LEVERAGING DIGITAL TECHNOLOGY FOR ENVIRONMENT, SOCIAL AND GOVERNANCE (ESG) COMPLIANCE

FION TING YEE JIE

UNIVERSITI TUNKU ABDUL RAHMAN

LEVERAGING DIGITAL TECHNOLOGY FOR ENVIRONMENT, SOCIAL AND GOVERNANCE (ESG) COMPLIANCE

FION TING YEE JIE

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Science (Honours) Quantity Surveying

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

September 2025

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Name	:	Fion Ting Yee Jie
ID No.	:	2005074
Date	:	18 April 2025

COPYRIGHT STATEMENT

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Sr Dr. Wong Phui Fung for her invaluable advice, guidance and her enormous patience throughout the development of the research.

I also wish to express my sincere appreciation to my supportive parents and friends for their encouragement and assistance along the way.

ABSTRACT

The construction industry plays a pivotal role in economic growth but is also one of the largest contributors to environmental degradation and social challenges. With rising global pressure to achieve sustainability and meet stricter regulatory demands, Environmental, Social, and Governance (ESG) compliance has become an essential benchmark for responsible construction practices. ESG compliance is increasingly critical in the construction industry, yet the integration of digital technologies to support ESG initiatives remains fragmented and limited to isolated applications. Thus, this study aims to examine how digital technologies can enhance ESG compliance, the challenges impeding their adoption, and the strategies to support implementation in Malaysia's construction sector. A quantitative research approach was employed, with structured questionnaires distributed to construction professionals in Klang Valley, yielding 117 valid responses. The analysis employed Cronbach's Alpha, the arithmetic mean, the Mann-Whitney U test, the Kruskal-Wallis test, and Spearman's correlation. Results revealed that digital tools are perceived as highly effective in enhancing transparency, regulatory reporting, and energy efficiency; however, high implementation costs and workforce skill gaps were identified as critical barriers. Significant differences in perception emerged across professional roles and years of experience, highlighting diverse readiness levels for digital adoption. Correlation analysis further indicated strong linkages between digital upskilling and the successful deployment of ESG-focused technologies. The findings emphasise the need for a unified framework that integrates digital technologies into ESG practices, supported by industry-wide collaboration, government incentives, and standardized reporting mechanisms. This study contributes to advancing sustainable construction practices by offering practical recommendations for leveraging digital innovation to strengthen ESG compliance, thereby fostering accountability, resilience, and long-term competitiveness in the sector.

Keywords: Environmental, Social, and Governance (ESG); digital technology; construction industry; sustainability; governance; digital transformation

Subject Area: HD45-45.2 Technological innovations. Automation

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

n	sample size
z	z-scores of the desired confidence level
p	proportion of the population with attributes understudy
q	1 - p
e	margin of error

AI	Artificial Intelligence
BDA	Big Data Analytics
BIM	Building Information Modeling
BQSM	Board of Quantity Surveyor Malaysia
CIDB	Construction Industry Development Board
CLT	Central Limit Theorem
ESG	Environmental, Social, and Governance
EU	European Union
IoT	Internet of Things
IP	Intellectual Property
ML	Machine Learning
PPP	Public-Private Partnership
RFID	Radio Frequency Identification
SMEs	Small and Medium-sized Enterprises
SCM	Sustainable Construction Material
SPSS	Statistical Package for the Social Sciences

CHAPTER 1

INTRODUCTION

1.1 General Introduction

This section offers an in-depth overview of the study, covering the study's background, problem statement, the research aims and objectives, the methodology used, the scope of the study, and a structure of how the chapters are organized.

1.2 Background of Study

Environmental, Social, and Governance (ESG) compliance refers to a company's adherence to policies and regulations designed to advance sustainable business practices, ethical governance, and social responsibility (Balboni and Francis, 2024). It has become an institutionalized practice as sustainability concerns become increasingly relevant to society and capital markets (Nicolo et al., 2023). Organizations around the world are increasingly being evaluated not only on their financial performance, but also on their ESG impact (Aydoğmuş, Gulay and Ergun, 2022). Governments, regulators, consumers, employees, and investors now demand greater accountability and transparency in ESG-related activities (Enrica Bolognesi et al., 2025).

In recent years, with the increasing attention paid to global climate change, inequality, geopolitical conflicts, public health crises, social justice, corporate ethics and other issues, companies are facing pressure to incorporate ESG principles into their core strategies (Chen, Xie and He, 2024). This shift is driven by regulatory mandates, investor preferences, and consumer expectations, presents significant challenges, including data management complexities, regulatory inconsistencies, and the risk of greenwashing. A major challenge is the lack of a standardized reporting framework, which makes it difficult to compare ESG indicators across industries and regions (Lagasio, 2024). Additionally, ESG compliance requires extensive data collection and analysis, which can be costly and time-consuming.

Digital technologies are becoming a transformative force in the ESG compliance space, providing advanced tools to simplify data collection, analysis, and reporting (Liu et al., 2024). Digital technologies such as Artificial Intelligence (AI), Blockchain Technology, Big Data Analytics (BDA), and the Internet of Things (IoT) play an important role in improving ESG compliance by automating processes and ensuring data integrity (Dudek and Kulej-Dudek, 2024). By leveraging these technologies, businesses can enhance the accuracy and reliability of their ESG disclosures, mitigate compliance risks, and improve overall sustainability performance.

The regulatory landscape for ESG compliance is rapidly evolving, with governments and international organizations introducing increasingly stringent policies and disclosure requirements. In response, businesses are compelled to adopt technology-driven strategies to navigate these complex demands and ensure compliance (Kumar et al., 2024). Integrating digital solutions into ESG practices is no longer merely advantageous but it is essential for long-term business resilience and sustainability. With that, this research dedicates the focus to the implementation of digital technology for ESG compliance.

1.3 Problem Statement

A large number of studies have been conducted on the topic of ESG. For instance, Adams and Abhayawansa (2022) studied ESG compliance, examining its role in corporate accountability, transparency, and operational improvements. Additionally, Hao et al. (2024) investigated the relationship between ESG ratings and digital technology innovation. Moreover, Martiny et al. (2024) and Muhammad and Pathathai (2024) explored the connection between ESG practices and financial stability, particularly in reducing information asymmetry between companies and creditors. Furthermore, Kartal et al. (2024) analyzed the impact of ESG disclosures on stakeholder trust and engagement, while Zahari et al. (2024) examined ethical culture and leadership for sustainability and governance in public sector organisations within the ESG framework. In addition, Li, Duan, and Cai (2024), along with Khamisu, Paluri, and Sonwaney (2024), studied government regulations related to ESG disclosures. Furthermore, Wang and Wang (2024) explored the relationship between ESG performance and corporate innovation.

On the other hand, the topic of digital technology's role in achieving sustainability has also been widely studied. Li et al. (2025) conducted a comprehensive bibliometric analysis of digital technologies in sustainable construction, identifying key themes, research hotspots, and future directions. Omrany, Mehdipour, and Oteng (2024) investigated the potential of Digital Twin technology to advance social sustainability within the construction sector. Oke et al. (2023) examined the use of digital technologies in the Nigerian construction industry to enhance project efficiency and promote sustainable construction practices. Li et al. (2022) examined how adopting digital technologies impacts the environmental, social, and governance (ESG) outcomes of construction projects, highlighting the mediating role played by collaboration among stakeholders. Lu et al. (2024) conducted a systematic review on the application of digital technologies in construction sustainability, analyzing their impact across various stages of the construction lifecycle.

Furthermore, researchers have explored how digital technologies contribute to ESG initiatives. Asif, Searcy, and Castka (2023), along with Qing and Jin (2023), studied the role of Industry 5.0 and AI-driven data analytics in ESG implementation. Similarly, Bai et al. (2022) examined how digital technologies contribute to sustainability practices, resource efficiency, and transparency. Additionally, Nikmehr et al. (2021) investigated how Building Information Modeling (BIM), IoT-enabled sensors, and blockchain contribute to ESG-related goals. Furthermore, Tamburri (2020) analyzed AI-driven data analytics for ESG monitoring and reporting. Despite these previous studies, research on the integration of digital technologies for ESG compliance remains scarce.

Despite growing update of digital tools for ESG compliance, their deployment remains fragmented, focused on isolated use cases, rather than cross-functional integration. This siloed approach undermines the full potential of digital technologies to deliver cohesive ESG compliances. As such, it is suggested to have a research that investigates how to leverage digital technologies into a unified ESG compliance framework. By doing this, construction organizations can establish a cohesive ESG framework that strengthens long-term economic, environmental, and governance performance.

1.4 Aim

This research aims to explore how digital technology can enhance Environmental, Social, and Governance (ESG) compliance within the construction industry.

1.5 Research Objectives

To achieve the purpose of this study, the following research objectives have been formulated:

1. To explore the role of digital technology in enhancing ESG compliance within the construction industry.
2. To analyse the challenges associated with leveraging digital technologies into ESG compliance in the construction industry.
3. To propose relevant strategies for leveraging digital technologies to enhance ESG compliance in the construction industry.

1.6 Research Methodology

The study employed a quantitative approach, administering a structured questionnaire via Google Forms to gather data from construction professionals. The questionnaire link was distributed via email, social media platforms, LinkedIn, and Microsoft Teams, specifically targeting construction professionals to enhance the response rate. A total of 117 valid responses were obtained. Data analysis involved several statistical techniques: Cronbach's Alpha to evaluate internal consistency, the arithmetic mean to determine central tendencies, Spearman's correlation to explore relationships between variables, the Mann-Whitney U test to compare two independent groups, and the Kruskal-Wallis test to assess differences across multiple respondent groups.

1.7 Research Scope

This study focuses on construction professionals in the Klang Valley to investigate how digital technology contributes to enhancing ESG compliance. Klang Valley was selected due to its prominence as key construction hub in Malaysia, where digital transformation and ESG compliance are increasingly emphasized.

1.8 Chapter Outline

The study is organized into five chapters, with each chapter addressing a key aspect of the research. Chapter 1 introduces the research by outlining the background, problem statement, aim, objectives, methodology, and scope. It emphasizes the importance of ESG compliance in the construction industry and highlights the role of digital technologies in promoting sustainability, social responsibility, and governance integrity. Chapter 2 provides a comprehensive literature review on ESG compliance and digital technologies in construction, examining ESG principles, sustainability challenges, and the potential of technologies such as AI, Blockchain, IoT, and Big Data Analytics. It also identifies research gaps and establishes the theoretical framework underpinning the study.

Chapter 3 focuses on the research design and methodology, detailing the quantitative approach, the structured questionnaire method, and the selection of construction practitioners in Klang Valley as the study's target population. It also details the statistical methods applied, namely Cronbach's Alpha Reliability Test, the arithmetic mean, Spearman's Correlation Test, and the Kruskal-Wallis Test. Chapter 4 reports and interprets the results, examining the contribution of digital technologies to ESG compliance, highlighting the challenges of their integration, and assessing strategies for adoption within the construction sector.

Finally, Chapter 5 concludes the research by summarizing the key findings and discussing their implications for the construction industry. It offers practical recommendations for enhancing ESG compliance through digital technologies, while also acknowledging the study's limitations and suggesting directions for future research.

1.9 Summary of Chapter

This chapter underscores the significance of ESG compliance in construction and the role of digital technologies in advancing sustainability, social responsibility, and governance. It identifies research gaps, presents the problem statement, and outlines the research aims and objectives. Additionally, it introduces the quantitative methodology, including data collection and analysis methods, and concludes with an overview of the chapter structure.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter examines relevant literature on the integration of digital technologies in enhancing ESG compliance within the construction industry. It covers ESG principles, challenges, strategies, and the role of digital technologies in supporting ESG objectives.

2.2 ESG Compliance in the Construction Industry

This section explores the definition and importance of ESG compliance, key principles in construction, and the challenges faced by the industry in complying to ESG standards.

2.2.1 Definition and Importance of ESG Compliance

ESG compliance refers to the systematic incorporation of environmental, social and governance factors into corporate strategy formulation, daily operations and decision-making mechanisms. As companies continue to pay more attention to sustainable, ESG compliance has emerged as a critical framework for aligning business practices with societal and environmental goals. It reflects a company's commitment to reducing its environmental impact, ensuring social equity, and maintaining a transparent and accountable governance system (Yu et al., 2024).

The increased attention on ESG practices is driven by a combination of factors, including regulatory pressures, stakeholder expectations, and the use of ESG performance as an important basis for assessing a company's long-term development potential and risk management (Cardillo and Basso, 2024). Organizations today must not only pursue economic benefits, but also demonstrate a positive commitment to environmental protection, social responsibility and good governance. This trend reflects that society has higher expectations for companies to operate sustainably, considering their impact on the environment, their workforce and the communities they serve (Bolognesi et al., 2025; Shahid et al., 2024).

Both voluntary and mandatory reporting frameworks have greatly promoted the importance of ESG compliance. The European Union (EU), for example, has been a leader in driving ESG compliance through directives such as the Non-Financial Reporting Directive and the Sustainable Finance Disclosure Regulation, which have set clear guidelines for companies to disclose non-financial information (Bolognesi et al., 2025). These systems are designed to improve the consistency, comparability, and transparency of ESG disclosures, ultimately contributing to greater corporate accountability (Domingo et al., 2021). The increased adoption of these regulations has fostered a more systematic and formalized approach to ESG compliance, especially in Europe, where regulatory enforcement is robust (Bolognesi et al., 2025).

Furthermore, ESG compliance is no longer limited to regulatory obligations. It is increasingly seen as a competitive differentiator, with companies leveraging ESG factors to attract investors, enhance their brand reputation, and build consumer trust (Yu et al., 2024). Institutional investors, in particular, often regard excellent ESG performance as a strong sign of a company's long-term sustainability and financial stability. Consequently, companies are increasingly inclined to integrate ESG criteria into their business models, creating a favorable environment for responsible investment (Shahid et al., 2024).

With the increasing development of digital technologies, companies can significantly improve the accuracy and transparency of their ESG disclosures by using advanced tools such as data analytics, AI, and blockchain. These digital technologies facilitate real-time monitoring of ESG data, automate reporting processes, and enhance the comparability of non-financial information across firms (Yu et al., 2024). As a result, companies are better equipped to meet regulatory requirements and respond to the increasing demand for detailed, real-time ESG information from stakeholders (Bolognesi et al., 2025).

Moreover, applying digital technologies to ESG compliance helps companies achieve a more systematic and efficient sustainable development goals. For example, companies can use smart technology to monitor and optimize environmental performance in real time, while social impacts can be evaluated using digital platforms that track labor conditions, diversity, and community engagement (Domingo et al., 2021). In terms of governance, digital tools also play a key role, not only improving the transparency of corporate operations, but also strengthening communication with stakeholders and promoting the implementation and enforcement of ethical standards (Cardillo and Basso, 2024).

2.2.2 Key ESG Principles in Construction

This section explores the key principles of ESG compliance in the construction industry, highlighting how digital technologies are transforming the way the industry adheres to sustainable practices.

2.2.2.1 Environmental Principles

The environmental principles of ESG in construction are crucial for promoting sustainable practices and reducing the industry’s environmental footprint. A central strategy involves the use of Sustainable Construction Materials (SCMs), which replace non-renewable resources with waste products, effectively reducing greenhouse gas emissions and environmental degradation (Chen et al., 2024). Materials such as rice husk ash, bamboo, cork, and plant-based foams not only minimize reliance on raw materials but also enhance energy efficiency and support a circular economy where waste is continuously reused (Chen et al., 2024). In addition to promoting sustainability, SCMs can increase the durability and strength of concrete and other construction materials, thereby reducing long-term raw material consumption and enhancing environmental performance. The incorporation of industrial by-products like recycled steel, precast concrete, and eco-friendly foams diverts waste from landfills and conserves natural resources (Chen et al., 2024). Low-energy, low-emission alternatives such as rammed earth and bamboo offer further potential to reduce the industry’s carbon footprint (Chen et al., 2024).

Beyond material choices, knowledge dissemination plays a pivotal role in advancing ESG compliance. The growing emphasis on green knowledge diffusion within contractor groups fosters education and awareness about sustainable practices, encouraging informed and environmentally responsible decisions across the construction sector (Zhang et al., 2024). This exchange of environmental knowledge not only facilitates regulatory compliance but also equips contractors to mitigate environmental risks and align their practices with global sustainability targets. Additionally, the industry's shift toward sustainability is influenced by growing concerns over climate change, resource depletion, and human toxicity. Integrating renewable, biodegradable materials and green technologies into construction projects helps balance economic development with ecological responsibility, ensuring the built environment supports both societal needs and environmental preservation (Chen et al., 2024; Zhang et al., 2024).

2.2.2.2 Social Principles

The social dimension of ESG in the construction industry is important for promoting sustainable development, ethical labor practices, and long-term societal benefits. Human-centric values form the foundation of social responsibility in construction, with a strong emphasis on fair labor practices, respect for human rights, and creating a positive social impact both in the workplace and in the wider community. Fair labor practices ensure ethical treatment, proper wages, and safe working conditions, while upholding human rights throughout supply chains is essential for responsible sourcing and transparency (Tsang, Fan, and Feng, 2023). These practices not only safeguard workers' well-being but also improve a company's ESG performance and overall competitiveness. Social responsibility in construction also includes environmental stewardship and the ethical treatment of communities impacted by construction activities. By integrating corporate social responsibility and sustainable development goals, companies align their business operations with global social priorities (Tsang, Fan, and Feng, 2023).

Furthermore, human-centric principles within ESG emphasize employee well-being, inclusive workplace environments, and meaningful community engagement. In construction, this translates to creating safe, supportive spaces that foster social welfare and sustainability (Tsang, Fan, and Feng, 2023). The growing demand for ethical and socially responsible business practices is also driven by heightened public awareness and stakeholder influence. Companies are under increasing pressure to adopt transparent, sustainable strategies that prioritize both employee and community interests. Initiatives such as community engagement not only build stronger relationships with local stakeholders but also enhance corporate reputation and public trust

(Tian et al., 2025). As construction firms address ongoing challenges related to labor welfare and employee engagement, those embracing social ESG principles gain a competitive edge, stronger stakeholder relationships, and a resilient brand image. In this evolving landscape, robust ESG strategies that emphasize social sustainability are crucial for ensuring long-term success and societal contribution (Tian et al., 2025).

2.2.2.3 Governance Principles

Governance principles within the ESG framework are critical for ensuring that construction projects are executed transparently, ethically, and in alignment with societal and environmental goals. As construction projects grow more complex and involve diverse stakeholders, effective governance mechanisms are essential for managing innovation, mitigating risks, and balancing economic, social, and environmental considerations. A major challenge, as highlighted by Valkokari et al. (2024), is the evolution of governance beyond the traditional single-project model. In today’s dynamic business environments, governance must adapt to multi-project, interorganisational collaborations that constantly shift in structure and objectives. Construction projects, often part of larger networks or ecosystems, require flexible governance systems that can respond to evolving stakeholder needs and collaborative dynamics. Addressing conflicts between self-interest and collective collaboration is also crucial. Valkokari et al. (2024) note that tensions can arise when different entities, such as businesses and research organizations, pursue diverging goals, business value versus scientific output, necessitating governance mechanisms that mediate these conflicts through relational agreements and formal contracts that protect intellectual property (IP) and confidentiality.

Moreover, knowledge sharing and protection are fundamental to fostering innovation and sustainability in construction. Effective governance must strike a balance between openness and IP security, as overly restrictive practices, such as excessive use of non-disclosure agreements, can hinder ecosystem-level innovation (Valkokari et al., 2024). Governance structures should support safe information exchange while ensuring that benefits are equitably shared among stakeholders. Additionally, governance in construction must accommodate long timelines and multi-phase projects. Traditional contracts often lack the flexibility to adapt to shifting scopes, goals, or partners over time (Valkokari et al., 2024). Therefore, integrating relational governance with formal legal agreements becomes essential. Shen, Tang, and Mu (2024) advocate for a holistic governance approach that blends trust-building, co-creation, and communication with formalized structures to effectively manage the complexities of innovation ecosystems within the construction industry.

2.3 The Role of Digital Technologies for ESG Compliance

This section explores the roles of digital technologies in supporting ESG compliance within the construction sector.

Table 2.1: Literature Map of The Role of Digital Technologies for ESG Compliance.

No.	Roles	Previous Studies	Frequency
	Environmental Compliance		
1.	Carbon Footprint Tracking	Arshad et al. (2023); Chen et al. (2024); Liu et al. (2020); Tao et al. (2018); Xu et al. (2022); Yang et al. (2023)	6
2.	Sustainable Material Sourcing	Arshad et al. (2023); Li et al. (2025); Regona et al. (2024); Yang et al. (2023)	4
3.	Energy Efficiency Optimization	Arowoiya, Moehler and Fang (2024); Arsecularatne, Rodrigo and Chang (2024); Asif, Naeem and Khalid (2024); Bortolini et al. (2022); Jorgensen and Ma (2024)	5
4.	Waste Reduction & Circular Economy Integration	Banihashemi et al. (2024); Kurniawan et al. (2022); Seyyedi et al. (2024); Talla and McIlwaine (2024)	4
5.	Environmental Impact Monitoring	Asif, Naeem and Khalid (2024); Brozovsky, Labonnote and Vigren (2024); Rao et al. (2022); Tuhaise, Tah and Abanda (2023); Zhao et al. (2024)	5
	Social Compliance		
6.	Worker Safety & Well-being	Awolusi, Marks and Hallowell (2018); Calvard and Jeske (2018); Pasquale et al. (2022)	3
7.	Fair Labor Practices	Hassan, Negash and Hanum (2024); Raguel and Odeku (2023)	2
8.	Stakeholder Engagement	Arshad et al. (2023); Hassan, Negash and Hanum (2024); Liu et al. (2023); Toukola and Ahola (2022)	4
9.	Diversity, Equity & Inclusion Monitoring	Bayramoğlu and Gülmez (2024); Heydari et al. (2024)	2
10.	Training & Digital Upskilling	Brozovsky, Labonnote and Vigren (2024); Musarat et al. (2024); Rinchen, Banihashemi and Alkilani (2024); Siriwardhana and Moehler (2023)	4

Table 2.1: (Con’d)

No.	Roles	Previous Studies	Frequency
	Governance Compliance		
11.	Regulatory Reporting & Transparency	Arshad et al. (2023); Bin-Nashwan et al. (2025); Hassan, Negash and Hanum (2024); Liu et al. (2023); Liu et al. (2024)	5
12.	Risk Management	Arshad et al. (2023); Calvard and Jeske (2018); Dicuonzo et al. (2019); Lagasio (2024); Liu et al. (2023); Sun et al. (2024)	6
13.	Cybersecurity & Data Protection	Akanfe, Lawong and Rao (2024); Calvard and Jeske (2018)	2
14.	Audit Trail & Accountability Systems	Das et al. (2022); Luo et al. (2022); Msawil, Greenwood and Kassem (2022)	3
15.	Policy Implementation & Monitoring	Asif, Naeem and Khalid (2024); Musarat et al. (2024); Opoku et al. (2021); Rao et al. (2022); Uzairuddin and Jaiswal (2022)	5

2.3.1 Environmental Compliance

Environmental compliance in construction focuses on reducing ecological impact and ensuring sustainability. As regulations become stricter, companies use digital technologies like IoT, AI, blockchain, and BIM to monitor emissions, optimize resource use, and promote sustainable materials. These technologies improve regulatory compliance, save costs, increase efficiency, and support sustainability.

2.3.1.1 Carbon Footprint Tracking

The construction industry's growing focus on sustainability has led to the adoption of advanced technologies to track and reduce carbon footprints, ensuring environmental compliance. IoT sensors are central to this effort, enabling real-time monitoring of emissions, energy consumption, and waste throughout project phases. Tao et al. (2018) demonstrated this through a Greenhouse Gas Emission Monitoring system used during the prefabrication of building components. Similarly, Liu et al. (2020) showed how distributed sensor networks integrated with BIM enhance emission visualization and management. Xu et al. (2022) introduced the Entity Carbon Assessment and Monitoring System, which uses IoT to estimate emissions in real time. Effective carbon tracking also requires integrating IoT with robust data management systems to ensure seamless data flow and real-time analysis.

AI-powered analytics further support environmental compliance by optimizing energy usage, detecting inefficiencies, and forecasting emissions. Machine Learning (ML) models process IoT-generated data to identify patterns and guide carbon reduction strategies. These systems also help reduce waste and promote material reuse, aligning with circular economy practices (Chen et al., 2024). Additionally, Blockchain Technology enhances the reliability and transparency of emission data. Yang et al. (2023) demonstrated that integrating blockchain with IoT ensures secure, tamper-proof data sharing and supports carbon credit trading. Blockchain can also track and trace the carbon footprint across supply chains, offering stakeholders visibility into emissions at each stage of a product's lifecycle. This transparency is essential for identifying inefficiencies and ensuring ESG compliance through accurate, immutable emission data (Arshad et al., 2023).

2.3.1.2 Sustainable Material Sourcing

Sustainable material sourcing in construction is vital for environmental compliance, focusing on the use of eco-friendly and ethically sourced materials. Digital technology such as blockchain technology plays a key role in ensuring material traceability and transparency by providing secure, immutable records that confirm the sustainability of materials from production to disposal. Blockchain enables the traceability of sustainable materials from origin to final destination, ensuring compliance with environmental standards and providing transparent, verifiable information on the sustainability of materials used in production (Arshad et al., 2023). Yang et al. (2023) demonstrated how blockchain can track the lifecycle of building materials, linking the embodied phase to carbon reduction incentives, thereby supporting circular economy principles. This technology addresses transparency challenges and promotes the recycling and reuse of materials. Complementing blockchain, digital supply chain management optimizes material flow, reducing transportation emissions and monitoring energy consumption. Li et al. (2025) highlighted how real-time digital platforms enable the efficient management of eco-friendly materials, helping project managers select lower-carbon materials and minimize environmental impact. Additionally, Radio Frequency Identification (RFID) enhances supply chain transparency by providing real-time data on material consumption and transportation, ensuring ethical sourcing and alignment with sustainability standards (Li et al., 2025).

The integration of AI, blockchain, and BIM technologies further strengthens sustainable material sourcing by facilitating the circular economy. AI-driven tools optimize material selection, waste reduction, and resource use, ensuring construction projects minimize their environmental footprint. Regona et al. (2024) noted that AI supports sustainable practices by forecasting material demand and identifying recycling opportunities. BIM and IoT platforms, as highlighted by Li et al. (2025), contribute to sustainability by providing real-time data that lead to reductions in carbon emissions by optimizing production, transportation, and assembly processes. These technologies allow construction professionals to make informed material choices, using renewable and recycled materials that align with environmental compliance goals. By incorporating these technologies, the construction industry can significantly reduce its environmental impact while promoting the use of sustainable materials.

2.3.1.3 Energy Efficiency Optimization

Digital technologies play a transformative role in enhancing energy efficiency within the built environment by leveraging innovations such as BIM, IoT sensors, AI, and Digital Twin. These technologies allow for real-time data collection, simulation, and predictive analytics to optimize energy use throughout a building's lifecycle. Digital Twin, in particular, enable virtual replication of physical assets, facilitating the continuous monitoring, modeling, and optimization of energy systems (Arsecularatne, Rodrigo and Chang, 2024; Bortolini et al., 2022). By integrating BIM and IoT, information can be transferred from physical environments to digital platforms, enhancing the accuracy of simulations and energy assessments (Arowoiya, Moehler and Fang, 2024). AI and ML algorithms, such as artificial neural networks and reinforcement learning, further support energy prediction and adaptive control strategies, contributing to reductions in operational inefficiencies and overall energy consumption (Arowoiya, Moehler and Fang, 2024; Asif, Naeem and Khalid, 2024).

The operationalization of these digital systems allows for a shift from reactive to proactive energy management. Smart meters and grids, when combined with advanced controls and analytics, enable dynamic demand-response systems and automation that reduce energy waste and improve occupant comfort (Asif, Naeem and Khalid, 2024). Studies show that digitalization can reduce building sector energy demand by up to 10% by 2040 and improve the energy intensity of systems such as Heating, Ventilation, and Air Conditioning, lighting, and heating by 30%–50% (Asif, Naeem and Khalid, 2024). Digital Twin frameworks also allow energy scheduling in line with market dynamics and regional energy outputs, enhancing both efficiency and cost-effectiveness (Arsecularatne, Rodrigo and Chang, 2024). However, challenges such as data integration, standardization, and workforce skills remain. Addressing these will be key to unlocking the full potential of digital technologies in achieving sustainable, energy-efficient buildings (Arsecularatne, Rodrigo and Chang, 2024; Jorgensen and Ma, 2024).

2.3.1.4 Waste Reduction and Circular Economy Integration

Digital technologies play a pivotal role in advancing waste reduction and circular economy integration by enhancing the efficiency, traceability, and effectiveness of waste management systems. The integration of IoT sensors, AI, and automation allows for real-time monitoring of waste levels, enabling timely collection and reducing unnecessary trips, which optimizes routes and energy use (Seyyedi et al., 2024). These technologies facilitate data-driven decision-making and help identify trends in waste generation, thus supporting more targeted interventions. Innovations such as smart trash bins, AI for material identification, and robotic automation have demonstrated the ability to improve sorting accuracy and recycling rates. Digital platforms also promote the reuse of items by facilitating their recirculation, reducing the demand for new materials and lowering waste generation (Seyyedi et al., 2024). Moreover, simulation tools highlight the potential of digitalization to cut operational costs and energy consumption in waste management processes.

In the construction industry, the use of Digital Twin, material passports, and BIM enhances material traceability and end-of-life recovery planning (Banihashemi et al., 2024). These tools enable stakeholders to track materials throughout a building’s life cycle, ensuring that components are designed for disassembly, reuse, or recycling, thereby reducing construction and demolition waste (Talla and McIlwaine, 2024). Circularity Information Platforms and Information and Communication Technology based decision support systems further enable collaborative planning and informed choices in material recovery. On a broader scale, digitalization empowers communities by supporting mobile-based applications that facilitate the trading of recycled goods, increasing public participation and economic incentives for recycling (Kurniawan et al., 2022). This transformation not only drives resource recovery and operational efficiency but also aligns with Circular Economy principles by promoting sustainability through digital empowerment at both industrial and community levels. Ultimately, digital technology is a crucial enabler for reducing waste, fostering circularity, and creating inclusive, economically viable waste ecosystems across sectors.

2.3.1.5 Environmental Impact Monitoring

Digital technologies play a pivotal role in environmental impact monitoring within the construction and building sectors by enabling real-time data collection, analysis, and decision-making to enhance sustainability. Sensors and the IoT facilitate continuous monitoring of energy usage, waste management, and carbon emissions throughout a building's lifecycle, supporting more informed and dynamic control of environmental footprints (Asif, Naeem and Khalid, 2024; Rao et al., 2022). For example, integrating BIM with automated systems enables dynamic carbon monitoring and forecasting, helping project managers track and reduce carbon footprints effectively during construction phases (Zhao et al., 2024). The ability of Digital Twin to mirror physical assets in real-time through bi-directional data flow offers further opportunities for predictive maintenance, fault detection, and process optimization, which collectively contribute to reducing energy consumption and minimizing environmental impacts (Asif, Naeem and Khalid, 2024; Tuhaise, Tah and Abanda, 2023).

Moreover, digital technologies such as blockchain promote transparency and traceability in sustainable material sourcing and circular economy practices, fostering accountability in emissions reduction efforts across supply chains (Asif, Naeem and Khalid, 2024). The Construction 4.0 paradigm recognizes these advancements as critical tools to address the sector’s significant environmental challenges by integrating smart monitoring systems and real-time carbon tracking platforms, which support better stakeholder awareness and behavioral changes (Brozovsky, Labonnote and Vigren, 2024; Zhao et al., 2024). Together, these technologies enable comprehensive environmental impact monitoring by optimizing resource use, improving operational efficiency, and ensuring compliance with sustainability regulations, thus helping the industry move towards greener and more responsible construction practices.

2.3.2 Social Compliance

Social compliance encompasses an organization's commitment to upholding ethical labor practices, ensuring worker safety and well-being, and engaging stakeholders effectively. The integration of digital technologies has significantly enhanced social compliance by, promoting transparency, accountability, and improved working conditions.

2.3.2.1 Worker Safety and Well-being

Worker safety and well-being are critical aspects of social compliance, especially in high-risk industries like construction and manufacturing. Recent advancements in wearable technology and AI-powered monitoring systems have significantly improved the ability to track workers' health and safety conditions. Wearable devices monitor physiological data such as heart rate, breathing rate, and posture, providing real-time feedback that helps prevent accidents and health issues (Awolusi et al., 2018). These devices can also detect hazardous conditions like toxic gases, chemicals, and inclement weather, further protecting workers from environmental risks. Proximity warning systems based on wearable devices have been shown to prevent collisions between workers, machinery, and stationary structures, a major cause of injuries on construction sites (Awolusi et al., 2018). By continuously monitoring workers' physiological states, such as fatigue or dehydration, wearable technology allows for early intervention before these factors lead to accidents (Awolusi et al., 2018).

In addition to wearable devices, AI-powered monitoring systems provide advanced capabilities for predicting and preventing safety risks. These systems analyze real-time data from wearables, identifying patterns that may indicate health issues or safety risks, such as fatigue or abnormal heart rates (Pasquale et al., 2022). By offering predictive insights, AI systems enable employers to take proactive measures, such as adjusting workloads or scheduling breaks to reduce accidents. Furthermore, AI systems allow for comprehensive safety monitoring across multiple project sites, ensuring a broader overview of worker well-being (Awolusi et al., 2018). However, while these technologies enhance physical safety, it is essential to balance monitoring with respect for workers' psychological well-being. Excessive digital surveillance enabled by big data may negatively impact psychological health, raising concerns about privacy, stress, and fairness. Therefore, Human Resources led strategies for ethical monitoring, transparency, and data literacy are necessary to uphold ESG principles and foster a respectful work environment (Calvard and Jeske, 2018).

2.3.2.2 Fair Labor Practices

Fair labor practices are essential for ensuring workers' rights are respected, particularly for atypical workers such as temporary, contract, or part-time employees who often face discrimination, mistreatment, and denial of basic rights and benefits (Raguel and Odeku, 2023). Digital workforce management tools have become increasingly important in promoting fair labor practices by enabling organizations to track labor rights compliance, wages, and working hours efficiently and transparently. These tools automate workforce management processes, ensuring compliance with labor laws, preventing wage theft, and providing workers with real-time access to their records. By monitoring overtime and adherence to minimum wage laws, digital tools help ensure fair compensation and reduce the risk of exploitation (Hassan, Negash, and Hanum, 2024). Additionally, these tools can document employee benefits, such as healthcare and retirement plans, ensuring that all workers, regardless of employment status, receive the benefits to which they are entitled, promoting fairness and accountability in the workplace.

While digital workforce management tools offer substantial benefits, their adoption in sectors like construction has been hindered by several barriers, including resistance to change, lack of government support, poor digital literacy, and insufficient training (Hassan, Negash, and Hanum, 2024). Without government incentives or regulations promoting digital transformation in labor rights management, industries may be reluctant to invest in these technologies. Furthermore, addressing digital literacy gaps among workers, particularly those in atypical employment situations, is crucial to ensuring equitable access to these tools and their benefits. Overcoming these challenges is essential for harnessing the potential of digital tools to enhance transparency, efficiency, and accountability in workforce management, ultimately fostering fair labor practices and improving working conditions for all employees.

2.3.2.3 Stakeholder Engagement

Stakeholder engagement is a key aspect of social compliance, and the adoption of digital platforms has significantly improved communication, transparency, and collaboration in various business and construction projects. These platforms provide real-time data, facilitate feedback loops, and enhance visibility, allowing stakeholders such as local communities, non-governmental organizations, and regulatory bodies to participate more effectively in decision-making processes (Toukola and Ahola, 2022). Digital tools, including social media platforms like Facebook, have become valuable for municipalities to share information and address citizen concerns, creating direct channels for communication between project managers and local communities. This fosters trust, accelerates information flow, and encourages collaboration, particularly in complex construction projects where stakeholder engagement is essential for success (Toukola and Ahola, 2022). Additionally, centralized communication systems on digital platforms reduce the risk of misinformation, ensuring that all communications are accurate and consistent.

Transparency is a core principle of stakeholder engagement, and digital platforms enhance this by providing stakeholders with access to up-to-date information, making organizations more accountable and open to scrutiny (Hassan, Negash and Hanum, 2024). Blockchain facilitates stakeholder engagement by ensuring transparent and verifiable information flows between all parties in the supply chain or financial networks, allowing stakeholders such as consumers, investors, and regulatory bodies to access real-time climate-related data, fostering trust and accountability, and directly supporting better decision-making for ESG goals (Arshad et al., 2023). This level of transparency not only ensures regulatory compliance but also promotes accountability and reduces conflicts. Moreover, digital platforms allow regulatory authorities to monitor and review projects in real time, improving oversight and ensuring safety and environmental standards are met (Toukola and Ahola, 2022; Hassan, Negash and Hanum, 2024). The blockchain-enabled ESG assessment architecture promotes engagement among various stakeholders by allowing them to access transparent and verifiable ESG data, ensuring confidence in the data and fostering trust in the ESG assessment process (Liu et al., 2023). However, challenges like resistance to change, digital literacy gaps, and insufficient training must be addressed to ensure inclusive participation in digital engagement processes, which can be overcome through customized training and user-friendly interfaces (Hassan, Negash and Hanum, 2024).

2.3.2.4 Diversity, Equity, and Inclusion Monitoring

Digital technologies play an increasingly vital role in monitoring and advancing Diversity, Equity, and Inclusion within the construction industry, addressing a significant research gap identified by Heydari et al. (2024) regarding the impact of technological advancements on Diversity, Equity, and Inclusion. AI-powered tools enhance human resource functions by enabling data-driven decision-making, which promotes objectivity in recruitment and promotion processes. This objectivity helps mitigate biases linked to demographic characteristics, thereby fostering a more equitable and inclusive workforce (Bayramoğlu and Gülmez, 2024). Additionally, BDA allow organizations to detect disparities in employee treatment and opportunities, helping them identify root causes of inequity and implement targeted actions to cultivate diversity and fairness in the workplace (Bayramoğlu and Gülmez, 2024).

However, the use of algorithms and ML models carries the risk of perpetuating existing inequalities through algorithmic biases. To prevent this, organizations must establish robust oversight and monitoring systems that regularly audit these technologies for potential biases, ensuring that any identified inequities are promptly addressed (Bayramoğlu and Gülmez, 2024). Transparency and accountability in data inputs and decision-making processes are critical to maintain trust and fairness in Diversity, Equity, and Inclusion monitoring systems. By integrating digital technologies with careful governance, construction organizations can leverage advanced analytics and AI to foster a diverse, equitable, and inclusive workforce, overcoming traditional barriers and supporting sustainable industry growth (Heydari et al., 2024; Bayramoğlu and Gülmez, 2024).

2.3.2.5 Training and Digital Upskilling

Digital technologies play a pivotal role in training and upskilling the construction workforce, particularly in the context of Industry 4.0 and BIM adoption. As the industry undergoes a transformative shift toward smart, sustainable, and tech-driven practices, there is a growing demand for new skills to manage advanced design tools, data-driven workflows, and collaborative platforms (Musarat et al., 2024; Siriwardhana and Moehler, 2023). However, developing countries face acute challenges, including a shortage of skilled labor, limited access to training, and cost barriers to upgrading technology (Musarat et al., 2024). These issues are particularly pronounced among Small and Medium-sized Enterprises (SMEs), which struggle to keep pace with the digital competencies required for modern construction processes (Rinchen, Banihashemi and Alkilani, 2024). Consequently, digital technologies must be harnessed not only for automation and efficiency but also for creating scalable, accessible learning environments that support worker upskilling.

To close the widening digital divide, academia and industry must collaborate more effectively to align education with real-world construction demands. As Brozovsky, Labonnote and Vigren (2024) argue, integrating emerging technologies into construction education is critical for preparing future professionals, and educational institutions must take a proactive role in curriculum reform and knowledge transfer. Learner-centric training models that emphasize autonomy and adaptability are essential to develop interdisciplinary competencies required in Construction 4.0 (Siriwardhana and Moehler, 2023). Furthermore, national and international bodies must support structured skills development strategies to ensure consistent and inclusive access to digital upskilling across socio-economic groups. In underdeveloped nations, where BIM-related education is still nascent, there is a pressing need for targeted research and investment in digital literacy initiatives (Rinchen, Banihashemi and Alkilani, 2024). Ultimately, the effective adoption of digital technologies in construction hinges not just on technological readiness, but on empowering human capital through robust, context-aware training frameworks.

2.3.3 Governance Compliance

Governance compliance is crucial for ensuring that organizations follow the necessary regulations and ethical standards. As the focus on ESG issues grows, there is increasing pressure on companies to ensure transparency, accountability, and security in their operations. Compliance involves several key areas, including regulatory reporting, risk management, and data protection. To address these challenges, organizations are turning to digital technologies that help improve governance compliance.

2.3.3.1 Regulatory Reporting & Transparency

The integration of AI and Blockchain Technology has significantly enhanced regulatory reporting and transparency in ESG compliance. AI-powered tools have revolutionized ESG reporting by automating the aggregation, analysis, and verification of data, ensuring adherence to complex regulatory frameworks such as the EU's Sustainable Finance Disclosure Regulation (Liu et al., 2024). These tools help detect discrepancies in ESG disclosures, reducing the risk of greenwashing by analyzing large datasets, including textual ESG reports, for signs of exaggerated claims (Lagasio, 2024). AI technologies like Natural Language Processing and ML algorithms further improve the accuracy of reports, enhancing transparency and minimizing human error. By automating routine tasks, these tools ensure companies remain compliant with evolving regulatory standards and increase the credibility of their sustainability efforts (Bin-Nashwan et al., 2024).

AI's integration with Blockchain Technology further enhances the credibility and transparency of ESG reporting. Blockchain provides a secure, immutable record of ESG certifications, preventing tampering and ensuring that once a report is verified, it cannot be altered (Liu et al., 2024). This dual integration fosters trust among stakeholders by guaranteeing the authenticity of ESG disclosures. Blockchain Technology also streamlines regulatory reporting by providing a secure, immutable ledger for environmental transactions like carbon credits and renewable energy certifications, ensuring reliable data that can be easily audited by regulators (Arshad et al., 2023). AI-driven verification systems, such as Veri-Green, further improve impartiality and transparency by matching companies with suitable third-party verifiers based on historical data (Liu et al., 2024). However, the effective implementation of these digital tools in ESG reporting faces challenges such as regulatory barriers, inadequate policies, and insufficient government support for technologies like BIM, which are essential for driving digital transformation toward sustainable practices (Hassan, Negash, and Hanum, 2024).

2.3.3.2 Risk Management

The integration of BDA into risk management frameworks has significantly enhanced organizations' ability to predict and mitigate compliance risks. BDA tools provide firms with access to vast amounts of data, improving decision-making and enabling more accurate risk assessments (Sun et al., 2024). By analyzing patterns and trends, BDA helps organizations identify potential risks, such as regulatory changes or market shifts, and take proactive steps to mitigate them. However, the increased reliance on BDA also raises firm risk, particularly in high-risk areas like Research and Development or mergers and acquisitions. While BDA can offer competitive advantages, it also amplifies the likelihood of unforeseen risks arising from poorly managed data or inaccurate predictions (Sun et al., 2024). Therefore, effective governance is essential to ensure that BDA tools are used responsibly and in compliance with regulatory frameworks, such as the EU's General Data Protection Regulation (Sun et al., 2024).

Incorporating BDA into governance frameworks requires organizations to prioritize data integrity, transparency, and accountability. Dicuonzo et al. (2019) highlight that BDA provides a broader risk assessment framework, enhancing decision-making and safeguarding corporate assets. However, ensuring compliance with data privacy regulations and managing ethical concerns are critical to mitigating compliance risks (Sun et al., 2024). Blockchain's decentralized and tamper-proof features support risk management by reducing fraud, errors, and inefficiencies in environmental data tracking and reporting, especially in areas like carbon trading and climate finance. By providing secure and transparent financial transactions, blockchain reduces risks related to market inefficiencies and corruption, which is essential for ESG compliance (Arshad et al., 2023). Additionally, AI-driven tools like Natural Language Processing can help mitigate greenwashing risks, ensuring alignment with evolving ESG disclosure standards (Lagasio, 2024). The data-driven ESG assessment approach, such as Stochastic Multicriteria Acceptability Analysis version 2, offers an objective framework for evaluating ESG performance and managing associated risks (Liu et al., 2023). To reduce information asymmetry and improve decision-making, organizations must ensure that their BDA tools are secure, accurate, and compliant with regulatory standards. Collaboration between departments such as Human Resources and legal teams is crucial to managing employee data ethically and ensuring compliance with privacy laws (Calvard and Jeske, 2018).

2.3.3.3 Cybersecurity and Data Protection

Blockchain Technology combined with advanced encryption mechanisms, offers a robust solution for ensuring governance compliance, particularly in securing sensitive ESG-related data. Blockchain's decentralized, transparent, and immutable ledger ensures the secure storage and sharing of ESG data among stakeholders, significantly reducing the risk of tampering or loss, and protecting against cybersecurity threats. Additionally, advanced encryption techniques, such as hashing algorithms, ensure that only authorized users can access or modify ESG data. This level of protection aligns with data protection regulations like General Data Protection Regulation, safeguarding personal information without compromising data integrity (Akanfe, Lawong and Rao, 2024). Blockchain also supports governance compliance by providing a transparent and auditable system that streamlines ESG data tracking from its source to reporting. Smart contracts enhance compliance by automatically executing predefined conditions, enforcing governance policies without the need for intermediaries (Akanfe, Lawong and Rao, 2024).

Blockchain's immutability, however, presents challenges in complying with General Data Protection Regulation's right to erasure. To address this, solutions such as off-chain storage and cryptographic techniques like zero-knowledge proofs have been proposed. Off-chain storage ensures that sensitive data is stored outside the blockchain, while zero-knowledge proofs verify data without exposing personal details, ensuring both General Data Protection Regulation compliance and blockchain transparency (Akanfe, Lawong and Rao, 2024). These privacy-preserving techniques ensure that ESG data is securely handled, auditable, and aligned with regulatory standards. As big data ecosystems expand, organizations must address cybersecurity threats, third-party risks, and ethical lapses by adopting updated risk management frameworks and Human Resources led governance strategies that ensure secure, transparent, and compliant handling of sensitive ESG and employee data (Calvard and Jeske, 2018).

2.3.3.4 Audit Trail and Accountability Systems

Digital technologies, particularly blockchain, play a crucial role in establishing robust audit trail and accountability systems in the architecture, engineering, and construction sector. Blockchain's decentralized and immutable ledger structure ensures that all document-related actions, including approvals, revisions, and endorsements, are irreversibly recorded, thereby enhancing data integrity and traceability (Das et al., 2022). Smart contracts further enforce accountability by embedding irrevocable approval workflows, ensuring that actions are executed in a predefined, tamper-proof sequence (Das et al., 2022). This creates a transparent environment where each participant's identity is authenticated, their actions are logged, and the sequence of operations is auditable in real time, contributing to better control and reduced disputes.

Moreover, blockchain supports long-term monitoring and quality assurance by maintaining an unalterable document lifecycle history, whether integrated with traditional cloud repositories or decentralized file systems like IPFS (Das et al., 2022). In tandem with smart contracts, this enhances construction compliance inspections and post-construction evaluations by preserving detailed records of project milestones and decisions (Luo et al., 2022). Blockchain's inherent features, such as immutability, instant traceability, and self-executing logic, enable a high level of accountability and transparency among all stakeholders involved in complex construction workflows (Msawil, Greenwood and Kassem, 2022). These capabilities are vital for regulatory reporting, dispute resolution, and performance audits, reinforcing the foundational trust and integrity essential for digital transformation in the architecture, engineering, and construction industry.

2.3.3.5 Policy Implementation and Monitoring

Digital technologies play a critical role in policy implementation and monitoring within the construction industry by enabling real-time, automated oversight of various activities through advanced sensor technologies and the IoT. These technologies facilitate seamless interaction between multiple stakeholders, including contractors, suppliers, and logistics providers, through handheld devices and apps, thereby providing comprehensive, up-to-date insights into project progress, safety, and resource use (Rao et al., 2022). The use of digital tools such as BIM, Geographic Information Systems, and Digital Twin supports continuous monitoring of construction phases, improves coordination, and helps enforce compliance with environmental and safety policies (Uzairuddin and

Jaiswal, 2022; Opoku et al., 2021). Furthermore, IoT-enabled positioning and communication technologies offer real-time alerts and hazard warnings to workers, enhancing on-site safety and ensuring that safety regulations are actively monitored and implemented (Rao et al., 2022).

Despite these advances, the effective implementation and monitoring of digital policies face challenges, especially in regions like Malaysia, where industry stakeholders often lack awareness of digital benefits, and the high costs of adoption limit widespread use among small and medium enterprises (Musarat et al., 2024). To address these barriers, governments and industry bodies must develop clear regulatory frameworks and policies that foster innovation, investment, and capacity-building in digital skills (Asif, Naeem and Khalid, 2024). By continuously updating legal frameworks and providing financial support, such as Malaysia's allocation for SMEs digital transformation, digital technologies can be more broadly integrated into construction practices, ensuring effective policy enforcement, accountability, and improved sustainability outcomes across the sector (Musarat et al., 2024).

2.4 Challenges in Integrating Digital Technologies for ESG Compliance

Integrating digital technologies for ESG compliance faces challenges such as technical barriers, regulatory fragmentation, organizational resistance, financial constraints, and skill gaps. This section examines the challenges in the integrating digital technologies for ESG compliance.

Table 2.2: Literature Map of Challenges in Integrating Digital Technologies for ESG Compliance.

No.	Challenges	Previous Studies	Frequency
1.	Technological Barriers	Bhatia et al. (2024); De Silva, Gunarathne and Kumar (2024); Duran and Tierney (2023); Gorkhali (2022); Guo and Pang (2025); Bokolo et al. (2024); Pizzi et al. (2024); Radanliev et al. (2024)	8
2.	Regulatory & Policy Constraints	Cai, Tu and Li (2023); Duran and Tierney (2023); Faruq and Chowdhury (2025); Guo and Pang (2025); Pizzi et al. (2024); Radanliev et al. (2024)	6
3.	Stakeholder Engagement Constraints	Ali (2025); Hwabamungu and Shepherd (2024)	2
4.	High Implementation & Maintenance Costs	Bhatia et al. (2024); Cai, Tu and Li (2023); De Silva, Gunarathne and Kumar (2024); Duran and Tierney (2023); Faruq and Chowdhury (2025); Guo and Pang (2025); Pizzi et al. (2024)	7
5.	Skills & Training Gaps	Bhatia et al. (2024); Cai, Tu and Li (2023); De Silva, Gunarathne and Kumar (2024)	3
6.	Cybersecurity & Data Privacy Risks	Gorkhali (2022); Jin and Mirza (2024); Reddy, Kiranmayee and Julakanti (2025); Radanliev et al. (2024)	4
7.	Lack of Standardization	Duran and Tierney (2023); Bokolo et al. (2024); Radanliev et al. (2024); Telukdarie, Mahure and Sishi (2024)	4
8.	Data Quality & Accessibility Issues	Asif, Searcy and Castka (2023); Balboni and Francis (2024); Cai, Tu and Li (2023); Wang et al. (2023); Zhao and Cai (2023)	5
9.	Real-Time Monitoring & Analytics Complexity	Truant et al. (2023); Xu and Yin (2025); Zhao and Cai (2023)	3
10.	Organizational Change Resistance	Diener and Špaček (2021); Florek-Paszkowska, Ujwary-Gil and Godlewska-Dziobon (2021); Hassan et al. (2024); Ologeanu-Taddei et al. (2024); Pacolli (2022)	5

2.4.1 Technological Barriers

The integration of digital technologies for ESG compliance faces numerous technical barriers that hinder their full potential. Bhatia et al. (2024) identified concerns around the security, reliability, and integration of these technologies, with employees expressing doubts about the overwhelming amount of data generated and its usefulness in creating accurate carbon emission metrics. The rapid pace of technological change also raises concerns about obsolescence, causing hesitation in adopting solutions that may quickly become outdated. Silva, Gunarathne, and Kumar (2024) pointed out that integrating new technologies into existing infrastructures is difficult, citing issues such as system compatibility, contextual variations, and limited resources. Additionally, the slow integration and lack of prioritization for the dissemination of these technologies delay progress and innovation.

Furthermore, many ESG technology solutions assume that underlying data is both complete and reliable, which is often not the case. Duran and Tierney (2023) noted that the technology infrastructure for comprehensive ESG disclosure is still developing, relying on limited and inconsistent company reports or questionnaires that vary in scope. These solutions tend to be industry-specific and narrowly focused on areas like Greenhouse Gas emissions. Challenges also arise from the integration of emerging technologies such as 5G and IoT, which face issues with scalability, security, and compatibility (Gorkhali, 2022). The lack of standardization and interoperability in Distributed Ledger Technologies also limits their effectiveness, with difficulties in communication between public and private blockchains (Bokolo et al., 2023). As Guo and Pang (2025) noted, the asymmetry of information and resource allocation challenges further reduce the willingness of enterprises to engage in ESG practices. The absence of integrated reporting systems and the complexity of AI technologies also pose significant obstacles to effective and transparent ESG compliance (Pizzi et al., 2024; Radanliev et al., 2024).

2.4.2 Regulatory and Policy Constraints

The integration of digital technologies for ESG compliance is significantly affected by regulatory and policy constraints, which can create obstacles for both enterprises and investors. Cai, Tu, and Li (2023) highlighted a critical information asymmetry between investors and enterprises, particularly in relation to inadequate disclosure of financial and ESG information. This gap is further exacerbated by the difficulties faced by regulatory authorities in obtaining ESG data, which stifles the growth of ESG practices, particularly in regions like China. As global regulatory frameworks for ESG factors evolve rapidly, organizations face a challenge in navigating varying requirements, with countries pursuing policies that best serve their national interests (Duran and Tierney, 2023). This fragmented regulatory landscape complicates the consistent application of ESG standards, limiting the effectiveness of digital tools in achieving compliance.

Policymakers and regulators play an essential role in addressing these challenges by fostering an environment that supports sustainable investment. Faruq and Chowdhury (2025) argued that efforts should be directed toward technological advancements, financial reforms, and inflation control to bolster ESG investments. Additionally, accelerating digital government initiatives can provide enterprises with greater transparency and more accessible services, which would incentivize digital transformation (Guo and Pang, 2025). However, the lack of standardization and regulatory fragmentation remains a key issue, as noted by Pizzi et al. (2024), with fitness checks in the European Commission revealing gaps in consistency across member states. Moreover, as AI technologies continue to evolve, regulatory frameworks must remain dynamic and adaptive to ensure compliance while safeguarding privacy and ethical standards (Radanliev et al., 2024). These regulatory complexities underscore the need for international collaboration and adaptive policies to effectively integrate digital technologies into ESG compliance.

2.4.3 Stakeholder Engagement Constraints

One of the challenges in integrating digital technologies for ESG compliance is engaging stakeholders effectively throughout the digital transformation process. Stakeholders often possess varying levels of digital literacy, knowledge, and experience, making it difficult to reach a mutual understanding, especially concerning the technical specifications of new technologies. This complexity is further heightened by competing interests related to outputs, resource distribution, and cost implications (Ali, 2025). Additionally, factors such as limited internet connectivity, lack of infrastructure, and resistance to adopting unfamiliar technologies further hinder meaningful stakeholder involvement (Ali, 2025).

Stakeholder-related limitations also stem from inadequate planning, unclear digitalisation processes, and weak leadership. These issues contribute to gaps between ESG digitalisation goals and actual implementation. The inconsistent identification and inclusion of internal and external stakeholders in digital initiatives can result in poor alignment and lack of ownership (Hwabamungu and Shepherd, 2024). Furthermore, low awareness of digital benefits, lack of training, and perceived complexity discourage engagement. However, when stakeholders are properly identified, included, and their roles clearly defined, they contribute valuable expertise and help reduce barriers to adoption. Planned and managed stakeholder involvement has been shown to improve knowledge sharing and ensure better alignment with digital ESG objectives (Hwabamungu and Shepherd, 2024).

2.4.4 High Implementation and Maintenance Costs

The integration of digital technologies for ESG compliance presents significant financial barriers for many organizations, which can deter investment in the necessary infrastructure and processes. Bhatia et al. (2024) identified several financial challenges, including budgetary constraints, significant recurring expenses, and the complexities associated with evaluating projects aimed at improving ESG performance. Additionally, as noted by Cai, Tu, and Li (2023), the high costs associated with improving ESG performance often reduce the intrinsic motivation of businesses to pursue these initiatives. For many firms, especially those with limited intellectual and financial resources, investing in technology upgrades, training programs, and innovation becomes a considerable challenge (Silva, Gunarathne, and Kumar, 2024). Moreover, manual processes involved in sourcing and managing sustainability data increase both costs and the potential for errors, further complicating the financial burden of ESG compliance (Duran and Tierney, 2023). These financial concerns are particularly pronounced for SMEs, which bear a disproportionate share of the compliance costs given their fixed overheads (Duran and Tierney, 2023).

The financial implications extend beyond initial investment costs and can affect an organization's long-term sustainability strategy. Faruq and Chowdhury (2025) highlighted how economic uncertainty, driven by factors like high inflation, causes investors to prioritize short-term financial security over long-term ESG investments. Additionally, the costs associated with digital transformation, including the financial and intellectual resources required to integrate advanced technologies, may deter organizations from fully embracing sustainability reporting (Pizzi et al., 2024). This hesitation can lead companies to minimize the scope of their ESG disclosures, thereby limiting transparency and potentially misrepresenting their sustainability efforts (Duran and Tierney, 2023). Although digital transformation has been shown to alleviate financing constraints and improve corporate ESG performance (Guo and Pang, 2025), the asymmetry of information and resource allocation issues still hinder widespread adoption. The financial and investment risks associated with integrating digital technologies into ESG compliance reflect the need for a more supportive regulatory environment and enhanced investor awareness to mitigate these challenges (Faruq and Chowdhury, 2025).

2.4.5 Skills and Training Gaps

A major challenge in leveraging digital technology for ESG compliance is the lack of adequate skills and workforce readiness. Bhatia et al. (2024) identified significant gaps in both the availability of skilled labor and the readiness of existing workforces to adopt new technologies. Many organizations face difficulties in hiring the necessary technical experts, often due to limited access to individuals with the specialized skills required for implementing advanced digital solutions. This skills gap is further compounded by inadequate in-house technical expertise, which hinders organizations from effectively integrating digital technologies into their ESG practices. Additionally, there is a noticeable lack of training and development programs tailored to emerging technologies, which exacerbates the problem of workforce preparedness (Bhatia et al., 2024). Enterprises often struggle to equip their employees with the necessary capabilities to manage ESG data and processes effectively, leading to resistance to digital transformation and ESG improvements (Cai, Tu, and Li, 2023).

The absence of knowledge and competence in areas such as Sustainability, Accountability, and Risk Assessment poses another barrier to adopting digital technologies for ESG compliance. Silva, Gunarathne, and Kumar (2024) emphasized that organizations lack the expertise needed to efficiently utilize digital tools in managing environmental, social, and economic issues. The insufficient understanding of key concepts such as green capitalism and sustainability impedes the digital transformation process, as these ideas are integral to aligning business practices with ESG goals. Furthermore, the lack of shared knowledge on sustainability across different levels of the organization leads to misalignment in implementing ESG strategies and limits the effective use of digital solutions (Silva, Gunarathne, and Kumar, 2024). Without a strong foundation in digital knowledge and systematic processes, companies struggle to address complex ESG concerns, ultimately slowing the progress toward more sustainable and responsible business practices.

2.4.6 Cybersecurity and Data Privacy Risks

As digital technologies are increasingly leveraged for ESG compliance, significant concerns related to data privacy, security, and ethical risks emerge. The integration of Industry 4.0 platforms, which incorporate a wide array of enabling technologies, brings inherent security and reliability challenges. Gorkhali (2022) pointed out that, due to the platform's complexity, ensuring robust security measures, such as using Blockchain Technology for network privacy, is critical. However, while Blockchain Technology offers promising solutions for data protection, scalability issues remain a significant hurdle, particularly as it integrates with other technologies. In addition, while smart contracts are often proposed as tools to maintain privacy and security within such platforms, their performance optimization and ability to self-repair still require further development (Gorkhali, 2022). These security concerns, coupled with the rapid adoption of technologies like 5G, highlight the pressing need for continuous advancements in data protection mechanisms. As organizations collect increasingly sensitive ESG-related data, the risk of cyberattacks and data breaches grows, emphasizing the importance of robust data governance frameworks to mitigate these threats (Reddy, Kiranmayee and Julakanti, 2025).

Moreover, the ethical risks tied to data privacy and security are particularly concerning in the context of AI and other advanced digital technologies. The rise in cyberattacks and the increasing volume of sensitive information being processed raise significant privacy concerns (Reddy, Kiranmayee and Julakanti, 2025). Radanliev et al. (2024) emphasized that as AI systems become more prevalent in managing ESG data, the potential for privacy infringement grows, underscoring the need for AI algorithms that not only respect but actively safeguard individual privacy. Ethical considerations surrounding the design and deployment of these systems must be integrated from the outset, rather than being treated as an afterthought (Radanliev et al., 2024). Additionally, concerns around corporate governance, such as potential conflicts of interest between managers and shareholders, further complicate the ethical landscape, as these issues may reduce transparency in ESG disclosures and contribute to corporate fraud (Jin and Mirza, 2024). To mitigate these risks, a structured governance framework is necessary to ensure that organizations comply with legal and regulatory standards while maintaining ethical responsibility in their ESG data practices (Reddy, Kiranmayee and Julakanti, 2025).

2.4.7 Lack of Standardization

One of the major obstacles in integrating digital technologies for ESG compliance is the lack of standardized data and reporting formats. Duran and Tierney (2023) emphasized that there is often little consistency in the type, quality, and format of ESG data, which complicates both the collection and analysis of information. This inconsistency has resulted in significant hurdles for organizations in adopting and utilizing digital technologies for ESG reporting. Although there have been efforts to standardize ESG data, such as the EU's European Single Access Point, which aims to consolidate ESG company information in a machine-readable format, comprehensive standardization remains a distant goal. Moreover, the complexity of ESG data, with its various types and formats, makes it a time-consuming and burdensome task to define a universal ESG data standard (Duran and Tierney, 2023). Despite these challenges, the urgency to ensure that "perfect" standards do not hinder progress is highlighted as critical in achieving sustainability goals quickly and efficiently (Duran and Tierney, 2023).

The need for standardization extends beyond just data formats; it also impacts the technologies used in Industry 4.0 and Distributed Ledger Technologies. Bokolo et al. (2023) discussed the lack of interoperability and standardization in Distributed Ledger Technologies, which causes data silos and limits the potential for digital urban ecosystems. The absence of a universal standard for Distributed Ledger Technologies, which can help reduce vendor lock-in and enable better integration across systems, has hindered the adoption of distributed applications in smart cities. This challenge is compounded by the fact that the global nature of AI and other digital technologies requires international collaboration to establish frameworks that transcend national boundaries (Radanliev et al., 2024). Similarly, the lack of standardized ESG ratings, as identified by Telukdarie, Mahure, and Sishi (2024), causes difficulties in comparing and interpreting ESG scores across different organizations and jurisdictions. As ESG reporting frameworks continue to evolve, there is a pressing need for digitalization to consolidate and standardize ESG indicators, ensuring consistent units of measure and aggregation methodologies for more reliable and comparable reporting (Telukdarie, Mahure, and Sishi, 2024).

2.4.8 Data Quality and Accessibility Issues

One of the central challenges in integrating digital technologies into ESG compliance lies in the persistent issues surrounding data availability and quality. Despite advancements in digital infrastructure, many companies lack the internal capacity and external incentives to systematically collect, process, and disclose high-quality ESG data (Cai, Tu and Li, 2023). Regulatory bodies and investors continue to face difficulties in accessing reliable ESG information, leading to a significant information asymmetry that undermines trust and decision-making (Zhao and Cai, 2023). Even when digital transformation is pursued, firms encounter high implementation costs and capability gaps, which hinder the transformation of raw data into meaningful ESG reports (Asif, Searcy, and Castka, 2023). The complexity of real-time monitoring and analytics, paired with limited interoperability of digital systems, further exacerbates the challenge of ensuring accurate and timely ESG disclosures.

Furthermore, the ethical dimension of data processing remains problematic. As noted by Balboni and Francis (2024), legal frameworks such as General Data Protection Regulation have not effectively ensured ethical data handling or societal benefit, often prioritizing corporate profit over individual empowerment. Lawful data practices do not necessarily align with ethical standards, creating a gap that digital technologies alone cannot bridge. The absence of enforceable ethical standards and tangible incentives means firms may continue to process and report ESG data in ways that lack transparency and accountability. This undermines both the credibility and utility of ESG disclosures. Hence, without addressing the broader ethical and institutional barriers, including inadequate legislative protection, limited corporate motivation, and underdeveloped reporting standards, digital technologies alone cannot resolve the foundational challenges of ESG data availability and quality (Balboni and Francis, 2024; Wang et al., 2023).

2.4.9 Real-Time Monitoring and Analytics Complexity

One of the most pressing challenges in integrating digital technologies for ESG compliance lies in the complexity of real-time monitoring and analytics. The dynamic nature of digital transformation presents difficulties in mapping its direct and indirect impacts on the ESG dimensions (Xu and Yin, 2025). While digital tools offer enhanced tracking and reporting capabilities, the mechanism between corporate digitalization and ESG performance remains intricate and underexplored, especially given the chain mediating effects of technological innovation and financing constraints (Xu and Yin, 2025). Despite the potential of digital transformation to improve information efficiency and establish more transparent ESG reporting systems, the lack of universally agreed-upon ESG evaluation criteria, coupled with the disruptive and often opaque nature of emerging technologies, poses significant obstacles (Truant et al., 2023).

Moreover, fragmented research and inconsistent methodologies contribute to the difficulty of achieving cohesive and real-time ESG analytics frameworks (Truant et al., 2023). The challenges are further compounded by difficulties regulators and investors face in accessing timely, reliable ESG data, which hinders decision-making and undermines trust in digital ESG systems (Zhao and Cai, 2023). While digital transformation can enhance the comprehensiveness and efficiency of ESG disclosure, many firms, particularly heavy polluters, struggle with limited capacity and high implementation costs, reducing their internal motivation to adopt such systems (Zhao and Cai, 2023). These issues highlight the need for more structured, in-depth studies and standardization efforts to navigate the volatile strategic landscape of ESG monitoring through digital innovation (Truant et al., 2023; Zhao and Cai, 2023).

2.4.10 Organisational Change Resistance

Integrating digital technologies for ESG compliance faces significant challenges related to change management and cultural alignment. Organizational changes driven by digital transformation often emphasize technology and internal processes, neglecting the human element and its impacts on employees (Pacolli, 2022). Without employees' genuine commitment to the company's vision, digital initiatives risk failure despite the deployment of advanced technologies (Florek-Paszkowska, Ujwary-Gil and Godlewska-Dziobon, 2021). Resistance to change, unfamiliarity with new digital tools, and fears of job displacement contribute to organizational and cultural barriers that hinder adoption (Hassan et al., 2024; Pacolli, 2022). These barriers often breed negative emotions among employees, reducing their engagement and willingness to embrace innovation (Pacolli, 2022). Effective change management requires involving employees throughout the digitalization process and fostering a shared sense of purpose to reduce the risk of project failure and ensure sustainable transformation (Diener and Špaček, 2021; Pacolli, 2022).

Despite the increasing recognition of change culture's importance, many organizations struggle to modernize workplace cultures effectively, with only 31% rating their efforts as successful in 2021 (Harvard Business Review Report, 2022). Studies show a lack of holistic approaches that integrate change management fully into digital transformation efforts, limiting the sustainability of ESG-related digital initiatives (Pacolli, 2022). Moreover, insufficient stakeholder participation and misaligned interests further exacerbate these challenges, causing ineffective use of digital solutions (Hassan et al., 2024). There remains a need for more nuanced conceptualizations linking digital transformation and sustainability, as current literature reveals contradictions and inconsistencies in understanding their relationship (Ologeanu-Taddei et al., 2024). Addressing change management and cultural alignment barriers is therefore essential to realizing the full potential of digital technologies in ESG compliance.

2.5 Strategies for Leveraging Digital Technologies for ESG Compliance

This section explores the strategies for leveraging digital technologies for ESG compliance. Identifying and applying these strategies not only supports regulatory adherence and strengthens transparency but also enhances efficiency and accountability, thereby creating long-term value through more sustainable business practices.

Table 2.3: Literature Map of Strategies for Leveraging Digital Technologies for ESG Compliance.

No.	Strategies	Previous Studies	Frequency
1.	Develop a Robust Framework for Digital ESG Integration	Almadadha (2024); Lee and Kim (2023); Lee et al. (2024); Sang, Loganathan and Lin (2024); Solaimani (2024)	5
2.	Standardize Data Collection & Reporting	Li et al. (2024); Truant et al. (2023); Wang et al. (2023); Zhao and Cai (2023)	4
3.	Implement Cybersecurity Measures	Asif, Searcy and Castka (2023); Balboni and Francis (2024); Eccles, Lee and Stoehle (2020); Ogugua (2024); Tamimi and Sebastianelli (2017); Wang et al. (2023)	6
4.	Foster Public-Private Partnerships & Industry Consortia	Eisaqui (2023); Lee et al. (2024); Steelyana and Wahyuni (2024)	3
5.	Provide Government Incentives	Chen, Meng and Yu (2022); Li et al. (2023); Zhang and Zhang (2024)	3
6.	Invest in Training	Cranford (2023); Miasayedava, McBride and Tuhtan (2020); Sang, Loganathan and Lin (2024); Solaimani (2024)	4
7.	Establish ESG Performance Evaluation	Guo and Pang (2025); Hunhevicz, Motie and Hall (2022); Mahboub et al. (2023); Sajjad et al. (2023); Wang and Esperanca (2023); Xu and Yin (2025); Yang, Huang and Chen (2024)	7
8.	Automate ESG Reporting & Collection	Saxena et al. (2023); Zahedi et al. (2024)	2
9.	Provide Friendly-user Interface of Software by Production Company	Lop et al. (2024); Shojaei, Oti and Burgess (2023)	2

2.5.1 Develop a Robust Framework for Digital ESG Integration

The integration of digital technologies, such as blockchain and AI, into ESG compliance frameworks has gained significant attention in recent years. Blockchain, for example, is increasingly recognized for its potential to enhance the transparency and accountability of ESG reporting, particularly within financial accounting (Almadadha, 2024). By ensuring accurate, immutable records of ESG data, blockchain can significantly reduce the risk of manipulation or misreporting, fostering greater trust among stakeholders. Furthermore, Quigley et al. (2025) highlighted the applicability of blockchain in environmental compliance, particularly in maritime industries, where real-time data collection and smart contracts can automate compliance checks. These applications exemplify how digital technologies can be harnessed to streamline ESG reporting, improve regulatory adherence, and facilitate more informed decision-making among investors and organizations.

In addition to blockchain, the role of AI and data analytics in ESG compliance is also gaining prominence. The development of ESG classifiers, such as those proposed by Lee and Kim (2023), allows for the automated extraction and classification of ESG-related information, enhancing the efficiency and accuracy of reporting processes. Moreover, integrating AI with ESG frameworks has led to the creation of structured guidelines, such as the ESG-AI framework developed by Lee et al. (2024), which provides a toolkit for companies to adopt responsible AI practices aligned with ESG goals. These innovations are essential for advancing corporate sustainability, and a well-defined strategy for digital transformation is crucial for enterprises to successfully adopt and integrate these technologies into their ESG strategies (Sang, Loganathan, and Lin, 2024). A comprehensive conceptual framework, as outlined by Solaimani (2024), provides companies with the necessary data and technology foundation to enhance their ESG capabilities, paving the way for more responsible and effective ESG practices.

2.5.2 Standardize Data Collection and Reporting

Standardizing ESG data collection and reporting through digital technologies is essential to ensuring transparent, timely, and reliable ESG disclosures. As firms undergo digital transformation, they can leverage big data, cloud computing, IoT, and blockchain to collect, store, and disseminate ESG-related information more systematically. This digital shift not only enhances operational efficiency but also addresses regulatory challenges and reduces information asymmetry between companies and stakeholders (Zhao and Cai, 2023; Wang et al., 2023). The integration of digital tools with production and operational processes enables firms to continuously monitor ESG metrics, track performance in real time, and ensure accurate reporting, thereby strengthening both internal governance and external accountability (Truant et al., 2023; Wang et al., 2023).

Moreover, digital platforms improve the overall quality of ESG disclosure by enhancing firms' information management capabilities and aligning corporate reporting with stakeholder expectations (Zhao and Cai, 2023; Li et al., 2024). As regulatory demands for ESG transparency intensify, digital solutions allow enterprises to meet mandatory disclosure requirements while streamlining internal workflows and improving capital market oversight (Truant et al., 2023). However, the absence of universally accepted ESG standards and the risks associated with the opaque use of digital tools highlight the need for standardized frameworks and ethical governance of digital ESG practices (Truant et al., 2023). Ultimately, by embedding digital technologies into ESG reporting processes, firms can boost data accuracy, foster stakeholder trust, and support sustainable development goals through more data-driven and accountable decision-making.

2.5.3 Implement Cybersecurity Measures

Implementing robust cybersecurity measures is crucial to protecting the integrity and authenticity of ESG data, which is foundational for reliable ESG compliance and reporting. Under the umbrella of Corporate Social Responsibility and ESG paradigms, ethical data protection and cybersecurity practices have become essential to safeguard sensitive ESG information (Balboni and Francis, 2024). Organizations must implement measures such as encryption, multi-factor authentication, secure virtual private networks, regular security audits, and employee cybersecurity training to prevent unauthorized access and data breaches (Ogugua, 2024). By adopting comprehensive frameworks such as the Maastricht University in the development of the Data Protection as a Corporate Social Responsibility, which align with and extend beyond regulations like General Data Protection Regulation, the Data Governance Act, and the Cyber Resilience Act, organizations can ensure auditable and ethical data processing. These measures not only comply with legal mandates but also build stakeholder trust by enhancing transparency and minimizing risks related to data breaches or manipulation in ESG reporting (Balboni and Francis, 2024).

The integration of digital technologies within Industry 5.0 provides a powerful means to improve ESG disclosure's comprehensiveness, timeliness, and authenticity, supported by advanced cybersecurity practices (Asif, Searcy and Castka, 2023). Since ESG reporting relies on diverse internal and external data sources, ranging from environmental management systems to social media analytics, the security of data collection, storage, processing, and exchange becomes paramount (Eccles, Lee and Stoehle, 2020; Tamimi and Sebastianelli, 2017). Cybersecurity safeguards enable real-time and prospective reporting, reduce the costs of disclosure, and support governance structures that maintain system integrity across complex supply chains. Thus, digital transformation paired with rigorous cybersecurity enhances firms’ capacity to fulfill their ESG responsibilities effectively and fosters confidence among investors, regulators, and other stakeholders (Wang et al., 2023; Asif, Searcy and Castka, 2023).

2.5.4 Foster Public-Private Partnerships and Industry Consortia

Public-private partnerships (PPPs) and industry consortia play a crucial role in advancing ESG compliance by fostering collaborative efforts between government bodies, private sector operators, and civil society organizations. Eisaqui (2023) argues that PPPs are not only financially motivated but also represent pathways to sustainable development. This shift towards incorporating environmental and social responsibility into PPP frameworks calls for amendments in laws and policies to ensure that private entities comply with ESG standards while engaging in public projects. The integration of ESG principles within PPP schemes promotes sustainable infrastructure development, ensuring that environmental and social considerations are embedded throughout the project lifecycle. This approach underscores the importance of collaborative governance and highlights the role of public administration in driving private sector accountability.

The importance of industry consortia and academic partnerships in fostering ESG compliance is also evident in the work of Lee et al. (2024), who co-developed a framework for ESG integration with industry practitioners, emphasizing the value of collaborative research. This industry-academic approach facilitates the development of tools and strategies that can help businesses meet ESG goals effectively. Real-world examples, such as Hyundai Motor's partnership with Healthy Seas in 2024 to address pollution from abandoned fishing nets, demonstrate how such collaborations can lead to significant environmental impacts. Steelyana and Wahyuni (2024) further explored how integrating ESG principles into PPP schemes for Indonesian infrastructure development requires coordinated efforts from multiple stakeholders, emphasizing the need for a collective approach to sustainability. These examples illustrate the potential of PPPs and industry consortia to drive meaningful change in ESG compliance by bringing together diverse perspectives and expertise to address complex sustainability challenges.

2.5.5 Provide Government Incentives

Government incentives are a crucial strategy to promote the adoption of digital technologies for ESG compliance in the construction industry. By offering targeted tax incentives, subsidies, and credit policies, governments can reduce the financial burdens that often hinder construction enterprises from pursuing digital transformation (Li et al., 2023). A supportive policy and market environment, along with a strong digital culture, are key drivers of green innovation in construction (Li et al., 2023). Investment subsidies help lower the cost of building digital infrastructure, while usage subsidies reduce the cost for consumers, encouraging the adoption of digital services and technologies (Chen, Meng and Yu, 2022).

Well-designed government subsidy programs can motivate firms to expand their use of digital technologies such as BIM, IoT, and AI for ESG monitoring and reporting (Chen, Meng and Yu, 2022). At the same time, digital government initiatives, including cloud platform development and open data policies, can create a favorable external environment that supports enterprise innovation and transformation (Zhang and Zhang, 2024). Improvements in the business environment through digital governance reduce institutional transaction costs and allow companies to allocate more resources to ESG-related innovation and compliance (Zhang and Zhang, 2024). Providing these incentives not only promotes digital adoption but also strengthens the overall ESG performance of the construction sector.

2.5.6 Invest in Training

Effective adoption of digital technologies for ESG compliance requires a significant investment in training and capacity building across organizations. Cranford (2023) emphasized that the successful implementation of technologies like Digital Twin depends not only on the technology itself but also on having the right personnel with the necessary skills and capabilities. Transformational change in ESG practices, particularly through technological adoption, necessitates strong leadership and skilled talent. Similarly, Miasayedava, McBride, and Tuhtan (2022) identify the training of system users as a key direction for future research, recognizing that capacity building is essential for maximizing the benefits of ESG technologies. Ensuring that the workforce is equipped with the right knowledge and skills will be a critical factor in successfully embedding ESG principles into an organization’s operations and decision-making processes.

In addition to technical training, organizations should prioritize creating multidisciplinary teams with a balanced mix of theoretical knowledge and practical abilities. Sang, Loganathan, and Lin (2024) highlight the importance of education and expertise within top management teams to foster the right environment for ESG integration. Solaimani (2024) suggests the formation of ESG-focused groups, such as a Center of Excellence or steering committees, to guide the company’s ESG vision and initiatives. These teams should be equipped to assess existing skills, explore new technologies, and prioritize areas that require improvement in ESG performance. By building a cohesive, knowledgeable team, organizations can ensure that they effectively leverage digital technologies and foster a culture of continuous improvement toward sustainability and compliance. These strategic efforts in training and capacity building create a foundation for sustained progress in ESG adoption and digital transformation.

2.5.7 Establish ESG Performance Evaluation

Establishing digital ESG performance evaluation mechanisms can significantly enhance the adoption of digital technologies for ESG compliance in the construction industry. By providing a structured framework for assessing digital transformation outcomes, these mechanisms enable clearer benchmarking and performance tracking, thereby encouraging greater investment in digital solutions (Mahboub et al., 2023). Structured evaluations are essential for integrating Industry 4.0 technologies into sustainable construction practices, offering external support and internal governance that drive digital adoption (Sajjad et al., 2023; Yang, Huang and Chen, 2024). Tools such as digital twins can further enable performance-based ESG contracting by simulating and measuring building operations and maintenance in real time, while blockchain-based smart contracts can align stakeholder incentives with ESG objectives across the building lifecycle (Hunhevicz, Motie and Hall, 2022).

Moreover, clear performance indicators and ESG ratings can drive technological innovation by easing financial constraints, increasing stakeholder confidence, and enhancing organizational efficiency (Yang, Huang, and Chen, 2024). Digital transformation has been shown to improve ESG performance through mechanisms such as green innovation and media engagement (Guo and Pang, 2025), and its impact is especially strong in construction-relevant contexts like high-pollution industries and large enterprises (Xu and Yin, 2025). Therefore, establishing comprehensive digital ESG evaluation frameworks not only clarifies return on digital investment but also provides a foundation for performance comparison and strategic alignment across the construction sector (Mahboub et al., 2023; Wang and Esperanca, 2023). These efforts collectively foster a digitally enabled, ESG-compliant construction environment.

2.5.8 Automate ESG Reporting and Collection

Automating ESG data collection and reporting enhances sustainability in the construction industry through the use of digital technologies. Industry 4.0 technologies such as AI, IoT, blockchain, and Digital Twin support real-time monitoring, efficient data management, and accurate reporting of ESG metrics (Saxena et al., 2023; Zahedi et al., 2024). Blockchain enables transparent and automated data collection processes, simplifying the preparation of ESG reports, reducing manual work, and allowing organizations to track sustainability efforts across a project's lifecycle (Saxena et al., 2023). AI supports the evaluation of ESG metrics by filtering and analyzing key data, enabling more strategic planning and scalable sustainable investment (Saxena et al., 2023).

Digital Twin technology, the evolution of BIM, integrates AI, IoT, and data analytics to automate monitoring and control across construction phases (Zahedi et al., 2024). It enables real-time data exchange and supports optimization in energy use, material efficiency, and environmental performance, which are critical components of ESG. During the operation and maintenance phase, Digital Twin improves occupant comfort and energy efficiency, contributing to ESG outcomes. Continuous innovation in smart systems and real-time condition monitoring using Digital Twin provides a foundation for reliable, automated ESG data reporting in construction (Zahedi et al., 2024). As cyber-physical and AI-driven Digital Twins emerge, these technologies will play an increasingly important role in automating ESG compliance and supporting sustainability goals in the built environment.

2.5.9 Provide Friendly-user Interface of Software by Production Company

A key strategy for leveraging digital technologies in ESG compliance involves the development of user-friendly software interfaces by production companies. Manufacturing businesses play a pivotal role in promoting digital integration in construction by prioritizing intuitive, easy-to-use software that requires minimal training (Shojaei, Oti and Burgess, 2023; Lop et al., 2024). This approach reduces resistance to adoption by enabling construction teams to quickly become familiar with the tools and seamlessly incorporate them into their workflows.

To maximize the effectiveness of this strategy, production companies should adopt a user-centric design approach by actively involving end users throughout the development process. Incorporating continuous feedback ensures that the software aligns with the functional needs of construction projects while improving the overall user experience (Lop et al., 2024). This approach facilitates the adoption of digital tools that support ESG initiatives, such as environmental monitoring and resource management, and also fosters a more positive perception of digital technologies across the construction sector. Ultimately, intuitive interfaces and active user collaboration contribute to broader digital transformation and enhance ESG compliance efficiency (Shojaei, Oti and Burgess, 2023; Lop et al., 2024).

2.6 Summary of Findings from Literature Review

Figure 2.1 presents a consolidated overview of the relationships among the roles, challenges, and strategies of digital technologies in ESG compliance, providing a clear and organized interpretation of the reviewed literature.

This study aims to explore the role of digital technology in enhancing ESG compliance within the construction industry, recognizing its potential to drive more efficient, transparent, and sustainable practices. A total of 15 roles have been identified, with 5 roles each related to Environmental, Social, and Governance aspects. However, the integration of digital technology is hindered by 10 key challenges. To address these, 9 strategic approaches are proposed to overcome these challenges and fully leverage digital technologies to strengthen ESG compliance, ultimately supporting the industry's transition toward more responsible and resilient operations.

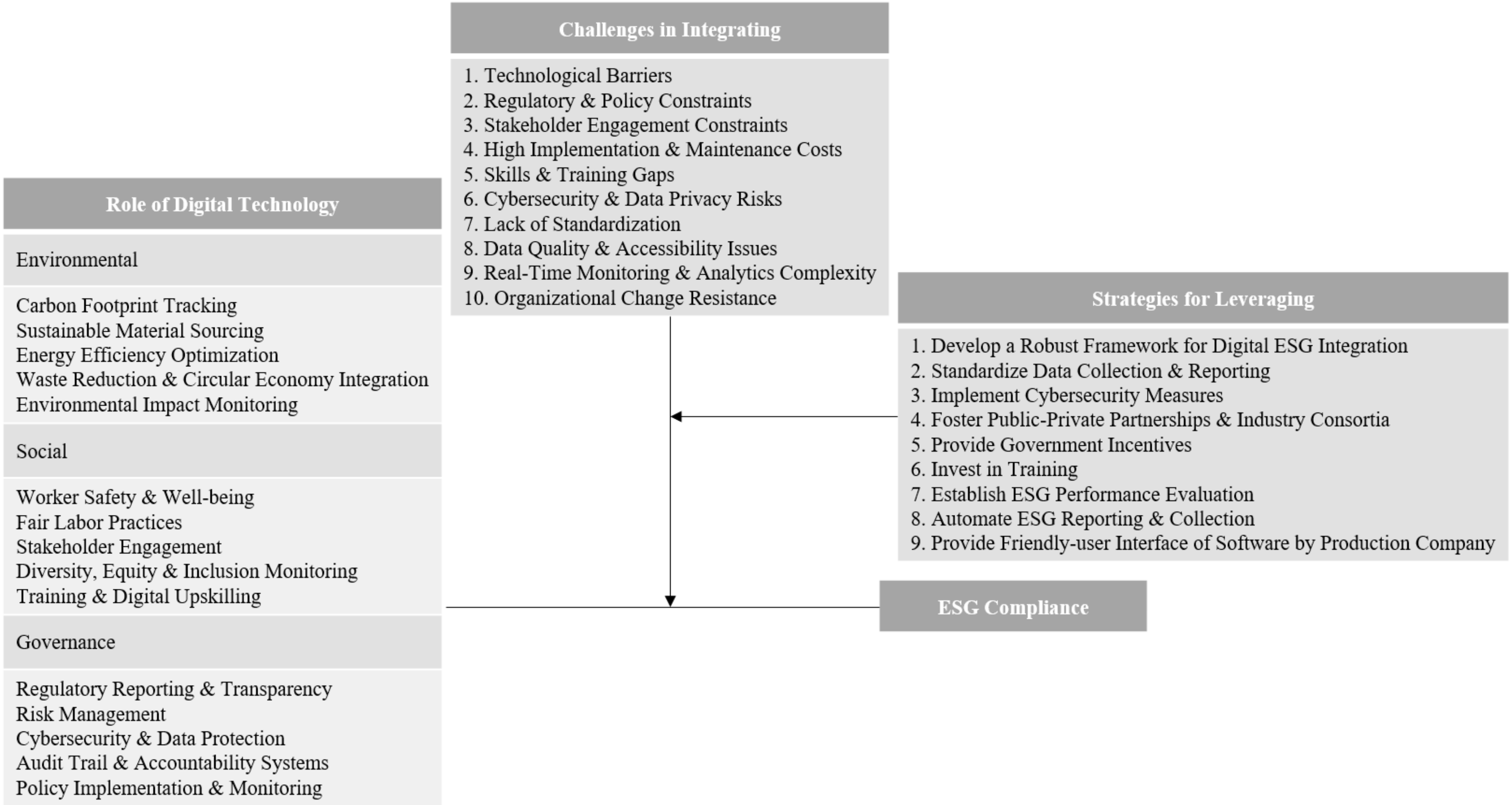

Figure 2.1: Overview of Key Findings from the Literature Review.

2.7 Summary of Chapter

This chapter explores the critical role of ESG compliance in business strategies, with a focus on the construction industry. It discusses how digital technologies enhance ESG efforts by improving transparency, real-time monitoring, and data security. The integration of these technologies helps address key ESG challenges. However, barriers such as financial costs, resistance to change, and lack of standardized reporting hinder full adoption. The chapter advocates for a comprehensive approach to overcoming these challenges, emphasizing investment in infrastructure, training, and collaboration between public and private sectors to ensure effective and sustainable ESG integration.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This section details the research methodology and work plan employed. It describes the research approach, data collection methods, and the techniques used for data analysis.

3.2 Research Method

Research methods are essential for guiding the collection, analysis, and interpretation of data. There are three main approaches: qualitative, quantitative, and mixed methods. The choice of method depends on the research questions, with each approach offering unique strengths in understanding different aspects of the study (Leppink, 2017; Saunders, Lewis, and Thornhill, 2019).

3.2.1 Quantitative Research Method

The systematic process of quantitative research is used to test objective theories by examining relationships among variables. This method relies on the measurement of variables through instruments, allowing for the collection of numerical data that can be analyzed using statistical procedures. The structured nature of quantitative research typically results in reports that include an introduction, literature review, methods, results, and discussion. Researchers in this field adopt deductive reasoning to test hypotheses, often working to minimize bias, control for alternative explanations, and ensure that findings can be generalized and replicated. This structured and objective approach allows researchers to draw conclusions based on measurable data, which is essential for testing theories in a variety of disciplines (Creswell and Creswell, 2018).

Despite its strengths, quantitative research in fields like manual therapy has been critiqued for offering a narrow perspective due to an overemphasis on numerical data. For example, simply using quantitative questionnaires to assess patient tolerance in a randomized controlled trial may overlook the deeper insights qualitative data could provide. While quantitative and qualitative methods stem from different philosophical approaches, they share commonalities and can complement each other. Researchers suggest that instead of maintaining a divide between the two methods, combining them can provide a more comprehensive understanding of complex phenomena (Griensven, Moore and Hall, 2014; Leppink, 2017). Thus, while quantitative research remains a powerful tool for hypothesis testing and data analysis, integrating qualitative insights may offer a more nuanced approach to understanding research subjects.

3.2.2 Qualitative Research Method

Qualitative research is an approach focused on exploring and understanding the meanings individuals or groups assign to social or human problems. This research method involves an evolving process where questions and procedures emerge organically as the study progresses. Data is typically collected in the natural settings of participants, allowing researchers to analyze it inductively, starting with specific observations and building toward broader generalizations or themes. The flexible structure of qualitative research reports accommodates the complexity and nuances of the data, as researchers interpret the meanings and significance of the findings. This approach prioritizes individual meaning and the intricacies of human experiences, making it particularly suited to issues in clinical practice and other areas where understanding context and depth is crucial (Creswell and Creswell, 2018).

Unlike quantitative research, qualitative data often consists of non-numeric material, such as interview transcripts, observational notes, or recordings of non-verbal communication, which cannot be easily quantified. The inductive nature of qualitative research means that theory develops from the data itself, rather than being preconceived or verified beforehand by the researcher. This allows for a deeper, more intimate understanding of participants' experiences, as researchers immerse themselves in the data to capture the richness of human experiences. While qualitative and quantitative methods come from different philosophical traditions, they share common ground and can complement each other. The emphasis should not be on dividing these methods, but on recognizing how both can provide valuable insights when used together (Griensven, Moore and Hall, 2014; Leppink, 2017).

3.3 Justification of Method Selection

The quantitative approach was chosen for this research due to the need to gather a large volume of numerical data from diverse participants within the construction sector. The primary objective of this research is to explore the role of digital technology in enhancing ESG compliance within the construction industry, analyze the challenges associated with its integration, and propose strategies to effectively leverage these technologies for improved ESG compliance in the construction sector. A survey-based method facilitates the efficient gathering of data from a broad spectrum of respondents, including professionals from different roles, regions, and company sizes. This method enables the analysis of these data using statistical tools to uncover significant patterns and correlations that can be generalized across the industry. Given the large and varied population involved in construction, a quantitative approach ensures that the findings are representative and robust.

Furthermore, quantitative research allows for the use of scientific, statistical methods to ensure objectivity and consistency in the data analysis. By employing a structured questionnaire, researchers can obtain measurable data on the perceptions, challenges, and strategies related to digital technologies and ESG compliance. The use of numerical data eliminates subjective biases, which might arise from qualitative approaches like interviews. Additionally, the ability to use statistical tests such as Spearman's Correlation, Kruskal-Wallis, Mann-Whitney U Test, and Cronbach's Alpha allows for a more rigorous and reliable evaluation of the relationships between different variables, providing concrete, evidence-based insights into how digital technology influences ESG compliance. This aligns with the goals of the study to provide clear, actionable insights that can be applied across the broader construction industry.

Conversely, a qualitative approach is less appropriate for this study, as it requires collecting data from a large and diverse sample of professionals in the construction industry. Interviews or focus groups would be time-consuming, and data collected from a small number of participants may not accurately represent the broader population. Qualitative methods also lack the statistical tools necessary for testing hypotheses and generalizing findings to a larger group. While qualitative research can offer in-depth insights into individual perspectives, the broad and generalizable nature of the research objectives requires a more structured and scalable approach, making quantitative research the most appropriate choice.

3.4 Literature Review

A literature review systematically gathers, evaluates, and synthesizes existing research to understand current knowledge, identify gaps, and frame the study (Snyder, 2019). For this research, academic databases were searched to identify studies related to digital technologies and ESG compliance in the construction industry. The findings were organized into key thematic areas, including the role of digital technology, challenges in integration, and strategies for effective implementation. This approach aligns with Creswell and Creswell's (2018) view that a literature review accomplishes several important objectives. Literature mapping tools were used to visualize these connections, providing a solid foundation to justify the study and highlight areas for further investigation.

3.5 Quantitative Data Collection

The study utilized a questionnaire to collect quantitative data, selected for its effectiveness in reaching a large number of respondents.

3.5.1 Questionnaire Design

The questionnaire for this study is designed to collect data that aligns with the research objectives. A brief definition of digital technology and ESG compliance is provided at the beginning of the questionnaire to ensure a common understanding among respondents. Following this, a question is included to assess respondents' familiarity with the topic, helping to ensure that only those with relevant knowledge proceed with the questionnaire.

The questionnaire consists of four main sections. Section A gathers respondents' demographic details, such as their company's business activities, profession, position, years of experience, and organization size. Section B examines the role of digital technologies in strengthening ESG compliance. In this section, respondents are required to evaluate the roles of digital technology in ESG compliance. Section C focuses on the challenges associated with integrating digital technologies into ESG compliance while section D presents a list of strategies for leveraging digital technologies in ESG compliance.

A five-point Likert scale, ranging from 1 = Strongly Disagree to 5 = Strongly Agree, was used in Sections B, C, and D to measure the level of agreement with each item. Table 3.1 presents an overview of the questionnaire design, detailing the types of questions, their measurement scales, and their purposes in relation to the study objectives. A copy of the questionnaire is provided in the Appendix for reference.

Table 3.1: Overview of Questionnaire Design.

Section	Type of Question	Number of Question	Scale	Purpose of Question
A	Closed-ended question	5	Nominal	To obtain respondents' demographic information
B	5-point Likert scale of agreement level	15	Ordinal	To achieve the objective 1 of the study
C	5-point Likert scale of agreement level	10	Ordinal	To achieve the objective 2 of the study
D	5-point Likert scale of agreement level	9	Ordinal	To achieve the objective 3 of the study

3.5.2 Pre-Test

Pre-testing is the process of administering a translated instrument to a small sample from the target population to identify and address any issues related to wording, administration, or clarity before proceeding with full-scale validation studies (DuBay and Watson, 2019). In this study, a pre-test was conducted to evaluate the questionnaire's clarity and ease of understanding.

A total of five participants, comprising construction practitioners from various sectors such as quantity surveying, civil engineering, and site supervision, took part in the pre-test. Overall, the feedback received was positive, with most professionals commenting that the questionnaire was clear and understandable. However, two participants suggested including a question to assess whether respondents understand the concept of ESG compliance. Based on this feedback, adjustments were made to enhance the instrument. Following these improvements, the final version of the questionnaire was distributed to target respondents within the Klang Valley.

3.5.3 Sampling Determination

Sampling determination is the process of selecting a group of individuals from a larger population in order to draw conclusions or make inferences about the entire population (Sekaran and Bougie, 2016). For this study, the target population consists of construction professionals within the Klang Valley, including architects, quantity surveyors, engineers, developers, and other relevant stakeholders in the construction industry. Due to the broad scope of the population and practical constraints in reaching all potential respondents, convenience sampling and snowball sampling techniques were employed. Convenience sampling was used to recruit easily accessible participants, while snowball sampling allowed initial respondents to refer other qualified professionals, expanding the respondent pool (Saunders, Lewis, and Thornhill, 2019).

To determine an adequate sample size, the Cochran formula was used. This formula is widely used for sample size calculation in studies involving proportions, and it is appropriate for ensuring sufficient power to detect meaningful effects. The Cochran formula is given by:

$$n = \frac{z^2pq}{e^2}$$

(3.1)

Where:

n = sample size

z = z-scores of the desired confidence level (1.96 for a 95% confidence level)

p = the proportion of the population with attributes understudy (0.5)

q = 1 - p

e = margin of error (5%)

$$n = \frac{1.96^2\ (0.5)\ (1 - 0.5)}{(0.05)^2} = 384$$

Thus, according to the Cochran formula, a minimum of 384 respondents would be necessary for statistical validity. However, given the practical constraints of this study and the application of the Central Limit Theorem (CLT), a minimum of 30 respondents per group was considered acceptable. The CLT asserts that for sample sizes of 30 or more, the sampling distribution will approximate a normal distribution, ensuring the results are reliable and representative of the population (Kwak and Kim, 2017).

As a result, the final sample size for this study was established at 30 participants per professional category within the construction industry. This sampling method was deemed appropriate for collecting valuable insights regarding the role of digital technologies in enhancing ESG compliance and the challenges faced in integrating these technologies into the construction industry.

3.5.4 Questionnaire Distribution

The questionnaire for this study was distributed through a multi-channel approach to reach a diverse group of construction practitioners in the Klang Valley. An electronic version of the survey was created using Google Forms, with links shared via email, LinkedIn, and various social media platforms, including WhatsApp, Facebook, Instagram, and Twitter. Email addresses of target respondents were obtained from official industry websites, including the Construction Industry Development Board (CIDB), Board of Quantity Surveyor Malaysia (BQSM), and the Board of Engineers Malaysia. The survey link was also directly sent through LinkedIn to engage professionals with relevant expertise. This approach was intended to maximize response rates by targeting a broad demographic, ensuring that the data gathered was representative of the construction industry's perspectives on leveraging digital technologies for ESG compliance. The distribution period lasted for six weeks, with an emphasis on overcoming potential sample biases associated with online surveys.

3.6 Data Analysis

Data analysis in this study involved processing the collected data to generate meaningful insights. The raw data were transformed into usable information to address the research questions. Statistical analysis was conducted using IBM SPSS software. Four tests were applied: Cronbach's Alpha, Arithmetic Mean, Mann-Whitney U Test, Kruskal-Wallis Test, and Spearman's Correlation. These analyses ensured the reliability and relevance of the findings on the role of digital technologies in ESG compliance within the construction industry.

3.6.1 Cronbach's Alpha Reliability Test

According to Tavakol and Dennick (2011), the Cronbach's Alpha reliability test is a statistical tool used to assess the internal consistency of data obtained from Likert scale-based questions, ensuring that the survey items reliably measure the intended constructs. The alpha coefficient ranges from 0 to 1, where a higher value indicates a greater degree of internal consistency, and a lower value suggests lower reliability. A Cronbach's Alpha value of 0.7 or above is generally considered acceptable, while values below 0.5 are deemed unacceptable for reliable measurement (Sekaran and Bougie, 2016). Within this research, the Cronbach's Alpha Reliability test will be applied to evaluate the internal consistency of responses from Sections B and C of the questionnaire, which assess the role of digital technologies in enhancing ESG compliance and the challenges associated with their integration. A higher alpha value will signify strong internal consistency between the responses, confirming the reliability of the Likert scale-based questions designed to meet the research objectives.

3.6.2 Arithmetic Mean

The arithmetic mean serves as a widely recognized method for identifying central tendency within a dataset. It is calculated by adding up all the values and then dividing the sum by the total number of values (Brase and Brase, 2009). In this study, the arithmetic mean will be used to identify the central tendency of the respondents' views on the role of digital technologies in enhancing ESG compliance, as well as the challenges associated with their integration. The Likert scale data collected from Sections B and C of the questionnaire will be analyzed using this measure. By calculating the arithmetic mean for each item, we can assess the overall level of importance or agreement on various digital technologies and challenges. The results will be categorized into three levels: low, moderate, and high, based on consistent intervals ranging from 1.00-2.33 for low, 2.34-3.67 for moderate, and 3.68-5.00 for high (Pimentel, 2019). This will help rank the relative significance of digital tools and the perceived barriers to ESG compliance in the construction industry.

3.6.3 Mann-Whitney U Test

The Mann-Whitney U test is a non-parametric method used to determine whether there are significant differences between two independent groups when the dependent variable is ordinal or continuous but does not follow a normal distribution (Nachar, 2008). It compares the distribution of ranks between the two groups, making it a suitable alternative to the independent samples t-test when normality assumptions are violated.

In this study, the Mann-Whitney U Test was applied to examine whether respondents' profession and working experience influenced their perceptions of "the role of digital technologies in enhancing ESG compliance", "the challenges of integrating digital technologies", and "the strategies for leveraging digital technologies". The test was conducted to determine whether significant differences existed across these groups. Accordingly, the following hypotheses were formulated:

Null Hypothesis (H_0): There is no significant difference across the two groups in their perceptions of leveraging digital technologies for ESG compliance.

Alternative Hypothesis (H_1): There is a significant difference across the two groups in their perceptions of leveraging digital technologies for ESG compliance.

3.6.4 Kruskal-Wallis Test

Ostertagová, Ostertag, and Kováč (2014) describe the Kruskal-Wallis test as a non-parametric statistical method used to determine if there is significant variation among two or more independent groups when the outcome variable is either ranked or measured on a continuous scale. Unlike parametric tests such as one-way ANOVA, the Kruskal-Wallis test does not require the assumption of normally distributed data, making it particularly suitable for Likert-scale responses. It works by ranking all values across groups and assessing whether the mean ranks differ significantly, thereby indicating if different groups perceive a variable differently.

In this study, the Kruskal-Wallis test is used to evaluate differences in how various demographic groups perceive the adoption of technological tools for ESG alignment and the challenges associated with their implementation. The demographic variables considered include respondents' educational background, job position, years of experience in the construction industry, and the size of their company. As Sections B and C of the questionnaire involve responses measured on a five-point Likert scale, the ordinal nature of the data justifies the application of this test. The test allowed the study to compare how each demographic group evaluates the importance of digital technologies and the extent of challenges faced in their integration for ESG compliance.

Statistical significance was determined by comparing the H-value from the Kruskal-Wallis test with the critical Chi-square value. When the H-value exceeded the Chi-square value, the null hypothesis (H_0) was rejected, indicating a significant difference among the groups. Conversely, if the H-value was lower than the critical value, the null hypothesis was not rejected. The hypotheses tested in this context were: H_0 – There is no significant difference in the perceptions of leveraging digital technology adoption for ESG compliance across different demographic groups; H_1 – There is a significant difference in the perceptions of leveraging digital technology adoption for ESG compliance across different demographic groups. This analysis aimed to uncover patterns that could guide the development of more inclusive and effective strategies for implementing digital solutions in ESG practices within the construction industry.

3.6.5 Spearman's Correlation Test

Spearman's correlation test represents a distribution-free approach for assessing both strength and direction in relationships involving paired data, especially when responses are ordinal or deviate from normal distribution patterns (Kumar and Abirami, 2018). Unlike parametric tests that assume normality, Spearman's test is rank-based, making it suitable for Likert scale responses often used in questionnaire surveys. The Spearman rank correlation coefficient measures the degree of a monotonic relationship between two sets of variables. The coefficient ranges from -1 to 1, where a value of 1 signifies a perfect positive correlation, -1 indicates a perfect negative correlation, and 0 denotes no correlation.

In the context of this study, Spearman's correlation test is used to assess the correlation between the perceived importance of digital tools and the challenges in adopting these technologies. It will also examine the relationship between various types of digital technologies and the barriers to ESG compliance, as well as the link between current ESG compliance strategies and respondents' agreement on their adoption.

According to Leclezio et al. (2015), Spearman rank-order correlation coefficients can be interpreted as follows: a coefficient of 0.70 or above indicates a very strong relationship, values between 0.40 and 0.69 indicate a strong relationship, 0.30 to 0.39 suggest a moderate relationship, 0.20 to 0.29 reflect a weak relationship, and values between 0.01 and 0.19 indicate no or negligible relationship.

3.7 Summary of Chapter

The quantitative approach used to examine how digital technologies support ESG compliance in construction is detailed in Chapter 3. Data was collected through a structured questionnaire covering demographics, technology use, and integration challenges, with Likert scales enabling standardized analysis. Convenience and snowball sampling were used, and the sample size was determined using the Cochran formula. SPSS was used for analysis, including reliability testing, correlation, and group comparisons. This approach ensured valid and relevant insights for the study.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter reports the findings from the questionnaire survey conducted among construction professionals in Klang Valley to investigate the role of digital technologies in ESG compliance. It begins by presenting the demographic profile of respondents and assessing the reliability of the dataset using Cronbach's Alpha. The analysis then evaluates the role, challenges, and strategies of digital technology adoption through the Arithmetic Mean Test, while group differences are examined using the Mann-Whitney U Test and Kruskal-Wallis Test. Finally, Spearman's Correlation is applied to identify relationships between key variables, offering deeper insights into how digital technologies can support ESG practices.

4.2 Demographic Background of Respondents

A total of 146 responses were collected from construction practitioners in the Klang Valley via online questionnaires. After screening, 29 responses were excluded as they did not meet the study's criteria. The criterion required respondents to be familiar with ESG and digital technologies, as indicated by selecting "Yes, I am familiar with it." Responses of "I have heard of it but I am not familiar with it" and "No, I have never heard of it" were excluded. Consequently, 117 valid responses were retained and analysed. Table 4.1 presents the demographic characteristics of the respondents, including company business activities, profession, organizational position, work experience, and company size, summarized in terms of frequencies and percentages.

Table 4.1: Summary of Respondents' Demographics.

Demographic Information	Categories	Frequency (n)	Percentage (%)
Company Business Activities	Developer	34	29.1
	Consultant	47	40.2
	Contractor	31	26.5
	Sub-Contractor / Supplier	5	4.2

Table 4.1: (Con'd)

Demographic Information	Categories	Frequency (n)	Percentage (%)
Profession	Architect	35	29.9
	Engineer	37	31.6
	Quantity Surveyor	37	31.6
	Others	8	6.9
Organisational Position	Junior Executive	52	44.4
	Senior Executive	32	27.4
	Manager / Team Leader / Supervisor	16	13.7
	Assistant Director / Technical Director	11	9.4
	Director	5	4.3
	Others	1	0.8
Working Experience	Less than 5 years	45	38.5
	5 – 10 years	26	22.2
	11 – 15 years	22	18.8
	16 – 20 years	10	8.5
	More than 20 years	14	12.0
Company Size	Less than 5 employees	1	0.9
	5 – 29 employees	22	18.8
	30 – 75 employees	50	42.7
	More than 75 employees	44	37.6

As shown in Table 4.1, a total of 117 valid responses were collected from construction practitioners in the Klang Valley. The respondents represent a diverse mix of company business activities, with the majority working in consultancy firms (40.2%), followed by developers (29.1%), contractors (26.5%), and sub-contractors or suppliers (4.2%). In terms of profession, the distribution is relatively balanced, consisting of engineers (31.6%), quantity surveyors (31.6%), and architects (29.9%), while 6.9% of respondents reported other professional roles.

With respect to organisational positions, the largest proportion of respondents are junior executives (44.4%), followed by senior executives (27.4%). A smaller group comprises managers, team leaders, or supervisors (13.7%), while 9.4% are assistant directors or technical directors. Only 4.3% of respondents hold director positions, and 0.8% occupy other roles. In terms of working experience, most respondents have less than 5 years of experience (38.5%), reflecting a considerable presence of young professionals in the sample. Meanwhile, 22.2% of respondents possess 5–10 years of experience, 18.8%

have 11–15 years, 8.5% have 16–20 years, and 12.0% have more than 20 years of experience.

In terms of company size, the largest proportion of respondents are from medium-sized companies with 30–75 employees (42.7%), followed by large firms with more than 75 employees (37.6%). A smaller proportion are from small companies with 5–29 employees (18.8%), while only 0.9% of respondents are employed in micro firms with fewer than 5 employees. This distribution indicates that the survey captured perspectives from a broad spectrum of industry players, ranging from small enterprises to large organisations.

4.3 Cronbach's Alpha Reliability Test

The Cronbach's Alpha reliability test was performed to assess the internal consistency of the data collected in this study. Table 4.2 shows that the Cronbach's Alpha values for Section B, Section C, and Section D were 0.947, 0.902, and 0.848, respectively.

According to Bougie and Sekaran (2019), a Cronbach's Alpha value above 0.70 is generally considered acceptable, while values greater than 0.80 indicate good reliability, and those exceeding 0.90 demonstrate excellent internal consistency. In this study, Section B and Section C achieved coefficients above 0.90, reflecting excellent reliability, whereas Section D, with a coefficient of 0.848, indicates good reliability. Therefore, the results confirm that the dataset possesses strong internal consistency and is suitable for further statistical analyses.

Table 4.2: Reliability Statistics.

Section	Number of Items	Cronbach's Alpha Values
Section B: Role of Digital Technology in Enhancing ESG Compliance	15	0.947
Section C: Challenges of Integrating Digital Technologies in ESG Compliance	10	0.902
Section D: Strategies for Leveraging Digital Technologies in ESG Compliance	9	0.848

4.4 Arithmetic Mean Test

This section analyzes the mean values of three parts of the questionnaire: the role of digital technology in enhancing ESG compliance (Section B), the challenges of integrating digital technologies in ESG compliance (Section C), and the strategies for leveraging digital technologies in ESG compliance (Section D).

4.4.1 Mean Ranking of Role of Digital Technology in Enhancing ESG Compliance

As presented in Table 4.3, the mean rankings for the role of digital technology in enhancing ESG compliance were derived from the perspectives of construction practitioners in the Klang Valley. A total of 15 roles were ranked according to their mean scores, with higher values indicating greater importance.

Table 4.3: Mean Ranking of Role of Digital Technology in Enhancing ESG Compliance.

Code	Roles	Mean	Standard Deviation	Ranking
SC5	Digital technologies enhance the training and upskilling of construction workers, supporting skills development and the adoption of Industry 4.0.	4.59	0.589	1
SC1	Digital technologies enhance worker safety and well-being by health tracking, hazard detection, and risk prediction.	4.57	0.620	2
EC3	Digital technologies improve energy efficiency through real-time monitoring and predictive management in construction.	4.48	0.761	3
EC5	Digital technologies support environmental impact monitoring for sustainability and compliance.	4.43	0.791	4
GC1	AI and Blockchain technologies improve ESG regulatory reporting and transparency and prevent data tampering.	4.37	0.783	5

Table 4.3: (Con’d)

Code	**Roles**	**Mean**	**Standard Deviation**	**Ranking**
GC5	Digital technologies enable real-time policy implementation and monitoring, improving coordination, safety compliance, and resource management.	4.36	0.814	6
EC2	Digital technologies support sustainable material sourcing in improving traceability and resource optimization.	4.32	0.795	7
GC2	Big Data, Blockchain, and AI technologies improve risk management by enhancing prediction, data integrity and regulatory compliance.	4.31	0.793	8
GC3	Advanced cybersecurity technologies effectively protect ESG data by ensuring security, integrity, and regulatory compliance.	4.29	0.788	9
EC1	Digital technologies enable real-time carbon footprint tracking and transparent emission reporting in construction.	4.27	0.837	10
GC4	Blockchain technology and smart contracts enhance audit trail integrity and accountability through transparent, and real-time records.	4.13	0.783	11
EC4	Digital technologies support waste reduction and circular economy integration through tracking and resource recovery.	4.00	0.719	12
SC3	Digital technologies improve stakeholder engagement through transparency and real-time communication.	3.99	0.689	13
SC2	Digital workforce management tools ensure fair labor practices, compliance and transparent working conditions.	3.97	0.730	14
SC4	Digital technologies support diversity, equity, and inclusion monitoring by enabling fair, transparent human resources practices.	3.50	0.887	15

The highest-ranked role of digital technology in enhancing ESG compliance was **SC5** = "Digital technologies enhance the training and upskilling of construction workers, supporting skills development and the adoption of Industry 4.0," with a mean score of 4.59. This result reflects the growing emphasis on human capital development within the construction industry, where digital solutions play a crucial role in equipping workers with Industry 4.0 competencies. Training through digital platforms not only strengthens worker productivity but also ensures long-term adaptability to rapidly changing technologies, which is essential for sustaining ESG performance (Guo et al., 2025). In this regard, digital upskilling aligns closely with both environmental and social goals, as a skilled workforce contributes to safer, more efficient, and more sustainable construction practices (Gembali, Kumar, and Sarma, 2024).

The second-highest role was **SC1** = "Digital technologies enhance worker safety and well-being by health tracking, hazard detection, and risk prediction," with a mean score of 4.57. The findings underscore the centrality of occupational health and safety in ESG compliance, particularly in a high-risk sector such as construction. Digital applications, including IoT sensors, wearable devices, and predictive analytics, support real-time monitoring and accident prevention, which directly improves worker welfare and project safety outcomes (Chen, et al., 2023). Prioritising safety through digital solutions not only reduces workplace incidents but also enhances organisational reputation and strengthens stakeholder trust (Daniel, et al., 2025).

At the lower end of the ranking, **SC2** = "Digital workforce management tools ensure fair labor practices, compliance and transparent working conditions" was ranked 14th with a mean score of 3.97. Although still above the neutral level, this relatively lower ranking suggests that digital workforce management may not yet be widely implemented or prioritised in practice. Barriers such as cost, system integration issues, and resistance to change may have contributed to this perception, despite its long-term potential to improve fairness and transparency in labor management (Daniel, et al., 2024).

The lowest-ranked role was **SC4** = "Digital technologies support diversity, equity, and inclusion monitoring by enabling fair, transparent human resources practices," with a mean score of 3.50. This indicates that while diversity and inclusion are recognised as ESG principles, their monitoring through digital means is not yet considered a pressing priority by respondents. This finding is consistent with Lima, et al. (2021), who observed that construction firms often emphasise tangible ESG dimensions, such as safety and environmental efficiency, over social sustainability initiatives. Nevertheless, as global ESG standards increasingly emphasise social equity, the role of digital technologies in supporting diversity and inclusion is expected to grow in importance (Tumewang et al., 2024).

Overall, the results suggest that construction practitioners prioritise workforce development and safety as the most critical digital contributions to ESG compliance, while aspects related to fair labor practices and diversity monitoring are currently perceived as less significant. This highlights both the progress being made in immediate, practical areas of ESG implementation and the opportunities for strengthening attention to broader social sustainability dimensions.

4.4.2 Mean Ranking of Challenges of Integrating Digital Technologies in ESG Compliance

As presented in Table 4.4, the mean rankings highlight the major challenges associated with the integration of digital technologies in ESG compliance. A total of ten challenges were assessed and ranked based on their mean scores, with higher values indicating greater concern among respondents.

Table 4.4: Mean Ranking of Challenges of Integrating Digital Technologies in ESG Compliance.

Code	Challenges	Mean	Standard Deviation	Ranking
CH4	High implementation and maintenance costs.	4.21	0.667	1
CH5	Lack of skilled workforce and insufficient training programs.	3.94	0.874	2
CH1	Technical barriers such as system integration challenges with existing infrastructure.	3.91	0.754	3
CH2	Regulatory and policy challenges, including inconsistent standards and information disclosure issues.	3.80	0.883	4
CH6	Cybersecurity and data privacy risks.	3.74	0.845	5

Table 4.4: (Con’d)

Code	Challenges	Mean	Standard Deviation	Ranking
CH7	Lack of standardized ESG data formats and reporting frameworks.	3.64	0.876	6
CH9	Real-time digital monitoring and analytics is complex and complicated.	3.48	0.826	7
CH3	Limited stakeholder engagement and collaboration.	3.48	0.816	8
CH8	Poor data quality and limited access to reliable ESG data.	3.48	0.805	9
CH10	Resistance from management and employees due to cultural misalignment or fear of change.	3.25	0.964	10

The highest-ranked challenge was **CH4** = “High implementation and maintenance costs,” with a mean score of 4.21. This finding reflects the significant financial burden faced by construction firms when adopting digital technologies for ESG purposes. The upfront investment in hardware, software, and supporting infrastructure, combined with the recurring expenses for system upgrades and maintenance, was identified as a primary obstacle (Thirumal et al., 2024). Such financial constraints are especially critical for SMEs, which may lack the resources to make long-term digital investments despite recognising their ESG benefits (Tawil et al., 2023).

The second-highest ranked challenge was **CH5** = “Lack of skilled workforce and insufficient training programs,” with a mean score of 3.94. This underscores the talent gap in the construction sector, where digital transformation requires specialised skills that are not yet widely available. Respondents highlighted that while digital tools are increasingly available, their effective use is constrained by the shortage of trained personnel capable of leveraging them (Rikala et al., 2024). Insufficient training opportunities further exacerbate this issue, leading to underutilisation of digital solutions and slower adoption rates.

Towards the lower end of the ranking, **CH8** = “Poor data quality and limited access to reliable ESG data” received a mean score of 3.48, ranked 9th. Although data serves as the backbone for ESG reporting and compliance, respondents perceived this issue as less pressing compared to cost and skills shortages. This may indicate that many companies have already taken initial steps to improve data collection processes but still face challenges in ensuring its accuracy and reliability (Sakiewicz, Ober and Kopiec, 2024).

The lowest-ranked challenge was **CH10** = "Resistance from management and employees due to cultural misalignment or fear of change," with a mean score of 3.25. This suggests that while organisational resistance exists, it is not regarded as a major barrier compared to financial and technical challenges. Nevertheless, change management remains a critical consideration in the successful adoption of digital technologies, as studies have shown that cultural resistance can hinder innovation if not properly addressed (Inampudi et al., 2024).

Overall, the findings indicate that financial constraints and the shortage of skilled workers are the most significant barriers to digital technology adoption in ESG compliance. In contrast, challenges such as data quality and cultural resistance are perceived as less severe, though they still require attention to ensure the smooth and sustainable integration of digital solutions.

4.4.3 Mean Ranking of Strategies for Leveraging Digital Technologies in ESG Compliance

As presented in Table 4.5, the mean rankings highlight the strategies for leveraging digital technologies in ESG compliance from the perspective of construction practitioners. A total of nine strategies were assessed and ranked based on their mean scores, with higher values indicating greater perceived importance.

Table 4.5: Mean Ranking of Strategies for Leveraging Digital Technologies in ESG Compliance.

Code	Strategies	Mean	Standard Deviation	Ranking
ST6	Invest in ESG digital skills training.	4.67	0.630	1
ST5	Provide government incentives for digital ESG adoption.	4.56	0.564	2
ST1	Develop a robust digital framework that integrates technologies.	4.54	0.714	3

Table 4.5: (Con’d)

Code	Strategies	Mean	Standard Deviation	Ranking
ST9	Provide Friendly-user Interface of Software by Production Company.	4.53	0.677	4
ST2	Standardize ESG data collection and reporting using digital technologies.	4.51	0.702	5
ST7	Establish digital ESG performance evaluation mechanisms.	4.41	0.721	6
ST8	Automate ESG data collection and reporting, reduces manual work.	4.38	0.775	7
ST3	Implement cybersecurity measures, such as encryption, multi-factor authentication, secure Virtual Private Networks (VPNs) and regular security audits.	4.33	0.731	8
ST4	Promote public-private partnerships and industry consortia.	3.86	0.556	9

The highest-ranked strategy was **ST6** = “Invest in ESG digital skills training,” with a mean score of 4.67. This result reflects the pressing need for upskilling the construction workforce to adapt to rapid technological changes and ensure effective ESG integration. Digital skills training equips employees with the technical knowledge and competencies required to adopt tools such as BIM, artificial intelligence, and IoT, thereby improving productivity, safety, and sustainability performance (Musarat et al., 2023). This finding aligns with previous studies that emphasised workforce training as a cornerstone of successful digital transformation in the construction sector (Gao, Gonzalez and Yiu, 2018).

The second highest ranked strategy was **ST5** = “Provide government incentives for digital ESG adoption,” with a mean score of 4.56. This finding highlights the importance of policy support and financial encouragement in accelerating digital integration across the industry. Incentives such as tax benefits, subsidies, or grants can reduce the high upfront costs associated with digital ESG solutions, encouraging more firms, particularly small and medium sized enterprises, to adopt innovative technologies (OECD, 2022). This result is consistent with Bezerra, Martins, and Macedo (2024), who noted that effective government intervention plays a pivotal role in overcoming financial barriers to sustainable practices.

At the lower end of the ranking, **ST3** = "Implement cybersecurity measures, such as encryption, multi-factor authentication, secure Virtual Private Networks (VPNs) and regular security audits" received a mean score of 4.33, ranking 8th. Although still regarded as important, this result suggests that cybersecurity is often perceived as a secondary priority compared to workforce training and financial incentives. This may be due to limited awareness of digital risks within the construction sector, despite the increasing reliance on data-driven technologies (García de Soto et al., 2022). Nevertheless, cybersecurity remains crucial for ensuring data integrity, privacy, and trust in digital ESG platforms.

The lowest-ranked strategy was **ST4** = "Promote public-private partnerships and industry consortia," with a mean score of 3.86. This indicates that collaboration between government, industry associations, and private firms is not yet viewed as a primary driver for ESG digital adoption among construction practitioners in the Klang Valley. The result contrasts with findings by Ciulli et al. (2022), who highlighted that industry-wide collaboration often accelerates knowledge sharing, standardisation, and the scaling of sustainable innovations. While respondents in this study placed lower emphasis on partnerships, fostering stronger collaboration may still play a key role in achieving long-term ESG objectives.

Overall, the findings reveal that construction practitioners prioritise direct capacity-building measures and supportive government policies as the most effective strategies for leveraging digital technologies in ESG compliance. Conversely, strategies that focus on collaboration or cybersecurity are perceived as less critical, though they remain essential components of a comprehensive approach to digital ESG adoption.

4.5 Mann-Whitney U Test

The Mann-Whitney U test was used to assess significant differences in perceptions of digital technology adoption for ESG compliance according to respondents' profession and working experience.

4.5.1 Mann-Whitney U Test on Profession

For the purpose of analysis, the respondents were categorised into two groups of professions: (i) Engineers and Architects, and (ii) Quantity Surveyors and Others. The Mann-Whitney U tests showed significant differences across professions in perceptions of digital technologies for ESG compliance.

4.5.1.1 Role of Digital Technology in Enhancing ESG Compliance

Two hypotheses were formulated for this test:

Null Hypothesis (H_0): There is no significant difference across professions in the perceived role of digital technologies in enhancing ESG compliance.

Alternative Hypothesis (H_1): There is a significant difference across professions in the perceived role of digital technologies in enhancing ESG compliance.

Table 4.6: Mann-Whitney U Test Results: Role of Digital Technoloy in Enhancing ESG Compliance Across Professions.

Code	Roles	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
EC5	Digital technologies support environmental impact monitoring for sustainability and compliance.	1159.5	2194.5	-2.921	0.003
SC1	Digital technologies enhance worker safety and well-being by health tracking, hazard detection, and risk prediction.	1323.0	2358.0	-1.965	0.049

Table 4.6 presents the Mann-Whitney U test results comparing perceptions between two professional groups, namely Architects and Engineers (design-focused) and Quantity Surveyors with other related roles (cost/others). The analysis revealed two items with p-values below 0.05, namely **EC5** = "Digital technologies support environmental impact monitoring for sustainability and compliance" (p = 0.003) and **SC1** = "Digital technologies enhance worker safety and well-being by health tracking, hazard detection, and risk prediction" (p = 0.049). As both items recorded statistically significant differences, the null

hypothesis (H_0) was rejected, indicating that perceptions of the role of digital technologies in enhancing ESG compliance differ significantly across professions.

Table 4.7: Mean Rank on Role of Digital Technoloy in Enhancing ESG Compliance Across Professions.

Code	Roles	Profession	N	Mean Rank	Sum of Ranks
EC5	Digital technologies support environmental impact monitoring for sustainability and compliance.	**Architect + Engineer (design-focused)**	**72**	**65.40**	**4708.5**
		Quantity Surveyor + Others (cost/other roles)	45	48.77	2194.5
SC1	Digital technologies enhance worker safety and well-being by health tracking, hazard detection, and risk prediction.	**Architect + Engineer (design-focused)**	**72**	**63.13**	**4545.0**
		Quantity Surveyor + Others (cost/other roles)	45	52.40	2358.0

Note: **Bold** indicates the highest mean rank

Further insights are presented in Table 4.7, which reports the mean ranks of the two professional groups. For **EC5**, Architects and Engineers recorded a higher mean rank (65.40) compared to Quantity Surveyors and others (48.77). This indicates that design-focused professionals place greater emphasis on the role of digital technologies in environmental impact monitoring. This finding is consistent with Feng, Lu and Wang (2019), who highlighted that environmental performance tracking is more integrated within the design and engineering domain, where sustainability decisions are embedded early in project lifecycles.

Similarly, for **SC1**, Architects and Engineers again rated the role higher (mean rank = 63.13) compared to Quantity Surveyors and others (mean rank = 52.40). This suggests that design-focused professionals perceive digital technologies as more critical in enhancing worker safety and well-being. This aligns with the work of Elrifaee et al. (2025), who noted that safety-focused digital solutions such as wearables and IoT devices are often integrated into project planning and site operations, areas more familiar to engineers than cost managers.

Overall, the Mann-Whitney U test results underscore that professional background influences how digital technologies are valued in enhancing ESG compliance. Design-focused professionals appear more attuned to the technological roles in environmental monitoring and worker safety, likely due to their direct involvement in planning, technical design, and on-site applications. In contrast, cost- and contract-focused professionals may prioritize other aspects of digital ESG integration, such as reporting and governance-related compliance.

4.5.1.2 Challenges of Integrating Digital Technologies in ESG Compliance

Two hypotheses are formulated as follows:

Null Hypothesis (H_0): There is no significant difference across professions in their perceptions of the challenges of integrating digital technologies in ESG compliance.

Alternative Hypothesis (H_1): There is a significant difference across professions in their perceptions of the challenges of integrating digital technologies in ESG compliance.

Table 4.8: Mann-Whitney U Test Results: Challenges of Integrating Digital Technologies in ESG Compliance Across Professions.

Code	Challenges	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
CH4	High implementation and maintenance costs.	1302.5	3930.5	-1.986	0.047
CH10	Resistance from management and employees due to cultural misalignment or fear of change.	1168.5	3796.5	-2.683	0.007

Table 4.8 displays the Mann-Whitney U test results for the challenges of integrating digital technologies in ESG compliance among different professional groups. The findings show that two challenges yielded p-values below the 0.05 significance threshold. These are **CH4** = “High implementation and maintenance costs” (p = 0.047) and **CH10** = “Resistance from management and employees due to cultural misalignment or fear of change” (p = 0.007). Therefore, the null hypothesis (H_0) is rejected for these two items, indicating that perceptions of these challenges significantly differ across professional groups.

Table 4.9: Mean Rank on Challenges of Integrating Digital Technologies in ESG Compliance Across Professions.

Code	Challenges	Profession	N	Mean Rank	Sum of Ranks
CH4	High implementation and maintenance costs.	Architect + Engineer (design-focused)	72	54.59	3930.5
		Quantity Surveyor + Others (cost/other roles)	**45**	**66.06**	**2972.5**
CH10	Resistance from management and employees due to cultural misalignment or fear of change.	Architect + Engineer (design-focused)	72	52.73	3796.5
		Quantity Surveyor + Others (cost/other roles)	**45**	**69.03**	**3106.5**

Note: **Bold** indicates the highest mean rank

Table 4.9 further provides the mean rank scores for the two challenges. For **CH4** = “High implementation and maintenance costs”, Quantity Surveyors and respondents from other roles recorded a higher mean rank (66.06) compared to Architects and Engineers (54.59). This suggests that cost-oriented professionals are more sensitive to financial burdens associated with digital adoption, likely due to their professional responsibilities in cost management and financial planning. This aligns with Kuruneri (2025), who emphasized that implementation and maintenance costs pose a disproportionate barrier for stakeholders responsible for budgeting and procurement.

For **CH10** = "Resistance from management and employees due to cultural misalignment or fear of change", Quantity Surveyors and others also recorded a higher mean rank (69.03) compared to Architects and Engineers (52.73). This implies that cost-focused professionals perceive greater challenges in organizational resistance, possibly because they often engage directly with contract administration, procurement processes, and organizational compliance structures where change resistance is more visible. These findings resonate with Gadan (2023), who highlighted that organizational culture and fear of change often impede the successful integration of digital solutions in ESG practices.

Overall, the results indicate that cost and compliance-oriented professionals place greater emphasis on both financial and cultural barriers than design-focused professionals. This reflects the varying priorities shaped by professional roles in the construction industry, where cost-related practitioners are more attuned to the financial viability and organizational acceptance of digital transformation initiatives.

4.5.1.3 Strategies for Leveraging Digital Technologies in ESG Compliance

Two hypotheses were formulated for this test:

Null hypothesis (H_0): There is no significant difference across professions in their views on strategies for leveraging digital technologies in ESG compliance.

Alternative hypothesis (H_1): There is a significant difference across professions in their views on strategies for leveraging digital technologies in ESG compliance.

Table 4.10: Mann-Whitney U Test Results: Strategies for Leveraging Digital Technologies in ESG Compliance Across Professions.

Code	Strategies	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
ST1	Develop a robust digital framework that integrates technologies.	1182.0	2217.0	-2.904	0.004

Table 4.10: (Con'd)

Code	Strategies	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
ST2	Standardize ESG data collection and reporting using digital technologies.	1309.5	2344.5	-2.014	0.044
ST7	Establish digital ESG performance evaluation mechanisms.	1255.5	2290.5	-2.282	0.023
ST8	Automate ESG data collection and reporting, reduces manual work.	1225.0	2260.0	-2.467	0.014

Table 4.10 presents the Mann-Whitney U test results comparing the perceptions of two professional groups: Architects and Engineers (design-focused) versus Quantity Surveyors and others (cost/contract-related roles). Four strategies recorded p-values below the 0.05 significance threshold, namely **ST1** = "Develop a robust digital framework that integrates technologies" (p = 0.004), **ST2** = "Standardize ESG data collection and reporting using digital technologies" (p = 0.044), **ST7** = "Establish digital ESG performance evaluation mechanisms" (p = 0.023), and **ST8** = "Automate ESG data collection and reporting, reduces manual work" (p = 0.014). Since these values fall below the threshold, the null hypothesis (H_0) is rejected for these items, indicating that perceptions of these strategies differ significantly across professions.

Table 4.11: Mean Rank on Strategies for Leveraging Digital Technologies in ESG Compliance Across Professions.

Code	Strategies	Profession	N	Mean Rank	Sum of Ranks
ST1	Develop a robust digital framework that integrates technologies.	**Architect + Engineer (design-focused)**	**72**	**65.08**	**4686.0**
		Quantity Surveyor + Others (cost/other roles)	45	49.27	2217.0

Table 4.11: (Con'd)

Code	Strategies	Profession	N	Mean Rank	Sum of Ranks
ST2	Standardize ESG data collection and reporting using digital technologies.	**Architect + Engineer (design-focused)**	**72**	**63.31**	**4558.5**
		Quantity Surveyor + Others (cost/other roles)	45	52.10	2344.5
ST7	Establish digital ESG performance evaluation mechanisms.	**Architect + Engineer (design-focused)**	**72**	**64.06**	**4612.5**
		Quantity Surveyor + Others (cost/other roles)	45	50.90	2290.5
ST8	Automate ESG data collection and reporting, reduces manual work.	**Architect + Engineer (design-focused)**	**72**	**64.49**	**4643.0**
		Quantity Surveyor + Others (cost/other roles)	45	50.22	2260.0

Note: **Bold** indicates the highest mean rank

Table 4.11 further illustrates the mean rank scores of the two professional groups. For all four significant strategies (**ST1, ST2, ST7, ST8**), Architects and Engineers consistently recorded higher mean ranks than Quantity Surveyors and others. Specifically, design-focused professionals placed greater emphasis on developing robust frameworks (mean rank = 65.08), standardizing data (mean rank = 63.31), establishing digital ESG performance evaluation (mean rank = 64.06), and automating ESG reporting (mean rank = 64.49), compared to their cost-focused counterparts, whose mean ranks ranged between 49.27 and 52.10.

These results suggest that design-focused professionals perceive a stronger need for systematic and technologically integrated strategies to strengthen ESG compliance. This emphasis may stem from their direct involvement in technical design, planning, and digital integration processes where such frameworks and automation tools play a critical role. The findings align with Chen (2024), who highlighted the importance of digital standardization and automation in achieving transparent and efficient ESG reporting. Similarly, Zhou, Yuan and He (2025) emphasized that robust digital frameworks and evaluation mechanisms enhance the credibility of ESG performance by reducing human error and improving accountability.

In contrast, Quantity Surveyors and cost-related professionals, while recognizing the value of these strategies, appear less likely to prioritize them compared to financial and governance-related measures. Their professional focus on cost management and contractual compliance may explain this divergence, as these roles often emphasize economic viability and regulatory alignment over technical digital integration.

Overall, the Mann-Whitney U results underscore that professional background significantly influences perceptions of digital ESG strategies. Design-focused professionals advocate strongly for digital standardization, automation, and evaluation mechanisms, whereas cost-focused professionals may prioritize governance and financial feasibility. This indicates the necessity of adopting a multidisciplinary approach to ESG digitalization, ensuring that both technical integration and financial considerations are adequately addressed to achieve balanced and sustainable outcomes in the construction industry.

4.5.2 Mann-Whitney U Test on Working Experience

For this analysis, respondents' working experience was divided into two categories: (i) those with 10 years or less, and (ii) those with more than 10 years. The Mann-Whitney U Test was applied to examine whether significant differences existed between these two groups in their perceptions of the role of digital technologies, the challenges to adoption, and the strategies for enhancing ESG compliance.

4.5.2.1 Role of Digital Technology in Enhancing ESG Compliance

The Mann-Whitney U test results indicated no significant difference in perceptions of the role of digital technology in enhancing ESG compliance across different working experience groups. Thus, the null hypothesis is failed to rejected, indicating that perceptions are consistent regardless of seniority.

4.5.2.2 Challenges of Integrating Digital Technologies in ESG Compliance

Two hypotheses were formulated for this test:

Null Hypothesis (H_0): There is no significant difference across working experience in the perceived challenges of integrating digital technologies in ESG compliance.

Alternative Hypothesis (H_1): There is a significant difference across working experience in the perceived challenges of integrating digital technologies in ESG compliance.

Table 4.12: Mann-Whitney U Test Results: Challenges of Integrating Digital Technologies in ESG Compliance Across Working Experience.

Code	Challenges	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
CH1	Technical barriers such as system integration challenges with existing infrastructure.	1198.5	2279.5	-2.619	0.009
CH3	Limited stakeholder engagement and collaboration.	1267.5	2348.5	-2.242	0.025
CH4	High implementation and maintenance costs.	1246.0	2327.0	-2.410	0.016
CH5	Lack of skilled workforce and insufficient training programs.	1273.0	2354.0	-2.148	0.032
CH8	Poor data quality and limited access to reliable ESG data.	1251.0	2332.0	-2.334	0.020

Table 4.12 presents the Mann-Whitney U test results on the challenges between two respondent groups: those with ≤10 years of working experience and those with >10 years. The analysis revealed five items with p-values below the 0.05 significance threshold, namely **CH1** (technical barriers such as system integration challenges with existing infrastructure, p = 0.009), **CH3** (limited

stakeholder engagement and collaboration, $p = 0.025$), **CH4** (high implementation and maintenance costs, $p = 0.016$), **CH5** (lack of skilled workforce and insufficient training programs, $p = 0.032$), and **CH8** (poor data quality and limited access to reliable ESG data, $p = 0.020$). As these items recorded statistically significant differences, the null hypothesis (H_0) was rejected, confirming that working experience influences respondents' perceptions of these challenges.

Table 4.13: Mean Rank on Challenges of Integrating Digital Technologies in ESG Compliance Across Working Experience.

Code	Challenges	Working Experience	N	Mean Rank	Sum of Ranks
CH1	Technical barriers such as system integration challenges with existing infrastructure.	**≤ 10 years**	**71**	**65.12**	**4623.5**
		>10 years	46	49.55	2279.5
CH3	Limited stakeholder engagement and collaboration.	**≤ 10 years**	**71**	**64.15**	**4554.5**
		>10 years	46	51.05	2348.5
CH4	High implementation and maintenance costs.	**≤ 10 years**	**71**	**64.45**	**4576.0**
		>10 years	46	50.59	2327.0
CH5	Lack of skilled workforce and insufficient training programs.	**≤ 10 years**	**71**	**64.07**	**4549.0**
		>10 years	46	51.17	2354.0
CH8	Poor data quality and limited access to reliable ESG data.	**≤ 10 years**	**71**	**64.38**	**4571.0**
		>10 years	46	50.70	2332.0

Note: **Bold** indicates the highest mean rank

Table 4.13 provides the mean rank scores. For all five items, respondents with ≤ 10 years of experience consistently recorded higher mean ranks compared to those with > 10 years of experience. Specifically, less experienced professionals rated technical barriers (mean rank = 65.12 vs. 49.55), limited stakeholder engagement (64.15 vs. 51.05), high costs (64.45 vs. 50.59), skills and training gaps (64.07 vs. 51.17), and poor data quality (64.38 vs. 50.70) as more significant obstacles.

The findings indicate that early-career professionals are more attuned to operational and technical barriers, likely because they are directly engaged in the daily use of digital systems and ESG data management, where challenges related to integration, costs, and data handling are most apparent. By contrast, senior professionals may perceive these barriers as less pressing, given their focus on strategic oversight and reliance on institutional support systems.

This finding resonates with Ciborowska, Chakarov and Pandita (2021), who emphasized that younger professionals often struggle more with technical and training-related gaps due to limited exposure to legacy systems and fewer opportunities for specialized upskilling. Similarly, Graetsh et al. (2023) highlighted that poor data quality and accessibility remain pressing concerns for practitioners managing real-time reporting tasks, which are commonly delegated to less experienced staff.

Overall, the Mann-Whitney U test results underscore that working experience shapes perceptions of digital ESG integration challenges. Less experienced professionals place greater emphasis on technical, financial, and data-related issues, while more experienced practitioners may view these barriers as manageable within broader organizational and strategic contexts.

4.5.2.3 Strategies for Leveraging Digital Technologies in ESG Compliance

Two hypotheses were formulated for this test:

Null Hypothesis (H_0): There is no significant difference across working experience in the perceived strategies for leveraging digital technologies in ESG compliance.

Alternative Hypothesis (H_1): There is a significant difference across working experience in the perceived strategies for leveraging digital technologies in ESG compliance.

Table 4.14: Mann-Whitney U Test Results: Strategies for Leveraging Digital Technologies in ESG Compliance Across Working Experience.

Code	Strategies	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
ST4	Promote public-private partnerships and industry consortia.	1337.0	3893.0	-2.054	0.040

Table 4.14 presents the Mann-Whitney U test results comparing the perceptions of respondents with different levels of working experience (≤ 10 years and > 10 years). The results show that one strategy, **ST4** = "Promote public-private partnerships and industry consortia", recorded a p-value of 0.040, which is below the 0.05 significance threshold. Hence, the null hypothesis (H_0) is rejected for this item, indicating that perceptions of this strategy differ significantly across working experience groups.

Table 4.15: Mean Rank on Strategies for Leveraging Digital Technologies in ESG Compliance Across Working Experience.

Code	Strategies	Working Experience	N	Mean Rank	Sum of Ranks
ST4	Promote public-private partnerships and industry consortia.	≤ 10 years	71	54.83	3893.0
		>10 years	**46**	**65.43**	**3010.0**

Note: **Bold** indicates the highest mean rank

Table 4.15 further provides the mean rank scores for the two groups. Respondents with more than 10 years of working experience recorded a higher mean rank (65.43) compared to those with 10 years or less (54.83). This suggests that more experienced professionals place greater importance on promoting PPPs and industry consortia as a strategy for enhancing ESG compliance.

This finding reflects the practical exposure of senior professionals, who are often more involved in stakeholder collaboration, regulatory alignment, and cross-industry initiatives, thus recognizing PPPs as critical in driving sector-wide ESG adoption. This is consistent with Chen, Xie and He (2024), who emphasized that collaborative governance structures, including PPPs, strengthen knowledge sharing, innovation, and capacity-building in ESG integration. Similarly, Teubner, Henkel and Bekkers (2021) highlighted that consortia provide platforms for standard-setting, resource pooling, and joint problem-solving, which are especially valued by seasoned practitioners who have witnessed the challenges of fragmented industry efforts.

In contrast, less experienced professionals may prioritize more immediate and operational strategies, such as digital training or automation, rather than large-scale collaborative frameworks. This explains the lower ranking among respondents with ≤ 10 years of experience.

Overall, the results indicate that working experience influences the prioritization of strategies for digital ESG adoption. Senior practitioners perceive collaborative and institutional mechanisms as crucial enablers of long-term ESG compliance, while younger professionals may focus more on internal, organization-level digital initiatives.

4.6 Kruskal-Wallis Test

The Kruskal-Wallis test was conducted to determine whether significant differences exist in perceptions of digital technologies for ESG compliance across company business activities, organizational positions, and company sizes. The test determines significance by evaluating the p-value against the threshold of 0.05, with the degrees of freedom calculated as the number of groups minus one.

4.6.1 Kruskal-Wallis Test on Company Business Activities

The Kruskal-Wallis test was used to evaluate differences in perceptions across company business activities, categorized into four groups: (i) developers, (ii) consultants, (iii) contractors, and (iv) sub-contractors/suppliers. The findings are presented in three parts: role of digital technology, challenges of integration, and strategies for leveraging digital technologies in ESG compliance.

4.6.1.1 Role of Digital Technology in Enhancing ESG Compliance

The Kruskal-Wallis test was conducted to examine the role of digital technology in enhancing ESG Compliance. The results showed no significant difference across company business activities; therefore, the null hypothesis is failed to reject.

4.6.1.2 Challenges of Integrating Digital Technologies in ESG Compliance

Two hypotheses are formulated as follows:

Null hypothesis (H_0): There is no significant difference in the perceived challenges of integrating digital technologies in ESG compliance across company business activities.

Alternative hypothesis (H_1): There is a significant difference in the perceived challenges of integrating digital technologies in ESG compliance across company business activities.

Table 4.16: Kruskal-Wallis Test Results: Challenges of Integrating Digital Technologies in ESG Compliance Across Company Business Activities.

Code	Challenges	Kruskal-Wallis H	Asymp. Sig.
CH7	Lack of standardized ESG data formats and reporting frameworks.	12.031	0.007

Table 4.16 presents the Kruskal-Wallis test results on challenges across company business activities. The results indicate that **CH7**, “Lack of standardized ESG data formats and reporting frameworks”, has a p-value of 0.007 (below 0.05) and an H-value of 12.031 (above 7.815). This result indicates a statistically significant difference in viewpoints across company business activities concerning this challenge. Therefore, the null hypothesis (H_0) is rejected for CH7.

Table 4.17: Mean Rank on Challenges of Integrating Digital Technologies in ESG Compliance Across Company Business Activities.

Code	Challenges	Company Business Activities	N	Mean Rank
CH7	Lack of standardized ESG data formats and reporting frameworks.	**Developer**	**34**	**71.84**
		Consultant	47	58.45
		Contractor	31	50.45
		Sub-Contractor / Supplier	*5*	*29.90*

Note: **Bold** indicates the highest mean rank

Italic indicates the lowest mean rank

Table 4.17 further illustrates the mean rank differences. Developers recorded the highest mean rank of 71.84, suggesting they perceive the lack of standardization as the most critical challenge, whereas sub-contractors/suppliers reported the lowest mean rank of 29.90.

This result suggests that developers, being primarily responsible for project initiation, planning, and regulatory compliance, are more directly affected by fragmented ESG reporting frameworks. Their emphasis reflects concerns over ensuring consistency and comparability of ESG disclosures, which are essential for attracting investors and meeting regulatory obligations. This aligns with Vijaya et al. (2025), who noted that inconsistent ESG data formats hinder the effectiveness of digital compliance tools and complicate benchmarking efforts.

On the other hand, sub-contractors and suppliers appear less concerned with standardized ESG frameworks, possibly because their operational scope is narrower and more focused on technical execution rather than strategic reporting. This aligns with the findings of Ali et al. (2025), who noted that smaller industry players often lack the resources or incentives to prioritize ESG data standardization.

Overall, the results reinforce the literature that the lack of standardized ESG data formats remains one of the most pressing barriers to digital ESG compliance, disproportionately affecting developers and consultants who face greater reporting accountability (Phan et al., 2025). Without a unified standard, industry stakeholders risk inefficiencies, duplication of reporting efforts, and reduced comparability across projects.

4.6.1.3 Strategies for Leveraging Digital Technologies in ESG Compliance

The two hypotheses are formulated as follows:

Null hypothesis (H_0): There is no significant difference across company business activities in their perceptions of strategies for leveraging digital technologies in ESG compliance.

Alternative hypothesis (H_1): There is a significant difference across company business activities in their perceptions of strategies for leveraging digital technologies in ESG compliance.

Table 4.18: Kruskal-Wallis Test Results: Strategies for Leveraging Digital Technologies in ESG Compliance Across Company Business Activities.

Code	Strategies	Kruskal-Wallis H	Asymp. Sig.
ST6	Invest in ESG digital skills training.	8.750	0.033

Table 4.18 presents the Kruskal-Wallis test results for strategies. It shows that the strategy **ST6** = "Invest in ESG digital skills training" recorded a p-value less than 0.05 (Asymp. Sig. = 0.033) and a chi-square value greater than the critical value of 7.815. This indicates a statistically significant difference in perception across company business activities. Hence, the null hypothesis (H_0) for this strategy is rejected.

Table 4.19: Mean Rank on Strategies for Leveraging Digital Technologies in ESG Compliance Across Company Business Activities.

Code	Strategies	Company Business Activities	N	Mean Rank
ST6	Invest in ESG digital skills training.	Developer	34	60.75
		Consultant	**47**	**62.64**
		Contractor	31	56.65
		Sub-Contractor / Supplier	*5*	*27.50*

Note: **Bold** indicates the highest mean rank
Italic indicates the lowest mean rank

Table 4.19 shows the mean rank of **ST6** across company business activities. Consultants obtained highest mean rank of 62.64, while subcontractors/suppliers recorded the lowest mean rank of 27.50. This suggests that consultants and developers view ESG digital skills training as a more critical strategy compared to contractors and, particularly, subcontractors/suppliers.

This finding can be explained by the nature of responsibilities within each group. Consultants and developers are often involved in planning, design, and compliance reporting, where digital literacy is crucial for managing ESG data effectively. Their higher ranking aligns with Celik, Petri and Rezgio (2023), who emphasized that professional upskilling in digital tools such as BIM, AI, and blockchain is fundamental for integrating sustainability into construction practices. Similarly, Heldal et al. (2024) highlighted the importance of aligning education and training with emerging technologies to prepare professionals for ESG-related digital transformation.

Conversely, subcontractors and suppliers gave the lowest importance to ESG digital training. This could be attributed to limited exposure to ESG reporting and digital compliance processes, as their role is primarily focused on material provision and site-level execution. Their lower prioritization resonates with Kang and Hew (2025), who found that SMEs often face barriers such as cost constraints, lack of awareness, and limited access to structured training opportunities, making ESG-focused digital upskilling less of a priority.

In summary, the results suggest that while consultants and developers recognize the necessity of ESG digital skills training to meet regulatory and client demands, contractors and especially subcontractors/suppliers may require greater institutional support and incentives to adopt this strategy. Targeted policies and collaborative initiatives could help bridge this gap, ensuring that all stakeholders across the construction value chain are equally equipped to leverage digital technologies for ESG compliance.

4.6.2 Kruskal-Wallis Test on Organisation Position

The Kruskal-Wallis test was carried out to examine differences in perceptions across organizational positions, categorized into six groups: junior executive, senior executive, manager/team leader/supervisor, assistant director/technical director, director, and others. The test examined whether significant differences existed among these groups regarding the roles, challenges, and strategies of adopting digital technologies for ESG compliance.

4.6.2.1 Role of Digital Technology in Enhancing ESG Compliance

The hypotheses tested are as follows:

Null hypothesis (H_0): There is no significant difference across organisational positions in their perceptions of the role of digital technologies in enhancing ESG compliance.

Alternative hypothesis (H_1): There is a significant difference across organisational positions in their perceptions of the role of digital technologies in enhancing ESG compliance.

Table 4.20: Kruskal-Wallis Test Results: Role of Digital Technology in Enhancing ESG Compliance Across Organisation Position.

Code	Roles	Kruskal-Wallis H	Asymp. Sig.
EC1	Digital technologies enable real-time carbon footprint tracking and transparent emission reporting in construction.	11.146	0.049
EC2	Digital technologies support sustainable material sourcing in improving traceability and resource optimization.	16.199	0.006
GC1	AI and Blockchain technologies improve ESG regulatory reporting and transparency and prevent data tampering.	13.497	0.019
GC2	Big Data, Blockchain, and AI technologies improve risk management by enhancing prediction, data integrity and regulatory compliance.	11.514	0.042
GC4	Blockchain technology and smart contracts enhance audit trail integrity and accountability through transparent, and real-time records.	11.443	0.043

Table 4.20 presents the Kruskal-Wallis test results on organisational positions. Several items recorded p-values less than 0.05, indicating statistically significant differences in perception. Specifically, **EC1** ($p = 0.049$, $H = 11.146$), **EC2** ($p = 0.006$, $H = 16.199$), **GC1** ($p = 0.019$, $H = 13.497$), **GC2** ($p = 0.042$, $H = 11.514$), and **GC4** ($p = 0.043$, $H = 11.443$) all exceed the chi-square critical value of 7.815. Therefore, the null hypothesis (H_0) is rejected for these roles,

confirming that perceptions of digital technology's role in ESG compliance differ significantly across organisational positions.

Table 4.21: Mean Rank on Role of Digital Technology in Enhancing ESG Compliance Across Organisation Position.

Code	Roles	Organisation Position	N	Mean Rank
EC1	Digital technologies enable real-time carbon footprint tracking and transparent emission reporting in construction.	Junior Executive	52	57.18
		Senior Executive	32	56.91
		Manager/ Team Leader/ Supervisor	16	48.22
		Assistant Director/ Technical Director	11	77.18
		Director	**5**	**89.50**
		Others	*1*	*40.50*
EC2	Digital technologies support sustainable material sourcing in improving traceability and resource optimization.	Junior Executive	52	59.51
		Senior Executive	32	49.09
		Manager/ Team Leader/ Supervisor	16	52.53
		Assistant Director/ Technical Director	11	82.41
		Director	**5**	**90.50**
		Others	*1*	*38.00*
GC1	AI and Blockchain technologies improve ESG regulatory reporting and transparency and prevent data tampering.	Junior Executive	52	57.07
		Senior Executive	32	56.47
		Manager/ Team Leader/ Supervisor	16	47.44
		Assistant Director/ Technical Director	11	81.91
		Director	**5**	**86.50**
		Others	*1*	*36.00*
GC2	Big Data, Blockchain, and AI technologies improve risk management by enhancing prediction, data integrity and regulatory compliance.	Junior Executive	52	58.45
		Senior Executive	32	56.00
		Manager/ Team Leader/ Supervisor	16	46.53
		Assistant Director/ Technical Director	11	76.59
		Director	**5**	**89.00**
		Others	*1*	*39.50*

Table 4.21: (Con'd)

Code	Roles	Organisation Position	N	Mean Rank
GC4	Blockchain technology and smart contracts enhance audit trail integrity and accountability through transparent, and real-time records.	Junior Executive	52	57.79
		Senior Executive	32	53.16
		Manager/ Team Leader/ Supervisor	16	51.72
		Assistant Director/ Technical Director	11	80.05
		Director	**5**	**87.90**
		Others	*1*	*49.50*

Note: **Bold** indicates the highest mean rank

Italic indicates the lowest mean rank

Table 4.21 illustrates the mean rank values across different organisational positions. Directors consistently recorded the highest mean ranks (ranging from 86.50 to 90.50), indicating a stronger perception of digital technologies as critical enablers of ESG compliance. Assistant/Technical Directors also ranked relatively high (ranging from 76.59 to 82.41), suggesting alignment with directors in recognising the strategic importance of technologies such as AI, blockchain, and big data. By contrast, "Others" consistently recorded the lowest mean ranks (as low as 36.00 for GC1), while junior and senior executives displayed more moderate perceptions.

These findings suggest that individuals in higher leadership positions such as Directors and Assistant Directors perceive digital technologies as essential tools for driving ESG compliance. Their emphasis reflects their responsibilities in governance, strategic planning, and regulatory accountability, where transparent reporting, risk management, and audit integrity are of critical importance. This aligns with the arguments of Strazzullo (2024), who observed that senior leadership is more likely to prioritise digital innovation to ensure compliance and maintain stakeholder trust.

Conversely, lower-ranked employees, such as junior and senior executives, perceive these roles as less critical, potentially due to their limited involvement in strategic ESG reporting and technology-driven governance. This is consistent with Mahroof et al. (2025), who noted that operational staff often face barriers such as limited exposure to compliance frameworks and digital decision-making processes.

Overall, the results highlight that the recognition of digital technologies in enhancing ESG compliance is stratified by organisational hierarchy. Senior leaders attribute higher importance to digital tools for achieving regulatory alignment and transparency, while lower-level staff show relatively lower concern. Bridging this gap through targeted training and awareness initiatives could foster a more unified organisational perspective on the role of technology in ESG compliance.

4.6.2.2 Challenges of Integrating Digital Technologies in ESG Compliance

The hypotheses are formulated as follows:

Null hypothesis (H_0): There is no significant difference in the perceived challenges of integrating digital technologies in ESG compliance across organisational positions.

Alternative hypothesis (H_1): There is a significant difference in the perceived challenges of integrating digital technologies in ESG compliance across organisational positions.

Table 4.22: Kruskal-Wallis Test Results: Challenges of Integrating Digital Technologies in ESG Compliance Across Organisation Position.

Code	Challenges	Kruskal-Wallis H	Asymp. Sig.
CH10	Resistance from management and employees due to cultural misalignment or fear of change.	16.093	0.007

Table 4.22 presents the Kruskal-Wallis test results for challenges across organizational positions. The results show that **CH10** = “Resistance from management and employees due to cultural misalignment or fear of change” has a chi-square (H) value of 16.093 with a p-value of 0.007 (less than 0.05). Since the test result is statistically significant, the null hypothesis (H_0) is rejected for CH10. This indicates that perceptions of cultural resistance as a challenge vary significantly across different organisational positions.

Table 4.23: Mean Rank on Challenges of Integrating Digital Technologies in ESG Compliance Across Organisation Position.

Code	**Challenges**	**Organisation Position**	**N**	**Mean Rank**
CH10	Resistance from management and employees due to cultural misalignment or fear of change.	Junior Executive	52	64.88
		Senior Executive	32	53.75
		Manager/ Team Leader/ Supervisor	16	70.81
		Assistant Director/ Technical Director	*11*	*34.95*
		Director	5	36.30
		Others	**1**	**110.00**

Note: **Bold** indicates the highest mean rank

Italic indicates the lowest mean rank

Table 4.23 further illustrates the mean rank distribution. The results reveal that Managers/Team Leaders/Supervisors recorded the highest mean rank of 70.81, suggesting that this group perceives resistance from management and employees as the most critical challenge. In contrast, Assistant Directors/Technical Directors (mean rank = 34.95) and Directors (36.30) reported much lower mean ranks, with Senior Executives (53.75) and Junior Executives (64.88) falling in between. Interestingly, the “Others” category reported the highest rank (110.00), although the small sample size (N = 1) limits its representativeness.

The high ranking by managers indicates their unique position in the organisational hierarchy, where they often act as intermediaries between top management and operational staff. This role exposes them to both downward pressures from directors seeking efficiency and compliance and upward resistance from employees reluctant to adopt new digital practices. Their perception aligns with Bagrationi and Thurner (2023), who argued that middle management plays a pivotal role in either enabling or obstructing digital ESG initiatives due to their direct influence on employee attitudes and workflows.

On the other hand, directors and assistant directors appear less concerned with this challenge, likely because their strategic focus prioritises long-term digital transformation goals over day-to-day cultural frictions. Similarly, junior executives, while recognising the presence of resistance, may not experience the organisational burden of leading change initiatives, which explains their moderately high but not the highest ranking. This distribution resonates with Bagrationi and Thurner (2023), who observed that perceptions of digital adoption challenges differ by hierarchical role, with middle management typically perceiving greater obstacles due to their dual accountability.

Overall, the findings highlight that cultural resistance remains a critical barrier to digital ESG integration, particularly at the managerial level where change must be operationalised. Without addressing cultural misalignment and fear of change, organisations risk undermining the effectiveness of their digital ESG initiatives. Consistent with Hariyani, Hariyani and Mishra (2025), targeted change management strategies such as leadership training, employee engagement, and transparent communication are essential to mitigate resistance and ensure smoother adoption of digital technologies for ESG compliance.

4.6.2.3 Strategies for Leveraging Digital Technologies in ESG Compliance

The two hypotheses are formulated as follows:

Null hypothesis (H_0): There is no significant difference across organisational positions in their perceptions of strategies for leveraging digital technologies in ESG compliance.

Alternative hypothesis (H_1): There is a significant difference across organisational positions in their perceptions of strategies for leveraging digital technologies in ESG compliance.

Table 4.24: Kruskal-Wallis Test Results: Strategies for Leveraging Digital Technologies in ESG Compliance Across Organisation Position.

Code	Strategies	Kruskal-Wallis H	Asymp. Sig.
ST1	Develop a robust digital framework that integrates technologies.	12.051	0.034

Table 4.24 presents the Kruskal-Wallis test results on strategies. The strategy **ST1**, “Develop a robust digital framework that integrates technologies”, recorded a p-value of 0.034 (below 0.05) and an H-value of 12.051. This indicates a statistically significant difference in perception across organisational positions. Therefore, the null hypothesis (H_0) is rejected for ST1.

Table 4.25: Mean Rank on Strategies for Leveraging Digital Technologies in ESG Compliance Across Organisation Position.

Code	Strategies	Organisation Position	N	Mean Rank
ST1	Develop a robust digital framework that integrates technologies.	Junior Executive	52	54.15
		Senior Executive	32	64.20
		Manager/ Team Leader/ Supervisor	16	48.78
		Assistant Director/ Technical Director	11	75.09
		Director	**5**	**80.00**
		Others	*1*	*26.00*

Note: **Bold** indicates the highest mean rank
Italic indicates the lowest mean rank

Table 4.25 further demonstrates the mean rank differences across positions. Directors scored the highest mean rank of 80.00, followed closely by Assistant/Technical Directors (mean rank = 75.09), while junior executives (mean rank = 54.15), senior executives (mean rank = 64.20), and managers/team leaders/supervisors (mean rank = 48.78) fell within the mid-range. The lowest ranking was reported under “Others” (mean rank = 26.00).

These findings suggest that directors and assistant directors/technical directors place greater importance on developing a robust digital framework for ESG compliance. Their elevated perception may stem from their strategic oversight roles, where ensuring long-term sustainability and regulatory alignment is paramount. This aligns with the argument of Qiao et al. (2024), who emphasized that leadership commitment to digital integration is crucial for overcoming fragmentation in ESG systems and driving organisation-wide adoption.

In contrast, mid-level managers and junior executives recorded relatively lower mean ranks, indicating a less critical view of framework development. This may be due to their operational focus on task execution rather than high-level strategic planning, as also noted by Boge et al. (2021), who found that operational staff often prioritize immediate project deliverables over long-term digital governance. Similarly, the significantly low ranking among “Others” could reflect limited engagement with ESG compliance responsibilities in their roles.

Overall, the results reinforce the literature that the establishment of a robust, technology-integrated digital framework is perceived as a leadership-driven priority. Higher-ranking executives, tasked with regulatory accountability and corporate reputation, recognize its critical role in ensuring consistent ESG practices across organisational levels. Conversely, lower-ranking staff may require stronger top-down communication and institutional support to appreciate the broader benefits of such frameworks.

4.6.3 Kruskal-Wallis Test on Company Size

The Kruskal-Wallis test was conducted to determine whether perceptions of the roles, challenges, and strategies of digital technologies in ESG compliance vary across different company sizes. Company size was determined based on the number of employees and categorised into four groups: micro, small, medium, and large enterprises.

4.6.3.1 Role of Digital Technology in Enhancing ESG Compliance

The following hypotheses were formulated:

Null hypothesis (H_0): There is no significant difference across company sizes in their perceptions of the role of digital technologies in enhancing ESG compliance.

Alternative hypothesis (H_1): There is a significant difference across company sizes in their perceptions of the role of digital technologies in enhancing ESG compliance.

Table 4.26: Kruskal-Wallis Test Results: Role of Digital Technology in Enhancing ESG Compliance Across Company Size.

Code	Roles	Kruskal-Wallis H	Asymp. Sig.
EC1	Digital technologies enable real-time carbon footprint tracking and transparent emission reporting in construction.	22.925	0.000
EC2	Digital technologies support sustainable material sourcing in improving traceability and resource optimization.	11.092	0.011

Table 4.26: (Con’d)

Code	Roles	Kruskal-Wallis H	Asymp. Sig.
EC3	Digital technologies improve energy efficiency through real-time monitoring and predictive management in construction.	11.885	0.008
EC4	Digital technologies support waste reduction and circular economy integration through tracking and resource recovery.	14.831	0.002
EC5	Digital technologies support environmental impact monitoring for sustainability and compliance.	20.607	0.000
SC1	Digital technologies enhance worker safety and well-being by health tracking, hazard detection, and risk prediction.	10.143	0.017
SC2	Digital workforce management tools ensure fair labor practices, compliance and transparent working conditions.	9.663	0.022
SC3	Digital technologies improve stakeholder engagement through transparency and real-time communication.	11.052	0.011
SC4	Digital technologies support diversity, equity, and inclusion monitoring by enabling fair, transparent human resources practices.	12.433	0.006
SC5	Digital technologies enhance the training and upskilling of construction workers, supporting skills development and the adoption of Industry 4.0.	12.468	0.006
GC1	AI and Blockchain technologies improve ESG regulatory reporting and transparency and prevent data tampering.	14.756	0.002
GC2	Big Data, Blockchain, and AI technologies improve risk management by enhancing prediction, data integrity and regulatory compliance.	14.173	0.003
GC3	Advanced cybersecurity technologies effectively protect ESG data by ensuring security, integrity, and regulatory compliance.	13.280	0.004
GC4	Blockchain technology and smart contracts enhance audit trail integrity and accountability through transparent, and real-time records.	14.190	0.003
GC5	Digital technologies enable real-time policy implementation and monitoring, improving coordination, safety compliance, and resource management.	8.885	0.031

Table 4.10 presents the Kruskal-Wallis test results on the role of digital technologies across various company sizes. All the roles (EC1–EC5, SC1–SC5, GC1–GC5) recorded p-values below 0.05, indicating statistically significant differences in perception across company sizes. For example, EC1 = "Digital technologies enable real-time carbon footprint tracking and transparent emission reporting in construction" shows an H-value of 22.925 and a p-value of 0.000, while GC5 = "Digital technologies enable real-time policy implementation and monitoring" also recorded significance with an H-value of 8.885 and p-value of 0.031. Thus, the null hypothesis (H_0) is rejected for all roles.

Table 4.27: Mean Rank on Role of Digital Technology in Enhancing ESG Compliance Across Company Size.

Code	Roles	Company Size	N	Mean Rank
EC1	Digital technologies enable real-time carbon footprint tracking and transparent emission reporting in construction.	*Micro*	*1*	*3.00*
		Small	22	43.57
		Medium	50	52.53
		Large	**44**	**75.34**
EC2	Digital technologies support sustainable material sourcing in improving traceability and resource optimization.	*Micro*	*1*	*8.00*
		Small	22	48.23
		Medium	50	55.64
		Large	**44**	**69.36**
EC3	Digital technologies improve energy efficiency through real-time monitoring and predictive management in construction.	*Micro*	*1*	*7.00*
		Small	22	48.89
		Medium	50	55.39
		Large	**44**	**69.34**
EC4	Digital technologies support waste reduction and circular economy integration through tracking and resource recovery.	*Micro*	*1*	*2.50*
		Small	22	51.11
		Medium	50	52.69
		Large	**44**	**71.40**
EC5	Digital technologies support environmental impact monitoring for sustainability and compliance.	*Micro*	*1*	*2.50*
		Small	22	38.20
		Medium	50	59.19
		Large	**44**	**70.47**

Table 4.27: (Con’d)

Code	Roles	Company Size	N	Mean Rank
SC1	Digital technologies enhance worker safety and well-being by health tracking, hazard detection, and risk prediction.	*Micro*	*1*	*3.50*
		Small	22	46.66
		Medium	50	59.74
		Large	**44**	**65.59**
SC2	Digital workforce management tools ensure fair labor practices, compliance and transparent working conditions.	*Micro*	*1*	*3.00*
		Small	22	45.86
		Medium	50	61.29
		Large	**44**	**64.24**
SC3	Digital technologies improve stakeholder engagement through transparency and real-time communication.	*Micro*	*1*	*1.50*
		Small	22	45.82
		Medium	50	58.83
		Large	**44**	**67.09**
SC4	Digital technologies support diversity, equity, and inclusion monitoring by enabling fair, transparent human resources practices.	*Micro*	*1*	*9.50*
		Small	22	55.52
		Medium	50	50.88
		Large	**44**	**71.09**
SC5	Digital technologies enhance the training and upskilling of construction workers, supporting skills development and the adoption of Industry 4.0.	*Micro*	*1*	*3.00*
		Small	22	43.59
		Medium	50	61.96
		Large	**44**	**64.61**
GC1	AI and Blockchain technologies improve ESG regulatory reporting and transparency and prevent data tampering.	*Micro*	*1*	*2.00*
		Small	22	41.89
		Medium	50	59.17
		Large	**44**	**68.66**
GC2	Big Data, Blockchain, and AI technologies improve risk management by enhancing prediction, data integrity and regulatory compliance.	*Micro*	*1*	*2.00*
		Small	22	42.98
		Medium	50	58.10
		Large	**44**	**69.33**
GC3	Advanced cybersecurity technologies effectively protect ESG data by ensuring security, integrity, and regulatory compliance.	*Micro*	*1*	*10.00*
		Small	22	42.30
		Medium	50	58.66
		Large	**44**	**68.85**

Table 4.27: (Con'd)

Code	Roles	Company Size	N	Mean Rank
GC4	Blockchain technology and smart contracts enhance audit trail integrity and accountability through transparent, and real-time records.	*Micro*	*1*	*2.50*
		Small	22	47.36
		Medium	50	54.45
		Large	**44**	**71.27**
GC5	Digital technologies enable real-time policy implementation and monitoring, improving coordination, safety compliance, and resource management.	*Micro*	*1*	*2.00*
		Small	22	55.34
		Medium	50	53.93
		Large	**44**	**67.89**

Note: **Bold** indicates the highest mean rank

Italic indicates the lowest mean rank

Table 4.27 illustrates the mean rank distribution across company sizes. Larger firms with more than 75 employees consistently reported the highest mean ranks across almost all roles, such as EC1 (75.34), EC5 (70.47), and GC4 (71.27). This indicates that larger companies place greater importance on digital technologies for enhancing ESG compliance. In contrast, micro firms with fewer than 5 employees consistently recorded the lowest mean ranks (e.g., EC1 = 3.00; SC3 = 1.50; GC1 = 2.00), suggesting limited emphasis or capability to leverage digital technologies for ESG purposes. Small and medium-sized firms (5–29 employees; 30–75 employees) ranked in between, showing moderate recognition of digital technologies' roles.

The stronger emphasis from larger firms can be explained by their greater exposure to regulatory scrutiny, investor requirements, and stakeholder expectations. As Xue and Zhu (2025) noted, larger organizations are often mandated to provide transparent ESG disclosures, making digital tools critical for real-time tracking, reporting, and compliance assurance. For instance, developers and contractors within larger firms are more likely to adopt advanced technologies such as blockchain, AI, and IoT for emission tracking (EC1), sustainable sourcing (EC2), and waste reduction (EC4), which streamline compliance and enhance credibility with investors.

On the other hand, smaller firms, particularly micro-enterprises, appear less concerned with or capable of adopting these digital roles. This could be attributed to limited financial resources, digital infrastructure, and technical expertise. Moreira et al. (2025) highlighted that SMEs face challenges in integrating digital solutions due to high costs and lack of skilled personnel. As seen in SC5 (“Enhancing training and upskilling of workers”), larger firms scored higher (64.61) than smaller firms (3.00), reinforcing the idea that digital readiness is strongly linked to organizational size.

Overall, these findings suggest that while all company sizes recognize the role of digital technologies in ESG compliance, larger firms are better positioned to leverage them comprehensively. Smaller firms may require targeted policy support, subsidies, or industry-wide platforms to adopt digital tools effectively. Without such support, disparities in ESG compliance readiness across company sizes may persist, leading to fragmented industry practices.

4.6.3.2 Challenges of Integrating Digital Technologies in ESG Compliance

A Kruskal–Wallis test was conducted to examine whether perceptions of the challenges of integrating digital technologies in ESG compliance differ across company sizes. The results showed that none of the challenges recorded p-values below 0.05, indicating no statistically significant difference across groups. Therefore, the null hypothesis (H_0) is failed to rejected. This suggests that companies, regardless of size, share similar views on the challenges associated with adopting digital technologies for ESG compliance.

4.6.3.3 Strategies for Leveraging Digital Technologies in ESG Compliance

The following hypotheses were formulated:

Null hypothesis (H_0): There is no significant difference across company sizes in their perceptions of strategies for leveraging digital technologies in ESG compliance.

Alternative hypothesis (H_1): There is a significant difference across company sizes in their perceptions of strategies for leveraging digital technologies in ESG compliance.

Table 4.28: Kruskal-Wallis Test Results: Strategies for Leveraging Digital Technologies in ESG Compliance Across Company Size.

Code	Strategies	Kruskal-Wallis H	Asymp. Sig.
ST1	Develop a robust digital framework that integrates technologies.	13.779	0.003
ST2	Standardize ESG data collection and reporting using digital technologies.	9.037	0.029
ST3	Implement cybersecurity measures, such as encryption, multi-factor authentication, secure Virtual Private Networks (VPNs) and regular security audits.	19.956	0.000
ST7	Establish digital ESG performance evaluation mechanisms.	18.072	0.000
ST8	Automate ESG data collection and reporting, reduces manual work.	29.697	0.000

Table 4.28 presents the Kruskal-Wallis test results on company size in relation to strategies for leveraging digital technologies. The findings indicate that five strategies, namely **ST1** (“Develop a robust digital framework that integrates technologies”), **ST2** (“Standardize ESG data collection and reporting using digital technologies”), **ST3** (“Implement cybersecurity measures, such as encryption, multi-factor authentication, secure Virtual Private Networks (VPNs) and regular security audits”), **ST7** (“Establish digital ESG performance evaluation mechanisms”), and **ST8** (“Automate ESG data collection and reporting, reduces manual work”), all recorded p-values below 0.05. Their chi-square values also exceeded the critical value of 7.815, confirming statistically significant differences in perceptions across company sizes. Therefore, the null hypothesis (H_0) is rejected for all five strategies.

Table 4.29: Mean Rank on Strategies for Leveraging Digital Technologies in ESG Compliance Across Company Size.

Code	Strategies	Company Size	N	Mean Rank
ST1	Develop a robust digital framework that integrates technologies.	*Micro*	*1*	*26.00*
		Small	22	41.00
		Medium	50	60.29
		Large	**44**	**67.28**

Table 4.29: (Con'd)

Code	Strategies	Company Size	N	Mean Rank
ST2	Standardize ESG data collection and reporting using digital technologies.	*Micro*	*1*	*27.50*
		Small	22	44.43
		Medium	50	60.05
		Large	**44**	**65.81**
ST3	Implement cybersecurity measures, such as encryption, multi-factor authentication, secure Virtual Private Networks (VPNs) and regular security audits.	**Micro**	**1**	**90.50**
		Small	*22*	*39.05*
		Medium	50	55.03
		Large	44	72.77
ST7	Establish digital ESG performance evaluation mechanisms.	*Micro*	*1*	*34.00*
		Small	22	39.89
		Medium	50	56.32
		Large	**44**	**72.17**
ST8	Automate ESG data collection and reporting, reduces manual work.	Micro	1	34.50
		Small	*22*	*34.43*
		Medium	50	55.23
		Large	**44**	**76.13**

Note: **Bold** indicates the highest mean rank

Italic indicates the lowest mean rank

Table 4.29 further illustrates the mean rank distribution across company sizes. For **ST1** and **ST2**, large companies recorded the highest mean ranks (67.28 and 65.81, respectively), indicating that they place the greatest emphasis on building robust digital frameworks and standardizing ESG reporting. In contrast, the smallest companies (less than 5 employees) consistently recorded the lowest mean ranks, suggesting limited prioritization of such strategies.

A similar pattern is evident for **ST3** (cybersecurity measures), where larger companies scored substantially higher (mean rank = 72.77) compared to micro-sized firms (39.05). Notably, the single firm under the "less than 5 employees" category reported an exceptionally high mean rank (90.50), which may reflect outlier bias rather than a generalizable trend. This reinforces that mid-to-large firms perceive cybersecurity as a more critical enabler of digital ESG compliance.

For **ST7** (digital ESG performance evaluation) and **ST8** (automation of ESG data collection and reporting), larger companies again reported the highest mean ranks (72.17 and 76.13, respectively). This reflects their stronger reliance on systematic monitoring and automation to manage complex ESG obligations across multiple projects and operations. Smaller firms (less than 30 employees) ranked these strategies the lowest, underscoring their limited resources and capacity to implement advanced digital mechanisms.

Overall, the results suggest that company size significantly influences the perceived importance of strategies for digital ESG compliance. Larger firms prioritize robust frameworks, standardization, cybersecurity, performance evaluation, and automation because they face greater regulatory scrutiny, investor expectations, and reporting complexities. This aligns with Ding et al. (2024) and Zhou, Yuan and He (2025), who noted that digital transformation in ESG is often resource-intensive, favoring organizations with greater financial and technical capacity. Conversely, smaller firms tend to underemphasize these strategies, consistent with Liou, Liu and Huang (2023), who found that SMEs often encounter cost, expertise, and awareness barriers in adopting ESG digitalization.

In conclusion, while larger companies are better positioned to leverage digital technologies for ESG compliance, policy interventions, industry collaborations, and targeted support mechanisms are needed to ensure that SMEs can also build digital ESG capacity. Without such support, disparities in ESG reporting practices may persist, undermining the comparability and integrity of sustainability disclosures across the construction sector.

4.7 Spearman's Correlation Test

This section presents the findings of the Spearman's correlation analysis, which examines the relationships between the roles of digital technology (Section B), the challenges of integrating digital technologies (Section C), and the strategies for leveraging digital technologies in ESG compliance (Section D).

4.7.1 Roles of Digital Technology and Challenges of Integrating Digital Technologies in ESG Compliance

Table 4.30 presents the correlations between the roles of digital technology and the challenges of integrating digital technologies in ESG compliance. A total of 64 significant correlations were identified. Each role of digital technology had between 1 to 7 significant correlations with the challenges. Most challenges had significant correlations with one or more roles of digital technology, except for Technical barriers such as system integration challenges with existing infrastructure (**CH1**) and Lack of skilled workforce and insufficient training programs (**CH5**), which showed no significant correlations.

Among the roles, the most substantial correlations were observed in **SC4**: Digital technologies support diversity, equity, and inclusion monitoring by enabling fair, transparent human resources practices, and **SC3**: Digital technologies improve stakeholder engagement through transparency and real-time communication, with 7 and 6 significant correlations, respectively. These roles demonstrate the crucial function of digital technologies in improving ESG compliance by enabling transparency, accountability, and inclusivity. For instance, digital platforms for diversity, equity, and inclusion monitoring (**SC4**) ensure fair and equitable human resource practices by tracking workforce demographics, promoting unbiased decision-making, and supporting inclusive policies, which is consistent with the findings of Faruk (2024). Likewise, stakeholder engagement tools (**SC3**) facilitate real-time communication between project teams, regulatory authorities, and other stakeholders, enhancing collaboration and transparency, as highlighted by Suvvari and Saxena (2023) and Osinakachukwu et al. (2024).

The most pervasive challenges were **CH2**: Regulatory and policy challenges and **CH6**: Cybersecurity and data privacy risks, each with 13 significant correlations, followed closely by **CH7**: Lack of standardized ESG data formats and reporting frameworks with 12 correlations. Regulatory inconsistency (**CH2**) limits the effective deployment of digital tools for ESG compliance due to varying standards, fragmented reporting requirements, and policy gaps, which is supported by the work of Tonello (2025). Cybersecurity and data privacy risks (**CH6**) pose additional barriers, particularly as sensitive ESG data is stored, shared, and analyzed digitally, increasing vulnerability to breaches, as noted by Layode et al. (2024). Furthermore, lack of standardized data formats (**CH7**) complicate interoperability, diminish the reliability of ESG monitoring outputs, and hinder informed decision-making, as emphasized by Cardillo and Basso (2024).

The highest correlation, with a ρ-value of 0.442, was found between **EC2**: Digital technologies support sustainable material sourcing and **CH2**:

Regulatory and policy challenges. This indicates that while digital technologies improve traceability and resource optimization, regulatory inconsistencies and lack of standardization hinder their full potential in ESG compliance. Sustainable material sourcing relies on accurate reporting and adherence to environmental regulations, yet variations in national or local ESG standards, coupled with disclosure limitations, can limit the effectiveness of these digital interventions (Tonello, 2025). Consequently, organizations must navigate complex regulatory landscapes to fully leverage digital technologies for ESG outcomes.

Similarly, **GC5**: Digital technologies enable real-time policy implementation and monitoring also demonstrated a high correlation of 0.442 with **CH2**: Regulatory and policy challenges. The integration of digital technologies for monitoring ESG compliance allows organizations to track policies in real time, improve coordination, and ensure safety compliance. However, the presence of inconsistent regulations and incomplete policy guidance presents significant obstacles, potentially limiting the capacity of these tools to guarantee compliance and efficient resource management (Davier et al., 2023). This underscores the importance of harmonized ESG standards and transparent reporting frameworks to maximize the benefits of digital monitoring.

The third-highest correlation, with a ρ-value of 0.429, was observed between **SC4**: Digital technologies support diversity, equity, and inclusion monitoring and **CH8**: Poor data quality and limited access to reliable ESG data. Digital tools facilitate fair and transparent human resource practices, enabling organizations to monitor diversity, equity, and inclusion effectively. Nevertheless, poor data quality and limited availability of accurate ESG-related information can significantly undermine the ability to track and evaluate diversity, equity, and inclusion metrics. Ensuring robust data collection processes, reliable reporting mechanisms, and accessible datasets is therefore critical to fully realizing the potential of digital technologies in promoting inclusive and responsible organizational practices (Bernardo et al., 2024).

These findings demonstrate that while digital technologies play a pivotal role in enhancing ESG compliance by improving traceability, transparency, stakeholder engagement, policy monitoring, and equitable practices, several challenges must be addressed to fully leverage these technologies. Regulatory harmonization, robust cybersecurity measures, standardized ESG reporting formats, and enhanced data quality are essential to maximize the potential of digital solutions in ESG compliance.

Table 4.30: Correlation between Role of Digital Technology and Challenges of Integrating Digital Technologies in ESG Compliance.

Roles / Challenges	EC1	EC2	EC3	EC4	EC5	SC1	SC2	SC3	SC4	SC5	GC1	GC2	GC3	GC4	GC5	Total Correlations
CH1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
CH2	.367**	.442**	.275**	.322**	.234*	-	.371**	.422**	.392**	.294**	.399**	.358**	.221*	-	.442**	**13**
CH3	-	-	-	-	-	-	-	.185*	.284**	-	-	-	-	-	-	**2**
CH4	-	.193*	-	-	-	-	-	-	-	-	-	-	-	-	-	**1**
CH5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0**
CH6	.381**	.361**	.296**	.217*	.278**	-	.314**	.311**	.314**	.278**	.250**	.226*	.408**	-	.275**	**13**
CH7	.224*	.305**	-	.256**	.274**	-	.236*	.251**	.243**	.326**	.281**	.331**	.275**	-	.348**	**12**
CH8	.229*	-	.189*	.200*	.211*	-	-	.255**	.429**	.200*	.249**	.233*	.216*	-	.218*	**11**
CH9	.190*	.265**	-	.302**	-	-	.241**	.237*	.294**	.210*	-	-	.224*	-	.306**	**9**
CH10	-	-	-	-	-	-.205*	-	-	.201*	-	-	-	-	-.186*	-	**3**
Total correlations	**5**	**5**	**3**	**5**	**4**	**1**	**4**	**6**	**7**	**5**	**4**	**4**	**5**	**1**	**5**	

Note. **. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.7.2 Roles of Digital Technology and Strategies for Leveraging Digital Technologies in ESG Compliance

Table 4.31 presents the correlations between the roles of digital technology and strategies for leveraging digital technologies in ESG compliance. A total of 125 significant correlations were identified, with each role showing between 4 and 9 significant correlations with various strategies. Similarly, most strategies were significantly correlated with multiple roles of digital technology, indicating the intertwined relationship between technological capabilities and strategic implementation for ESG outcomes.

Among the roles, the most substantial correlations were observed in **EC1–EC5**, **SC2**, **SC5**, **GC1**, **GC2**, **GC4**, and **GC5**, each with 9 significant correlations. These findings highlight the centrality of environmental monitoring, sustainable sourcing, energy efficiency, waste reduction, skills development, and governance-related functions such as transparency, accountability, and regulatory reporting in ESG digitalization. For instance, digital platforms for carbon footprint tracking (**EC1**) and energy efficiency monitoring (**EC3**) enable organizations to reduce emissions and optimize energy use, thereby aligning with global sustainability targets, as emphasized by Bhatia et al. (2024) and Mondal et al. (2023). Similarly, digital tools for workforce training and upskilling (**SC5**) support the development of industry-ready skills, ensuring that employees can adapt to Industry 4.0 requirements, consistent with the findings of Mhaske et al. (2025). Governance-focused roles such as blockchain-enabled audit trails (**GC4**) and AI-supported risk management (**GC2**) enhance transparency, accountability, and regulatory compliance, in line with the work of Thanasas, Kampiotis and Karkantzou (2025) and Alevizos (2025). Collectively, these roles demonstrate that digital technologies are not isolated tools but integrated enablers of ESG compliance, strengthening both operational efficiency and strategic sustainability outcomes.

On the strategy side, **ST1**: Developing a robust digital framework, **ST7**: Establishing ESG performance evaluation mechanisms, and **ST8**: Automating ESG data collection and reporting recorded the highest number of correlations (15 each). These strategies represent foundational enablers of ESG digitalization, ensuring that technologies are not only deployed but also systematically integrated, evaluated, and automated to maximize efficiency and minimize manual intervention. Such findings echo prior research emphasizing that robust frameworks, evaluation systems, and automation are indispensable for the success of digital ESG integration (Ikram, 2025).

The strongest individual correlation was identified between **EC3**: Digital technologies improve energy efficiency through real-time monitoring and predictive management and **ST8**: Automating ESG data collection and reporting (ρ = 0.657). This highlights the complementary relationship between automation and energy management, where real-time, automated data collection enhances the accuracy and timeliness of efficiency monitoring. Automating these processes reduces human error, minimizes reporting delays, and supports predictive management, thereby strengthening sustainability outcomes. This aligns with the findings of Khan et al. (2025), who emphasize that automation in ESG data management significantly improves the reliability of energy efficiency strategies by enabling continuous monitoring and predictive analytics.

The second-highest correlation was observed between **EC5**: Digital technologies support environmental impact monitoring and **ST1**: Developing a robust digital framework (ρ = 0.653). This finding underscores that effective environmental monitoring depends heavily on an integrated and well-structured digital infrastructure. Without a robust framework, data fragmentation and poor interoperability could undermine the effectiveness of monitoring systems. This is consistent with the work of Santarius et al. (2023), who highlight the importance of holistic digital ecosystems for sustainability monitoring.

The third-highest correlation was recorded between **EC5**: Environmental impact monitoring and **ST2**: Standardizing ESG data collection and reporting (ρ = 0.622). This correlation emphasizes the critical role of standardization in ensuring that environmental data is reliable, comparable, and actionable. In the absence of standardized processes, inconsistencies in ESG data can limit the effectiveness of monitoring, reducing the capacity of organizations to meet compliance requirements and align with global benchmarks (Rangel, Batista, and Macedo, 2024).

Overall, the results demonstrate that digital technologies contribute to ESG compliance most effectively when paired with strong enabling strategies. Automation, framework development, and standardization emerge as pivotal strategies that amplify the potential of digital roles in energy efficiency, environmental monitoring, and governance. By embedding these strategies into ESG digitalization efforts, organizations can enhance transparency, streamline reporting, and strengthen compliance with regulatory and sustainability standards.

Table 4.31: Correlation between Roles of Digital Technology and Strategies for Leveraging Digital Technologies in ESG Compliance.

Strategies \ Roles	EC1	EC2	EC3	EC4	EC5	SC1	SC2	SC3	SC4	SC5	GC1	GC2	GC3	GC4	GC5	Total Correlations
ST1	.620**	.459**	.585**	.423**	.653**	.372**	.438**	.297**	.382**	.510**	.328**	.482**	.594**	.370**	.518**	**15**
ST 2	.544**	.421**	.567**	.386**	.622**	.371**	.405**	.287**	-	.433**	.377**	.440**	.430**	.463**	.470**	**14**
ST 3	.474**	.412**	.464**	.395**	.381**	.269**	.301**	-	-	.272**	.432**	.429**	.528**	.360**	.343**	**13**
ST 4	.332**	.317**	.202*	.359**	.483**	-	.380**	.473**	.289**	.273**	.456**	.340**	.284**	.444**	.396**	**14**
ST 5	.290**	.321**	.278**	.201*	.279**	.212*	.189*	.214*	-	.227*	.271**	.253**	.206*	.331**	.296**	**14**
ST 6	.435**	.437**	.445**	.321**	.410**	.400**	.308**	-	-	.433**	.269**	.388**	.360**	.280**	.319**	**13**
ST 7	.574**	.530**	.378**	.521**	.538**	.290**	.418**	.296**	.417**	.517**	.440**	.520**	.462**	.484**	.483**	**15**
ST 8	.609**	.487**	.657**	.523**	.587**	.350**	.358**	.201*	.266**	.448**	.494**	.571**	.584**	.493**	.520**	**15**
ST 9	.362**	.295**	.294**	.433**	.323**	.295**	.234*	-	-	.259**	.289**	.415**	-	.393**	.394**	**12**
Total correlations	**9**	**9**	**9**	**9**	**9**	**8**	**9**	**6**	**4**	**9**	**9**	**9**	**8**	**9**	**9**	

Note. **. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.7.3 Challenges of Integrating Digital Technologies and Strategies for Leveraging Digital Technologies in ESG Compliance

Table 4.32 presents the correlations between the challenges of integrating digital technologies and the strategies for leveraging them in ESG compliance. A total of 21 significant correlations were identified. Each challenge had between 0 to 6 significant correlations, while strategies ranged between 0 to 4 correlations. This indicates that although the alignment between challenges and strategies is not as extensive as in the roles dimension, several key relationships highlight pathways for addressing barriers to ESG digitalization.

Among the challenges, **CH7**: Lack of standardized ESG data formats and reporting frameworks exhibited the highest number of significant correlations (6), followed by **CH2**: Regulatory and policy challenges (4) and **CH10**: Resistance from management and employees due to cultural misalignment or fear of change (4). These results emphasize that data standardization, regulatory inconsistencies, and cultural resistance remain central issues in digital ESG adoption. The findings are consistent with prior studies highlighting that fragmented standards and regulatory divergence complicate ESG reporting (Nipper, Ostermaier and Theis, 2025), while organizational inertia and employee resistance often delay technology adoption (Zhang, Kathy and Xu, 2024).

On the strategy side, **ST1**: Developing a robust digital framework, **ST3**: Implementing cybersecurity measures, **ST4**: Promoting public-private partnerships and industry consortia, and **ST8**: Automating ESG data collection and reporting each recorded four significant correlations, suggesting these approaches are widely applicable in addressing multiple barriers. For instance, automation (**ST8**) directly supports the resolution of data-related challenges by minimizing manual inputs, reducing reporting inconsistencies, and enhancing efficiency, as also noted by Bedford et al. (2025). Similarly, robust cybersecurity protocols (**ST3**) are increasingly recognized as critical enablers of ESG digitalization, protecting sensitive data and ensuring compliance in line with Tan, Hashim and Zheng (2025).

The strongest correlation was observed between **CH6**: Cybersecurity and data privacy risks and **ST3**: Implementing cybersecurity measures, with a ρ-value of 0.374. This finding underscores the critical need to align digital ESG initiatives with robust data security practices. Cybersecurity risks represent a significant barrier to digital adoption in ESG reporting, as the storage, processing, and transmission of sensitive ESG-related data increase exposure to breaches and unauthorized access (Hariyani, Hariyani and Mishra, 2025). The implementation of advanced measures such as encryption, multi-factor authentication, secure Virtual Private Networks, and continuous security audits (Flowerday, Blundell and Solms, 2006) directly mitigates these risks by safeguarding organizational and stakeholder information. As highlighted by Balboni and Francis (2024), ensuring data security is not only a compliance requirement but also a prerequisite for building trust among stakeholders, thereby enhancing the credibility and effectiveness of digital ESG systems.

The second-highest correlation (ρ = 0.298) was also associated with cybersecurity, linking **CH6** and **ST4**: Promoting public-private partnerships and industry consortia. This finding suggests that collaboration across industries and with public institutions enhances the collective capacity to mitigate cyber risks. Shared knowledge, standardized practices, and joint investment in security infrastructure can reduce exposure to threats and improve ESG data protection (Trocoso et al., 2022).

The third-highest correlation (ρ = 0.282) was found between **CH2**: Regulatory and policy challenges and **ST4**: Promoting public-private partnerships and industry consortia. This demonstrates that collaborative platforms can also help navigate fragmented policy environments by fostering dialogue between regulators, industries, and civil society, leading to more consistent ESG frameworks and improved compliance (Paton, 2006).

Overall, these results underscore the interdependence of challenges and strategies in ESG digitalization. The persistence of regulatory inconsistencies, data standardization issues, and cultural resistance highlights the need for integrated solutions. Effective responses include the development of robust digital frameworks, cross-sector collaborations, automation of ESG processes, and implementation of advanced cybersecurity measures. Addressing these dimensions concurrently can accelerate the effective use of digital technologies in ESG compliance, ensuring organizations achieve both operational efficiency and long-term sustainability objectives.

Table 4.32: Correlation between Challenges of Integrating Digital Technologies and Strategies for Leveraging Digital Technologies in ESG Compliance.

Challenges / Strategies	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10	Total Correlations
ST1	-	-	-	-	-	.241**	.237*	.217*	-	-.222*	**4**
ST 2	-	-	-.230*	-	-	-	-	-	-	-.275**	**2**
ST 3	-	.229*	-	-	-	.374**	.197*	-	-	-.191*	**4**
ST 4	-	.282**	-	-	-	.298**	.193*	.205*	-	-	**4**
ST 5	-	-	-	-	-	-	-	-	-	-	**0**
ST 6	-	-	-	-	-	-	.246**	-	-	-	**1**
ST 7	-	.186*	-	-	-	-	.205*	-	-	-	**2**
ST 8	-	.241**	-.200*	-	-	-	.224*	-	-	-.201*	**4**
ST 9	-	-	-	-	-	-	-	-	-	-	**0**
Total correlations	**0**	**4**	**2**	**0**	**0**	**3**	**6**	**2**	**0**	**4**	

Note. **. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

4.8 Summary of Chapter

This chapter analysed the survey responses of 117 construction professionals in the Klang Valley to examine the role of digital technologies in ESG compliance. The reliability of the dataset was validated using Cronbach's Alpha, and descriptive analysis highlighted that worker training, upskilling, and safety monitoring were seen as the most critical digital applications, whereas diversity and inclusion received less emphasis. High implementation costs and the lack of skilled personnel were identified as the most significant challenges, while strategies such as skills training and government incentives were prioritised over partnerships and cybersecurity initiatives.

Inferential analyses revealed significant differences in perceptions across professional backgrounds, work experience, company size, and organisational hierarchy. Design-oriented professionals and senior leaders placed greater importance on technology adoption, while cost professionals and smaller firms highlighted financial and technical barriers. The Kruskal-Wallis and Mann-Whitney U tests showed that company business activity and individual seniority influenced views on both challenges and strategies. Spearman's correlation further demonstrated strong alignment between the perceived role of digital technologies and the strategies for adoption. Overall, the findings suggest that while digitalisation is widely recognised as essential for ESG compliance, targeted interventions such as capacity-building, supportive policies, and industry standards are necessary to address sectoral differences and enable more consistent implementation.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter concludes the study by outlining the accomplishment of the research objectives. It further presents the key findings, contributions, limitations, and recommendations of the research, followed by a brief summary of the chapter.

5.2 The Accomplishment of Research Objectives

The aim of this study was to explore how digital technologies can enhance ESG compliance in the construction industry. To achieve this, three objectives were established: (i) to examine the role of digital technology in enhancing ESG compliance, (ii) to analyse the challenges associated with its adoption, and (iii) to propose strategies to support effective integration. The following sub-sections revisit each objective, presenting how they were accomplished based on evidence from the literature review and the findings of the quantitative analyses, including the Arithmetic Mean Test, Mann-Whitney U Test, Kruskal-Wallis Test, and Spearman's Correlation Test.

5.2.1 Objective 1: To explore the role of digital technology in enhancing ESG compliance within the construction industry.

The initial objective was addressed through a combination of literature synthesis and survey analysis involving construction professionals in Klang Valley. From the literature, fifteen distinct roles of digital technologies were identified under the three ESG pillars: environmental, social, and governance.

The Arithmetic Mean Test was applied to rank the roles of digital technology in ESG compliance. Results showed that "Digital technologies enhance the training and upskilling of construction workers, supporting skills development and the adoption of Industry 4.0" (SC5) was ranked the highest, followed by "Digital technologies enhance worker safety and well-being by health tracking, hazard detection, and risk prediction" (SC1). In contrast, "Digital workforce management tools ensure fair labor practices, compliance and transparent working conditions" (SC2) and "Digital technologies support diversity, equity, and inclusion monitoring by enabling fair, transparent human resources practices" (SC4) were ranked lowest.

The Mann-Whitney U Test revealed profession-based differences. Architects and Engineers placed greater importance on environmental impact monitoring (EC5) and worker safety (SC1), reflecting their stronger involvement in design, planning, and site-level applications. Conversely, Quantity Surveyors and other cost- or contract-focused professionals emphasized reporting and governance-related roles, indicating a stronger focus on compliance and documentation. No significant differences were found across experience levels, suggesting that perceptions of digital technologies in ESG compliance are consistent regardless of seniority.

The Kruskal-Wallis Test identified differences across organizational positions and firm sizes. Directors and Assistant Directors consistently gave higher ranks to roles such as EC1 = "Real-time carbon footprint tracking" and GC1 = "AI and Blockchain for regulatory reporting," demonstrating stronger recognition of digital technologies as enablers of ESG compliance. In contrast, junior and senior executives showed more moderate views, while the "Others" group ranked these roles lowest. Similarly, large firms with over 75 employees placed higher emphasis on monitoring and compliance roles such as EC1 and EC5, reflecting stronger regulatory and stakeholder pressures. Micro firms with fewer than five employees ranked lowest, particularly on roles like SC3 = "Stakeholder engagement" and GC1 = "Regulatory reporting," underscoring their limited capacity to adopt advanced digital tools.

Finally, the Spearman's Correlation Test revealed strong associations between the roles of digital technologies and ESG strategies. The highest correlation was observed between EC3: "Digital technologies improve energy efficiency through real-time monitoring and predictive management" and ST8: "Automating ESG data collection and reporting" ($\rho = 0.657$). This finding highlights the complementary relationship between automation and energy management, where automated data collection ensures accuracy, timeliness, and continuous monitoring, thereby reducing errors, enabling predictive management, and strengthening sustainability outcomes.

Overall, these results demonstrate that digital technologies play a vital role in enhancing ESG compliance in the construction industry. While workforce skills development and safety are viewed as top priorities, broader social concerns remain underemphasized. Moreover, differences across professions, organizational hierarchies, and firm sizes indicate that adoption and prioritization are shaped by professional responsibilities, leadership perspectives, and organizational resources. Collectively, these findings confirm the attainment of Objective 1.

5.2.2 Objective 2: To analyse the challenges associated with leveraging digital technologies into ESG compliance in the construction industry.

The second objective was fulfilled through a combination of literature synthesis and survey analysis involving construction professionals in Klang Valley. Ten key challenges to digital technology adoption in ESG compliance were identified from literature review.

The Arithmetic Mean Test ranked "High implementation and maintenance costs" (CH4) as the most critical challenge, followed by "Lack of skilled workforce and insufficient training programs" (CH5). In contrast, "Poor data quality and limited access to reliable ESG data" (CH8) and "Resistance from management and employees due to cultural misalignment or fear of change" (CH10) received the lowest mean ranks.

The Mann-Whitney U Test revealed both profession- and experience-based differences. Quantity Surveyors and other cost-focused professionals emphasized financial and cultural barriers such as CH4 and CH10, consistent with their roles in budgeting, procurement, and compliance. Conversely, Architects and Engineers placed less emphasis on these challenges, likely reflecting their design and site-oriented responsibilities. Experience level also influenced perceptions, as respondents with 10 years or less experience consistently rated technical, financial, and data-related challenges including CH1, CH3, CH4, CH5, and CH8 as more significant compared to senior professionals. This suggests that younger practitioners are more sensitive to operational-level obstacles.

The Kruskal-Wallis Test showed significant differences across organizational positions but not across firm sizes. Managers and team leaders ranked CH10 ("Resistance from management and employees") as the most critical challenge, while Directors and Assistant Directors rated it lower, reflecting their strategic rather than operational focus. Junior and senior executives held intermediate views, and the "Others" group reported the highest mean ranks, though its sample size was limited. The absence of differences across firm sizes suggests that organizations of all scales, from micro to large, face similar barriers in digital ESG adoption.

Finally, the Spearman's Correlation Test revealed strong associations between challenges and strategies for leveraging digital technologies. The highest correlation was observed between CH6: "Cybersecurity and data privacy risks" and ST3: "Implementing cybersecurity measures" ($\rho = 0.374$). This highlights the critical need to align digital ESG initiatives with robust security protocols, where measures such as encryption, multi-factor authentication, and continuous security audits directly mitigate risks, strengthen stakeholder trust, and enhance the credibility of ESG systems.

Overall, these findings demonstrate that cost, workforce capacity, and system integration represent the most pressing barriers, while cultural resistance and data quality remain secondary but noteworthy. The analysis also shows that perceptions vary across professions, experience levels, and organizational hierarchies, reflecting the diverse realities of ESG digitalization in construction. Collectively, these results confirm that Objective 2 has been achieved.

5.2.3 Objective 3: To propose relevant strategies for leveraging digital technologies to enhance ESG compliance in the construction industry.

The third objective was achieved through a combination of literature synthesis and survey analysis involving construction professionals in Klang Valley. Nine key strategies for leveraging digital technologies in ESG compliance were identified from literature review.

The Arithmetic Mean Test ranked "Invest in ESG digital skills training" (ST6) as the most critical strategy, followed by "Provide government incentives for digital ESG adoption" (ST5). In contrast, "Implement cybersecurity measures" (ST3) and "Promote public-private partnerships and industry consortia" (ST4) received the lowest mean ranks.

The Mann-Whitney U Test revealed both profession- and experience-based differences in perceptions of digital ESG strategies. Architects and Engineers consistently emphasized systematic digital approaches such as developing robust frameworks (ST1), standardizing data collection (ST2), establishing evaluation mechanisms (ST7), and automating reporting (ST8), reflecting their design and technology integration roles. In contrast, Quantity Surveyors and other cost-focused professionals placed lower importance on these strategies, aligning with their stronger orientation toward financial feasibility and governance considerations. Experience level also shaped perceptions: respondents with more than 10 years of experience placed greater value on collaborative strategies such as public-private partnerships and industry consortia (ST4), while less experienced practitioners prioritized operational and organizational-level digital solutions. These findings suggest that professional background and seniority influence whether practitioners emphasize technical integration or collaborative frameworks in advancing ESG digitalization.

The Kruskal-Wallis Test further revealed significant differences across organizational positions and firm sizes. Directors and Assistant/Technical Directors ranked ST1 ("Develop a robust digital framework that integrates technologies") the highest, consistent with their strategic oversight responsibilities, whereas junior executives, managers, and supervisors ranked it lower, reflecting their operational focus. Similarly, larger firms (with more than 75 employees) consistently assigned higher mean ranks to strategies such as digital frameworks, standardization, cybersecurity, performance evaluation, and automation, while smaller firms, particularly those with fewer than 30 employees, reported the lowest rankings due to resource and capacity constraints.

The Spearman's Correlation Test identified notable associations between challenges and strategies for leveraging digital technologies in ESG compliance. The strongest relationship was observed between CH6: "Cybersecurity and data privacy risks" and ST3: "Implementing cybersecurity measures" ($\rho = 0.374$), highlighting the necessity of embedding robust security protocols into ESG digital initiatives. Advanced practices such as encryption, multi-factor authentication, secure networks, and continuous security audits are essential to mitigate risks, safeguard sensitive data, build stakeholder trust, and enhance the overall credibility of digital ESG systems.

Overall, these findings demonstrate that while workforce training, policy incentives, and robust digital frameworks are prioritized by construction professionals, cybersecurity measures and collaborative partnerships remain essential to ensure long-term resilience and inclusivity in ESG digital adoption. Moreover, differences across professions, experience levels, organizational hierarchies, and firm sizes emphasize that strategies must be tailored to diverse industry needs and capacities. Collectively, these results confirm that Objective 3 has been successfully achieved.

5.3 Research Contributions

This study contributes significantly to the construction industry by examining how digital technologies can enhance ESG compliance within Malaysia, particularly in the Klang Valley. It provides practical insights for construction professionals, property developers, and industry stakeholders such as the CIDB and the Ministry of Works. By exploring the role of technologies including AI, Blockchain, Big Data Analytics, and the IoT, the research demonstrates how these tools can improve ESG performance through more efficient data management, automation of reporting processes, and enhanced transparency in compliance efforts. The study highlights how firms can align digital adoption with ESG goals to improve operational efficiency and sustainability outcomes.

The research also offers value to government agencies and policymakers, including the Ministry of Local Government Development and the Department of Environment. It outlines the key challenges facing digital ESG integration, such as regulatory inconsistencies, high implementation costs, and digital skills gaps. These findings can inform the development of strategic policies, regulatory reforms, and support programs to foster wider adoption of ESG-compliant digital solutions. Recommendations for strengthening public-private collaboration, incentivizing digital transformation, and investing in workforce training can help policymakers shape a more robust ESG landscape across the construction sector.

From an academic perspective, the study fills a critical gap in existing literature by combining ESG compliance and digital technology in an integrated framework. While prior research has often treated these areas in isolation, this study provides a holistic view of how digital tools support ESG implementation across environmental, social, and governance dimensions. By applying statistical analyses such as the Kruskal-Wallis Test and Spearman's Correlation, the research reveals how demographic variables influence perceptions of digital ESG adoption, offering a deeper understanding of stakeholder behaviour. These insights pave the way for further empirical studies and theoretical advancements in ESG-tech integration, especially in emerging markets.

Moreover, the proposed strategies for enhancing ESG compliance through digital technology adoption serve as a foundation for developing implementation roadmaps and performance evaluation mechanisms. These findings are relevant for guiding construction firms in identifying key focus areas and improving ESG practices using digital innovations. The research also assists educators and training institutions in designing curricula that reflect the evolving demands of ESG and digital transformation, preparing future professionals with the competencies needed in a sustainable construction ecosystem.

Overall, the study offers practical, policy, and academic contributions that support the integration of digital technologies in ESG compliance, promoting long-term sustainability, accountability, and innovation within Malaysia's construction industry.

5.4 Research Limitation

Despite its contributions, this study is subject to several limitations that should be acknowledged. First, the research was geographically limited to the Klang Valley region. While Klang Valley is a key construction hub in Malaysia, the perspectives captured in this study may not fully reflect the attitudes and practices of construction professionals in other regions. Different states may have varying levels of digital adoption, ESG awareness, and regulatory enforcement, which could influence the generalisability of the findings to a nationwide context.

Second, the study adopted a purely quantitative research design using structured, close-ended questionnaires. While this approach enabled the collection of measurable and comparable data, it limited the depth and richness of insights. Respondents were restricted to predetermined answer choices, which may have prevented them from fully expressing their views on the integration of digital technologies in ESG compliance. Consequently, the findings may not capture more nuanced or context-specific challenges that could be revealed through qualitative methods such as interviews or case studies.

Third, the data collected relied on self-reported responses, which are inherently susceptible to biases. Respondents may have overestimated or underestimated their organization's level of digital integration or ESG compliance due to social desirability bias, limited understanding of technical terms, or misinterpretation of the questionnaire items. These factors may affect the reliability and accuracy of the responses and, by extension, the conclusions drawn from them.

Fourth, the sample distribution across demographic categories was not entirely balanced. Some groups, such as older professionals or individuals from smaller firms, were underrepresented in the dataset. This uneven distribution may affect the validity of statistical tests like the Kruskal-Wallis and Spearman's correlation, particularly when examining differences or associations across demographic variables.

Lastly, while the study identified key challenges and proposed strategies for enhancing ESG compliance through digital technologies, it did not evaluate the practical feasibility, cost-effectiveness, or implementation barriers of these strategies in real-world settings. Without field validation or longitudinal tracking, the study's strategic recommendations remain theoretical. Future research should incorporate multi-stakeholder perspectives and adopt mixed-method approaches to assess the real-world impact and sustainability of digital ESG initiatives in Malaysia's construction sector.

5.5 Research Recommendation

To enhance the generalisability of future findings, it is recommended that the scope of research be extended beyond the Klang Valley to include construction professionals from other regions in Malaysia, including Sabah, Sarawak, and rural areas. Broader geographic coverage would capture regional variations in ESG awareness, digital adoption, and policy implementation, leading to a more representative understanding of the national construction landscape.

Future research should also consider adopting a mixed-methods approach that combines both quantitative and qualitative methods. While this study relied on structured questionnaires, incorporating interviews or focus group discussions would enable researchers to gather in-depth insights into the experiences, challenges, and motivations of stakeholders in adopting digital ESG solutions. This holistic approach would enhance the richness and depth of the findings.

To ensure the robustness of statistical analyses, future studies should aim for a more balanced demographic distribution among respondents. Uneven representation across age groups, company sizes, or educational backgrounds can affect the accuracy of comparative tests. Stratified sampling techniques and careful monitoring of response rates could help achieve more equitable representation and valid results.

Moreover, it is important for future studies to evaluate the real-world feasibility of the strategies proposed in this study. Pilot programs, industry case studies, or field experiments could assess the practical implementation of digital ESG frameworks, cybersecurity protocols, and training initiatives. This would offer empirical evidence to support or refine the recommendations and guide stakeholders in applying them effectively.

Lastly, longitudinal research is recommended to track how ESG digital adoption evolves over time in response to technological advancements, regulatory shifts, and market dynamics. Such studies would help capture emerging trends, monitor the long-term effectiveness of ESG strategies, and provide updated guidance for sustainable development in Malaysia’s construction sector.

5.6 Summary of Chapter

This chapter has provided a summary of the research objectives, key findings, and contributions of the study. The limitations were acknowledged, and recommendations were provided to guide future research on ESG digitalisation in the Malaysian construction industry.

REFERENCES

Adams, C.A. and Abhayawansa, S. (2022) “Connecting the COVID-19 pandemic, environmental, social and governance (ESG) investing and calls for ‘harmonisation’ of sustainability reporting,” *Critical Perspectives on Accounting*, 82. Available at: https://doi.org/10.1016/j.cpa.2021.102309.

Akanfe, O., Lawong, D. and Rao, H.R. (2024) “Blockchain technology and privacy regulation: Reviewing frictions and synthesizing opportunities,” *International Journal of Information Management*. Available at: https://doi.org/10.1016/j.ijinfomgt.2024.102753.

Alevizos, L. (2025) ‘Automated cybersecurity compliance and threat response using AI, blockchain and smart contracts’, *International Journal of Information Technology* [Preprint]. Available at: https://doi.org/10.1007/s41870-024-02324-9.

Ali, H. (2025) *The role of technology in stakeholder engagement in sustainable project development: trends and implications /*, *Epublications.vu.lt*. Available at: https://epublications.vu.lt/object/elaba:229581638/.

Ali, N.B.M. *et al.* (2025) ‘The Effect of Environmental, Social, and Governance (ESG) Disclosure on the Profitability of Saudi-Listed Firms: Insights from Saudi Vision 2030’, *Sustainability*, 17(7), p. 2977. Available at: https://doi.org/10.3390/su17072977.

Almadadha, R. (2024) ‘Blockchain Technology in Financial Accounting: Enhancing Transparency, Security, and ESG Reporting’, *Blockchains*, 2(3), pp. 312–333. Available at: https://doi.org/10.3390/blockchains2030015.

Annas Vijaya *et al.* (2025) ‘ESGOnt: An ontology-based framework for Enhancing Environmental, Social, and Governance (ESG) assessments and aligning with Sustainable Development Goals (SDG)’, *Resources Environment and Sustainability*, pp. 100262–100262. Available at: https://doi.org/10.1016/j.resenv.2025.100262.

Arowoiya, V.A., Moehler, R.C. and Fang, Y. (2024) “Digital twin technology for thermal comfort and energy efficiency in buildings: A state-of-the-art and future directions,” *Energy and Built Environment*. Available at: https://doi.org/10.1016/j.enbenv.2023.05.004.

Arsecularatne, B.P., Rodrigo, N. and Chang, R. (2024) ‘Review of reducing energy consumption and carbon emissions through digital twin in built environment’, *Journal of Building Engineering*, 98, p. 111150. Available at: https://doi.org/10.1016/j.jobe.2024.111150.

Arshad, A. *et al.* (2023) “A systematic literature review of blockchain technology and environmental sustainability: Status quo and future research,” *International Review of Economics and Finance*, 88. Available at: https://doi.org/10.1016/j.iref.2023.07.044.

Asif, M., Naeem, G. and Khalid, M. (2024) ‘Digitalization for sustainable buildings: Technologies, applications, potential, and challenges’, *Journal of Cleaner Production*, 450, pp. 141814–141814. Available at: https://doi.org/10.1016/j.jclepro.2024.141814.

Asif, M., Searcy, C. and Castka, P. (2023) “ESG and Industry 5.0: The role of technologies in enhancing ESG disclosure,” *Technological Forecasting and Social Change*, 195. Available at: https://doi.org/10.1016/j.techfore.2023.122806.

Awolusi, I., Marks, E. and Hallowell, M. (2018) “Wearable technology for personalized construction safety monitoring and trending: Review of applicable devices,” *Automation in Construction*, 85. Available at: https://doi.org/10.1016/j.autcon.2017.10.010.

Aydoğmuş, M., Gülay, G. and Ergun, K. (2022) “Impact of ESG performance on firm value and profitability,” *Borsa Istanbul Review*. Available at: https://doi.org/10.1016/j.bir.2022.11.006.

Bagrationi, K. and Thurner, T. (2023) “Middle Management’s Resistance to Digital Change,” *Foresight and STI Governance*, 17(2). Available at: https://doi.org/10.17323/2500-2597.2023.2.49.60.

Bai, C., Orzes, G. and Sarkis, J. (2022) “Exploring the impact of Industry 4.0 technologies on social sustainability through a circular economy approach,” *Industrial Marketing Management*, 101. Available at: https://doi.org/10.1016/j.indmarman.2021.12.004.

Balboni, Prof.Dr.P. and Francis, K.E. (2024) ‘Data ethics and digital sustainability: Bridging legal data protection compliance and ESG for a responsible data-driven future’, *Journal of Responsible Technology*, p. 100099. Available at: https://doi.org/10.1016/j.jrt.2024.100099.

Banihashemi, S. *et al.* (2024) “Circular economy in construction: The digital transformation perspective,” *Cleaner Engineering and Technology*. Available at: https://doi.org/10.1016/j.clet.2023.100715.

Bayramoğlu, B. and Gülmez, N. (2024) “The Role of Big Data, Artificial Intelligence, and Robotics in Human Resource Management: A Diversity, Equity, and Inclusion Perspective”, *TABAD Journal*, 1(1), pp. 1–15. Available at: https://tabadjournal.org/ojs/index.php/tbd/article/view/16.

Bedford, D.S. *et al.* (2025) ‘Digitalization of the finance function: Automation, analytics, and finance function effectiveness’, *Management Accounting Research* [Preprint]. Available at: https://doi.org/10.1016/j.mar.2025.100942.

Bernardo, B.M.V. *et al.* (2024) ‘Data governance & quality management—Innovation and breakthroughs across different fields’, *Journal of Innovation & Knowledge*, 9(4), p. 100598. Available at: https://doi.org/10.1016/j.jik.2024.100598.

Bhatia, M. *et al.* (2024) ‘Digital technologies and carbon neutrality goals: An in-depth investigation of drivers, barriers, and risk mitigation strategies’, *Journal of Cleaner Production*, 451, pp. 141946–141946. Available at: https://doi.org/10.1016/j.jclepro.2024.141946.

Boge, K. *et al.* (2021) “Facilitating building projects’ short-term and long-term value creation,” *Buildings*, 11(8). Available at: https://doi.org/10.3390/buildings11080332.

Bokolo, A. *et al.* (2023) “A Framework for Standardization of Distributed Ledger Technologies for Interoperable Data Integration and Alignment in Sustainable Smart Cities,” *Journal of the Knowledge Economy* [Preprint]. Available at: https://doi.org/10.1007/s13132-023-01554-9.

Bortolini, R. *et al.* (2022) “Digital Twins’ Applications for Building Energy Efficiency: A Review,” *Energies*. Available at: https://doi.org/10.3390/en15197002.

Bougie, R. and Sekaran, U. (2019) *Research Methods for Business A Skill-Building Approach Eight Edition, John Wiley &Sons Ltd*.

Brase, C.H. and Brase, C.P. (2009) *Understandable statistics : concepts and methods*, *thuvienso.hoasen.edu.vn*. Houghton Mifflin Company. Available at: https://thuvienso.hoasen.edu.vn/handle/123456789/8911.

Brozovsky, J., Labonnote, N. and Vigren, O. (2024) “Digital technologies in architecture, engineering, and construction,” *Automation in Construction*. Available at: https://doi.org/10.1016/j.autcon.2023.105212.

Cai, C., Tu, Y. and Li, Z. (2023) “Enterprise digital transformation and ESG performance,” *Finance Research Letters*, 58. Available at: https://doi.org/10.1016/j.frl.2023.104692.

Calvard, T.S. and Jeske, D. (2018) “Developing human resource data risk management in the age of big data,” *International Journal of Information Management*, 43. Available at: https://doi.org/10.1016/j.ijinfomgt.2018.07.011.

Cardillo, M.A. dos R. and Basso, L.F.C. (2024) ‘Revisiting knowledge on ESG/CSR and financial performance: A bibliometric and systematic review of moderating variables’, *Journal of Innovation & Knowledge*, 10(1), p. 100648. Available at: https://doi.org/10.1016/j.jik.2024.100648.

Celik, Y., Petri, I. and Rezgui, Y. (2023) “Integrating BIM and Blockchain across construction lifecycle and supply chains,” *Computers in Industry*, 148. Available at: https://doi.org/10.1016/j.compind.2023.103886.

Chen, H. *et al.* (2023) “The Impact of Wearable Devices on the Construction Safety of Building Workers: A Systematic Review,” *Sustainability (Switzerland)*. Available at: https://doi.org/10.3390/su151411165.

Chen, L. *et al.* (2024) ‘Conversion of waste into sustainable construction materials: A review of recent developments and prospects’, *Materials Today Sustainability*, 27, pp. 100930–100930. Available at: https://doi.org/10.1016/j.mtsust.2024.100930.

Chen, R., Meng, Q. and Yu, J.J. (2022) “Optimal government incentives to improve the new technology adoption: Subsidizing infrastructure investment or usage?,” *Omega (United Kingdom)*, 114. Available at: https://doi.org/10.1016/j.omega.2022.102740.

Chen, S. (2024) ‘The Influence of Artificial Intelligence and Digital Technology on ESG Reporting Quality’, *International journal of global economics and management*, 3(1), pp. 301–310. Available at: https://doi.org/10.62051/ijgem.v3n1.36.

Chen, W., Xie, Y. and He, K. (2024) “Environmental, social, and governance performance and corporate innovation novelty,” *International Journal of Innovation Studies*, 8(2). Available at: https://doi.org/10.1016/j.ijis.2024.01.003.

Ciborowska, A., Chakarov, A. and Pandita, R. (2021) ‘Contemporary COBOL: Developers’ Perspectives on Defects and Defect Location’, *2021 IEEE International Conference on Software Maintenance and Evolution (ICSME)* [Preprint]. Available at: https://doi.org/10.1109/icsme52107.2021.00027.

Ciulli, F. *et al.* (2022) “Sustainable business model innovation and scaling through collaboration,” *Environmental Innovation and Societal Transitions*, 45. Available at: https://doi.org/10.1016/j.eist.2022.11.003.

Coleta Eisaqui, D. dela (2023) “Environmental and Social Compliance through the Financial Market: ESG Investments as a Condition for Public-Private Partnerships,” *Beijing Law Review*, 14(03). Available at: https://doi.org/10.4236/blr.2023.143077.

Cranford, R. (2023) “Conceptual application of digital twins to meet ESG targets in the mining industry,” *Frontiers in Industrial Engineering*, 1. Available at: https://doi.org/10.3389/fieng.2023.1223989.

Creswell, J.W. and J. David, C. (2018) *Fifth Edition Research Design Qualitative, QUantitave, and Mixed Methods Approaches, SAGE Publication India Pvt. Ltd*.

Daniel, E.I. *et al.* (2025) ‘The Use of Digital Technologies in Construction Safety: A Systematic Review’, *Buildings*, 15(8), pp. 1386–1386. Available at: https://doi.org/10.3390/buildings15081386.

Das, M. *et al.* (2022) “A blockchain-based integrated document management framework for construction applications,” *Automation in Construction*, 133. Available at: https://doi.org/10.1016/j.autcon.2021.104001.

Davier, von *et al.* (2023) 'We Are Not There Yet: The Implications of Insufficient Knowledge Management for Organisational Compliance', *arXiv (Cornell University)* [Preprint]. Available at: https://doi.org/10.48550/arxiv.2305.04061.

Dicuonzo, G. *et al.* (2019) "RISK MANAGEMENT 4.0: THE ROLE OF BIG DATA ANALYTICS IN THE BANK SECTOR," *International Journal of Economics and Financial Issues*, 9(6). Available at: https://doi.org/10.32479/ijefi.8556.

Diener, F. and Špaček, M. (2021) "Digital transformation in banking: A managerial perspective on barriers to change," *Sustainability (Switzerland)*, 13(4). Available at: https://doi.org/10.3390/su13042032.

Ding, X. *et al.* (2024) 'Enhancing ESG Performance through Digital Transformation: Insights from China's Manufacturing Sector', *Technology in Society*, p. 102753. Available at: https://doi.org/10.1016/j.techsoc.2024.102753.

DuBay, M. and Watson, L.R. (2019) "Translation and cultural adaptation of parent-report developmental assessments: Improving rigor in methodology," *Research in Autism Spectrum Disorders*. Available at: https://doi.org/10.1016/j.rasd.2019.02.005.

Dudek, D. and Kulej-Dudek, E. (2024) 'Modern technologies in ESG reporting - evidence from Polish enterprises', *Procedia Computer Science*, 246, pp. 5359–5367. Available at: https://doi.org/10.1016/j.procs.2024.09.659.

Duran, R.E. and Tierney, P. (2023) "Fintech Data Infrastructure for ESG Disclosure Compliance," *Journal of Risk and Financial Management*, 16(8). Available at: https://doi.org/10.3390/jrfm16080378.

Eccles, R.G., Lee, L.E. and Stroehle, J.C. (2020) "The Social Origins of ESG: An Analysis of Innovest and KLD," *Organization and Environment*, 33(4). Available at: https://doi.org/10.1177/1086026619888994.

Elrifaee, M. *et al.* (2025) 'IoT Contributions to The Safety of Construction Sites: A Comprehensive Review of Recent Advances, Limitations, And Suggestions for Future Directions', *Internet of Things*, p. 101387. Available at: https://doi.org/10.1016/j.iot.2024.101387.

Emmanuel Itodo Daniel *et al.* (2024) 'Barriers to the Application of Digital Technologies in Construction Health and Safety: A Systematic Review', *Buildings*, 14(8), pp. 2386–2386. Available at: https://doi.org/10.3390/buildings14082386.

Enrica Bolognesi *et al.* (2025) 'Stakeholders and regulatory pressure on ESG disclosure', *International Review of Financial Analysis*, pp. 104145–104145. Available at: https://doi.org/10.1016/j.irfa.2025.104145.

Faruq, A T M Omor and Chowdhury, (2025) *Financial Markets and ESG: How Big Data is Transforming Sustainable Investing in Developing* *countries*, *arXiv.org*. Available at: https://arxiv.org/abs/2503.06696 (Accessed: 17 April 2025).

Faruk, F. (2024) 'Create diversity and equality in the workplace through inclusive and fair HR management practices', *International Journal on Social Science, Economics and Art*, 14(1), pp. 54–62. Available at: https://doi.org/10.35335/ijosea.v14i1.466.

Feng, K., Lu, W. and Wang, Y. (2019) "Assessing environmental performance in early building design stage: An integrated parametric design and machine learning method," *Sustainable Cities and Society*, 50. Available at: https://doi.org/10.1016/j.scs.2019.101596.

Florek-Paszkowska, A., Ujwary-Gil, A. and Godlewska-Dzioboń, B. (2021) "Business innovation and critical success factors in the era of digital transformation and turbulent times," *Journal of Entrepreneurship, Management and Innovation*, 17(4). Available at: https://doi.org/10.7341/20211741.

Flowerday, S., Blundell, A.W. and von Solms, R. (2006) "Continuous auditing technologies and models: A discussion," *Computers and Security*, 25(5). Available at: https://doi.org/10.1016/j.cose.2006.06.004.

Gagan Deep (2023) "Digital transformation's impact on organizational culture," *International Journal of Science and Research Archive*, 10(2). Available at: https://doi.org/10.30574/ijsra.2023.10.2.0977.

Gao, Y., Gonzalez, V. and Yiu, T.W. (2018) *The Effectiveness of Traditional Tools and Computer-Aided Technologies for Health and Safety Training in the Construction Sector: A Systematic Review*, *arXiv.org*. Available at: https://doi.org/10.48550/arXiv.1808.02021.

García de Soto, B. *et al.* (2022) "Understanding the Significance of Cybersecurity in the Construction Industry: Survey Findings," *Journal of Construction Engineering and Management*, 148(9). Available at: https://doi.org/10.1061/(asce)co.1943-7862.0002344.

Gorkhali, A. (2022) "Industry 4.0 and Enabling Technologies: Integration Framework and Challenges," *Journal of Industrial Integration and Management*, 7(3). Available at: https://doi.org/10.1142/S2424862222500075.

Graetsch, U.M. *et al.* (2023) 'Dealing with Data Challenges when Delivering Data-Intensive Software Solutions', *arXiv (Cornell University)* [Preprint]. Available at: https://doi.org/10.48550/arxiv.2209.14055.

van Griensven, H., Moore, A.P. and Hall, V. (2014) "Mixed methods research - The best of both worlds?," *Manual Therapy*, 19(5). Available at: https://doi.org/10.1016/j.math.2014.05.005.

Guo, P. *et al.* (2025) 'Does Digital Transformation Improve Manufacturing ESG Performance: Evidence from China', *Sustainability*, 17(16), pp. 7278–7278. Available at: https://doi.org/10.3390/su17167278.

Guo, X. and Pang, W. (2025) ‘The impact of digital transformation on corporate ESG performance’, *Finance Research Letters*, 72, p. 106518. Available at: https://doi.org/10.1016/j.frl.2024.106518.

Hao, P. *et al.* (2024) ‘How do ESG ratings promote digital technology innovation?’, *International Review of Financial Analysis*, 97, p. 103886. Available at: https://doi.org/10.1016/j.irfa.2024.103886.

Hariyani, D., Hariyani, P. and Mishra, S. (2025) ‘The role of leadership in sustainable digital transformation of the organization’, *Sustainable Futures*, 10, p. 101130. Available at: https://doi.org/10.1016/j.sftr.2025.101130.

Harvard Business Review (HBR). (2022). “Digital Transformation Refocused: New Goals Require New Strategies”, by Emily Brand. https://www.redhat.com/rhdc/managed-files/so-hbr-ditigal-transformation-refocused-analyst-material-f31628-202205-en.pdf

Hassan, A.M., Negash, Y.T. and Hanum, F. (2024) “An assessment of barriers to digital transformation in circular Construction: An application of stakeholder theory,” *Ain Shams Engineering Journal*, 15(7). Available at: https://doi.org/10.1016/j.asej.2024.102787.

Heydari, M.H. *et al.* (2024) “Paving the Way for Progress: A Systematic Literature Review on Diversity, Equity, and Inclusion in the AEC Industry,” *Journal of Management in Engineering*, 40(3). Available at: https://doi.org/10.1061/jmenea.meeng-5886.

Hunhevicz, J.J., Motie, M. and Hall, D.M. (2022) “Digital building twins and blockchain for performance-based (smart) contracts,” *Automation in Construction*, 133. Available at: https://doi.org/10.1016/j.autcon.2021.103981.

Hwabamungu, B. and Shepherd, P. (2024) ‘The Influence of Stakeholder Involvement in the Adoption of Digital Technologies in the UK Construction Industry’, *Informatics*, 11(4), p. 97. Available at: https://doi.org/10.3390/informatics11040097.

Ikram Abbes (2025) ‘Strategic pathways for innovation and sustainability in digital transformation: Insights from leading global companies’, *Social Sciences & Humanities Open*, 12, pp. 101906–101906. Available at: https://doi.org/10.1016/j.ssaho.2025.101906.

Inampudi, S. *et al.* (2024) ‘Barriers to implementation of digital transformation in the Indian health sector: a systematic review’, *Humanities and Social Sciences Communications*, 11(1), pp. 1–10. Available at: https://doi.org/10.1057/s41599-024-03081-7.

J, A.K. and Abirami, S. (2018) “Aspect-based opinion ranking framework for product reviews using a Spearman’s rank correlation coefficient method,” *Information Sciences*, 460–461. Available at: https://doi.org/10.1016/j.ins.2018.05.003.

Jin, X.Y. and Mirza, S.S. (2024) "The impact of digitalization on CSR disclosure: a governance perspective," *Journal of Enterprise Information Management*, 37(1). Available at: https://doi.org/10.1108/JEIM-04-2023-0177.

Jorgensen, B.N. and Ma, Z. (2024) 'Towards energy efficient buildings by digital transformation of the building lifecycle', *Energy Informatics*, 7(1). Available at: https://doi.org/10.1186/s42162-024-00405-4.

Kang, A.S. and Hew, S.L. (2025) 'Sustainable ESG practices and smart manufacturing adoption readiness for SME operational agility: The conditional mediating role of financial access', *Sustainable Futures*, 10, pp. 101081–101081. Available at: https://doi.org/10.1016/j.sftr.2025.101081.

Khan, M.I. *et al.* (2025) 'Integrating industry 4.0 for enhanced sustainability: Pathways and prospects', *Sustainable Production and Consumption*, 54. Available at: https://doi.org/10.1016/j.spc.2024.12.012.

Kumar, M. *et al.* (2024) "Moderating ESG compliance between industry 4.0 and green practices with green servitization: Examining its impact on green supply chain performance," *Technovation*, 129. Available at: https://doi.org/10.1016/j.technovation.2023.102898.

Kurniawan, T.A. *et al.* (2022) "Unlocking digital technologies for waste recycling in Industry 4.0 era: A transformation towards a digitalization-based circular economy in Indonesia," *Journal of Cleaner Production*, 357. Available at: https://doi.org/10.1016/j.jclepro.2022.131911.

Kuruneri, J. (2025) 'Exploring the challenges of sustainable procurement implementation: insights from Botswana's public sector', *Frontiers in Sustainability*, 6. Available at: https://doi.org/10.3389/frsus.2025.1645902.

Kwak, S.G. and Kim, J.H. (2017) "Central limit theorem: The cornerstone of modern statistics," *Korean Journal of Anesthesiology*, 70(2). Available at: https://doi.org/10.4097/kjae.2017.70.2.144.

Lagasio, V. (2024) 'ESG-washing detection in corporate sustainability reports', *International Review of Financial Analysis*, 96, p. 103742. Available at: https://doi.org/10.1016/j.irfa.2024.103742.

Layode, N.O. *et al.* (2024) 'Data privacy and security challenges in environmental research: Approaches to safeguarding sensitive information', *International Journal of Applied Research in Social Sciences*, 6(6), pp. 1193–1214. Available at: https://doi.org/10.51594/ijarss.v6i6.1210.

Leclezio, L. *et al.* (2015) "Pilot validation of the tuberous sclerosis-associated neuropsychiatric disorders (TAND) checklist," *Pediatric Neurology*, 52(1). Available at: https://doi.org/10.1016/j.pediatrneurol.2014.10.006.

Lee, J. and Kim, M. (2023) "ESG information extraction with cross-sectoral and multi-source adaptation based on domain-tuned language models," *Expert*

Systems with Applications, 221. Available at: https://doi.org/10.1016/j.eswa.2023.119726.

Lee, S.U. *et al.* (2024) 'Integrating ESG and AI: A Comprehensive Responsible AI Assessment Framework', *arXiv (Cornell University)* [Preprint]. Available at: https://doi.org/10.48550/arxiv.2408.00965.

Leppink, J. (2017) "Revisiting the quantitative–qualitative-mixed methods labels: Research questions, developments, and the need for replication," *Journal of Taibah University Medical Sciences*, 12(2). Available at: https://doi.org/10.1016/j.jtumed.2016.11.008.

Li, B., Duan, Z. and Cai, Q. (2024) 'Exploring the Nexus between Past Financial Performance and Voluntary GRI Adoption: The Role of Environmental Certification', *Finance research letters*, pp. 105656–105656. Available at: https://doi.org/10.1016/j.frl.2024.105656.

Li, L. *et al.* (2023) "Exploring the mechanism of digital transformation empowering green innovation in construction enterprises," *Developments in the Built Environment*, 15. Available at: https://doi.org/10.1016/j.dibe.2023.100199.

Lima, L. *et al.* (2021) "Sustainability in the construction industry: A systematic review of the literature," *Journal of Cleaner Production*. Available at: https://doi.org/10.1016/j.jclepro.2020.125730.

Liou, J.J.H., Liu, P.Y.L. and Huang, S.W. (2023) "Exploring the key barriers to ESG adoption in enterprises," *Systems and Soft Computing*, 5. Available at: https://doi.org/10.1016/j.sasc.2023.200066.

Li, X. *et al.* (2025) 'Integrated BIM-IoT platform for carbon emission assessment and tracking in prefabricated building materialization', *Resources, Conservation and Recycling*, 215, p. 108122. Available at: https://doi.org/10.1016/j.resconrec.2025.108122.

Li, Y. *et al.* (2022) "Effects of Digital Technology Adoption on Sustainability Performance in Construction Projects: The Mediating Role of Stakeholder Collaboration," *Journal of Management in Engineering*, 38(3). Available at: https://doi.org/10.1061/(asce)me.1943-5479.0001040.

Li, Y. *et al.* (2024) 'The Impact of Digital Transformation on ESG performance', *International Review of Economics & Finance*, p. 103686. Available at: https://doi.org/10.1016/j.iref.2024.103686.

Li, Z. *et al.* (2024) 'Supply chain digitalization, green technology innovation and corporate energy efficiency', *Energy Economics*, p. 108153. Available at: https://doi.org/10.1016/j.eneco.2024.108153.

Liu, G. *et al.* (2020) "Real-time carbon emission monitoring in prefabricated construction," *Automation in Construction*, 110. Available at: https://doi.org/10.1016/j.autcon.2019.102945.

Liu, L. *et al.* (2024) "Trust in ESG reporting: The intelligent Veri-Green solution for incentivized verification," *Blockchain: Research and Applications*, 5(2). Available at: https://doi.org/10.1016/j.bcra.2024.100189.

Liu, X. *et al.* (2023) "Data-driven ESG assessment for blockchain services: A comparative study in textiles and apparel industry," *Resources, Conservation and Recycling*, 190. Available at: https://doi.org/10.1016/j.resconrec.2022.106837.

Lop, S. *et al.* (2024) *Building Tomorrow: Shaping The Future of Construction Through The Adoption of Digital Technologies, Malaysian Journal of Sustainable Environment Special issue*, pp. 165–182. Available at: https://ir.uitm.edu.my/id/eprint/107324/1/107324.pdf.

Lu, W. *et al.* (2024) 'Digital technologies for construction sustainability: Status quo, challenges, and future prospects', *npj Materials Sustainability*, 2(1). Available at: https://doi.org/10.1038/s44296-024-00010-2.

Luo, H. *et al.* (2022) "Digital technology for quality management in construction: A review and future research directions," *Developments in the Built Environment*. Available at: https://doi.org/10.1016/j.dibe.2022.100087.

Mahboub, H. *et al.* (2023) "Measuring the Digital Transformation: A Key Performance Indicators Literature Review," in *Procedia Computer Science*. Available at: https://doi.org/10.1016/j.procs.2023.10.455.

Mahroof, K. *et al.* (2025) 'Navigating power dynamics in the public sector through AI-driven algorithmic decision-making', *Government Information Quarterly*, 42(3), p. 102053. Available at: https://doi.org/10.1016/j.giq.2025.102053.

Martiny, A. *et al.* (2024) 'Determinants of Environmental Social and Governance (ESG) Performance: A Systematic Literature Review', *Journal of Cleaner Production*, 456, pp. 142213–142213. Available at: https://doi.org/10.1016/j.jclepro.2024.142213.

Mhaske, P. *et al.* (2025) 'Bridging digital skill gaps in the global workforce: A synthesis and conceptual framework building', *Research in Globalization*, p. 100311. Available at: https://doi.org/10.1016/j.resglo.2025.100311.

Miasayedava, L., McBride, K. and Tuhtan, J.A. (2022) "Automated environmental compliance monitoring of rivers with IoT and open government data," *Journal of Environmental Management*, 303. Available at: https://doi.org/10.1016/j.jenvman.2021.114283.

Mondal, S. *et al.* (2023) "GEECO: Green Data Centers for Energy Optimization and Carbon Footprint Reduction," *Sustainability (Switzerland)*, 15(21). Available at: https://doi.org/10.3390/su152115249.

Montalbán-Domingo, L. *et al.* (2021) "An integrated method for the assessment of social sustainability in public-works procurement," *Environmental Impact*

Assessment Review, 89. Available at: https://doi.org/10.1016/j.eiar.2021.106581.

Moreira, L.L. *et al.* (2025) 'Evaluating digital transformation in small and medium enterprises using the Alkire-Foster method', *Heliyon*, 11(2), p. e41838. Available at: https://doi.org/10.1016/j.heliyon.2025.e41838.

Msawil, M., Greenwood, D. and Kassem, M. (2022) "A Systematic evaluation of blockchain-enabled contract administration in construction projects," *Automation in Construction*, 143. Available at: https://doi.org/10.1016/j.autcon.2022.104553.

Muhammad Azhar Khalil, Khalil, S. and Pathathai Sinliamthong (2024) 'From Ratings to Resilience: The Role and Implications of Environmental, Social, and Governance (ESG) Performance in Corporate Solvency', *Sustainable Futures*, pp. 100304–100304. Available at: https://doi.org/10.1016/j.sftr.2024.100304.

Muhammad Sani Khamisu, Ratna Achuta Paluri and Vandana Sonwaney (2024) 'Stakeholders' perspectives on critical success factors for environmental social and governance (ESG) implementation', *Journal of environmental management*, 365, pp. 121583–121583. Available at: https://doi.org/10.1016/j.jenvman.2024.121583.

Musarat, M.A. *et al.* (2023) "A Systematic Review on Enhancement in Quality of Life through Digitalization in the Construction Industry," *Sustainability (Switzerland)*. Available at: https://doi.org/10.3390/su15010202.

Musarat, M.A. *et al.* (2024) "Digitalization in malaysian construction industry: Awareness, challenges and opportunities," *Results in Engineering*, 21. Available at: https://doi.org/10.1016/j.rineng.2024.102013.

Mustafa Tevfik Kartal *et al.* (2024) 'Effects of Environment, Social, and Governance (ESG)disclosures on ESGscores: Investigating therole ofcorporategovernance forpubliclytraded Turkishcompanies', *Journal of Environmental Management*, 368, pp. 122205–122205. Available at: https://doi.org/10.1016/j.jenvman.2024.122205.

Nachar, N. (2008) 'The mann-whitney u: a test for assessing whether two independent samples come from the same distribution', *Tutorials in Quantitative Methods for Psychology*, 4(1), pp. 13-20.

Nicolo, G. *et al.* (2023) "Worldwide evidence of corporate governance influence on ESG disclosure in the utilities sector," *Utilities Policy*, 82. Available at: https://doi.org/10.1016/j.jup.2023.101549.

Nikmehr, B. *et al.* (2021) "Bim-based tools for managing construction and demolition waste (Cdw): A scoping review," *Sustainability (Switzerland)*, 13(15). Available at: https://doi.org/10.3390/su13158427.

Nipper, M., Ostermaier, A. and Theis, J. (2025) 'Mandatory Disclosure of Standardized Sustainability Metrics: The Case of the EU Taxonomy

Regulation', *arXiv (Cornell University)* [Preprint]. Available at: https://doi.org/10.48550/arxiv.2205.15576.

OECD (2022) 'Financing SMEs for sustainability', *OECD SME and Entrepreneurship Papers* [Preprint]. Available at: https://doi.org/10.1787/a5e94d92-en.

Ogugua, O.C. (2024) 'ESG, Cybersecurity, And The Remote Workforce: Navigating The New Realities Of Corporate Governance', *SSRN Electronic Journal* [Preprint]. Available at: https://doi.org/10.2139/ssrn.5055739.

Oke, A.E. *et al.* (2023) "Application of Digital Technologies Tools for Social and Sustainable Construction in a Developing Economy," *Sustainability (Switzerland)*, 15(23). Available at: https://doi.org/10.3390/su152316378.

Ologeanu-Taddei, R. *et al.* (2024) 'The relationship of digital transformation and corporate sustainability: Synergies and tensions', *Technological Forecasting and Social Change*, 210, pp. 123809–123809. Available at: https://doi.org/10.1016/j.techfore.2024.123809.

Omrany, H., Mehdipour, A. and Oteng, D. (2024) 'Digital Twin Technology and Social Sustainability: Implications for the Construction Industry', *Sustainability*, 16(19), p. 8663. Available at: https://doi.org/10.3390/su16198663.

Opoku, D.G.J. *et al.* (2021) "Digital twin application in the construction industry: A literature review," *Journal of Building Engineering*. Available at: https://doi.org/10.1016/j.jobe.2021.102726.

Osinakachukwu, M. *et al.* (2024) 'Stakeholder engagement and influence: Strategies for successful energy projects', *International Journal of Management & Entrepreneurship Research*, 6(7), pp. 2375–2395. Available at: https://doi.org/10.51594/ijmer.v6i7.1330.

Ostertagová, E., Ostertag, O. and Kováč, J. (2014) "Methodology and application of the Kruskal-Wallis test," *Applied Mechanics and Materials*, 611. Available at: https://doi.org/10.4028/www.scientific.net/AMM.611.115.

Pacolli, M. (2022) "Importance of Change Management in Digital Transformation Sustainability," in *IFAC-PapersOnLine*. Available at: https://doi.org/10.1016/j.ifacol.2022.12.034.

di Pasquale, V. *et al.* (2022) "Wearable devices for health and safety in production systems: a literature review," in *IFAC-PapersOnLine*. Available at: https://doi.org/10.1016/j.ifacol.2022.09.410.

Paton, B. (2006) "Collaboration among industry, civil society, and government for sustainability: A framework for identifying opportunities," *Progress in Industrial Ecology*, 3(1–2). Available at: https://doi.org/10.1504/pie.2006.010046.

Phan, Q.-H. *et al.* (2025) ‘TOWARD SUSTAINABLE LOGISTICS IN EMERGING ECONOMIES: IDENTIFYING ESG BARRIERS USING NEUTROSOPHIC DELPHI-DEMATEL MODEL’, *Journal of Open Innovation: Technology, Market, and Complexity*, p. 100601. Available at: https://doi.org/10.1016/j.joitmc.2025.100601.

Pimentel, J.L. (2019) “Some Biases in Likert Scaling Usage and its Correction,” *International Journal of Sciences: Basic and Applied Research*, 45(1).

Piotr Sakiewicz, Ober, J. and Małgorzata Kopiec (2024) ‘CHALLENGES AND OPPORTUNITIES OF ERP AND SCADA SYSTEMS IN ESG REPORTING’, *Scientific Papers of Silesian University of Technology Organization and Management Series*, 214, pp. 235–254. Available at: https://doi.org/10.29119/1641-3466.2024.214.17.

Pizzi, S. *et al.* (2024) “The digitalization of sustainability reporting processes: A conceptual framework,” *Business Strategy and the Environment*, 33(2). Available at: https://doi.org/10.1002/bse.3544.

Qiao, P. *et al.* (2024) ‘Unleashing Digital Leadership: Driving ESG Sustainability’, *Research in International Business and Finance*, pp. 102644–102644. Available at: https://doi.org/10.1016/j.ribaf.2024.102644.

Qing, C. and Jin, S. (2023) “Does ESG and Digital Transformation affects Corporate Sustainability? The Moderating role of Green Innovation,” *arXiv.org* [Preprint], (3).

Radanliev, P. *et al.* (2024) “Ethics and responsible AI deployment,” *Frontiers in Artificial Intelligence*. Available at: https://doi.org/10.3389/frai.2024.1377011.

Raguel, M.M. and Odeku, K.O. (2023) “Critical analysis of the failure of labour law to adequately protect atypical workers and its impact on human rights and fair labour practice,” *Juridical Tribune*, 13(1). Available at: https://doi.org/10.24818/TBJ/2023/13/1.05.

Rangel, R., Batista, W. and Macedo, A.N. (2024) ‘Validation of Challenges for Implementing ESG in the Construction Industry Considering the Context of an Emerging Economy Country’, *Applied Sciences*, 14(14), pp. 6024–6024. Available at: https://doi.org/10.3390/app14146024.

Rao, A.S. *et al.* (2022) “Real-time monitoring of construction sites: Sensors, methods, and applications,” *Automation in Construction*. Available at: https://doi.org/10.1016/j.autcon.2021.104099.

Reddy, J.S., Kiranmayee, S.N.S and Julakanti, R. (2025) ‘Data Protection through Governance Frameworks’, *arXiv (Cornell University)* [Preprint]. Available at: https://doi.org/10.48550/arxiv.2502.10404.

Regona, M. *et al.* (2024) ‘Artificial Intelligence and Sustainable Development Goals: Systematic Literature Review of the Construction Industry’, *Sustainable* *cities and society*, 108, pp. 105499–105499. Available at: https://doi.org/10.1016/j.scs.2024.105499.

Rikala, P. *et al.* (2024) "Understanding and measuring skill gaps in Industry 4.0 — A review," *Technological Forecasting and Social Change*, 201. Available at: https://doi.org/10.1016/j.techfore.2024.123206.

Rinchen, S., Banihashemi, S. and Alkilani, S. (2024) 'Driving Digital Transformation in construction: Strategic Insights into Building Information Modelling Adoption in Developing Countries', *Project leadership and society*, 5, pp. 100138–100138. Available at: https://doi.org/10.1016/j.plas.2024.100138.

Rogardt Heldal *et al.* (2024) 'Sustainability Competencies and Skills in Software Engineering: An Industry Perspective'. Available at: https://doi.org/10.48550/arxiv.2305.00436.

Saeed Awadh Bin-Nashwan *et al.* (2024) 'Does AI adoption redefine financial reporting accuracy, auditing efficiency, and information asymmetry? An integrated model of TOE-TAM-RDT and big data governance', *Computers in Human Behavior Reports*, pp. 100572–100572. Available at: https://doi.org/10.1016/j.chbr.2024.100572.

Sajjad, M. *et al.* (2023) "Evaluation of the Success of Industry 4.0 Digitalization Practices for Sustainable Construction Management: Chinese Construction Industry," *Buildings*, 13(7). Available at: https://doi.org/10.3390/buildings13071668.

Sang, Y., Kannan Loganathan and Lin, L. (2024) 'Digital Transformation and Firm ESG Performance: The Mediating Role of Corporate Risk-Taking and the Moderating Role of Top Management Team', *Sustainability*, 16(14), pp. 5907–5907. Available at: https://doi.org/10.3390/su16145907.

Santarius, T. *et al.* (2023) "Digitalization and Sustainability: A Call for a Digital Green Deal," *Environmental Science and Policy*, 147. Available at: https://doi.org/10.1016/j.envsci.2023.04.020.

Saunders, M.N.K., Philip, L. and Thornhill, A. (2019) *Research methods for business students, Pearson Education Limited*.

Saxena, A. *et al.* (2023) "Technologies Empowered Environmental, Social, and Governance (ESG): An Industry 4.0 Landscape," *Sustainability (Switzerland)*, 15(1). Available at: https://doi.org/10.3390/su15010309.

Sekaran Uma; Bougie Roger (2016) "Research Methods for Business: A Skill Building Approach Seventh Edition WileyPLUS Learning Space Card.," *Internation Labour Office*, 1(September).

Seyyedi, S.R. *et al.* (2024) 'A comprehensive review integration of digitalization and circular economy in waste management by adopting artificial intelligence approaches: Towards a simulation model', *Journal of cleaner* *production*, pp. 142584–142584. Available at: https://doi.org/10.1016/j.jclepro.2024.142584.

Shahid, H., Sabelfeld, L. and Johansson, J. (2024) ‘Sustainability Reporting in Construction and Real Estate Sector: A Conceptualization and a Review of Existing Literature’, *Journal of Cleaner Production*, p. 143886. Available at: https://doi.org/10.1016/j.jclepro.2024.143886.

Shen, L., Tang, L. and Mu, Y. (2024) “Critical success factors and collaborative governance mechanism for the transformation of existing residential buildings in urban renewal: From a social network perspective,” *Heliyon*, 10(6). Available at: https://doi.org/10.1016/j.heliyon.2024.e27672.

Shojaei, R.S., Oti-Sarpong, K. and Burgess, G. (2023) “Enablers for the adoption and use of BIM in main contractor companies in the UK,” *Engineering, Construction and Architectural Management*, 30(4). Available at: https://doi.org/10.1108/ECAM-07-2021-0650.

Silva, P.D., Nuwan Gunarathne and Kumar, S. (2024) ‘Exploring the impact of digital knowledge, integration and performance on sustainable accounting, reporting and assurance’, *Meditari Accountancy Research* [Preprint]. Available at: https://doi.org/10.1108/medar-02-2024-2383.

Siriwardhana, S. and Moehler, R.C. (2023) “Enabling productivity goals through construction 4.0 skills: Theories, debates, definitions,” *Journal of Cleaner Production*, 425. Available at: https://doi.org/10.1016/j.jclepro.2023.139011.

Snyder, H. (2019) “Literature review as a research methodology: An overview and guidelines,” *Journal of Business Research*, 104. Available at: https://doi.org/10.1016/j.jbusres.2019.07.039.

Solaimani, S. (2024) ‘From Compliance to Capability: On the Role of Data and Technology in Environment, Social, and Governance’, *Sustainability*, 16(14), p. 6061. Available at: https://doi.org/10.3390/su16146061.

Strazzullo, S. (2024) ‘Fostering digital trust in manufacturing companies: Exploring the impact of industry 4.0 technologies’, *Journal of Innovation & Knowledge*, 9(4), p. 100621. Available at: https://doi.org/10.1016/j.jik.2024.100621.

Sun, P. *et al.* (2024) ‘Big data analytics, firm risk and corporate policies: Evidence from China’, *Research in international business and finance*, pp. 102371–102371. Available at: https://doi.org/10.1016/j.ribaf.2024.102371.

Suvvari, S.K. and Saxena, DR.V.D. (2023) ‘Stakeholder Management in Projects: Strategies for Effective Communication’, *Innovative Research Thoughts*, 9(5), pp. 188–201. Available at: https://doi.org/10.36676/irt.v9.i5.1479.

Talla, A. and McIlwaine, S. (2024) “Industry 4.0 and the circular economy: using design-stage digital technology to reduce construction waste,” *Smart and Sustainable Built Environment*, 13(1). Available at: https://doi.org/10.1108/SASBE-03-2022-0050.

Tamburri, D.A. (2020) “Sustainable MLOps: Trends and Challenges,” in *Proceedings - 2020 22nd International Symposium on Symbolic and Numeric Algorithms for Scientific Computing, SYNASC 2020*. Available at: https://doi.org/10.1109/SYNASC51798.2020.00015.

Tamimi, N. and Sebastianelli, R. (2017) “Transparency among S&P 500 companies: an analysis of ESG disclosure scores,” *Management Decision*, 55(8). Available at: https://doi.org/10.1108/MD-01-2017-0018.

Tan, Q.L., Hashim, S. and Zheng, Z. (2025) ‘Environmental Social Governance (ESG) in Digitalization research: A bibliometric analysis’, *SAGE Open*, 15(1). Available at: https://doi.org/10.1177/21582440241310953.

Tao, X. *et al.* (2018) “Greenhouse gas emission monitoring system for manufacturing prefabricated components,” *Automation in Construction*, 93. Available at: https://doi.org/10.1016/j.autcon.2018.05.015.

Tavakol, M. and Dennick, R. (2011) “Making sense of Cronbach’s alpha,” *International journal of medical education*. Available at: https://doi.org/10.5116/ijme.4dfb.8dfd.

Tawil, A.-R. *et al.* (2023) *Trends and Challenges Towards an Effective Data-Driven Decision Making in UK SMEs: Case Studies and Lessons Learnt from the Analysis of 85 SMEs*, *arXiv.org*. Available at: https://doi.org/10.48550/arXiv.2305.15454.

Telukdarie, A., Mahure, H. and Sishi, M. (2024) ‘The digitization of ESG matrix’, *Procedia Computer Science*, 239, pp. 808–815. Available at: https://doi.org/10.1016/j.procs.2024.06.436.

Teubner, L.K., Henkel, J. and Bekkers, R. (2021) “Industry consortia in mobile telecommunications standards setting: Purpose, organization and diversity,” *Telecommunications Policy*, 45(3). Available at: https://doi.org/10.1016/j.telpol.2020.102059.

Thanasas, G.L., Kampiotis, G. and Karkantzou, A. (2025) ‘Enhancing Transparency and Efficiency in Auditing and Regulatory Compliance with Disruptive Technologies’, *Theoretical Economics Letters*, 15(01), pp. 214–233. Available at: https://doi.org/10.4236/tel.2025.151013.

Thirumal, S. *et al.* (2024) ‘Barriers to Adopting Digital Technologies to Implement Circular Economy Practices in the Construction Industry: A Systematic Literature Review’, *Sustainability*, 16(8), pp. 3185–3185. Available at: https://doi.org/10.3390/su16083185.

Tian, J. *et al.* (2025) 'ESG introduction mechanism of construction firms based on Bayesian network coupled with machine learning: Evidence from Zhengzhou', *Journal of Environmental Management*, 375, p. 124185. Available at: https://doi.org/10.1016/j.jenvman.2025.124185.

Tonello, M. (2025) *Regulatory Shifts in ESG: What Comes Next for Companies?*, *The Harvard Law School Forum on Corporate Governance*. Available at: https://corpgov.law.harvard.edu/2025/04/12/regulatory-shifts-in-esg-what-comes-next-for-companies.

Toukola, S. and Ahola, T. (2022) "Digital tools for stakeholder participation in urban development projects," *Project Leadership and Society*, 3. Available at: https://doi.org/10.1016/j.plas.2022.100053.

Trocoso-Pastoriza, J.R. *et al.* (2022) 'Orchestrating Collaborative Cybersecurity: A Secure Framework for Distributed Privacy-Preserving Threat Intelligence Sharing', *arXiv (Cornell University)* [Preprint]. Available at: https://doi.org/10.48550/arxiv.2209.02676.

Truant, E. *et al.* (2023) "ESG performance and technological change: Current state-of-the-art, development and future directions," *Journal of Cleaner Production*, 429. Available at: https://doi.org/10.1016/j.jclepro.2023.139493.

Tsang, Y.P., Fan, Y. and Feng, Z.P. (2023) "Bridging the gap: Building environmental, social and governance capabilities in small and medium logistics companies," *Journal of Environmental Management*, 338. Available at: https://doi.org/10.1016/j.jenvman.2023.117758.

Tuhaise, V.V., Tah, J.H.M. and Abanda, F.H. (2023) "Technologies for digital twin applications in construction," *Automation in Construction*. Available at: https://doi.org/10.1016/j.autcon.2023.104931.

Tumewang, Y.K. *et al.* (2024) 'The effects of diversity and inclusion on ESG performance: A comparison between Islamic and conventional banks', *Borsa Istanbul Review* [Preprint]. Available at: https://doi.org/10.1016/j.bir.2024.10.001.

Uzairuddin, S. and Jaiswal, M. (2022) "Digital monitoring and modeling of construction supply chain management scheme with BIM and GIS: An overview," in *Materials Today: Proceedings*. Available at: https://doi.org/10.1016/j.matpr.2022.05.160.

Valkokari, K. *et al.* (2024) 'Governance mechanisms and practices in project-based interorganisational collaboration for innovation', *International Journal of Project Management*, 42(8), p. 102652. Available at: https://doi.org/10.1016/j.ijproman.2024.102652.

Vidyasagar Gembali, Kumar, A. and Sarma, P.R.S. (2024) 'A knowledge roadmap for digitally enabled sustainable construction and building supply chain management', *Elsevier eBooks*, pp. 167–187. Available at: https://doi.org/10.1016/b978-0-443-21651-0.00005-x.

Wang, H. *et al.* (2023) “Digital transformation and manufacturing companies’ ESG responsibility performance,” *Finance Research Letters*, 58. Available at: https://doi.org/10.1016/j.frl.2023.104370.

Wang, S. and Esperança, J.P. (2023) “Can digital transformation improve market and ESG performance? Evidence from Chinese SMEs,” *Journal of Cleaner Production*, 419. Available at: https://doi.org/10.1016/j.jclepro.2023.137980.

Wang, Y. and Wang, X. (2024) “From ratings to action: The impact of ESG performance on corporate innovation,” *Heliyon*, 10(4). Available at: https://doi.org/10.1016/j.heliyon.2024.e26683.

W Evy Steelyana and Ersa Tri Wahyuni (2024) ‘Environmental Social Governance Integration for Infrastructure Development in Public Private Partnership Toll Road Sector’, *IOP conference series. Earth and environmental science*, 1324(1), pp. 012054–012054. Available at: https://doi.org/10.1088/1755-1315/1324/1/012054.

Xue, D. and Zhu, Z. (2025) ‘Digital Transformation of Energy Enterprises, ESG Performance, and Green Total Factor Productivity’, *Finance Research Letters*, p. 108398. Available at: https://doi.org/10.1016/j.frl.2025.108398.

Xu, J. and Yin, J. (2025) ‘Digital transformation and ESG performance: The chain mediating role of technological innovation and financing constraints’, *Finance Research Letters*, 71, p. 106387. Available at: https://doi.org/10.1016/j.frl.2024.106387.

Xu, J. *et al.* (2022) “Internet of Things (IoT)-Integrated Embodied Carbon Assessment and Monitoring of Prefabricated Buildings,” in *IOP Conference Series: Earth and Environmental Science*. Available at: https://doi.org/10.1088/1755-1315/1101/2/022031.

Yang, B., Huang, J. and Chen, Y. (2024) ‘The Relationship Between ESG Ratings and Digital Technological Innovation in Manufacturing: Insights via Dual Machine Learning Models’, *Finance research letters*, pp. 106362–106362. Available at: https://doi.org/10.1016/j.frl.2024.106362.

Yang, Z. *et al.* (2023) “Blockchain technology in building environmental sustainability: A systematic literature review and future perspectives,” *Building and Environment*. Available at: https://doi.org/10.1016/j.buildenv.2023.110970.

Yu, Z. *et al.* (2024) “How does environmental, social, and governance (ESG) performance determine investment mix? New empirical evidence from BRICS,” *Borsa Istanbul Review*, 24(3). Available at: https://doi.org/10.1016/j.bir.2024.02.007.

Zahari, A.I. *et al.* (2024) “Ethical culture and leadership for sustainability and governance in public sector organisations within the ESG framework,” *Journal of Open Innovation: Technology, Market, and Complexity*, 10(1). Available at: https://doi.org/10.1016/j.joitmc.2024.100219.

Zahedi, F. *et al.* (2024) ‘Digital Twins in the Sustainable Construction Industry’, *Buildings*, 14(11), pp. 3613–3613. Available at: https://doi.org/10.3390/buildings14113613.

Zhang, L. and Zhang, X. (2024) ‘Impact of digital government construction on the intelligent transformation of enterprises: Evidence from China’, *Technological Forecasting and Social Change*, 210, p. 123787. Available at: https://doi.org/10.1016/j.techfore.2024.123787.

Zhang, X., Kathy, N.S. and Xu, B. (2024) ‘Double-edged sword of knowledge inertia: Overcoming healthcare professionals’ resistance in innovation adoption’, *Technovation*, 133, pp. 103011–103011. Available at: https://doi.org/10.1016/j.technovation.2024.103011.

Zhang, Y. *et al.* (2024) ‘Sustainable ripples: Unveiling contractor knowledge-state transitions and group consensus based on environmental sanction violations’, *Environmental Impact Assessment Review*, 110, pp. 107722–107722. Available at: https://doi.org/10.1016/j.eiar.2024.107722.

Zhao, X. and Cai, L. (2023) “Digital transformation and corporate ESG: Evidence from China,” *Finance Research Letters*, 58. Available at: https://doi.org/10.1016/j.frl.2023.104310.

Zhao, Y. *et al.* (2024) ‘Managing carbon emissions in construction: Current status and emerging trends’, *Renewable and Sustainable Energy Reviews*, 211, pp. 115237–115237. Available at: https://doi.org/10.1016/j.rser.2024.115237.

Zhou, Z., Yuan, Z. and He, C. (2025) ‘Can digital transformation promote firms’ sustainable development? Evidence based on ESG performance’, *International Review of Financial Analysis*, pp. 104434–104434. Available at: https://doi.org/10.1016/j.irfa.2025.104434.

APPENDICES

Appendix A: Questionnaire

Dear Sir/Madam,

I am Fion Ting Yee Jie, a final year undergraduate student pursuing Bachelor of Science (Honours) Quantity Surveying from Lee Kong Chian Faculty of Engineering and Science (LKCFES) at University Tunku Abdul Rahman (UTAR). I am currently conducting a survey for my Final Year Project entitled "Leveraging Digital Technology for Environment, Social and Governance (ESG) Compliance" as a partial fulfilment of my degree programme. The purpose of this research is to explore how digital technologies can enhance ESG compliance within the construction industry.

This questionnaire consists of FOUR (4) sections and will take approximately 10 minutes to complete. I believe your professional experience and insights are extremely valuable and will greatly contribute to the success of this research. Your responses will remain anonymous and confidential and will be used solely for academic purposes.

If you have any questions or require further clarification regarding this survey, please do not hesitate to contact me.

Student Name: Fion Ting Yee Jie
Contact Number: 018-2112928
Email: yeejie02@1utar.my

Thank you very much for your time and participation.

ESG refers to Environmental, Social, and Governance which guide responsible and sustainable business practices. Environmental focuses on how a company reduces emissions, conserves resources, and uses sustainable materials. Social emphasizes fair labor practices, human rights, workplace safety, and community engagement. Governance involves transparent decision making, accountability, and effective risk management to align business operations.

Digital technologies such as Artificial Intelligence (AI), Blockchain Technology, Big Data Analytics (BDA), and the Internet of Things (IoT) help companies track and report ESG compliance. These technologies automate data collection, improve accuracy, and support better decision-making for sustainability.

Are you familiar with the concept of ESG (Environmental, Social, and Governance) and digital technologies?

- Yes, I am familiar with it. (Proceed to Section A: Demographic Data)
- I have heard of it but I am not familiar with it. (Left the survey)
- No, I have never heard of it. (Left the survey)

Section A: Demographic Data

1. Which of the following best describes your company's business activities?
   - Developer
   - Consultant
   - Contractor
   - Sub-Contractor / Supplier
   - Others: ___________
2. Which of the following best describes your profession?
   - Architect
   - Engineer
   - Quantity Surveyor
   - Others: ___________
3. What is your position in your organization?
   - Junior Executive
   - Senior Executive
   - Manager / Team Leader / Supervisor
   - Assistant Director / Technical Director

- Director
- Others: ___________

4. How many years of working experience do you have in the construction industry?
   - Less than 5 years
   - 5 - 10 years
   - 11 - 15 years
   - 16 - 20 years
   - More than 20 years
5. How many employees are there in your organization?
   - Less than 5 employees
   - 5 - 29 employees
   - 30 - 75 employees
   - More than 75 employees

Section B: Role of Digital Technology in Enhancing ESG Compliance

This section contains a list of roles of digital technology in enhancing ESG compliance. Rank each of the following questions from scale 1 (Strongly Disagree) to 5 (Strongly Agree).

[Strongly Disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, Strongly Agree = 5]

	1	2	3	4	5
Environmental Compliance					
Digital technologies enable real-time carbon footprint tracking and transparent emission reporting in construction.	○	○	○	○	○
Digital technologies support sustainable material sourcing in improving traceability and resource optimization.	○	○	○	○	○
Digital technologies improve energy efficiency through real-time monitoring and predictive management in construction.	○	○	○	○	○
Digital technologies support waste reduction and circular economy integration through tracking and resource recovery.	○	○	○	○	○
Digital technologies support environmental impact monitoring for sustainability and compliance.	○	○	○	○	○
Social Compliance					
Digital technologies enhance worker safety and well-being by health tracking, hazard detection, and risk prediction.	○	○	○	○	○
Digital workforce management tools ensure fair labor practices, compliance and transparent working conditions.	○	○	○	○	○
Digital technologies improve stakeholder engagement through transparency and real-time communication.	○	○	○	○	○

Digital technologies support diversity, equity, and inclusion monitoring by enabling fair, transparent human resources practices.	○	○	○	○	○
Digital technologies enhance the training and upskilling of construction workers, supporting skills development and the adoption of Industry 4.0.	○	○	○	○	○
<u>Governance Compliance</u>					
AI and Blockchain technologies improve ESG regulatory reporting and transparency and prevent data tampering.	○	○	○	○	○
Big Data, Blockchain, and AI technologies improve risk management by enhancing prediction, data integrity and regulatory compliance.	○	○	○	○	○
Advanced cybersecurity technologies effectively protect ESG data by ensuring security, integrity, and regulatory compliance.	○	○	○	○	○
Blockchain technology and smart contracts enhance audit trail integrity and accountability through transparent, and real-time records.	○	○	○	○	○
Digital technologies enable real-time policy implementation and monitoring, improving coordination, safety compliance, and resource management.	○	○	○	○	○

Section C: Challenges of Integrating Digital Technologies in ESG Compliance

This section contains a list of challenges of integrating digital technologies in ESG compliance. Rank each of the following questions from scale 1 (Strongly Disagree) to 5 (Strongly Agree).

[Strongly Disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, Strongly Agree = 5]

	1	**2**	**3**	**4**	**5**
Technical barriers such as system integration challenges with existing infrastructure.	○	○	○	○	○
Regulatory and policy challenges, including inconsistent standards and information disclosure issues.	○	○	○	○	○
Limited stakeholder engagement and collaboration.	○	○	○	○	○
High implementation and maintenance costs.	○	○	○	○	○
Lack of skilled workforce and insufficient training programs.	○	○	○	○	○
Cybersecurity and data privacy risks.	○	○	○	○	○
Lack of standardized ESG data formats and reporting frameworks.	○	○	○	○	○
Poor data quality and limited access to reliable ESG data.	○	○	○	○	○
Real-time digital monitoring and analytics is complex and complicated.	○	○	○	○	○
Resistance from management and employees due to cultural misalignment or fear of change.	○	○	○	○	○

<u>Section D: Strategies for Leveraging Digital Technologies in ESG Compliance</u>

This section contains a list of strategies for leveraging digital technologies in ESG compliance. Rank each of the following questions from scale 1 (Strongly Disagree) to 5 (Strongly Agree).

[Strongly Disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, Strongly Agree = 5]

	1	**2**	**3**	**4**	**5**
Develop a robust digital framework that integrates technologies.	○	○	○	○	○
Standardize ESG data collection and reporting using digital technologies.	○	○	○	○	○
Implement cybersecurity measures, such as encryption, multi-factor authentication, secure Virtual Private Networks (VPNs) and regular security audits.	○	○	○	○	○
Promote public-private partnerships and industry consortia.	○	○	○	○	○
Provide government incentives for digital ESG adoption.	○	○	○	○	○
Invest in ESG digital skills training.	○	○	○	○	○
Establish digital ESG performance evaluation mechanisms.	○	○	○	○	○
Automate ESG data collection and reporting, reduces manual work.	○	○	○	○	○
Provide Friendly-user Interface of Software by Production Company.	○	○	○	○	○