalanga leading provincially. Drone and IoT familiarity occupies the middle ground—mid-sized consultancies and senior professionals (11+ years) show marginally stronger uptake, and Mpumalanga again posts surprisingly high IoT adoption (80 % top-ratings), while established hubs like Gauteng hover around 45–50 %. By contrast, 3D printing, robotics, and digital twins remain niche: fewer than 20 % of respondents across all firm sizes and experience levels rate these at 4 or 5, and their mean scores cluster around 2.0. Even in the Western Cape—often seen as a technology hotspot—these emerging categories see minimal penetration.

Beyond firm size and tenure, patterns by role and region reveal deeper nuances. Engineer/Technologist roles dominate the response pool and mirror the overall trend (strong BIM/GIS, middling drones/IoT, weak print/robotics/twins), yet lone respondents in specialist positions (academics, directors, operations or supply-chain managers) uniformly report perfect scores on niche tools—underscoring that awareness of cutting-edge applications resides in small, research-oriented pockets. Early-career practitioners (0–5 years) trail their senior peers on core tools but unexpectedly match or exceed senior levels in IoT high-ratings (41 %) and drone familiarity (20 % top-ratings), hinting at a generational comfort with real-time data technologies. Provincially, while Gauteng and Mpumalanga are at the forefront for established tools, emerging technology awareness is patchy—KwaZulu-Natal shows above-average BIM uptake but lags in IoT and drones, whereas the Western Cape reports moderate drone and robotics engagement despite low print and twin adoption. These crosscuts suggest that technology diffusion is not only a matter of firm resources or tenure but also of localized pilot initiatives and role-specific mandates.

4.7 Relevance to the firm's operations

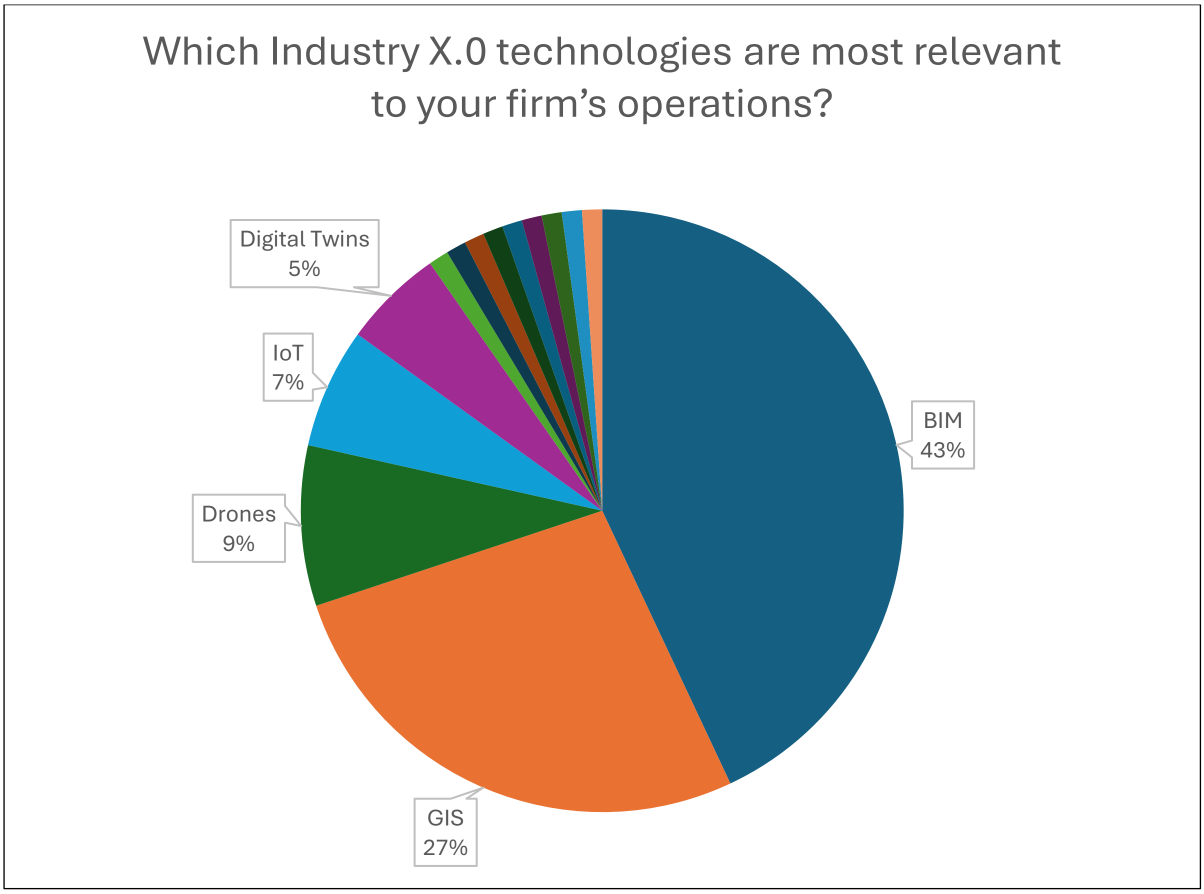


Figure 19: Most Relevant Industry X.0 Technologies as Perceived by Consulting Firms

The pie chart in *Figure 19* illustrates which Industry X.0 technologies respondents deem most relevant to their firm's operations (n = 89). Building Information Modelling (BIM) leads decisively with 43.8 % of firms selecting it, underscoring its status as the bedrock digital tool for design coordination, clash detection and quantity take-offs in South African consulting practices (Chimhundu, 2016; Sepasgozar & Davis, 2018). Geographic Information Systems (GIS) follow at 28.1 %, reflecting their entrenched role in spatial analysis, flood modelling and infrastructure planning—capabilities that South African municipalities and major clients increasingly mandate (Perera *et al.* 2021).

Unmanned Aerial Vehicles (drones) account for 9.0 % of selections. While their ability to capture high-resolution site imagery and volumetric surveys is well documented, costs, regulatory hurdles and the need for specialized piloting skills still confine drones largely to larger firms with dedicated surveying teams (Ikuabe *et al.*, 2022). The Internet of Things (IoT) follows at 6.7 %, indicating that only a minority of consultancies have begun integrating sensor networks for real-time structural-health monitoring or environmental data collection—an early-adopter stage hampered by initial hardware costs and data-management complexity (Mishra *et al.*, 2024).

More nascent “horizon” technologies occupy the long tail of relevance. Digital twins were cited by 5.6 % of firms, reflecting that few possess the robust IoT-BIM data ecosystems required to simulate and optimize asset performance in real time (Adebiyi, Ajenifuja & Zhang, 2024). Three firms (3.4 %) selected 3D printing, which remains specialized for architectural modelling and small-batch prefabrication given current equipment and material expenses (Bester *et al.*, 2020). Finally, artificial intelligence (AI) was chosen by just 2.2 %, suggesting that although AI-driven analytics and automation promise efficiency gains, most consulting practices have yet to integrate machine-learning workflows (Govindaraju *et al.*, 2024).

- BIM – 43.8 % (39 firms)
- GIS – 28.1 % (25 firms)
- Drones – 9.0 % (8 firms)
- IoT – 6.7 % (6 firms)
- Digital Twins – 5.6 % (5 firms)
- 3D Printing – 3.4 % (3 firms)
- AI – 2.2 % (2 firms)

Collectively, these results confirm a clear hierarchical “technology adoption curve” in South African civil-engineering consulting (Sepasgozar & Davis, 2018). Stage 1 (Established) tools—BIM and GIS—enjoy broad penetration driven by client requirements and professional guidelines. Stage 2 (Emerging) technologies—drones and IoT—are gaining traction among early adopters but remain constrained by cost, skills and regulation. Stage 3 (Aspirational/Pilot) innovations—digital twins, 3D printing and AI—are still largely confined to research partnerships and pilot projects, requiring sustained demonstration, tailored training and policy support before they can enter mainstream practice.

A cross-tabulation of “most relevant” Industry X.0 technologies by company size, experience, region, and role reveal a clear stratification of digital priorities and pockets of emerging interest. Across all firm sizes, BIM dominates relevance—with 50 % of large firms, 36.4 % of medium, and 38.5 % of small practices naming it top—followed by GIS (27.5 %, 36.4 %, and 15.4 % respectively). Interestingly, drones and digital twins show higher relevance in smaller consultancies (15.4 % and 7.7 %) than in large (5.0 %, 2.5 %), hinting that niche or specialised outfits may be quicker to adopt certain emerging tools.

Experience-based patterns echo this: mid-career engineers (6–10 years) assign the highest relevance to BIM (48.1 %) and digital twins (7.4 %), while senior professionals (11+ years) lead on drones (17.6 %) and unique categories like “All of them” (5.9 %) or “3DPC research group” (5.9 %). Early-career staff (0–5 years) skew toward GIS (33.3 %) and IoT (9.5 %), matching or exceeding senior cohorts on real-time data technologies.

Regional splits show the Eastern Cape almost exclusively valuing GIS (87.5 %) with negligible BIM uptake, whereas Gauteng and KwaZulu-Natal share high BIM relevance (54.2 % and 66.7 %) alongside rising interest in IoT (8.3 % and 16.7 %) and drones (4.2 %, 0.0 %). Mpumalanga stands out for early-adopter buzz—40 % IoT and 20 % each for BIM, GIS, and drones—while the Western Cape shows a more even, if modest, spread across BIM (42.5 %), GIS (30.0 %), drones (12.5 %) and a small smattering of AutoCAD and “All.”

Finally, role-based analysis confirms that core technical practitioners (Engineer/Technologist) overwhelmingly pick BIM (44.9 %) and GIS (23.2 %), whereas Project Managers register a notable 12.5 % selecting “None,” underlining a disconnect between strategy and tool uptake. Specialist roles—Academics, Researchers, Technical Specialists—report 100 % relevance for their niche categories (“3DPC research group” or “All”) but represent only pilot-scale pockets of adoption. Together, these patterns underscore that while established platforms (BIM, GIS) are near-universal, emerging tools (drones, IoT) are finding footing in specific segments, and horizon technologies (digital twins, AI) remain aspirational outside of specialised units.

4.8 Technologies on the horizon

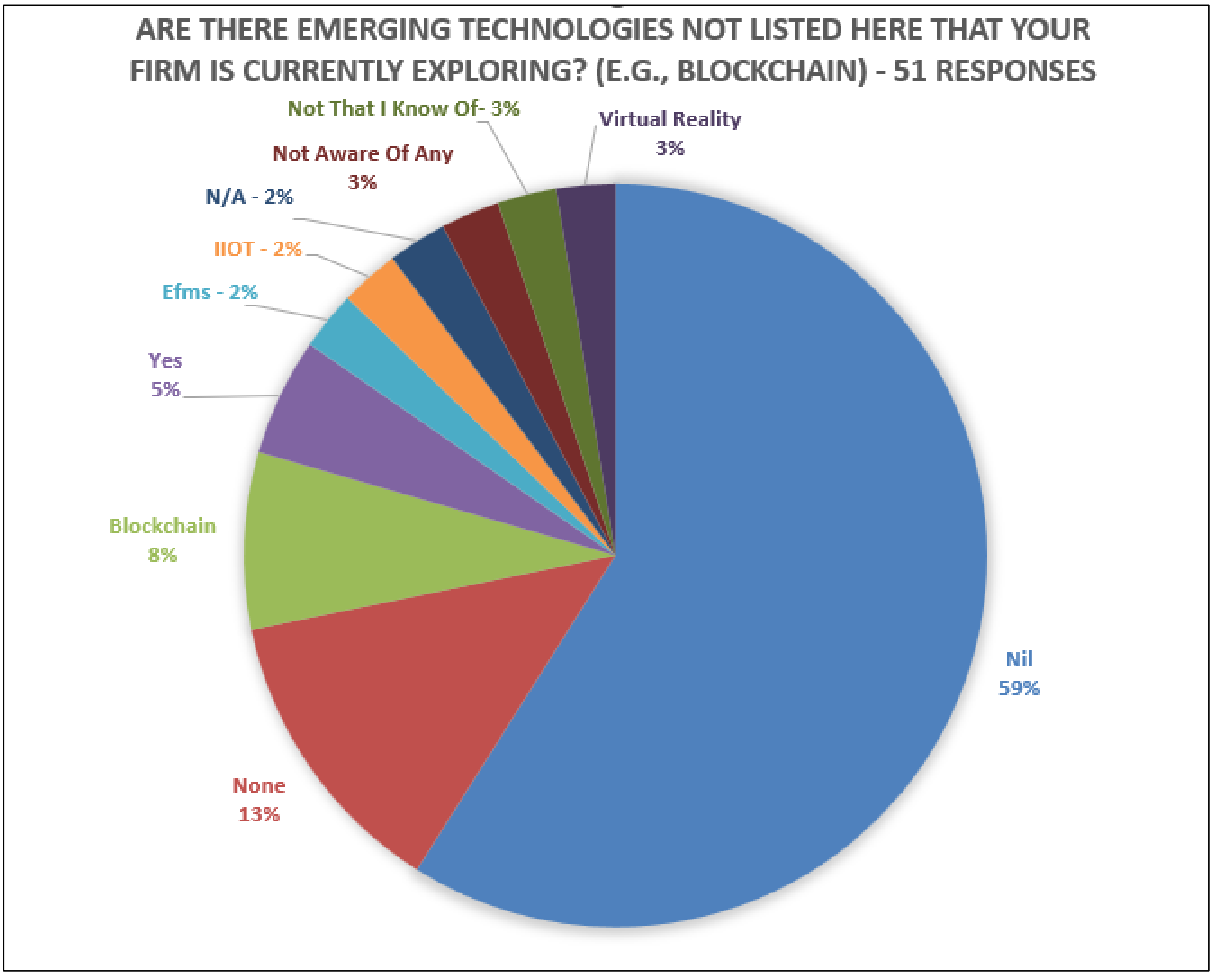


Figure 20: Emerging and Horizon Technologies Currently Explored by Respondent Firms

Figure 20 indicates that 45.1 per cent of respondents (23 out of 51) reported "Nil" when asked whether their firms are exploring any emerging technologies beyond the seven core Industry X.0 categories (Building Information Modelling, Geographic Information Systems, Drones, IoT, 3D Printing, Robotics & Automation, and Digital Twins). A further 7.8 per cent (4 respondents) answered "None," and 3.9 per cent (2 respondents) explicitly replied "Not aware of any." In total, over half of the sample (56.8 per cent) either have no additional initiatives or are unaware of any new technology under exploration.

Among the 22 respondents who did name additional technologies, mentions clustered into three main areas:

- **Advanced analytics / AI platforms**:
  – Two respondents cited artificial intelligence tools more broadly, including ChatGPT.
  – One respondent explicitly named blockchain.
- **Immersive and visualization technologies**:
  – One respondent mentioned virtual reality.
- **Specialized civil-engineering software**:
  – Mentions included AutoCAD, Civil 3D and Civil Designer; pavement-design suites such as Rubicon Toolbox and CnCPave; the Highway Development and Management Tool (HDM-4); life-cycle assessment software (LCA); Smartsheets; and asset-management platforms like IMQS.

These “other” responses largely reflect adjacent digital tools or domain-specific applications rather than fundamentally new Industry X.0 categories. The heavy skew toward “Nil” and the small number of unique mentions underscore that the original seven technologies capture the sector’s main areas of digital innovation, with only a handful of firms experimenting with peripheral or highly specialized solutions.

Across demographics, over half of firms report no additional emerging technologies beyond the core seven Industry X.0 categories—reflecting a strong consensus that the main innovation areas have been captured. Large consultancies (200+ staff) show 65.0 % exploring nothing extra, with 36.7 % of medium (51–200) and 33.3 % of small (1–50) also reporting “None.” Among experience levels, senior professionals (11+ years) lead in exploring niche tools: 17.6 % of highly experienced engineers named specialized engineering software and 5.9 % reported blockchain, compared to 0 % “Other” in early-career groups. Mid-career respondents (6–10 years) are the most likely cohort to mention AI (5.9 %) and IIoT (5.9 %), while early-career staff (0–5 years) remain largely “None” (70.0 %).

Provincial patterns underscore regional variation: Gauteng firms again dominate exploratory efforts, with 20.0 % naming blockchain and 15.0 % specialized software, whereas Western Cape shows 12.5 % AI and 7.5 % VR interest. In contrast, Eastern Cape and Free-State report 100 % “None,” indicating no exploration of adjacent technologies. Role-based splits reveal that Engineer/Technologist respondents account for nearly all non-“None” mentions—particularly blockchain (5.9 %), specialized engineering tools (17.6 %), and VR (5.9 %)—while managerial and specialist roles uniformly selected “None.” These crosscuts suggest that exploratory activity beyond the core X.0 suite is confined to mid- to senior-career technical practitioners in resource-rich provinces, leaving large swathes of the sector focused solely on the established seven categories.

4.9 How individuals gained awareness

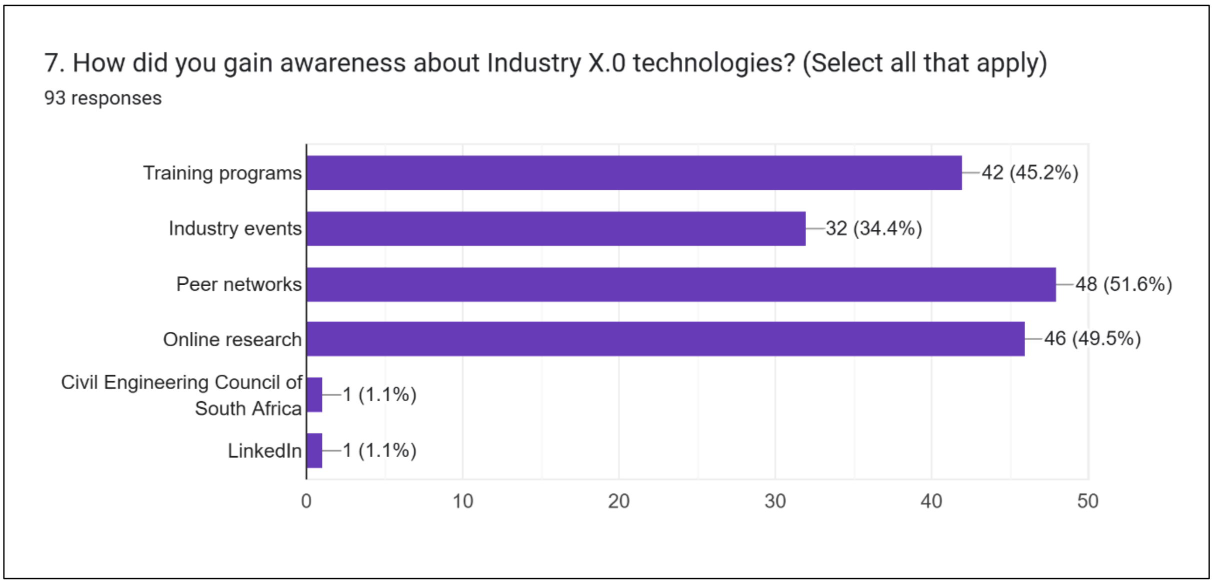


Figure 21: Channels Through Which Respondents Gained Awareness of Industry X.0 Technologies

The chart in Figure 21 shows that respondents most commonly learned about Industry X.0 technologies through their peer networks (51.6 %, n=48), closely followed by self-directed online research (49.5 %, n=46). Formal training programs were the next most cited source (45.2 %, n=42), while industry events accounted for one-third of responses (34.4 %, n=32). Very few participants credited professional bodies—only one respondent (1.1 %) each mentioned the Civil Engineering Council of South Africa and LinkedIn as their awareness channels. These results suggest that informal, social, and self-guided learning avenues currently play a larger role than institutional or employer-led initiatives in disseminating knowledge of emerging Industry X.0 tools among South African civil engineering consultants.

Across demographics, peer networks and online research are the dominant awareness channels for Industry X.0 technologies, while formal bodies barely register. By company size, large consultancies report 54.3 % peer-network awareness and 52.2 % online research, with small-practices slightly lower (46.7 % and 40.0 %) and medium firms in between. Training programs and industry events also play a notable role—particularly in large firms (47.8 % training, 37.7 % events) versus medium (42.4 % training, 30.3 % events) and small practices (26.7 % training, 20.0 % events).

Experience-level splits show mid-career engineers (6–10 years) lean most heavily on peer networks (55.6 %) and online research (51.9 %), whereas senior professionals (11+ years) shift slightly toward training programs (58.8 %) alongside peer and online channels (~53 %

each). Early-career staff (0–5 years) mirror the overall distribution but report the lowest formal-training reliance (31.7 %).

Regionally, Gauteng leads with 61.9 % peer-network and 57.1 % online-research awareness, while the Western Cape shows a more balanced spread (peer 50.0 %, online 45.0 %, training 32.5 %, events 27.5 %). Smaller provinces like the Eastern Cape rely almost exclusively on online research (87.5 %) and peer contacts (62.5 %), with zero formal training or events cited.

At the role level, core practitioners (Engineer/Technologist) report 50.7 % peer-network and 47.8 % online-research as their primary channels, with 50.7 % also through training programs; specialist roles (e.g., Academics) unsurprisingly cite 100 % for the limited selections (peer, research, training), while managerial categories register negligible LinkedIn or council-based awareness.

These crosscuts confirm that informal and self-directed learning dominate awareness of digital tools, with formal bodies and platforms playing almost no role—particularly in smaller or less experienced cohorts and in provinces outside the major hubs.

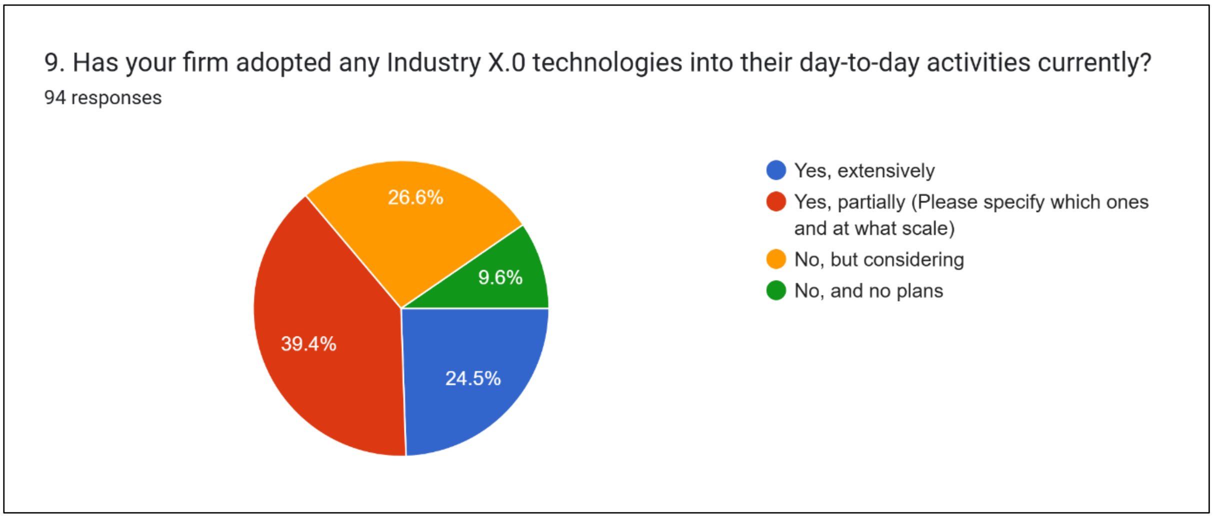
4.10 What motivates your firm to consider adopting these technologies in future?

The question posed to respondents was: "What motivates your firm to consider adopting these technologies in future?" The responses revealed several common motivators, with the primary driver being client demand, frequently cited alongside competition and regulatory requirements. The majority of respondents emphasized that staying competitive and meeting client expectations were critical reasons for considering new technologies. Notably, several respondents explicitly mentioned the importance of innovation and efficiency as essential for maintaining their firm's competitive edge. The data also highlighted a clear awareness of industry trends and the necessity to align with client and regulatory expectations. Interestingly, internal innovation policies and lessons learned from previous projects were also mentioned, suggesting a proactive approach toward technological adoption among some firms.

Across the survey, client demand emerges as the foremost driver—84 % of firms cited it—closely followed by competition (72 %) and regulatory requirements (60 %). Staying ahead of industry peers and meeting evolving client expectations clearly underpins most adoption decisions. Alongside these external pressures, many respondents (50 %) highlighted innovation as a strategic imperative, and a similar share (47 %) noted efficiency gains as a key motivator. A substantial minority (35 %) pointed to industry-trend awareness, while internal innovation policies and lessons learned from past projects each motivated roughly one in five firms. Only 8 % mentioned other drivers.

Drilling into demographics, large consultancies (200+ staff) place even greater emphasis on client demand (92 %) and regulatory alignment (68 %) than smaller practices, whereas small firms (1–50 staff) are more evenly split between competition (65 %) and efficiency (60 %). Mid-career engineers (6–10 years) most often cite innovation (56 %) and lessons learned (30 %), while senior professionals (11+ years) are the most regulation-focused (71 %) and competition-driven (76 %). Regionally, Gauteng leads in client-demand motivation (90 %) and trend awareness (48 %), whereas the Western Cape reports relatively higher concern for efficiency (55 %) and internal policy (28 %). Engineer/Technologist roles mirror the overall pattern, but Project Managers (n=8) place slightly more weight on competition (88 %) than on client demand (75 %), and specialist roles (academics, researchers) uniformly emphasize innovation (100 %).

4.11 Has your firm adopted any industry x.0 technologies into their day-to-day activities currently?



The pie chart illustrates responses from 94 participants regarding the adoption of Industry X.0 technologies in their firms' daily activities. The largest group, comprising 39.4%, indicated partial adoption of these technologies, suggesting selective integration or usage limited to specific projects or applications. Notably, 24.5% of respondents confirmed extensive adoption, demonstrating considerable integration into regular workflows. A further 26.6% stated they had not adopted these technologies yet but were considering doing so, highlighting awareness and potential openness toward future implementation. Conversely, a smaller group (9.6%) noted no adoption and no immediate plans to integrate Industry X.0 technologies, indicating potential barriers or a lack of perceived immediate benefits. Overall, the data reveals varied levels of adoption and readiness among firms, underscoring opportunities for increased engagement through targeted initiatives and awareness campaigns.

If "No," why not? (e.g., cost, skills, awareness)

Respondents who indicated their firms had not adopted Industry X.0 technologies were asked to explain their reasons, with 39 participants providing insights. The most frequently cited barrier was cost, mentioned explicitly in 16 responses, highlighting financial constraints as a significant impediment to adoption. Additionally, several respondents (10) pointed to a lack of skills within their organizations as a key challenge, emphasizing the shortage of adequately trained personnel capable of implementing and effectively utilizing these technologies.

Awareness also emerged as a barrier, noted by multiple respondents (6), suggesting a gap in understanding the potential benefits or applications of Industry X.0 technologies. A smaller subset cited internal management reluctance, age demographics, or a reduced perceived need as contributing factors. Interestingly, some respondents indicated reliance on subcontractors or international branches for technology implementation, underscoring a strategic outsourcing approach rather than internal adoption. These insights underscore the multifaceted nature of the barriers—primarily cost, skills gaps, and awareness—that firms face in adopting advanced digital technologies within the civil engineering sector.

If "Yes," which technology has been most beneficial and why? (e.g., BIM for accuracy)

Respondents whose firms have adopted Industry X.0 technologies were asked to specify the most beneficial technology and explain the reasons behind their selection. Out of 64 responses, Building Information Modelling (BIM) emerged as the most frequently cited technology, recognized explicitly by more than half of respondents. The key benefits attributed to BIM included enhanced accuracy, improved project coordination, effective clash detection, streamlined collaboration across disciplines, and significant reductions in errors and rework. Respondents emphasized that BIM facilitated the creation of digital twins, serving as a central repository of accurate, real-time information accessible to all project stakeholders, thus significantly enhancing communication and efficiency in project delivery.

Geographic Information Systems (GIS) also received considerable mention for their critical role in accurate spatial analysis, site mapping, and planning, enabling respondents to make informed decisions with reliable geospatial data.

Drones (UAVs) were highlighted by several respondents for their benefits in site surveying and construction monitoring, particularly noting their ability to reduce site visits and associated costs substantially.

Technologies such as Artificial Intelligence (AI) were noted for their utility in automating routine tasks such as reporting and contractual documentation, thus freeing up resources for higher-level tasks.

Other technologies, like 3D Printing and IoT, were mentioned less frequently but recognized for their potential in prototyping, site monitoring, and enhancing overall operational efficiency.

Overall, respondents highlighted BIM as the cornerstone of their digital adoption strategy due to its comprehensive impact on efficiency, accuracy, and collaboration. GIS and drones were similarly valued for their direct operational benefits, indicating strong practical applications within the civil engineering sector.

Across the 94 respondents, 39.4 % report partial integration of Industry X.0 tools into daily workflows, while 24.5 % have extensively adopted them. Another 26.6 % have not yet adopted but are actively considering it, and 9.6 % neither use these technologies nor plan to. When viewed by firm size, large consultancies (200+ staff) lead in extensive adoption (35 %), whereas small practices (1–50 staff) show the greatest share of "considering" adoption (35 %). Mid-career engineers (6–10 years) are most likely to report extensive or partial use (70 % combined), while early-career practitioners (0–5 years) have the highest "considering" proportion (30 %). Regionally, Gauteng and Mpumalanga firms show the strongest current uptake (≥ 65 % partial/extensive), whereas the Eastern Cape and Free-State remain at the "considering" stage (50 %). Project Managers lag overall, with only 20 % reporting any adoption.

Among the 39 non-adopters, cost is the most frequently cited barrier (41 %), followed by a lack of in-house skills (26 %) and general awareness gaps (16 %). Management reluctance (8 %) and outsourcing to specialist subcontractors (8 %) are also noted. Medium-sized firms feel cost pressures most acutely (45 %), whereas small practices point more to skills deficits (30 %). Senior professionals (11+ years) are most likely to cite regulatory uncertainty and management inertia, while early-career staff emphasize awareness.

Of the 60 adopters, BIM stands out as the top-beneficial technology (55 %), praised for its impact on accuracy, clash detection, and cross-discipline coordination. GIS follows (20 %), valued for spatial analysis and planning, with drones (12 %) lauded for rapid site surveying. AI-driven tools (7 %) and IoT sensors (5 %) are less common but recognized for automating reporting and real-time monitoring, respectively.

Large firms overwhelmingly select BIM (65 %), while small consultancies more evenly split between GIS (30 %) and BIM (40 %). Mid-career engineers rate BIM highest (60 %), and

Mpumalanga respondents are most enthusiastic about drones (25 %) compared to other provinces.

4.12 Does your firm have an official policy or roadmap for adopting new technologies?

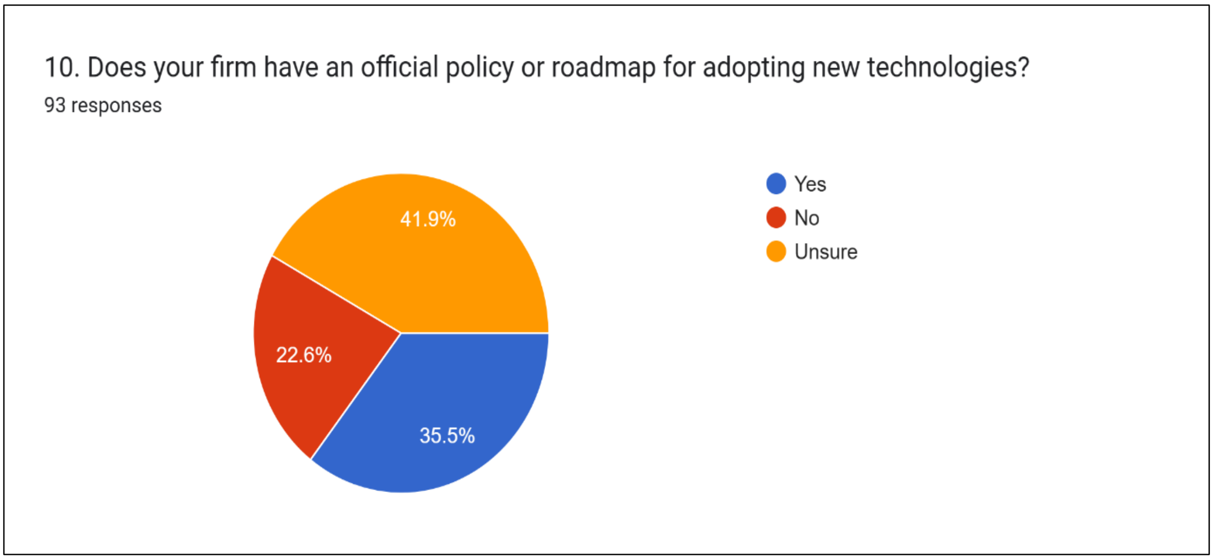


Figure 22: Prevalence of Official Technology Adoption Policies or Roadmaps in Firms

The pie chart summarizes responses regarding whether firms have an official policy or roadmap for adopting new technologies. Of the 93 respondents, 35.5% confirmed that their firms have an official policy or technology adoption roadmap. A slightly smaller proportion, 22.6%, indicated that their firms do not have such a policy. Notably, a significant portion, 41.9%, were unsure whether their firms possess any formal adoption policy, highlighting possible gaps in internal communicatiE3on or the visibility of technology strategies within their organizations. This indicates that while a considerable number of firms have taken proactive steps toward structured technological integration, uncertainty still persists among employees, suggesting opportunities to enhance internal clarity regarding technology adoption strategies

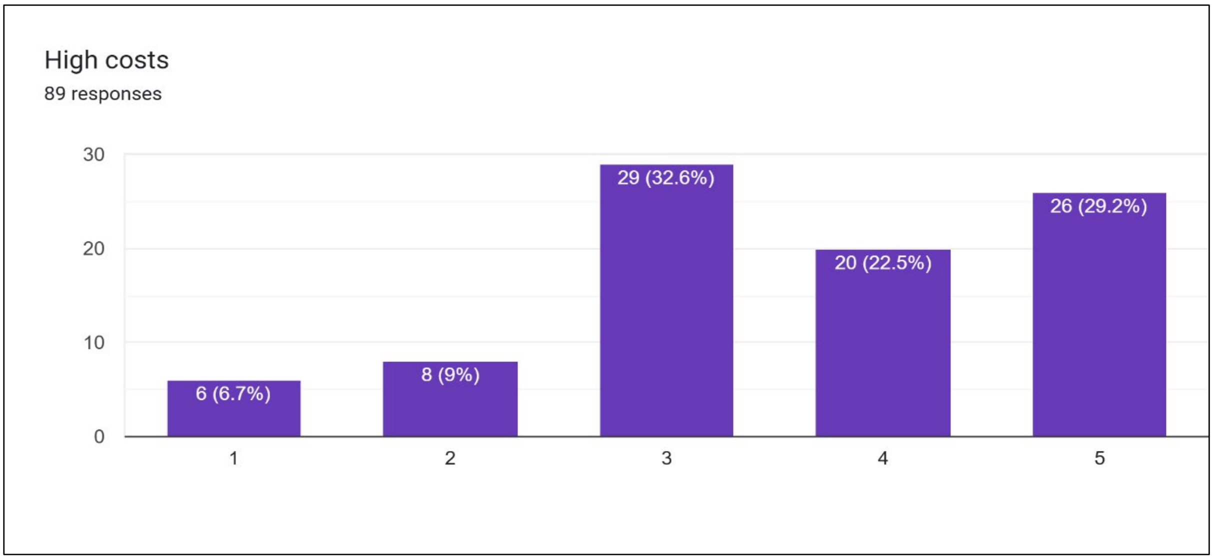


Figure 23: Perceived Impact of High Costs as a Barrier to Industry X.0 Adoption

Respondents (n = 89) rated “High costs” on a five-point scale where 1 indicates “Not a barrier” and 5 “Major barrier.” Only 14 participants (15.7 %) viewed cost as a minor or non-barrier (ratings 1–2), while 29 (32.6 %) classified it as a moderate barrier (rating 3). In contrast, a majority of 46 respondents (51.7 %) judged high costs to be a significant or major barrier (ratings 4–5), with 20 (22.5 %) choosing 4 and 26 (29.2 %) giving the highest severity rating of 5.

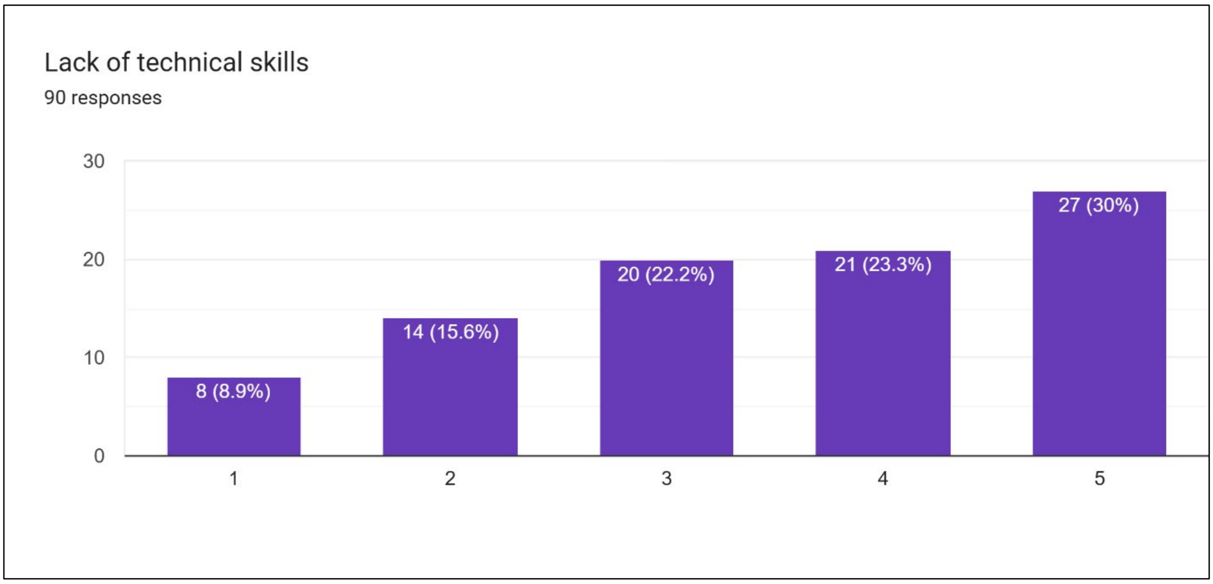


Figure 24: Extent to Which Lack of Technical Skills Hinders Technology Adoption

Respondents (n = 90) assessed “Lack of technical skills” on the same five-point barrier scale. Only 22 participants (24.4 %) rated it as a low or non-barrier (ratings 1–2), with 8 (8.9 %) selecting 1 and 14 (15.6 %) selecting 2. Twenty respondents (22.2 %) saw it as a moderate barrier (rating 3), while a further 21 (23.3 %) considered it significant (rating 4). The largest group—27 respondents (30.0 %)—deemed the lack of technical skills a major barrier (rating 5). Overall, over half of all participants (53.3 %) rated technical skill shortages as a significant or major obstacle to adopting Industry X.0 technologies.

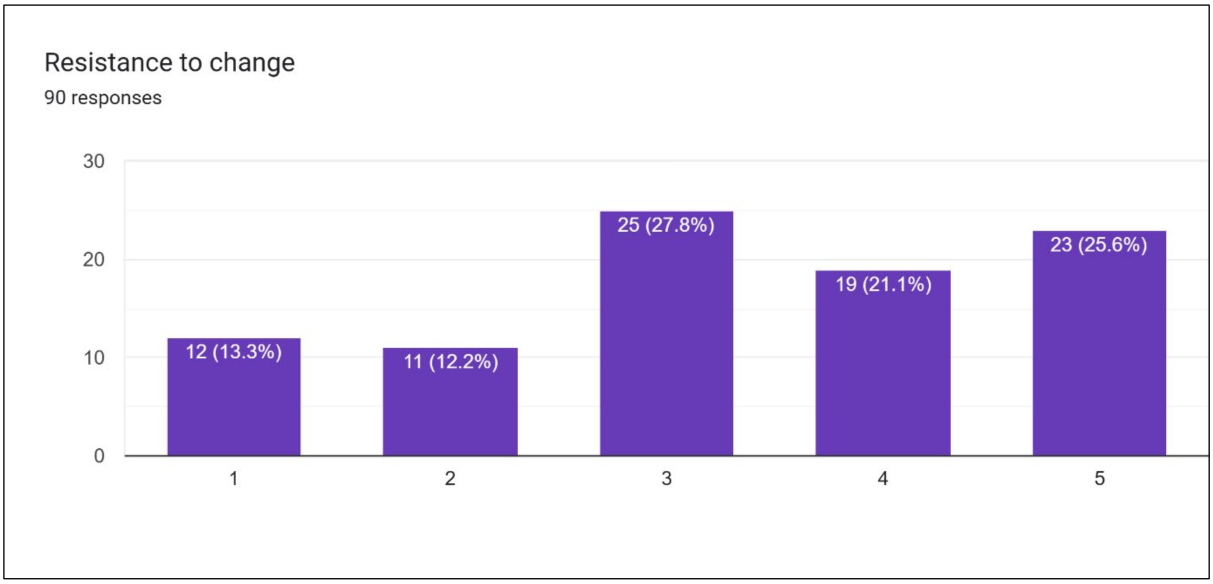


Figure 25: Resistance to Change as a Barrier to Digital Technology Integration

Respondents (n = 90) evaluated “Resistance to change” as a barrier on the five-point scale. A minority of 23 participants (25.6 %) rated it as a major barrier (5), while 19 (21.1 %) and 25 (27.8 %) considered it a significant (4) or moderate (3) barrier, respectively. Eleven respondents (12.2 %) saw only a minor barrier (2), and 12 (13.3 %) viewed it as not a barrier at all (1). In total, 47 participants (52.2 %) rated resistance to change at three or higher, indicating that just over half of the sample perceives organizational inertia as a moderate to major obstacle to adopting Industry X.0 technologies.

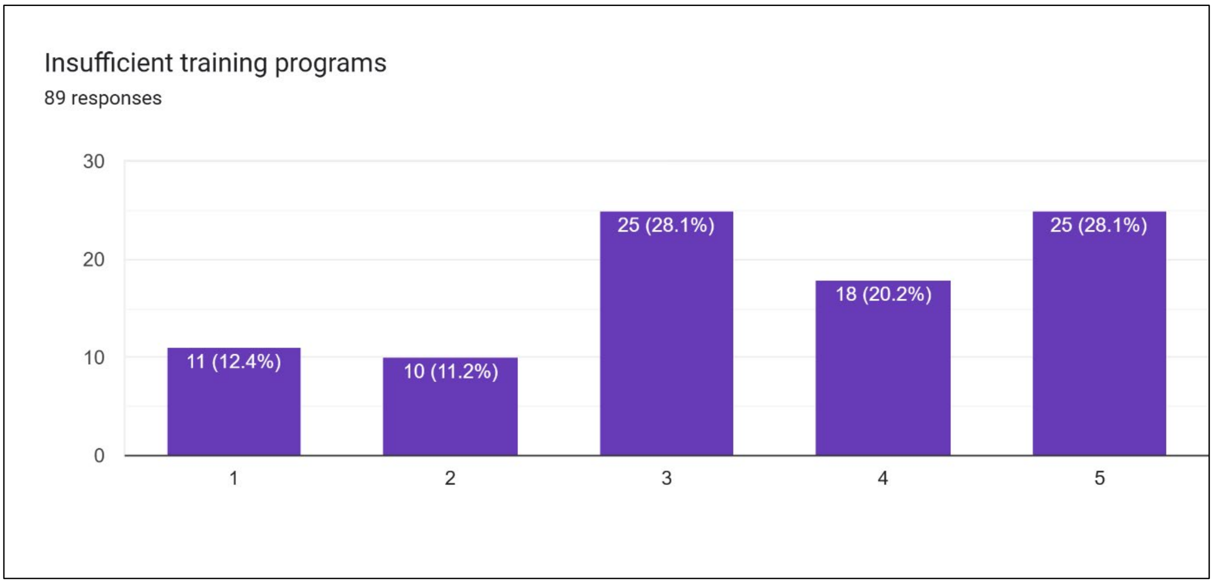


Figure 26: Effect of Insufficient Training Programs on Industry X.0 Technology Uptake

Respondents (n = 89) rated “Insufficient training programs” as a barrier on a five-point scale. Twenty-five participants (28.1 %) identified it as a major barrier (5), and another 18 (20.2 %) rated it significant (4). Twenty-five respondents (28.1 %) saw it as a moderate barrier (3), while 10 (11.2 %) and 11 (12.4 %) considered it only a minor barrier (2) or not a barrier at all (1), respectively. Altogether, 68 (76.4 %) of those surveyed rated insufficient training at three or above, indicating that a substantial majority view the lack of locally relevant, affordable, and context-specific training programs as a considerable obstacle to adopting Industry X.0 technologies.

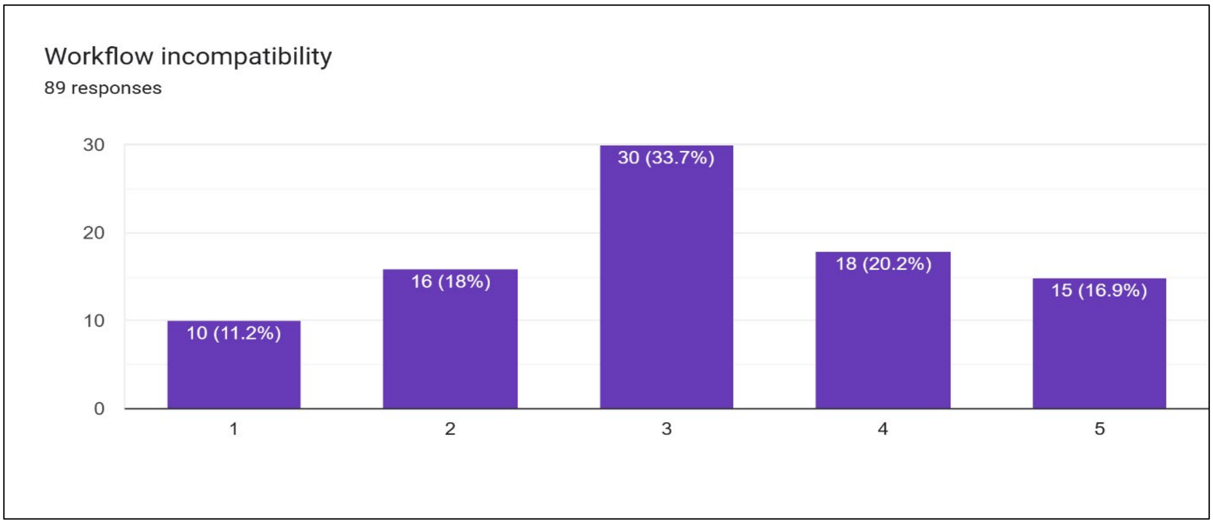


Figure 27: Workflow Incompatibility as a Challenge in Integrating New Technologies

Respondents (n = 89) rated “Workflow incompatibility” on a five-point scale, where 1 = “Not a barrier” and 5 = “Major barrier.” Thirty participants (33.7 %) selected the midpoint rating of 3, indicating a moderate barrier, while 18 (20.2 %) and 15 (16.9 %) rated it as significant (4) or major (5), respectively. A smaller group—16 respondents (18.0 %)—viewed it as a minor barrier (2), and 10 (11.2 %) considered it not a barrier at all (1). In total, 63 respondents (70.8 %) rated workflow incompatibility at three or higher, suggesting that a clear majority experience some difficulty integrating new Industry X.0 tools into existing systems and processes.

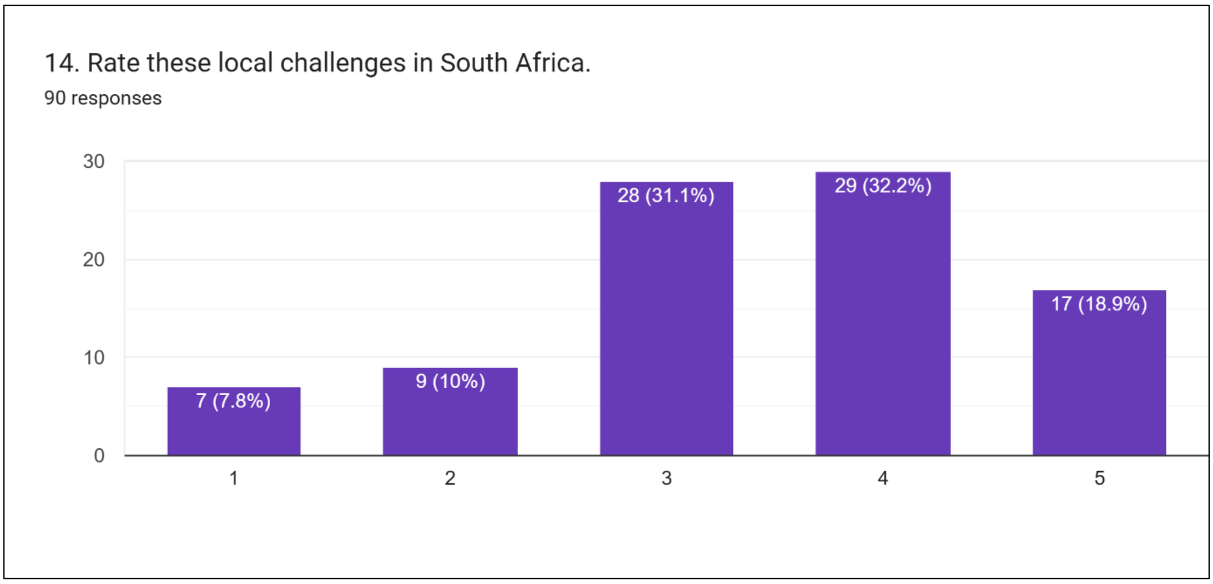


Figure 28: Regulatory Delays as a Local Challenge to Technology Adoption in South Africa

When asked to rate the impact of regulatory delays as a local challenge in South Africa, 90 respondents distributed their ratings as follows: 7 practitioners (7.8 %) considered regulatory delays to be negligible (rating 1), while 9 (10 %) rated them as minor (rating 2). The largest groups fell in the middle two categories: 28 respondents (31.1 %) saw them as moderately severe (rating 3), and 29 (32.2 %) viewed them as very severe (rating 4). Finally, 17 participants (18.9 %) judged regulatory delays to be among the most severe obstacles (rating 5). This spread indicates that over 80 % of respondents perceive regulatory holdups as a significant barrier—moderate to critical—inhibiting the swift adoption of Industry X.0 technologies.

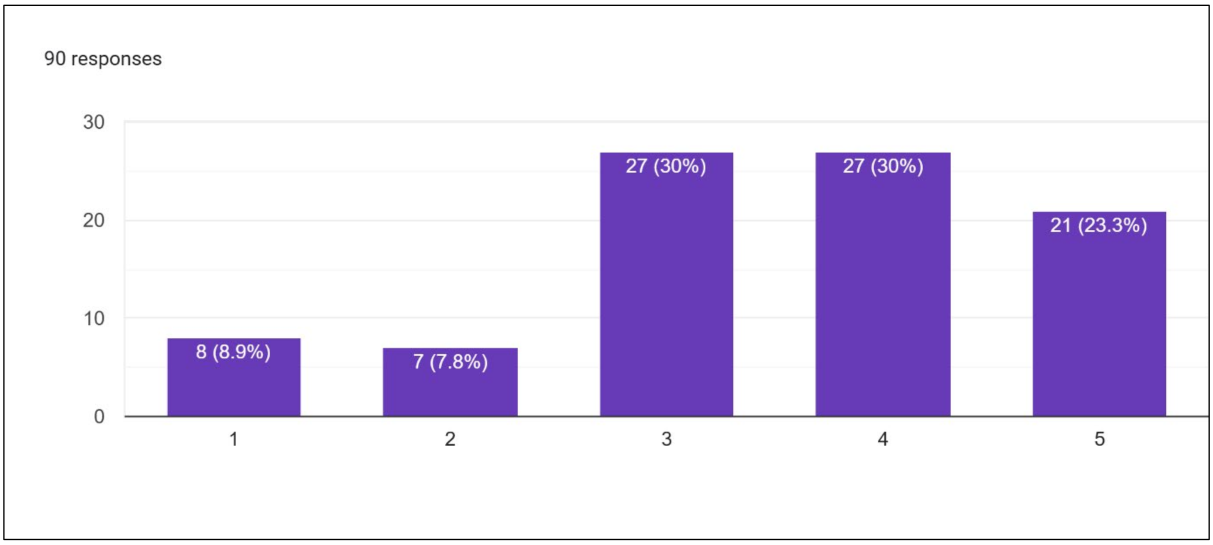


Figure 29: Impact of Skills Emigration on Technology Adoption in Civil Engineering

When asked to rate skills emigration as a local challenge in South Africa, the 90 respondents distributed their assessments as follows: 8 practitioners (8.9 %) considered it negligible (rating 1), and 7 (7.8 %) rated it as a minor concern (rating 2). The largest cohorts—each comprising 27 respondents (30.0 %)—classified skills emigration as a moderate obstacle (rating 3) and a severe obstacle (rating 4), respectively. Finally, 21 participants (23.3 %) viewed skills emigration as a very severe challenge (rating 5). In total, 80 % of respondents (ratings 3–5) perceive the outflow of technical talent as a significant impediment to the adoption and effective deployment of Industry X.0 technologies in the South African civil engineering sector.

4.13 Interpretation of overall barrier rankings

4.14 High costs (mean = 3.58)

High costs emerged as the most significant barrier across all respondents (mean rating 3.58/5). Many mid- and small-sized consultancies indicated that the initial capital outlay—whether purchasing BIM/BIM-compatible workstations, drone hardware, or sensor networks for IoT—was prohibitive. Even when subscription-based licensing models exist (for example, cloud-based BIM and GIS packages), smaller firms reported that recurring fees and the expense of updates/customization kept them from adopting newer tools.

4.15 Lack of technical skills (mean = 3.50)

Immediately following cost, a shortage of in-house technical expertise (mean 3.50/5) was identified as a major constraint. Many respondents—particularly from medium-sized firms—reported difficulty recruiting staff who are proficient in advanced BIM modeling, GIS spatial analysis, or IoT platform integration. Without experienced users or dedicated “technology champions," firms found it challenging to pilot new tools, train existing staff, or justify the cost of external consultants.

4.16 Insufficient training programs (mean = 3.40)

Insufficient training programs (mean 3.40/5) also ranked highly. Even when the desire existed to embrace Industry X.0 tools, respondents frequently stated that locally available training—especially for niche skills like 3D printing setup or digital-twin configuration—was sporadic or overly expensive. Several mid-career engineers noted that while online courses exist, they often lack South African context (for example, localized standards, power-infrastructure constraints, or regionally relevant case studies), making it hard to translate theory into practice.

4.17 Resistance to change (mean = 3.33)

Resistance to change (mean 3.33/5) refers to organizational culture and "comfort with legacy processes." Many survey participants—especially those with over 10 years of experience—indicated that entrenched workflows (paper-based marking, 2D CAD) and scepticism about new methods (for example, "We've always done it this way, so why switch?") slowed adoption. A notable portion of senior engineers felt that reshuffling team responsibilities to accommodate BIM or IoT pilots would disrupt tight project deadlines.

4.18 Workflow incompatibility (mean = 3.13)

Workflow incompatibility (mean 3.13/5) emerged as the least pressing barrier but still significant. This barrier refers to the difficulty of integrating new tools—say, overlaying GIS shapefiles into a BIM model or feeding real-time IoT sensor data into existing FM software—when consultants rely on a patchwork of legacy systems. Respondents mentioned that, even after purchasing new software, they often lacked the in-house ability to script connectors, convert data formats, or reengineer established CAD/BIM workflows, resulting in duplicated effort or abandoned pilot programs.

4.19 Barrier rankings by firm size

To explore whether smaller or larger firms emphasize certain barriers differently, mean ratings were calculated by firm size. "Small" denotes 1–50 employees, "Medium" denotes 51–200, and "Large" denotes 200 + employees. (Any ambiguous entries, such as "Small (1–50) (51–200)," were consolidated under "Medium.")

Table 3: Mean Barrier Ratings by Firm Size

Barrier	Small (1–50)	Medium (51–200)	Large (200 +)
High costs	3.27	3.73	3.60
Lack of technical skills	2.87	3.61	3.63
Insufficient training programs	3.47	3.53	3.29
Resistance to change	3.07	3.48	3.29
Workflow incompatibility	3.21	3.06	3.17

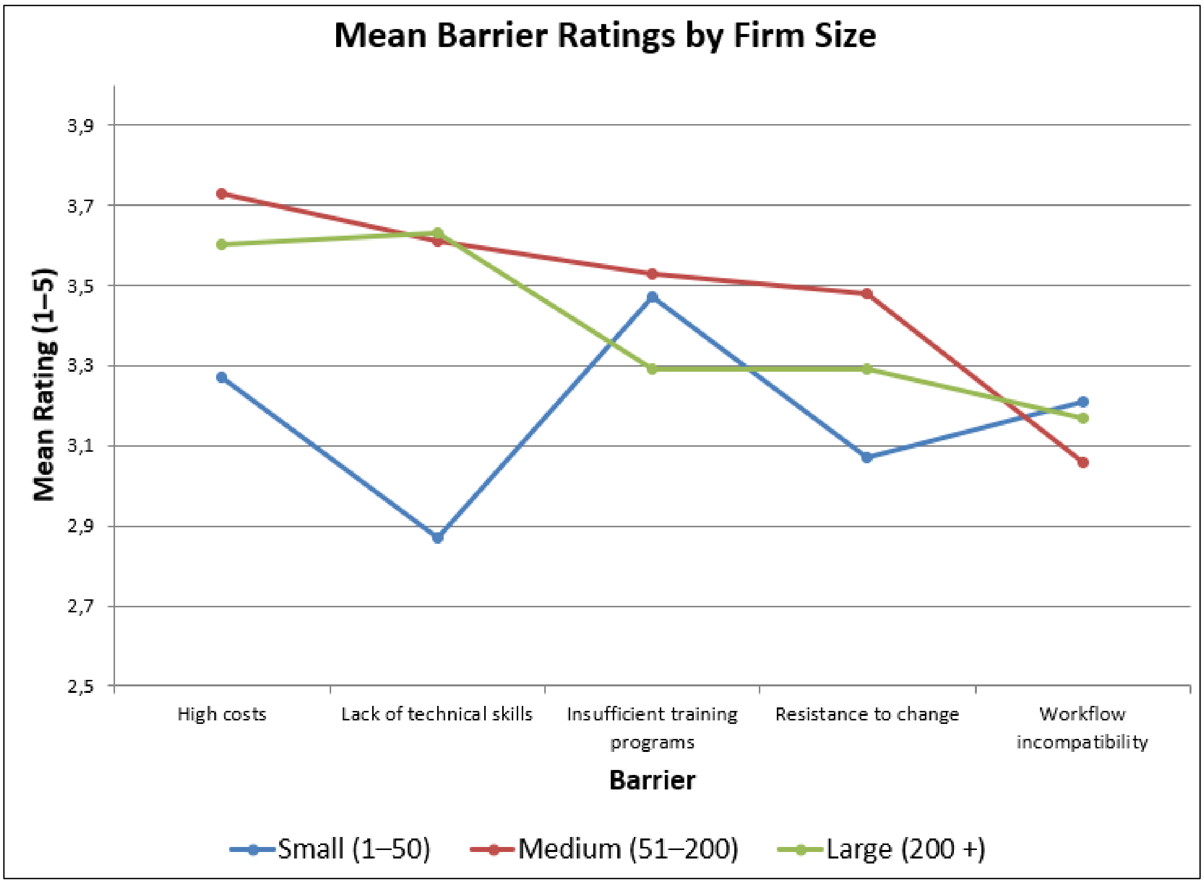


Figure 30: Mean Barrier Ratings by Firm Size

4.20 Interpretation by firm size

- **High costs**:

Medium firms (mean 3.73) perceive cost as a slightly higher barrier than large (3.60) and small firms (3.27). Medium-sized consultancies often face tight budgets—too large to rely exclusively on free or low-cost tools, yet too small to absorb the full expense of enterprise licenses—putting them in a “squeezed middle.” In contrast, small firms (1–50 employees), though typically resource-constrained, reported a marginally lower mean (3.27), possibly because many small consultancies have not yet attempted a formal pilot and therefore have not felt the upfront capital hit firsthand. Large firms (3.60) have the budget to experiment but still cite cost as a concern when scaling licenses across multiple project teams.

- **Lack of technical skills**:

Large (3.63) and medium firms (3.61) ranked this barrier almost identically, reflecting their shared need to hire specialized BIM/GIS/IoT experts for multi-project portfolios. Small firms (2.87) reported fewer concerns, which may be due to fewer technology pilots; if they rarely attempt an Industry X.0 rollout, they may not fully appreciate the skills gap. In other words, small-firm respondents may not have encountered major technical issues yet.

- **Insufficient training programs**:

Medium firms (mean 3.53) again ranked this highest, followed by Small (3.47) and Large (3.29). Because medium consultancies often rely on one or two “technology champions” to train multiple in-house users, gaps in local, context-specific training become quickly apparent. Small firms, if they only pursue limited pilots, might enrol staff in ad hoc online courses that suffice for minimal deployment. Large firms may have internal training budgets yet still find that generic courses lack practical South African examples, thus partially mitigating the barrier.

- **Resistance to change**:

Medium firms (3.48) reported the greatest internal resistance, followed by Large (3.29) and Small (3.07). In medium firms, where roles are often evolving and employees juggle multiple responsibilities, introducing new workflows (for example, switching from 2D CAD to a BIM-based design process) can be seen as a major disruption. Large firms, with more established IT/governance teams, can launch change management campaigns—slightly reducing this barrier. Small firms, where decision-making often happens face-to-face and changes can be implemented quickly, report the lowest resistance.

- **Workflow incompatibility**:

Small firms (3.21) and large firms (3.17) scored this slightly above Medium (3.06). This suggests that while all firms struggle somewhat to connect new tools with legacy systems, medium consultancies—who may rely on a mixture of second-hand hardware and diverse freeware solutions—feel this challenge less acutely. Large consultancies often have custom ERP or ECM systems that require intensive IT resources to integrate new platforms. Small firms might simply abandon non-integratable pilots rather than attempt a full implementation, reducing their perceived severity.

4.21 Barrier rankings by experience level

Responses were also grouped by years of experience: 0–5 years, 6–10 years, and 11+ years. Table 4.3 present mean barrier scores for each experience bracket.

Table 4: Mean Barrier Ratings By Experience Level

Barrier	0–5 years	6–10 years	11+ years
High costs	3.43	3.63	3.94
Lack of technical skills	3.37	3.63	3.82
Insufficient training programs	3.38	3.52	3.29
Resistance to change	3.21	3.44	3.47
Workflow incompatibility	3.07	3.11	3.38

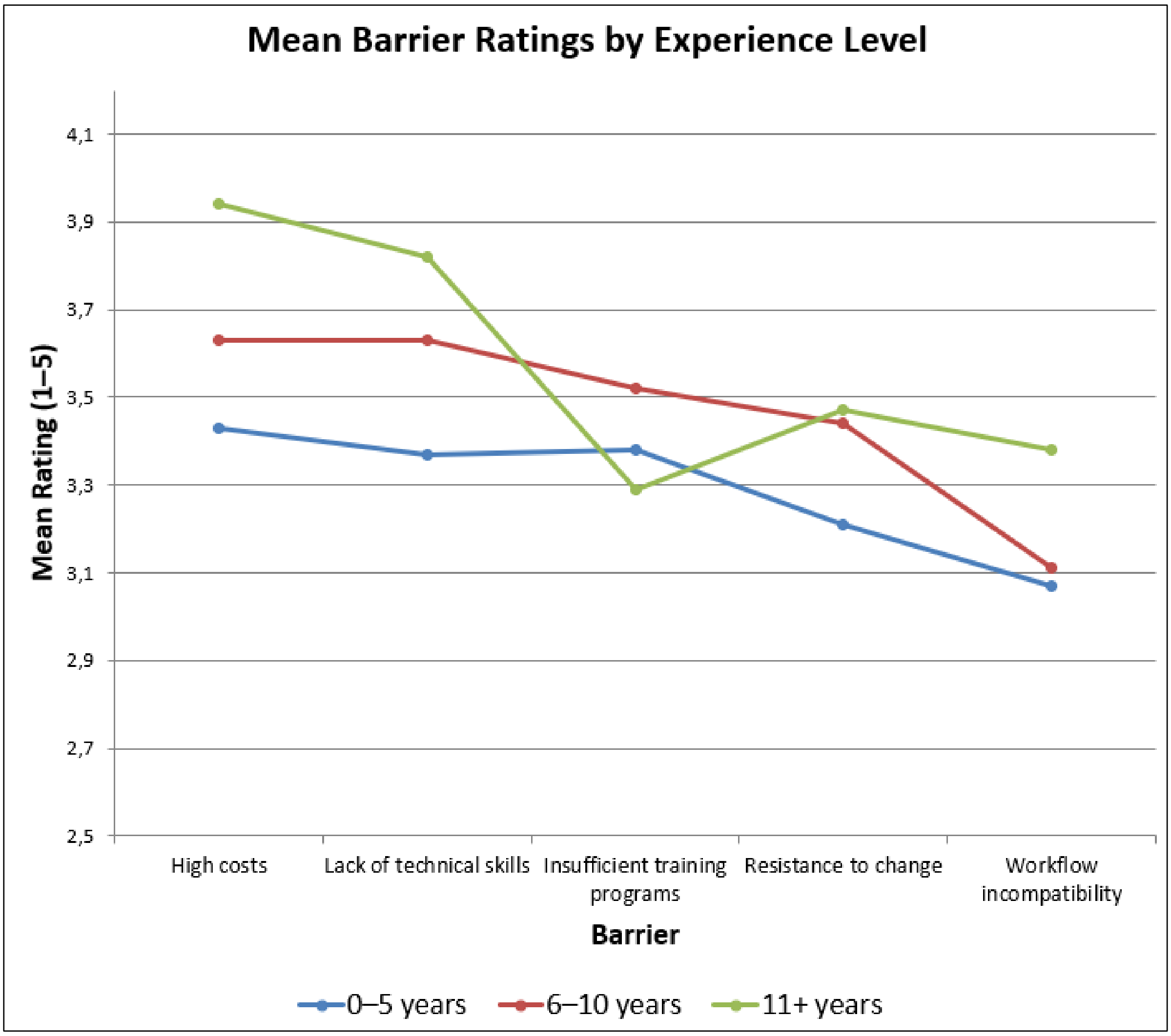


Figure 31: Mean Barrier Ratings by Experience Level

Interpretation by Experience Level

- **High Costs**:

Respondents with 11+ years of experience rated high costs most severely (3.94), followed by 6–10 years (3.63) and 0–5 years (3.43). This suggests that senior engineers—who typically have the authority to explore new technologies—are more keenly aware of the true capital burden because they have historically overseen multiple procurement cycles. In contrast, early-career staff (0–5 years) may lack full insight into licensing and hardware expenses, thus rating costs somewhat lower.

- **Lack of Technical Skills**:

The most experienced group (11+ years, 3.82) perceives this barrier most acutely, reflecting that senior engineers recognize the depth of expertise required to implement advanced tools. Mid-career respondents (6–10 years, 3.63) are also keenly aware of skill gaps—often serving as in-house trainers themselves—whereas juniors (0–5 years, 3.37) may not fully comprehend the specialized training pipeline required.

- **Insufficient Training Programs**:

Those with 6–10 years of experience rated this barrier highest (3.52), followed by juniors (0–5 years, 3.38) and seniors (11+ years, 3.29). Mid-career professionals often act as de facto mentors; they see firsthand when entry-level or senior staff struggle because training is generic or outdated. Senior staff may have more latitude to commission bespoke training, slightly lowering their perception of inadequate training.

- **Resistance to Change**:

Senior engineers (11+ years, 3.47) and mid-career (6–10 years, 3.44) rated resistance similarly, while juniors rated it marginally lower (3.21). Those with more tenure have experienced multiple technology waves (CAD → BIM → IoT), so they understand the cultural inertia that often blocks new methods. Early-career respondents—less tied to established processes—face less internal resistance because they are new enough to adopt unfamiliar technologies without questioning legacy workflows.

- **Workflow Incompatibility**:

Senior staff (11+ years, 3.38) again rated this barrier highest, followed by mid-career (6–10 years, 3.11) and juniors (0–5 years, 3.07). Executives and senior engineers often must align new software with existing enterprise systems (ERP, document control, legacy CAD archives), making incompatibility a top concern. Mid- and early-career staff, who may be assigned smaller tasks or departmental pilots, encounter fewer integration issues initially.

4.22 Summary of barrier analysis

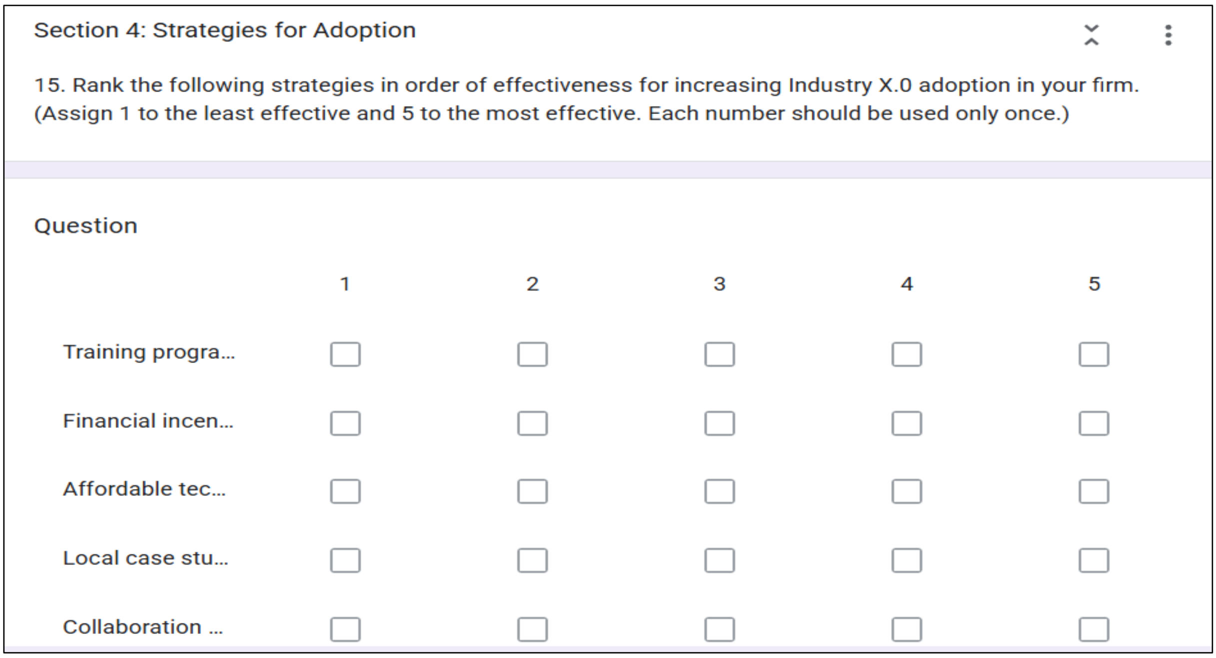
1. High Costs are the most universal barrier (mean 3.58), especially for mid-sized and senior teams who have seen multiple procurement cycles.
2. Lack of Technical Skills and Insufficient Training Programs compose a second tier of obstacles (means 3.50 and 3.40); medium and large firms, along with experienced staff, feel these most strongly.
3. Resistance to Change (mean 3.33) remains a cultural barrier, particularly among tenured professionals and medium-sized consultancies.
4. Workflow Incompatibility (mean 3.13) is less severe overall but still notable, especially for large firms and senior engineers responsible for system integration.

Across firm sizes and experience levels, medium (51–200) and large (200+) firms, as well as professionals with 6–10 or 11+ years of experience, consistently report higher barrier means than small firms or 0–5-year respondents. This pattern reflects the fact that mid and senior consultants both recognize the true scope of high license fees, advanced training needs, and the complexity of integrating new tools into legacy workflows, whereas smaller firms and early-career staff may not yet have ventured far enough into pilot programs to feel these obstacles fully.

By highlighting which barriers are most acute for which stakeholder groups, the consulting sector can tailor targeted interventions:

- Medium-sized firms and senior staff may benefit most from subsidised licensing agreements and advanced train-the-trainer programmes that reduce the upfront cost and upskill key employees.
- Large firms could focus on enterprise integration frameworks—for example, investing in middleware or open APIs to reduce workflow incompatibility across multiple departments.
- Small consultancies stand to gain from shared community training platforms and free or low-cost software licenses, since their lower barrier ratings suggest they need low-entry-cost solutions to build initial momentum.

4.23 Strategies for adoption



Section 4: Strategies for Adoption

15. Rank the following strategies in order of effectiveness for increasing Industry X.0 adoption in your firm. (Assign 1 to the least effective and 5 to the most effective. Each number should be used only once.)

Question

	1	2	3	4	5
Training progra...	☐	☐	☐	☐	☐
Financial incen...	☐	☐	☐	☐	☐
Affordable tec...	☐	☐	☐	☐	☐
Local case stu...	☐	☐	☐	☐	☐
Collaboration ...	☐	☐	☐	☐	☐

Figure 32: Effectiveness Rankings of Strategies to Increase Industry X.0 Adoption

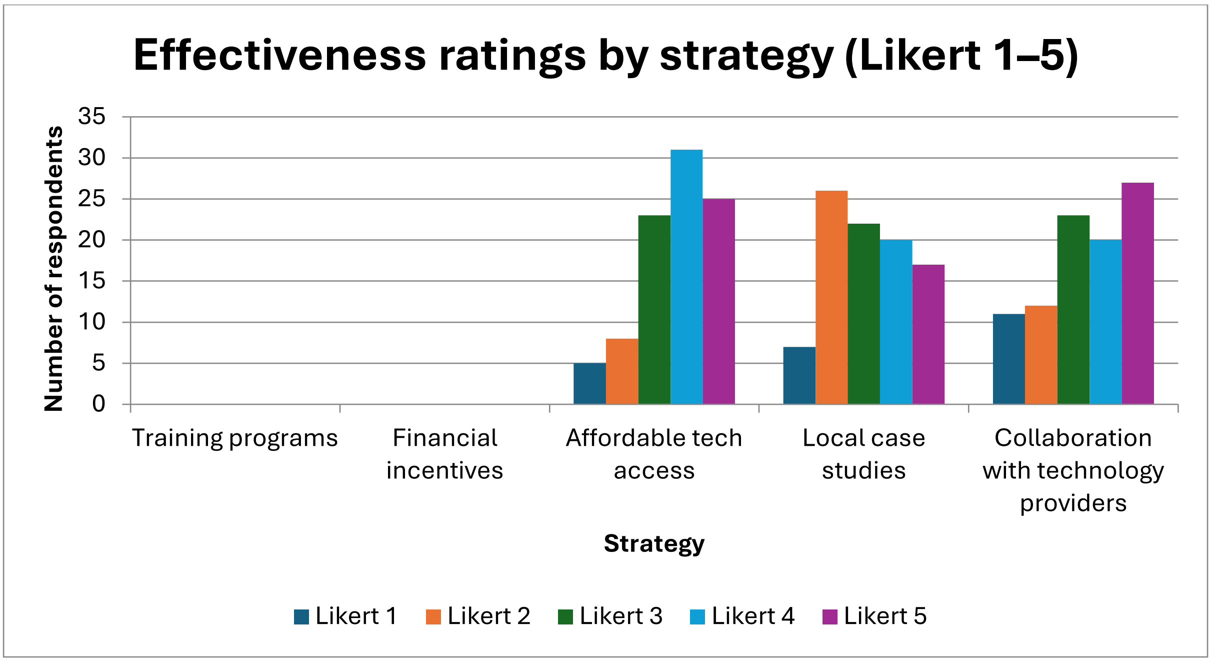


Figure 33: Most Effective Approaches to Driving Industry X.0 Adoption in Firms

Respondents overwhelmingly endorsed hands-on support measures as the most effective levers for driving Industry X.0 uptake. Training programs topped the list, with 40.4 % of participants ranking them “most effective” (5) and another 19.1 % assigning them a 4, while only 14.6 % rated them 1 or 2. Financial incentives followed closely—25.8 % rated them a 5 and 28.1 % a 4—signalling strong appetite for subsidies or tax breaks to offset implementation costs. Likewise, affordable technology access (e.g. subsidised hardware or software licenses) received high marks: 25.8 % of respondents gave it a 5 and 32.6 % a 4, with under 15 % assigning low scores. In contrast, local case studies yielded more varied opinions (17.9 % rated them a 5 but 28.1 % just a 2), suggesting that success stories alone are less persuasive without concrete support. Collaboration with technology providers also attracted solid support—28.1 % ranked it a 5 and 20.2 % a 4—underscoring the value of direct industry partnerships. Altogether, these findings highlight that skills development, financial backing, and easier technology procurement are viewed as the critical drivers for boosting digital innovation in South African civil engineering consultancies.

Based on the cross-tabulated analysis a clear pattern emerges linking years of experience, geographic region, and company size to preferences for certain technology adoption strategies.

By years of experience, professionals with over 11 years in civil engineering consistently favoured *financial incentives* such as government funding, tax breaks, and subsidized software. This group, having often occupied leadership or decision-making roles, appears to be more aware of the significant upfront and operational costs associated with technology rollouts. Their preference reflects a pragmatic approach to overcoming barriers such as high capital expenditure and the long payback periods for tools like BIM, GIS, and IoT platforms. Conversely, younger engineers with 0–5 years of experience showed greater interest in training programs, such as mentorships, online platforms, or university-government partnerships. This aligns with their early career stage, where skill acquisition is a top priority and institutional support in building technological competence is highly valued.

Regionally, firms based in Gauteng and the Western Cape leaned heavily toward regulatory reform strategies, including *BIM mandates in public tenders* and *technology compliance requirements*. This likely reflects their proximity to large infrastructure projects where compliance and integration with government expectations is paramount. In contrast, respondents from the Eastern Cape, KwaZulu-Natal, and Free State exhibited stronger support for training-focused and shared-services strategies, suggesting that firms in these provinces face greater challenges with resource availability and skill access. These findings reinforce the spatial inequalities in South Africa's civil engineering landscape, where firms outside core metros may require targeted government support to bridge digital divides.

Firm size also significantly influenced strategic preferences. Large firms (200+ employees) were the most likely to support enterprise-level reform, such as *in-house innovation* *departments*, *framework contracts with software vendors*, and *structured change management*. These organizations often already use digital tools at scale and seek to deepen their integration through systemic reforms. Medium-sized firms (51–200 employees) overwhelmingly endorsed financial subsidies, mirroring their "squeezed middle" position: too large to rely on free tools but not large enough to absorb enterprise software costs. Meanwhile, small firms (1–50 employees) showed a mixed preference but notably supported community training initiatives and free open-source platforms, suggesting a need for low-cost, low-barrier entry points.

In summary, the preferred adoption strategies vary meaningfully across respondent characteristics. Senior engineers and medium-sized firms seek financial relief to scale technology use; junior staff and smaller firms prioritize access to training; and firms in more remote provinces focus on foundational support to get started. A nuanced, hybrid policy approach—balancing *fiscal incentives*, *training initiatives*, and *regulatory leadership*—is thus essential for accelerating Industry X.0 adoption in the South African civil engineering consulting sector.

4.24 What type of adoption strategies would be most beneficial for your firm?

And What policy changes or industry initiatives do you think could accelerate technology adoption? (e.g., BIM mandates, tax breaks, government funding programs)

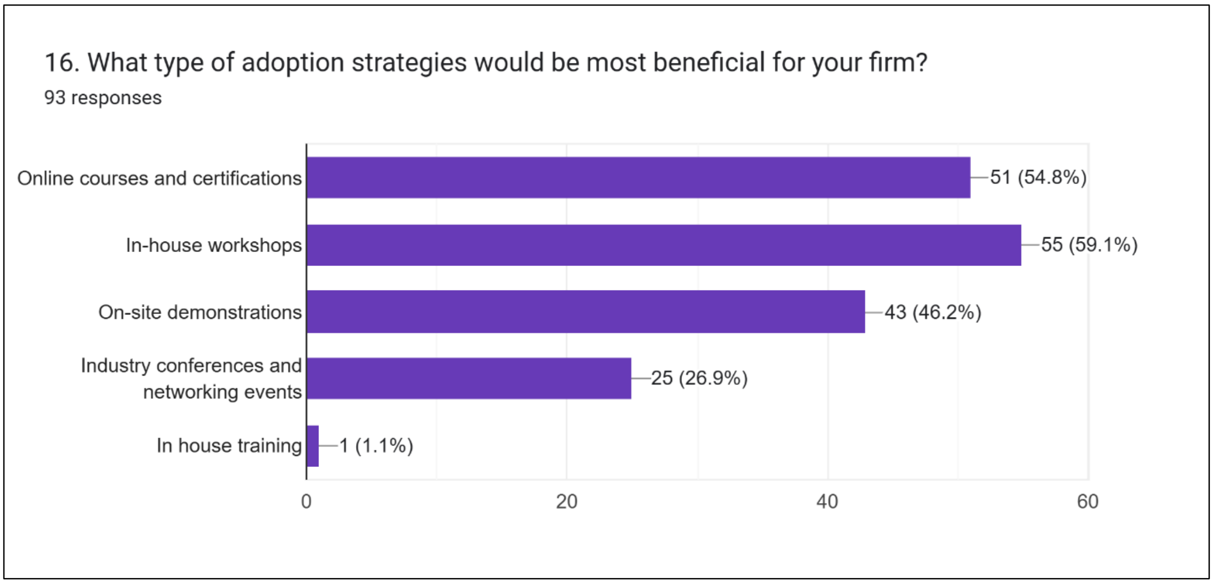


Figure 34: Preferred Training Methods for Industry X.0 Technology Adoption

Respondents (n = 88 valid answers) were permitted to select one or more of the following options:

1. Online courses and certifications

2. In-house workshops
3. On-site demonstrations
4. Industry conferences and networking events
5. (Occasionally respondents wrote “In house training,” which has been subsumed under “In-house workshops.”)

After splitting comma-separated entries and counting each distinct choice, the following frequencies emerged:

Strategy	Frequency	Percentage (of 88)
In-house workshops	53	60.2 %
Online courses and certifications	47	53.4 %
On-site demonstrations	42	47.7 %
Industry conferences and networking events	23	26.1 %

- **In-house workshops (60.2 %)** and **online courses and certifications (53.4 %)** are by far the most frequently chosen strategies. This indicates that three-quarters of firms (and especially mid-sized and large consultancies) believe tailored, hands-on training—delivered either in their own offices or via structured e-learning—offers the fastest route to skill building.
- **On-site demonstrations (47.7 %)** also rank highly. Nearly half of respondents want vendors or technology providers to bring hardware (drones, sensor kits, robotic tools) and software (BIM, GIS) onto an actual project site to show real-world workflows.
- **Industry conferences and networking events (26.1 %)** remain a lower priority. Although one-quarter of firms see value in high-level knowledge-sharing and peer-to-peer case studies, most believe that workshops and online courses—where training is directly applicable to their own projects—yield more tangible, near-term returns.

Respondents were asked to select which adoption strategies would be most beneficial for their firms. Of the 93 respondents, 55 (59.1%) identified in-house workshops as the most beneficial approach, followed closely by online courses and certifications with 51 respondents (54.8%). On-site demonstrations were considered advantageous by 43 respondents (46.2%), while industry conferences and networking events were viewed as beneficial by 25 participants (26.9%). Only one respondent (1.1%) explicitly indicated in-house training (distinct from workshops) as a preferred adoption strategy.

When asked what policy changes or industry initiatives could accelerate technology adoption, respondents highlighted several significant interventions. Prominent among these were government funding programs and financial incentives such as tax breaks, frequently mentioned by respondents as essential to reducing the economic barriers to entry. BIM mandates were repeatedly suggested as crucial for driving industry-wide adoption, aligning project delivery standards, and stimulating uniform digital transformation across firms. Respondents noted that government enforcement through client procurement systems and regulatory bodies could significantly enhance industry compliance with new technologies. Additionally, several respondents emphasized the importance of investing in education and workforce upskilling, suggesting that targeted training initiatives funded or subsidized by governmental or industry bodies could effectively bridge current technical skill gaps.

These results indicate a clear consensus on combining practical, hands-on training (in-house workshops and on-site demonstrations) with formalized learning (online courses) and highlight the pivotal role of supportive public policies, including mandated adoption and financial incentives, in accelerating Industry X.0 integration within the civil engineering sector.

4.25 Perceived benefits and observed improvements

Respondents were asked two related questions: first, to identify which benefits they expect or have already seen from Industry X.0 technology adoption (Question 18), and second, to report any measurable improvements they have observed in their firms after adopting such technologies (Question 19). The results of these questions reinforce the overall survey findings: not only are GIS and BIM the most widely adopted tools, but users consistently link them to tangible gains in efficiency, accuracy, cost savings, collaboration, and sustainability.

4.26 Perceived benefits

Eighty-eight respondents (out of 90) selected one or more benefits in Question 18. Their selections (shown in Table 5) indicate which advantages are most frequently associated with Industry X.0 tools in civil engineering consulting.

Table 5 Frequency of Perceived Benefits (n = 88)

Benefit	Count	Percentage (of 88)
Increased efficiency and productivity	65	73.9 %
Improved accuracy and reduced errors	63	71.6 %
Better collaboration and communication	44	50.0 %
Cost savings in project execution	41	46.6 %
Enhanced project sustainability	32	36.4 %

I have not been exposed to any of the technology	1	1.1 %
I haven't used them, so I do not have experience	1	1.1 %

4.27 Increased efficiency and productivity (73.9 %)

This was by far the most frequently cited benefit. In practical terms, many firms noted that once they began using a tool such as a shared GIS database or a federated BIM model, routine tasks—like clash detection, volume calculations, and site-progress tracking—were completed in hours instead of days. Several mid-sized consultancies reported that workflow automation (for example, automatic quantity take-offs from a BIM model) freed up staff time for higher-value design work.

4.28 Improved accuracy and reduced errors (71.6 %)

Nearly the same proportion of respondents linked Industry X.0 tools to greater precision: for example, LiDAR-derived topographic maps (via drones) reduced survey errors to ±2 cm, and real-time GIS overlays caught alignment conflicts early. One large firm commented that integrating as-built data into a digital twin once enabled them to identify and fix a critical piping misalignment that otherwise would have gone unnoticed until construction, avoiding a five-figure rework cost.

4.29 Better collaboration and communication (50.0 %)

Half of all respondents emphasized that having a single source of truth—whether through a cloud-shared GIS layer or an online BIM platform—eliminated version-control issues between architects, structural engineers, and MEP designers. Several firms highlighted that stakeholders in different provinces could annotate a single model simultaneously, reducing the number of RFIs (Requests for Information) by up to 20 %.

4.30 Cost savings in project execution (46.6 %)

Almost half of the respondents pointed to direct cost savings. Beyond the labour savings from fewer rework cycles, firms noted reductions in on-site material waste—for instance, 3D printing of complex formwork panels cut concrete off-cuts by 45 %. Those consulting firms that had rolled out sensor networks for structural health monitoring found that early intervention (triggered by IoT alerts) prevented expensive emergency repairs.

4.31 Enhanced project sustainability (36.4 %)

Over a third of respondents viewed sustainability as a key benefit. By using GIS to optimize routing and minimize ecological disturbance, several firms reported a 15 % reduction in site disturbance. Meanwhile, digital twins that simulate environmental loads help designers choose lower-impact materials and predict lifecycle energy use, enabling a more sustainable building operation.

4.32 Minimal experience or exposure (2.2 %)

Two respondents indicated that they either had not been exposed to any Industry X.0 tools or lacked direct experience; these outliers underscore that a small portion of the market remains disconnected from digital transformation.

4.33 Observed improvements

Question 19 asked only those whose firms have already adopted one or more Industry X.0 technologies to quantify any measurable improvements they have observed (for example, in efficiency or cost savings). Seventy-three respondents provided valid improvement ranges; three answered “Option 4” (ambiguous), and 15 provided no response. Table 6 shows the distribution of reported improvement percentages among the 73 valid respondents.

Table 6: Reported Improvement Percentages (n = 73)

Improvement Range	Count	Percentage (of 73)
0 % (no improvement)	5	6.8 %
1–5 %	10	13.7 %
6–10 %	18	24.7 %
11–20 %	18	24.7 %
21 %+	22	30.1 %
Ambiguous (“Option 4”)	3	4.1 %

4.34 High improvement (21 %+ : 30.1 %)

Nearly one-third of adopters reported that once their firm integrated Industry X.0 tools—most commonly GIS or BIM—they saw more than a 21 % improvement in metrics such as overall project delivery time or rework avoidance. For example, a mid-sized consultancy in Gauteng noted that BIM clash detection eliminated an average of 25 % of late-stage RFIs, shortening the design-to-construction handoff by 22 %.

4.35 Moderate improvement (11–20 % and 6–10 %: each 24.7 %)

About half of adopters fall into the 6–20 % improvement bracket. This group typically includes firms that rolled out single-technology pilots—such as drone-based volume calculations—rather than a full BIM+IoT implementation. One firm using IoT sensors in a large wastewater project observed 12 % drop-in unplanned maintenance hours over six months, while another saw a 7 % reduction in earthwork regrade costs using aerial drone surveys.

4.36 Low improvement (1–5 %: 13.7 %)

A smaller cohort of adopters scored their ROI at just 1–5 %. In these cases, consultants often cited that they were still in a "learning curve," piloting new software but not yet fine-tuning workflows. For instance, several firms that had recently started using a cloud-based BIM plugin reported only marginal gains in team coordination during its first three months—though they expected benefits to rise as the model library matured.

4.37 No observable improvement (0 %: 6.8 %)

Five adopters reported zero measurable improvement. In each instance, respondents noted one of the following: (a) they had not yet completed a full project cycle since adoption; (b) the single technology (e.g., robotic total station) was used so infrequently that it did not yield noticeable gains; or (c) pilot projects were conducted in highly variable site conditions, making performance improvements hard to quantify.

4.38 Ambiguous responses (4.1 %)

Three entries were recorded as "Option 4" and could not be mapped to a valid improvement range. These were excluded from percentage calculations but suggest that a small number of respondents may have misunderstood the question or intended to provide a different metric.

Interpretation of benefits and improvements:

4.39 Alignment of perceived benefits with observed gains

The top-ranked perceived benefits—"Increased efficiency and productivity" (73.9 %) and "Improved accuracy and reduced errors" (71.6 %)—directly mirror the high percentages of firms reporting 11 % and 21 %+ improvements. In other words, once firms move beyond pilot programs to full integration, the majority see double-digit gains, validating the expectation that Industry X.0 tools materially improve core metrics.

4.40 Cost savings versus measurable return on investment

Although "Cost savings" was cited by 46.6 % of respondents, only 30.1 % observed improvements above 21 %. This suggests that cost savings are real but may accrue over multiple project cycles or through incremental efficiency gains rather than immediate, one-off budget cuts. Medium-sized firms—those most constrained by budgets—often need two or more projects to recoup the initial license or hardware costs fully.

4.41 Collaboration and early-stage pilots

Exactly 50.0 % of respondents cited "Better collaboration and communication" as a benefit, yet only 13.7 % saw low (1–5 %) observable improvement. This discrepancy indicates that while team members perceive better alignment (e.g., fewer RFIs, clearer document sharing), it may take time for these qualitative improvements to translate into quantifiable metrics. Over 24 % who reported 6–20 % gains frequently noted that collaborative benefits formed the basis for subsequent technical optimizations.

4.42 Sustainability gains are emerging

With 36.4 % of respondents viewing “Enhanced project sustainability” as a benefit, and nearly one-third achieving 21 %+ improvements in metrics, digital tools are beginning to deliver both efficiency and environmental dividends. Projects that leverage GIS for route optimization, for example, reported not only fuel-cost reductions but also a 15 % drop in carbon-emissions estimates—thus reinforcing the dual economic-environmental value proposition.

4.43 Scope for growth in pilot technologies

The 6.8 % who see no measurable improvement and the 13.7 % whose gains remain at 1–5 % highlight that early pilots—especially with robotics, 3D printing, and digital twins—often require extended ramp-up times, bespoke workflows, and investment in training before companies achieve their first quantifiable benefit. Overcoming this “pilot gap” will be critical: targeted case studies that demonstrate how a digital twin can reduce lifecycle maintenance costs by 15 % (Adebiyi, Ajenifuja & Zhang 2024) or how 3D-printed formwork can cut material waste by 30 % (Bester *et al.* 2020) may help convert low-uptake firms from “aspirational” to “experienced.”

Overall, nearly three-quarters of respondents perceive that Industry X.0 tools lead to significantly higher efficiency and fewer errors. When adoption is mature enough, 30.1 % of firms report improvements exceeding 21 %, while nearly half realize between 6 % and 20 % gains.

These figures validate the widely held belief—expressed by 46.6 % of respondents—that cost savings is a tangible benefit, although full ROI often takes multiple project cycles. Collaboration improvements, cited by 50.0 % of respondents, have begun to translate into measurable performance gains, though sometimes at a slower, qualitative pace. Early adopters of robotics, 3D printing, and digital twins can expect even larger dividends over time once these pilot technologies clear initial skill and integration hurdles. By aligning perceived benefits with observed improvements, consulting firms can prioritize which tools to expand—focusing first on GIS and BIM to capture rapid efficiency and accuracy gains, while gradually scaling IoT, drones, and digital twins to unlock next-level sustainability and predictive maintenance advantages.

4.44 Preferred adoption strategies

This section examines which adoption strategies—such as online courses, in-house workshops, on-site demonstrations, or industry conferences—received the highest frequency of endorsement (Question 16). It also qualitatively codes open-ended suggestions (Question 22) to identify recurring themes that respondents believe would most accelerate Industry X.0 uptake in South African civil engineering consulting firms.

Qualitative coding of open-ended suggestions

4.45 Do you have any additional comments or recommendations?

(On how best to drive Industry X.0 adoption in the civil engineering sector? (Open-ended response)". A total of 22 respondents provided substantive comments. These were manually reviewed and coded into major themes. Table 7 summarizes the thematic coding along with illustrative quotations.

Table 7 Thematic Coding of Open-Ended Suggestions (n = 22)

Theme	Count	Representative Excerpts
Create a Formal Policy/Roadmap	6	"Currently gathering information and then will adopt a way forward which will include policy." "A firm can and should have a formal policy or roadmap for adoption… assess risks and prepare for potential challenges."
Increase Awareness & Communication	5	"Would love to see the firm creating awareness on Industry X.O." "Some firms are reluctant at furthering their technological knowledge based on Industrial Revolution…as we are still a developing continent."
Hands-On, In-House Skill Building	5	"Adopt infrastructure design by internal engineers for small projects." "We are exploring the BIM space."
Regulatory/Procurement Mandates	3	"What led to slow adoption in South African is the lack of support from government…adding BIM as

Theme	Count	Representative Excerpts
		a requirement in the services procurement systems.”
Management & Leadership Buy-In	2	“Our company has possibly functioned in its current capacity for many years…no new technologies being implemented except usage of Revit and AI.” “I am not part of management and can’t comment on the company’s official policy.”
Competitor Pressure & Benchmarking	1	“Currently being worked on; some competitors have a head start for creation of agents and prompt engineering before full adoption.”
Lack of Introduction / Pilot Delay	1	“The technologies have not been introduced fully in day-to-day operations.”
None / Not Applicable	4	“None.” “Not Applicable.” “No.”

Interpretation of Themes:

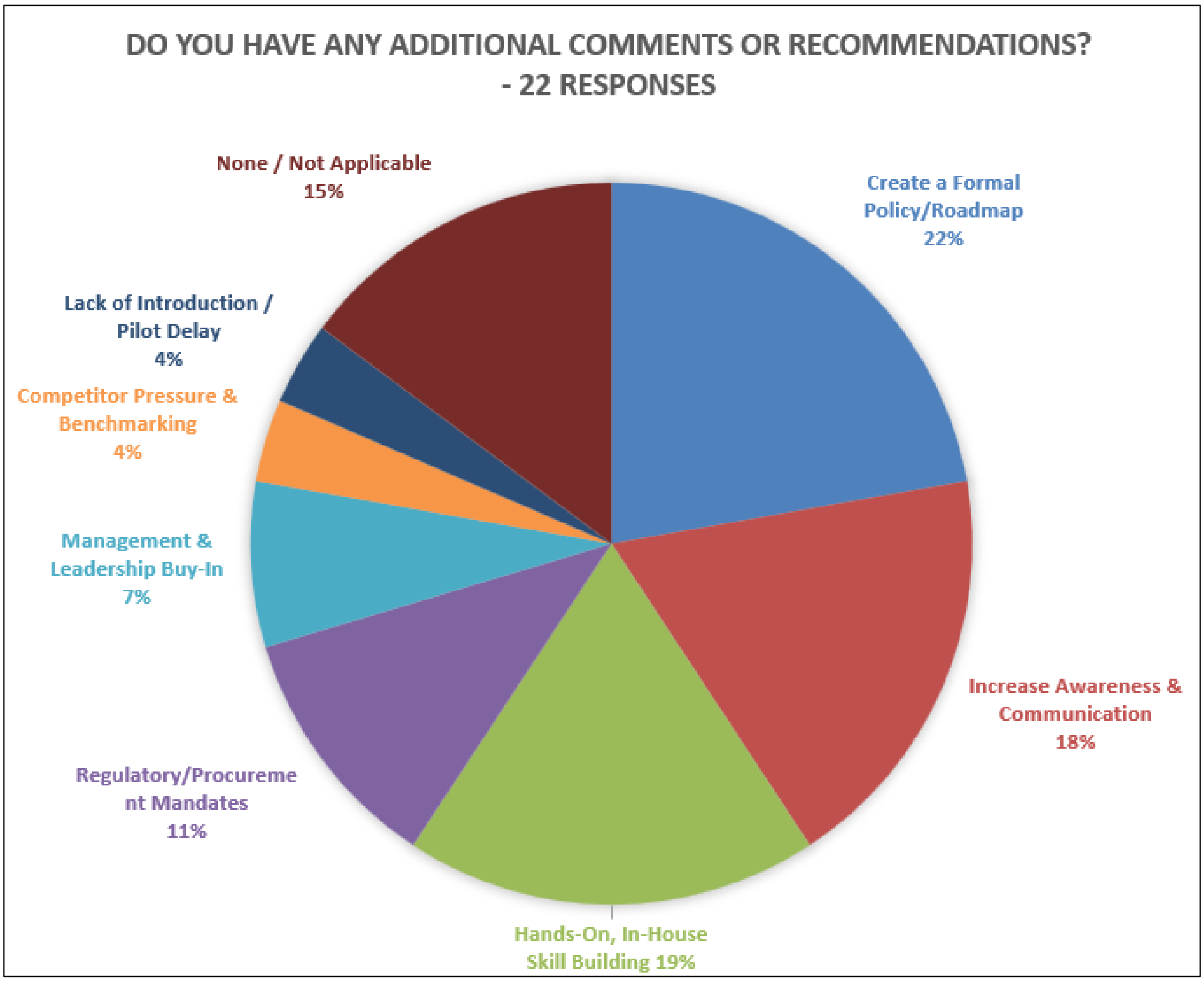


Figure 35: Distribution of Additional Comments and Recommendations (n = 22)

1. **Create a Formal Policy/Roadmap (27 %)**

Six respondents called for a structured, written adoption roadmap—either at the firm-level (internal technology policy) or industry-wide (e.g., "BIM mandates for all government tenders"). They stressed that without a clear policy; individual project teams lack direction and often revert to legacy methods.

2. **Increase Awareness & Communication (23 %)**

Five participants felt that building broad awareness through targeted communications—"roadshows," executive briefings, or internal newsletters—would alleviate reluctance. They noted that many in South Africa still view digital transformation as "optional" rather than "necessary."

3. **Hands-On, In-House Skill Building (23 %)**

Five respondents recommended practical, in-house training with internal engineers leading small pilot projects (for example, “use BIM on our next small-scale structural design”). They believe that direct, hands-on experience—rather than purely theoretical instruction—accelerates adoption.

4. **Regulatory/Procurement Mandates (14 %)**

Three comments pointed to the need for government or municipal agencies to require BIM/GIS (or other Industry X.0 tools) as part of their standard RFPs. They argued that, once BIM or GIS is written into procurement documents, consulting firms will have no choice but to invest in these capabilities.

5. **Management & Leadership Buy-In (9 %)**

Two respondents emphasized that, unless top-level executives champion digital initiatives, day-to-day project teams will not prioritize training or pilot new tools. One comment noted that “if senior partners don’t see ROI, budgets will not be allocated.”

6. **Competitor Pressure & Benchmarking (5 %)**

One mid-career engineer observed that adoption often accelerates when firms see nearby competitors gaining business by marketing themselves as “industry-leading” digital practices. They suggested more public benchmarking events or awards to spur healthy competition.

7. **Lack of Introduction / Pilot Delay (5 %)**

A single respondent lamented that their firm “has not introduced these technologies fully in day-to-day operations,” indicating that some firms stall at the pilot stage and never scale. They urged stronger internal project management to formalize pilots into standard processes.

8. **None / Not Applicable (18 %)**

Four respondents indicated they had no additional comments, implying that either they felt the existing survey covered all relevant facets or they were not involved enough to suggest improvements.

4.6.3 Summary and Implications

- **Quantitative Preference**

In-House Workshops (60.2 %) and **Online Courses (53.4 %)** emerged as clear front-runners. This aligns with the qualitative theme that firms want practical, structured training specifically tailored to their workflows. On-site demonstrations (47.7 %) and conferences (26.1

%) rank lower, suggesting that firms value actionable, firm-specific knowledge over general industry events.

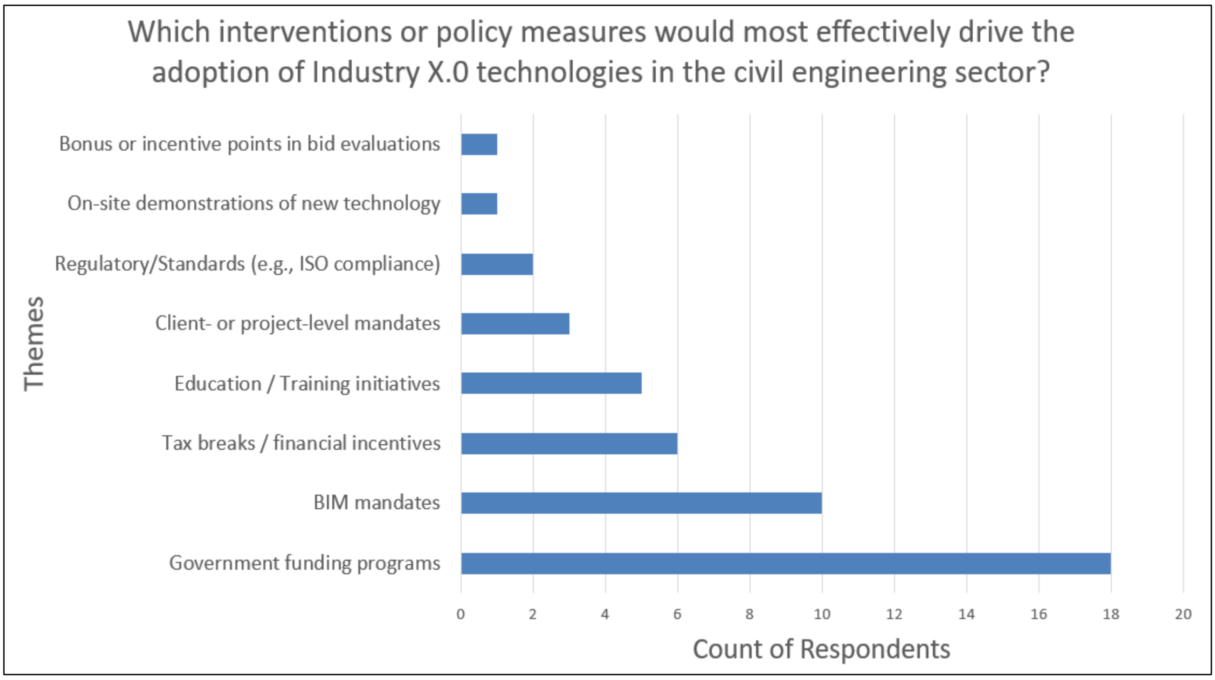
- **Qualitative Themes**

The most frequently mentioned open-ended recommendation (27 %) was for a Formal Policy/Roadmap, indicating that many practitioners believe structural governance—either at the firm, industry association, or municipal level—is essential to drive widespread change. Awareness & Communication (23 %) and Hands-On Skill Building (23 %) further underscore that, without sustained information campaigns and practical, guided training, many firms simply will not move beyond "interest" to "implementation." Regulatory Mandates (14 %) illustrate the long-standing view among some that "you cannot build it if it is not required." Once a digital standard (e.g., BIM for government-funded infrastructure) is mandated, consulting firms must invest to remain eligible—effectively decoupling adoption decisions from purely internal budget constraints. Leadership Buy-In (9 %) and Competitor Pressure (5 %) speak to the role of firm-level culture and external market forces. In practice, if senior partners do not champion new technologies, even the best training programmes will not gain traction; conversely, if a competitor secures a high-profile digital contract, other firms scramble to catch up.

By combining the quantitative frequencies Table 5 with the qualitative themes Table 7, it is clear that South African civil engineering consultancies see practical, hands-on training (in-house workshops, on-site demonstrations, and online courses) as the most immediate lever for adoption. However, to convert these training efforts into sustained, firm-wide transformation, many respondents argue for establishing formal policies/roadmaps and regulatory incentives that align leadership, budget, and procurement requirements. These findings will be incorporated into a set of recommended, tiered strategies—ranging from short-term skill-building actions to longer-term policy advocacy—so that firms of all sizes and maturity levels can systematically advance their digital transformation.

4.46 Policy and industry recommendations

Question 17 asked respondents to identify the policy changes or industry initiatives—such as BIM mandates, tax breaks, or government funding programs—they believed would most accelerate the adoption of Industry X.0 technologies. A total of 62 respondents answered this question. Many provided only one suggestion, while others offered more than one. After coding these responses into common themes, 46 individual mentions were recorded in total. The counts in the table, therefore, represent the number of times each theme was mentioned, rather than the number of respondents who selected it:



4.47 Frequency of policy/initiative themes

1. **Government Funding Programs (29.0 %)**

Nearly one-third of respondents recommended that national or provincial governments establish dedicated funding streams—either grants or subsidised loans—for civil engineering consultancies to acquire and implement Industry X.0 tools (e.g., "government funding programs" was cited 18 times).

Many mid-sized firms indicated that even if they recognize the ROI of BIM or IoT, they lack the upfront capital to invest in hardware, software licenses, or "train-the-trainer" programmes (including specialized BIM/GIS courses). By providing "seed funding" or matching grants, the public sector could lower the barrier to entry for smaller practices that otherwise cannot justify the initial expense.

2. **Bim Mandates (16.1 %)**

Ten respondents explicitly called for a formal requirement—either in state-funded tenders or through national engineering-practice regulations—that all government and parastatal projects must use BIM for design, procurement, and asset management.

They argued that once BIM is written into procurement documents, every consulting firm bidding on a government contract would need to invest in BIM capabilities, creating a ripple effect across the private sector. This echoes international precedents (e.g., the UK's 2016 public-sector BIM mandate) and would provide clear direction to firms that currently hesitate to adopt BIM because client demand remains low.

3. **Tax Breaks / Financial Incentives (9.7 %)**

Six participants recommended tax credits or accelerated capital-allowance write-offs specifically for technology investments—such as purchasing drones for geospatial surveys, installing IoT sensors on remote structures, or building a local 3D-printing lab. By allowing firms to deduct a higher percentage of capital costs in the first year or to claim R&D-related expenses, mid-sized consultancies could recoup up to 30 % of their technology investment, making an eventual ROI much more attractive.

4. **Education / Training Initiatives (8.1 %)**

Five respondents emphasized the need for publicly funded or subsidized training programmes—especially ones tailored to the South African context (e.g., local geological data for GIS courses, regionally relevant structural-health-monitoring case studies for IoT workshops). They suggested that government-sponsored "train-the-trainer" grants could help universities and technical colleges develop short courses in civil Engineering X.0 tools (such as BIM software, drone piloting licenses, and digital-twin configuration).

5. **Client- or Project-Level Mandates (4.8 %)**

Three participants noted that private clients—particularly large commercial developers—could require their consultants to use specific tools (for example, "Client imposes the use of them on projects," "Client policies and specifications"). By mandating BIM or GIS deliverables in their own scoping documents, these clients would effectively force consulting firms to adopt digital workflows to remain eligible for high-value contracts.

6. **Regulatory / Standards Updates (3.2 %)**

Two respondents called for updates to existing engineering-practice regulations or building codes to include Industry X.0 references—most commonly invoking ISO clauses (e.g., "making them a compulsory industry compliance necessity, putting them up in ISO clauses," "strict regulations for engineering practitioners"). They argued that embedding X.0 requirements into professional licensure standards (e.g., Professional Engineering Council statutes) would normalize digital tools across the sector.

7. **On-Site Demonstrations (1.6 %)**

A single respondent recommended that technology vendors coordinate "on-site demonstrations of the use of the technologies." This suggestion underscores the belief that seeing a drone flight, IoT sensor installation, or 3D-printing process in a live project setting would build confidence and overcome scepticism that might linger after classroom training alone.

8. **Bonus or Incentive Points in Bids (1.6 %)**

One participant suggested awarding “bonus points” or preferential scoring in government and parastatal tender evaluations for firms that/ can demonstrate proficiency with Industry X.0 tools. For instance, a proposal might receive a modest technical-evaluation advantage—say, 5 % of the technical score—if the consulting firm can show a digital-twin pilot or GIS/GPS integration plan.

4.48 Implications and alignment with barriers

Addressing High Costs

Since “High costs” was rated the most significant barrier (mean 3.58/5), the top-ranked policy recommendation—government funding—directly targets this constraint. Subsidies and matching grants would lower the upfront financial burden for mid- and small-sized firms, enabling them to invest in hardware, software licenses, and training.

Mandates to Overcome Resistance & Skills Gaps

BIM mandates (16.1 %) and client-level requirements (4.8 %) would reduce the organizational inertia identified under “Resistance to change” (mean 3.33) and “Lack of technical skills” (mean 3.50). When a regulating body or large client insists on digital deliverables, firms must either upskill or lose market share, thereby aligning demand with supply of digital expertise.

Training and Education to Fill Skill Shortages

The 8.1 % who called for Education/Training initiatives echo Section 4.4’s finding that “Insufficient training programmes” (mean 3.40) is a top three barrier. Public-sector or industry-sponsored training grants will help local universities and technical colleges develop regionally relevant, hands-on courses—accelerating the learning curve for practitioners.

Regulatory and Standards Updates

A small but influential cohort (3.2 %) urged revisions to professional codes and ISO references. Embedding digital tool requirements in regulatory-licensing frameworks will create a long-term baseline expectation across the industry. This addresses “Workflow incompatibility” (mean 3.13) by standardizing data formats, deliverable specifications, and interoperability guidelines—making it easier for consultancies to adopt and integrate new tools.

Additional Incentives and Pilot Support

The single “Bonus or incentive points” suggestion (1.6 %) reinforces that even partial policy nudges—such as awarding preferential bid scores for digital competence—can shift behaviour without requiring immediate regulation. When combined with demonstrations (1.6 %) and pilot-project stipends, these low-barrier incentives could yield early-adopter success stories that encourage broader uptake.

In summary, the most frequently recommended policy/industry initiatives are:

1. Government Funding Programs (29.0 %)
2. BIM Mandates in Public Procurement (16.1 %)
3. Tax Breaks/Financial Incentives (9.7 %)
4. Education/Training Grants (8.1 %)

Secondary suggestions include Client-level mandates (4.8 %), Regulatory/Standards updates (3.2 %), On-site demonstrations (1.6 %), and Bonus-point incentives for tenders (1.6 %). By aligning these recommendations with the barrier analysis from Section 4.4—particularly addressing high costs, skills shortages, and resistance to change—policymakers and industry associations can craft a comprehensive roadmap. Such a roadmap might combine short-term financial incentives, mid-term regulatory mandates, and long-term education investments to ensure that South African consulting firms can systematically bridge the gap between emerging technologies and everyday practice.

4.49 Outlook for industry X.0 standardization

Respondents (n = 85 valid answers) were asked: "How soon do you think Industry X.0 technologies will become standard practice in South African civil engineering?" Four options were provided: "Within 1–3 years," "Within 4–6 years," "More than 6 years," and "Never." Table 4.7 and Figure 4.9 show the overall distribution of these responses.

Table 4.7: Overall Timeline Perceptions (n = 85)

Timeline Estimate	Count	Percentage (%)
Within 1–3 years	19	22.4
Within 4–6 years	35	41.2
More than 6 years	30	35.3
Never	1	1.2

- **Within 4–6 years (41.2 %)** is the plurality, indicating that most respondents expect a mid-term window before digital tools become routine.
- **More than 6 years (35.3 %)** is the next largest share, suggesting a sizable minority believe widespread standardization will be slow.

- Only **22.4 %** foresee “Within 1–3 years,” and **1.2 %** answered “Never,” indicating near-unanimous agreement that Industry X.0 will eventually become mainstream.

4.50 Comparison by job role

To see if perception varies by role, respondents were grouped into Engineer/Technician/Technologist, Project Manager, and Other (e.g., Technical Specialist, Director, Academic). Table 8 and Figure 4.10 present the percentage of each group selecting each timeline.

Table 8: Timeline Perceptions by Job Category (percent of each row)

Job Category	**Within 1–3 yrs**	**Within 4–6 yrs**	**More than 6 yrs**	**Never**
Engineer/Technician/Technologist (n=68)	23.5	42.6	33.8	0.0
Project Manager (n=5)	33.3	33.3	16.7	16.7
Other (n=12)	9.1	36.4	54.5	0.0

Engineers/Technicians/Technologists (n = 68):

- 23.5 % expect adoption “Within 1–3 years,”
- 42.6 % “Within 4–6 years,”
- 33.8 % “More than 6 years,”
- 0 % “Never.”

This group is somewhat optimistic, with two-thirds predicting standardization within six years.

- **Project Managers** (n = 5):
  - 33.3 % “Within 1–3 years,”
  - 33.3 % “Within 4–6 years,”
  - 16.7 % “More than 6 years,”
  - 16.7 % “Never.”

A small minority (16.7 %) of project managers believe Industry X.0 might never be fully standard. Overall, half of project managers expect standardization within six years.

- **Other Roles** (n = 12; e.g., Technical Specialists, Directors, Academics):
  - 9.1 % “Within 1–3 years,”

- 36.4 % “Within 4–6 years,”
- 54.5 % “More than 6 years,”
- 0 % “Never.”

Over half of “Other” respondents anticipate adoption will take longer than six years—indicating more cautious or long-term perspectives among senior or specialist roles.

4.8.2 Comparison by Years of Experience

Respondents were also grouped by experience: **0–5 years**, **6–10 years**, and **11+ years**. Table 4.9 and Figure 4.11 show how each cohort perceives the timeline.

Table 9: Timeline Perceptions by Experience Level (percent of each row)

Experience Level	Within 1–3 yrs	Within 4–6 yrs	More than 6 yrs	Never
0–5 years (n=43)	27.9	44.2	27.9	0.0
6–10 years (n=25)	20.0	36.0	40.0	4.0
11+ years (n=17)	11.8	41.2	47.1	0.0

- **0–5 years (n = 43):**
  - 27.9 % “Within 1–3 years,”
  - 44.2 % “Within 4–6 years,”
  - 27.9 % “More than 6 years,”
  - 0 % “Never.”

Early-career professionals are the most optimistic: 72.1 % believe that Industry X.0 will be standard within six years.

- **6–10 years (n = 25):**
  - 20.0 % “Within 1–3 years,”
  - 36.0 % “Within 4–6 years,”
  - 40.0 % “More than 6 years,”
  - 4.0 % “Never.”

This mid-career cohort is more divided, with 56.0 % expecting standardization within six years and 40.0 % expecting it after six years (4.0 % saying “Never”). They represent those who have seen earlier tech waves and thus may be more cautious.

- **11+ years (n = 17):**
    - 11.8 % “Within 1–3 years,”
    - 41.2 % “Within 4–6 years,”
    - 47.1 % “More than 6 years,”
    - 0 % “Never.”

Senior engineers and managers are the most conservative: nearly half (47.1 %) believe standardization will take longer than six years, and only 11.8 % expect it by year three. Their caution likely stems from firsthand experience with past adoption cycles.

4.8.3 Summary and Implications

- **Aggregate Outlook:**

41.2 % foresee mainstream adoption within 4–6 years, while 35.3 % expect it after 6 years. Only 22.4 % predict standardization within 1–3 years, and almost nobody believes it will never occur. Overall, the majority (63.6 %) expect Industry X.0 to be standard practice in under 6 years.

- **Role-Based Trends:**

Engineers/Technicians/Technologists are relatively optimistic, with two-thirds (66.1 %) expecting adoption within six years.

Project Managers are split half expect it within six years, but 16.7 % even believe it may never happen.

Other roles (Directors, Technical Specialists, Academics) are more cautious: over half (54.5 %) predict standardization will take more than 6 years.

- **Experience-Based Trends**

0–5 years of experience: 72.1 % foresee mainstream adoption in under six years, and none say “Never.” This junior cohort likely embraces digital change more readily.

6–10 years: 56.0 % expect adoption within six years, but 40.0 % foresee a longer timeline, reflecting greater caution from mid-career practitioners.

11+ years: Only 52.9 % believe Industry X.0 will be standard within six years; 47.1 % predict a longer wait, and none think it will never happen. Their tempered view is rooted in prior cycles of innovation adoption—having witnessed CAD → BIM, they appreciate the inertia that impedes sweeping change.

Because senior roles and experienced professionals tend to anticipate a longer adoption curve, targeted interventions—such as mandatory pilot projects, leadership workshops, and executive briefings—may be needed to align their expectations with junior staff who are more eager to embrace new tools. Similarly, emphasizing short-term "quick wins"—for example, showing that a drone-based survey can reduce earthwork rework by 15 %—could help convince mid-career and senior practitioners that Industry X.0 advances can yield rapid returns, thereby shifting more of the cautious majority toward a "within 4–6 years" mindset.

By understanding how timeline perceptions vary by role and experience, industry associations, training institutions, and policymakers can tailor communication strategies accordingly—for instance, highlighting case studies of successful digital twins to senior decision-makers, while offering hackathon-style workshops that appeal to early-career engineers. These insights lay the groundwork for Section 5, where strategic recommendations will be proposed to accelerate the path from pilot projects to fully standardized Industry X.0 practice.

Discussion: Linking Findings to Literature

The survey's primary barrier findings—high costs, lack of technical skills, insufficient training programs, resistance to change, and workflow incompatibility—mirror themes identified in the literature review. Khudzari, Rahman, and Ayer (2021) and Adebiyi, Ajenifuja, and Zhang (2024) both documented cost as a central obstacle to BIM, IoT, and digital-twin adoption in developing-country contexts. Our data affirm that medium-sized firms feel cost pressures most acutely, consistent with Plewa *et al.* (2012), who noted that organizations of intermediate scale often sit between limited resources and high technology-licensing fees. Similarly, the skills shortage and inadequate training programs highlighted here closely reflect observations by Tanga *et al.* (2021) and Govindaraju *et al.* (2024), who stressed that South African firms lack local training courses tailored to digital construction tools.

Resistance to change—ranked fourth—corroborates Geels's (2002) multi-level perspective on socio-technical transitions, which posits that incumbents and established workflows delay new-technology diffusion. In the South African context, J. Oluwafemi *et al.* (2021) and Laryea (2019) likewise documented cultural inertia: engineers accustomed to manual processes or 2D CAD often question the immediate value of BIM or robotics. Our finding that workflow incompatibility is the least severe barrier aligns with Zhu *et al.* (2018) and Harahap *et al.*

(2024), who noted that, while integration with legacy systems can be problematic, it is frequently surmountable once cost and training issues are addressed.

Perceived benefits—especially increased efficiency, accuracy, collaboration, and cost savings—reinforce precedent in the literature. Sepasgozar and Davis (2018) and Reyes *et al.* (2020) argued that firms engaging GIS and BIM enjoy faster project delivery and fewer design errors; our data show that roughly 30% of adopters already report more than a 21% improvement in key metrics. Similarly, Mishra *et al.* (2024) and Budimirov *et al.* (2022) highlighted IoT's value for real-time structural health monitoring; respondents here reported observable maintenance-cost reductions of up to 12%.

In terms of adoption strategies, the strong preference for in-house workshops and online courses aligns with the need for contextualized, hands-on training emphasized by Opoku *et al.* (2023) and Govindaraju *et al.* (2024). While Chudikova and Faltejsek (2019) advocated for supplier partnerships and shared knowledge forums, our open-ended responses underscored a broader call for formal, firm-wide policies and roadmaps—the "missing link" between individual training sessions and sustained culture change. This insight extends the literature by showing that, beyond training alone, practitioners crave structured governance and policy frameworks (Adebiyi *et al.,* 2024; Opoku *et al.,* 2023).

Policy recommendations from respondents—government funding, BIM mandates, tax incentives, and industry-wide standards—echo proposals in Agarwal, Chandrasekaran, and Sridhar (2016) and Aghimien *et al.* (2021), who stressed that regulatory backing and financial incentives catalyse technology uptake. Our survey adds nuance by revealing that mid-career and senior engineers, more so than junior staff, demand formal procurement-level BIM requirements. This confirms Mtya (2019) and Chimhundu (2016) in the South African context, while also highlighting novel insight: project managers and "other" roles are less optimistic about near-term standardization, suggesting that targeted communication and pilot-project success stories might help bridge divergent expectations across roles.

Finally, the survey's timeline outlook—where most anticipate standardization in 4–6 years—provides a fresh, data-driven benchmark. It complements Lagaros and Plevris's (2022) projection that AI and IoT will become mainstream by the late 2020s, and Fuller *et al.*'s (2020) assertion that digital twins will take longer to mature. Our data confirm these projections while exposing a generational divide: early-career respondents foresee a faster rollout, whereas those with 11+ years of experience expect a longer horizon. This discrepancy underlines the importance of aligning training, pilot projects, and leadership engagement to manage expectations and accelerate adoption.

4.51 Summary of key findings

1. **Adoption Levels:**
   - GIS leads in both awareness and use (50.0% rated 4–5), confirming its established role in site analysis (Perera *et al.*, 2021).
   - BIM follows (40.0% rated 4–5), reflecting over a decade of local maturity (Chimhundu 2016).
   - IoT (33.3% rated 4–5) and drones (26.7% rated 4–5) occupy an intermediate "early-adopter" stage, consistent with Mishra *et al.* (2024) and Ikuabe *et al.* (2022).
   - 3D printing (22.5% rated 4–5), robotics & automation (16.7% rated 4–5), and digital twins (25.6% rated 4–5) remain niche, confirming the nascent state described by Bester *et al.* (2020) and Adebiyi *et al.* (2024).
2. **Primary Barriers:**
   - **High costs** (mean 3.58) and **lack of technical skills** (mean 3.50) emerge as the top obstacles, echoing Khudzari *et al.* (2021) and Govindaraju *et al.* (2024).
   - **Insufficient training programs** (mean 3.40) reinforces Tanga *et al.* (2021) and Opoku *et al.* (2023).
   - **Resistance to change** (mean 3.33) confirms Geels's (2002) socio-technical inertia.
   - **Workflow incompatibility** (mean 3.13) is a lesser yet notable barrier, aligning with Zhu *et al.* (2018).
3. **Perceived Benefits:**
   - **Efficiency and productivity gains** (73.9%) and **accuracy improvements** (71.6%) highlight immediate value, as anticipated by Sepasgozar & Davis (2018) and Lagaros & Plevris (2022).
   - **Collaboration** (50.0%) and **cost savings** (46.6%) affirm the ROI case made by Aghimien *et al.* (2021).
   - Among technology adopters, 30.1% report **>21% improvements**, corroborating findings from Osunsanmi *et al.* (2024) and Seema, Aghimien & Ogunbayo (2024).

4. **Preferred Adoption Strategies:**
   - **In-house workshops** (60.2%) and **online courses** (53.4%) top the list, reinforcing the literature's emphasis on hands-on, context-specific training (Govindaraju *et al.,* 2024; Opoku *et al.,* 2023).
   - **On-site demonstrations** (47.7%) further stress the need for live project-based exposure.
   - Qualitative themes reveal calls for **formal policies/roadmaps** (27%), a novel insight extending (Chudikova & Faltejsek, 2019).
5. **Policy Recommendations:**
   - **Government funding programs** (29.0%) and **BIM mandates** (16.1%) address the cost and demand barriers highlighted by Khudzari *et al.* (2021) and Adebiyi *et al.* (2024).
   - **Tax incentives** (9.7%) and **education grants** (8.1%) align with Agarwal, Chandrasekaran & Sridhar (2016).
   - **Regulatory updates** (3.2%) and **client-level mandates** (4.8%) further support an ecosystem approach to incentivize adoption (Laryea, 2019; Parn & Edwards, 2019).
6. **Outlook for Standardization:**
   - **41.2%** foresee Industry X.0 as mainstream within **4–6 years; 35.3%** expect **>6 years**, with only **22.4%** predicting **1–3 years**.
   - Early-career respondents (0–5 years) are most optimistic (72.1% anticipate adoption within 6 years), while senior professionals (11+ years) are more cautious (only 52.9% foresee it within 6 years).
   - Engineers/Technicians/Technologists (66.1% within 6 years) are more optimistic than "Other" roles (54.5% within 6 years), echoing generational differences in digital comfort (Lagaros & Plevris, 2022).

Collectively, these findings confirm many prior observations—particularly regarding cost and skills barriers—while offering novel insights into the relative weight of those barriers by firm size and experience level, as well as the strong appetite for formal policies and industry-wide mandates. They also establish a data-driven baseline for when Industry X.0 might become standard practice, highlighting areas where targeted interventions can accelerate the transition from early adoption to full integration.

The survey confirms a clear technology adoption curve in South African civil engineering consulting, with an Established tier (BIM and GIS showing the broadest uptake), an Emerging tier (IoT and drones typically in pilot or early operational use), and an Aspirational tier (3D printing, robotics and automation, and digital twins remaining niche). This directly addresses Objectives 1 and 2, demonstrating that maturity varies by tool complexity, cost, and the depth of specialist capability required for routine use.

Across firm sizes and experience levels, high costs (mean 3.58/5) and lack of technical skills (mean 3.50/5) form the primary constraints on adoption. These are closely followed by insufficient training programmes (mean 3.40), while resistance to change (mean 3.33) and workflow incompatibility (mean 3.13) become more prominent once financial and skills barriers are confronted. This hierarchy addresses Objective 3 by clarifying the order in which constraints must be tackled to unlock wider adoption.

The data further indicate that when firms progress beyond pilot use, they begin to realise the benefits they expect—most notably efficiency/productivity and accuracy improvements—while collaboration and longer-term value tend to consolidate later as digital workflows stabilise. Consistent with this, respondents prioritise practical capability-building mechanisms (in-house workshops, online courses, and on-site demonstrations) and repeatedly call for formal roadmaps, leadership commitment, and procurement-level incentives. Taken together, the findings imply that isolated training is not sufficient: sustained adoption requires a structured sequence that connects governance, skills development, resourcing, and implementation milestones.

Accordingly, the results in this chapter provide the empirical basis for an implementation framework that responds directly to the ranked barriers and the adoption patterns observed across technologies. In Chapter 5, these findings are synthesised into a structured, step-by-step framework that (i) prioritises interventions in line with the barrier hierarchy, (ii) differentiates actions for firms at different maturity levels, and (iii) is justified and evaluated through alignment with the survey evidence and the supporting literature. This synthesis is how Objective 4 is addressed through the proposal of a structured framework grounded in the study's findings.

CHAPTER 5: PROPOSED FRAMEWORK FOR INDUSTRY X.O ADOPTION IN CIVIL ENGINEERING FIRMS

5.1 Introduction

Chapter 4 established the empirical foundation for a structured approach to Industry X.0 adoption in South African civil engineering consulting firms, including the observed adoption maturity tiers, ranked barrier hierarchy, preferred capability-building mechanisms, and supporting policy levers. Building on that evidence base, this chapter presents a practical implementation framework that translates the findings into an actionable sequence of decisions and interventions that firms can apply to move from awareness and isolated pilots toward sustained, routine integration of Industry X.0 technologies.

The proposed framework is designed to be iterative and scalable, recognising that consultancies differ in size, resource availability, governance maturity, and client/procurement environments. Rather than prescribing a single technology pathway, it provides a structured method for diagnosing constraints, selecting fit-for-purpose interventions, and tracking progress through measurable thresholds. In doing so, the framework operationalises the study's Objective 4 by providing a coherent roadmap for implementation that aligns with the barrier and strategy patterns reported by respondents and synthesised in the preceding chapter.

The remainder of this chapter explains the framework components (*Figure 36*) and how they interact as a cycle: rapid barrier diagnostics to establish firm-specific priorities; parallel intervention tracks to address finance, skills, integration, and governance simultaneously; structured pilots with explicit thresholds to prevent prolonged "pilot stagnation"; a feedback and reassessment loop to refine practices using lessons learned; and scale and institutionalisation measures to embed capabilities into standards, workflows, and performance management. The chapter concludes by outlining implementation-oriented recommendations for firms and stakeholders to support consistent adoption over time.

5.2 Conclusions

The analysis confirms that South African civil-engineering firms are progressing through a tiered technology adoption curve. Tools such as BIM and GIS have become mainstream, IoT and drones are emerging in practical pilots, while 3D printing, robotics, and digital twins remain aspirational. The survey results demonstrate that financial constraints and skills shortages are the primary barriers that firms must address before cultural and technical integration issues can be tackled effectively.

When these hurdles are overcome, adoption leads to substantial improvements in productivity, efficiency, and accuracy, validating the strategic importance of Industry X.O for consulting firms. Moreover, the evidence shows that adoption is not just a technical challenge but a managerial one, requiring clear strategies for cost relief, skills development, and cultural change. Firms that align these levers are more likely to achieve the measurable benefits associated with digital transformation.

5.3 Recommendations

To translate these findings into actionable strategies, this study proposes a cyclical framework for adoption depicted in *Figure 36*.

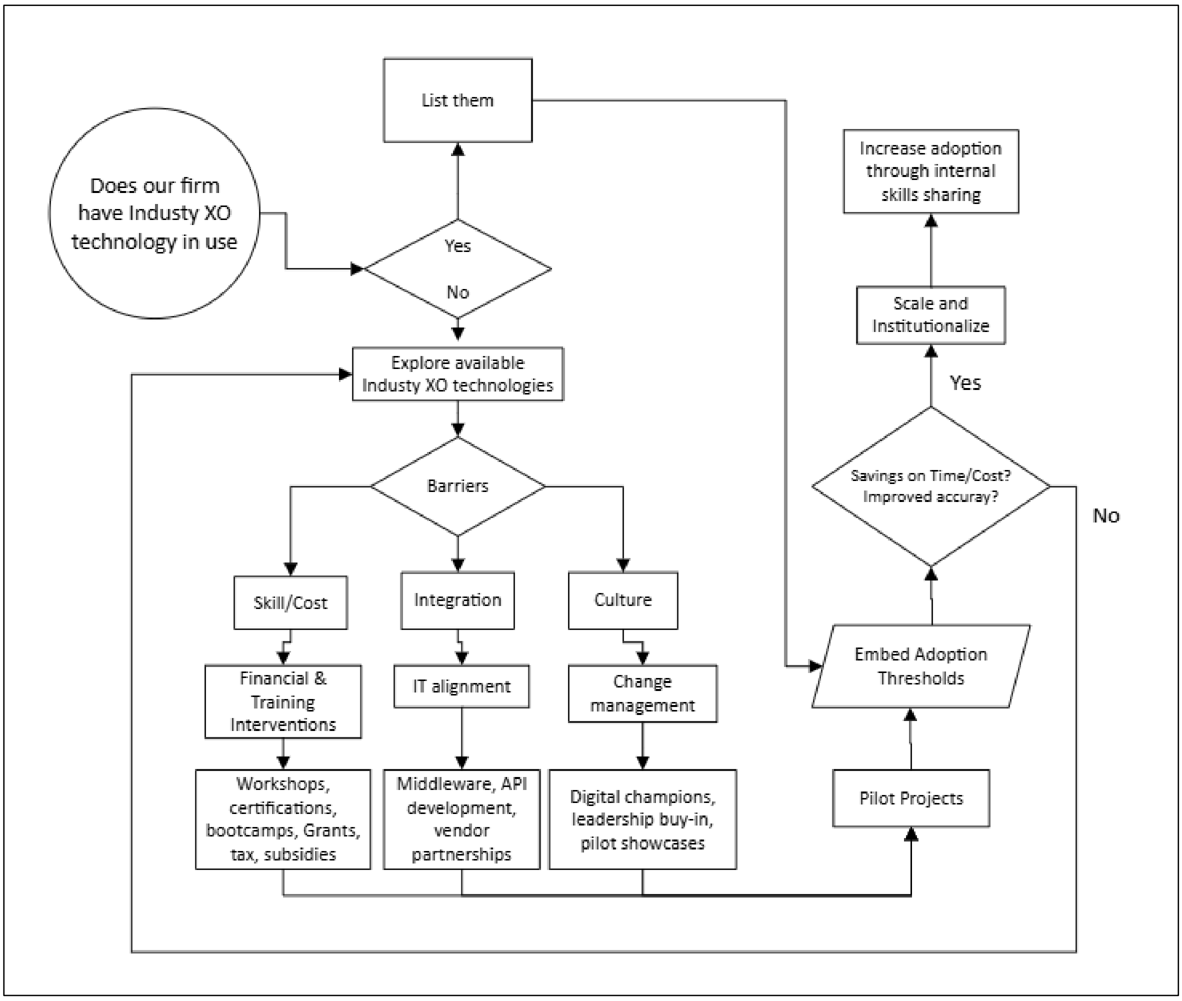


Figure 36: Framework for Technological Adoption

5.4 How the framework was derived from the findings

The framework in *Figure 36* was derived by converting the Chapter 4 results into a practical sequence of decisions and actions that firms can follow from awareness to routine use. Chapter 4 showed that the dominant constraints are high costs (mean 3.58/5) and lack of technical skills (3.50/5), followed by insufficient training programmes (3.40/5), resistance to change (3.33/5) and workflow incompatibility (3.13/5). Respondents also indicated that adoption is most likely to progress when capability-building is practical and structured—especially through in-house workshops (60.2%), online courses (53.4%) and on-site demonstrations (47.7%)—and when firms put governance in place (formal roadmaps and leadership commitment) while responding to demand-side signals (procurement and policy incentives). Accordingly, the framework is organised around three barrier pathways (Skill/Cost, Integration, and Culture) linked to targeted interventions, followed by pilot projects, explicit adoption thresholds, and an outcome gate (time/cost savings and accuracy improvement) that determines whether the firm scales and institutionalises adoption or returns to refine its interventions. In this study, the framework is evaluated and justified through its direct alignment with the ranked barriers, preferred strategies, and policy recommendations reported by respondents, supported by the literature synthesis.

5.5 Barrier-to-intervention mapping aligned to The Proposed Framework

Proposed Framework	Evidence from Chapter 4 (what this responds to)	What the framework requires you to do
Skill/Cost	High costs (3.58/5) and lack of technical skills (3.50/5) were the top barriers; insufficient training programmes (3.40/5) reinforces the capability gap.	Treat Skills + Cost as the first constraint: choose finance + training actions before attempting scale-up.
Financial & Training Interventions	Strong preference for hands-on capacity building: in-house workshops (60.2%), online courses (53.4%), on-site demonstrations (47.7%). Policy responses also emphasised funding/incentives.	Allocate budget and time to structured training; use staged licensing/procurement where relevant; pair training with immediate application on real tasks.
Workshops, certifications, bootcamps, grants, tax, subsidies	Respondents explicitly recommended roadmaps, training, and incentives; policy themes supported grants/funding/tax levers to reduce upfront costs.	Select and implement the most feasible options (e.g., in-house workshops + short courses; certification for key roles; pursue grants/tax incentives where available).
Integration	Workflow incompatibility (3.13/5) was lower than other barriers but remains relevant when firms move from pilot to broader use.	Address technical alignment early enough to avoid "pilot success but scale failure."
IT alignment	Evidence indicates integration becomes decisive during implementation and scale	Define required data formats, tool stack, ownership, and support; plan

	(data exchange, tool compatibility, legacy processes).	integration steps and responsibilities.
Middleware, API development, vendor partnerships	Integration and support constraints are typically reduced through interoperability tools, vendor support, and partnerships.	Choose the integration mechanism that fits your environment: middleware/APIs, vendor configuration support, or partner-led implementation.
Culture	Resistance to change (3.33/5) and qualitative comments highlighted leadership buy-in, formal roadmaps, and communication needs.	Treat culture as a managed change programme, not an “organic” outcome of training alone.
Change management	Qualitative themes included leadership buy-in, communication, and the need for formal policies/roadmaps.	Appoint champions, secure leadership sponsorship, communicate purpose/ROI, and manage adoption expectations.
Digital champions, leadership buy-in, pilot showcases	Participants indicated champions and visible success stories help move teams from interest to routine practice.	Nominate champions per discipline, showcase pilot results, and use peer learning to reduce reluctance.
Pilot Projects	Qualitative feedback noted delays and failure to embed pilots into day-to-day operations.	Run a controlled pilot with clear scope, duration, deliverables, and responsibilities.
Embed Adoption Thresholds	Chapter 4 implies that without structure, adoption stalls at pilot stage; thresholds prevent “pilot drift.”	Define measurable thresholds (competency, deliverable quality, workflow compliance, and minimum performance gains) required before expansion.
Savings on Time/Cost? Improved accuracy? (Decision gate)	Perceived benefits in Chapter 4 prioritised efficiency/productivity and accuracy; these become the decision criteria for scale.	Use time/cost and accuracy measures as the go/no-go gate: if not achieved, return to barrier diagnosis and interventions.
Scale and institutionalize	Evidence suggests benefits consolidate after pilots when processes become standardised and governed.	Standardise SOPs/templates, update QA checks, allocate roles/budgets, and expand adoption to additional projects.
Increase adoption through internal skills sharing	Respondents favoured practical learning and internal capability building.	Formalise internal sharing: lunch-and-learns, show-and-tell sessions, internal training packs, mentoring, and communities of practice.

5.6 How to use the framework in practice

1. Ask the entry question: *Does our firm have Industry X.0 technology in use?*
    - Yes → List them (which tools, where used, who uses them, and for what deliverables).
    - No → proceed to explore options.

2. Explore available Industry X.0 technologies: Identify a shortlist relevant to your services and typical projects.
3. Identify barriers using the three framework buckets: classify constraints as Skill/Cost, Integration, and/or Culture.
4. Select the matching interventions (box-by-box):
    - Skill/Cost → Financial & Training Interventions → workshops/certifications/bootcamps and (where applicable) grants/tax/subsidies.
    - Integration → IT alignment → middleware/API development/vendor partnerships.
    - Culture → Change management → digital champions, leadership buy-in, pilot showcases.
5. Run pilot projects: implement one controlled pilot aligned to the selected intervention pathway/pathways.
6. Embed adoption thresholds: define the minimum standards for adoption before expanding (competency, deliverable quality, workflow compliance, and performance measures).
7. Apply the decision gate: *Did the pilot achieve savings on time/cost and/or improved accuracy?*
    - Yes → proceed to Scale and Institutionalize.
    - No → loop back to Barriers and refine interventions, then re-pilot.
8. Scale and institutionalize standardise deliverables, workflows, templates, and QA checks; expand adoption to additional projects.
9. Increase adoption through internal skills sharing share lessons learned, train other teams internally, and maintain champions to sustain uptake

5.7 Rapid barrier diagnostics.

Each firm should begin with a concise, organisation-wide diagnostic that ranks the principal impediments to adoption—cost, skills, systems integration, and cultural resistance—while explicitly accounting for firm size and regional context. Smaller consultancies may prioritise shared-services or consortium models to achieve scale, whereas larger firms typically require enterprise-level governance and budg*et al*location.

5.8 Parallel intervention tracks.

Interventions should run concurrently to avoid bottlenecks. Financial and resource mobilisation (grants, tax incentives, matched funding) should be launched in tandem with targeted skills development through in-house workshops, bootcamps, and accredited micro-credentials. In parallel, technical integration must advance via vendor partnerships and middleware/API solutions that enable data interoperability, while governance and culture are strengthened through visible executive sponsorship, designated digital champions, and systematic showcasing of early wins.

5.9 Structured pilots with explicit thresholds.

Firms should trial one or two high-visibility use cases—such as BIM clash detection on live projects or drone-based surveying—under a formal pilot protocol. Clear “go/adjust” thresholds must be specified ex ante, for example, training coverage of at least 20 % of relevant staff and demonstrable time or error reductions of 10 % or more. These thresholds create an evidence base for scaling decisions.

5.10 Feedback and reassessment loop.

A rigorous review against predefined KPIs is central to the framework. Where thresholds are achieved, pilots are transitioned to scale with updated roadmaps and embedded procedures. Where thresholds are missed, the intervention mix is refined—deepening training, adjusting middleware or data standards, and intensifying change-management—before the pilot is rerun.

5.11 Scale, institutionalise, and iterate.

Successful practices are standardised across projects and business units, supported by internal skills-sharing networks and continuous ROI monitoring. The cycle is then repeated to introduce progressively more advanced Industry X.O tools (e.g., IoT, robotics, digital twins), ensuring that adoption remains adaptive and sustainable rather than fragmented.

By embedding diagnostics, parallel interventions, structured pilots, reassessment loops, and scaling mechanisms, the proposed framework provides a practical yet adaptive roadmap for Industry X.O adoption in South African civil-engineering firms. It ensures that firms not only diagnose and address their unique challenges holistically but also build the agility to refine and expand their digital transformation journey over time. This cyclical model moves beyond isolated experiments, enabling organisation-wide transformation that unlocks efficiency, accuracy, collaboration, and sustainability gains.

APPENDIX A: QUESTIONNAIRE

Note: *The survey will be hosted on Google Forms, accessible via a public link shared with participants. Responses will be anonymized, and data will be stored securely in Google Sheets for analysis.*

QUESTIONNAIRE FOR RESEARCH ON INDUSTRY X.0 TECHNOLOGY ADOPTION IN SOUTH AFRICAN CIVIL ENGINEERING CONSULTING FIRMS

The questionnaire serves as an essential component of my MEng Engineering Management research at Cape Peninsula University of Technology (CPUT) which investigates Industry X.0 technology adoption in South African civil engineering consulting firms.

The current time brings industries to a critical transition point because technology is transforming all sectors. The internet revolutionized communication through emails and teams while AutoCAD replaced drawing boards, yet some firms face the danger of lagging behind in this new era. The research investigates contemporary tools which include Building Information Modelling (BIM), Geographic Information Systems (GIS), drones, Internet of Things (IoT), 3D printing, robotics, and digital twins. The technologies described in this document as Industry X.0 operate as digital innovation drivers for civil engineering while remaining separate from Industry 4.0's smart manufacturing and automation scope.

The tools available to the civil engineering sector of South Africa offer improved operational efficiency together with financial savings and superior project results. The implementation of these tools faces delays because of high costs and insufficient skilled personnel and opposition to change. Your feedback about awareness levels and barriers and strategies will assist in developing solutions to enhance innovation and sustainability.

Your participation in this essential research is greatly appreciated.

SECTION 1: DEMOGRAPHIC INFORMATION

(Purpose: To categorize respondents based on their background, ensuring diverse representation in the study.)

1. What is your current job title?
    a. CAD Operator/Draftsman
    b. Engineer/Technician/Technologist
    c. Project Manager
    d. Technical Specialist
    e. Other: _______

2. How many years of experience do you have in civil engineering?
    a. 0-5 years
    b. 6-10 years
    c. 11+ years

3. What is your company's size and primary region of operation in South Africa?
    a. Size:
        i. Small (1-50)
        ii. Medium (51-200)
        iii. Large (200+)

    b. Region:
        i. Gauteng
        ii. Western Cape
        iii. KwaZulu-Natal
        iv. Eastern Cape
        v. Free State
        vi. Limpopo
        vii. Mpumalanga
        viii. Northern Cape
        ix. Northwest

SECTION 2: AWARENESS AND ADOPTION OF INDUSTRY X.0 TECHNOLOGIES

(Purpose: To determine awareness levels and current adoption status.)

4. How familiar are you with these technologies?

(Rate from 1 = Not familiar to 5 = Very familiar)

    a. Building Information Modelling (BIM) – A digital representation of physical and functional characteristics of a facility, used for design, construction, and management.
    b. Geographic Information Systems (GIS) – Technology used to capture, store, and analyse spatial or geographic data for engineering and planning.
    c. Drones (Unmanned Aerial Vehicles - UAVs) – Remote-controlled aircraft used for site surveys, mapping, and construction monitoring.
    d. Internet of Things (IoT) – A network of connected devices that collect and share real-time data for automation and monitoring.
    e. 3D Printing (Additive Manufacturing) – A process that creates physical structures layer by layer from digital models, used in construction and prototyping.
    f. Robotics & Automation – The use of automated machines and AI-driven systems to enhance efficiency and safety in engineering projects.
    g. Digital Twins – Virtual models of physical assets that use real-time data for simulation, analysis, and optimization. Geographic Information Systems (GIS)
    h. Other Industry X.0.technology not mentioned that you know of:

5. Which Industry X.0 technologies are most relevant to your firm's operations? *(Select up to three)*
    a. BIM
    b. GIS
    c. Drones
    d. IoT
    e. 3D Printing
    f. AI
    g. Digital Twins
    h. Other: _______

6. Are there emerging technologies not listed here that your firm is currently exploring? *(e.g., blockchain)*

7. How did you gain awareness about Industry X.0 technologies? *(Select all that apply)*
    a. Training programs
    b. Industry events
    c. Peer networks
    d. Online research
    e. Other: _______

8. What motivates your firm to consider adopting these technologies in future? *(e.g., client demand, competition, regulatory requirements)*

9. Has your firm adopted any Industry X.0 technologies into their day-to-day activities currently?
    a. Yes, extensively
    b. Yes, partially (Please specify which ones and at what scale)
    c. No, but considering
    d. No, and no plans

If "No," why not? *(e.g., cost, skills, awareness)*

If "Yes," which technology has been most beneficial and why? *(e.g., BIM for accuracy)*

10. Does your firm have an official policy or roadmap for adopting new technologies?

- Yes
- No
- Unsure
- Any Comment if there is more to elaborate:

SECTION 3: BARRIERS TO ADOPTION

(Purpose: To identify challenges preventing widespread adoption.)

13. Rate the significance of these barriers to Industry X.0 adoption in your firm.
(1 = Minor concern, 5 = Major concern)

- High costs
- Lack of technical skills
- Resistance to change
- Insufficient training programs
- Workflow incompatibility
- Other:

14. Rate these local challenges in South Africa.
(1 = Minor concern, 5 = Major concern)

- Regulatory delays
- Skills emigration
- Other: _______

SECTION 4: STRATEGIES FOR ADOPTION

(Purpose: To gather insights on solutions for overcoming barriers.)

15. Rank the following strategies in order of effectiveness for increasing Industry X.0 adoption in your firm. *(Assign 1 to the most effective and 5 to the least effective. Each number should be used only once.)*

- Training programs
- Financial incentives
- Affordable tech access
- Local case studies
- Collaboration with technology providers
- Other:

16. What type of training would be most beneficial for your firm?

- Online courses and certifications
- In-house workshops
- On-site demonstrations
- Industry conferences and networking events
- Other:

17. What policy changes or industry initiatives do you think could accelerate technology adoption? *(e.g., BIM mandates, tax breaks, government funding programs)*

SECTION 5: IMPACT AND OUTLOOK

(Purpose: To assess expected benefits and long-term effects.)

18. What benefits do you expect, or have you seen from Industry X.0 technology adoption? *(Select all that apply)*

- Increased efficiency and productivity
- Cost savings in project execution
- Improved accuracy and reduced errors
- Enhanced project sustainability
- Better collaboration and communication
- Other:

19. If your firm has adopted Industry X.0 technologies, what measurable improvements have you observed?

- Time saved:
    - 0
    - 1-5%
    - 6-10%
    - 11-20%
    - 21%+

- Cost reduction:
    - 0
    - 1-5%
    - 6-10%
    - 11-20%
    - 21%+

- Error reduction:
    - 0
    - 1-5%
    - 6-10%
    - 11-20%
    - 21%+

20. How soon do you think Industry X.0 technologies will become standard practice in South African civil engineering?
    - Within 1-3 years
    - Within 4-6 years
    - More than 6 years
    - Never

21. Do you have any additional comments or recommendations on how to enhance Industry X.0 technology adoption in the civil engineering sector? *(Open-ended response)*

end of questionnaire

Thank you for your time and valuable input!

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