

CAPITAL UNIVERSITY OF SCIENCE AND
TECHNOLOGY, ISLAMABAD



**Implementing Digital
Transformation in Construction
Industry: Challenges and
Opportunities**

by

Hammaad Khalid

A thesis submitted in partial fulfillment for the
degree of Master of Science

in the

Faculty of Engineering

Department of Civil Engineering

2026

Copyright © 2026 by Hammad Khalid

All rights reserved. No part of this thesis may be reproduced, distributed, or transmitted in any form or by any means, including photocopying, recording, or other electronic or mechanical methods, by any information storage and retrieval system without the prior written permission of the author.



CERTIFICATE OF APPROVAL

Implementing Digital Transformation in Construction

Industry: Challenges and Opportunities

by

Hammaad Khalid

(MCE241003)

THESIS EXAMINING COMMITTEE

S. No.	Examiner	Name	Organization
(a)	External Examiner	Dr. Jawad Hussain	UET, Taxila
(b)	Internal Examiner	Dr. Maria Ghufraan	CUST, Islamabad

Dr. Ishtiaq Hassan

Thesis Supervisor

April, 2026

Dr. Majid Ali
Head
Dept. of Civil Engineering
April, 2026

Dr. Imtiaz Ahmad Taj
Dean
Faculty of Engineering
April, 2026

Author's Declaration

I, **Hammaad Khalid** hereby state that my MS thesis titled “**Implementing Digital Transformation in Construction Industry: Challenges and Opportunities**” is my own work and has not been submitted previously by me for taking any degree from Capital University of Science and Technology, Islamabad or anywhere else in the country/abroad.

At any time if my statement is found to be incorrect even after my graduation, the University has the right to withdraw my MS Degree.



(Hammaad Khalid)

Registration No: MCE241003

Plagiarism Undertaking

I solemnly declare that research work presented in this thesis titled “**Implementing Digital Transformation in Construction Industry: Challenges and Opportunities**” is solely my research work with no significant contribution from any other person. Small contribution/help wherever taken has been duly acknowledged and that complete thesis has been written by me.

I understand the zero tolerance policy of the HEC and Capital University of Science and Technology towards plagiarism. Therefore, I as an author of the above titled thesis declare that no portion of my thesis has been plagiarized and any material used as reference is properly referred/cited.

I undertake that if I am found guilty of any formal plagiarism in the above titled thesis even after award of MS Degree, the University reserves the right to withdraw/revoke my MS degree and that HEC and the University have the right to publish my name on the HEC/University website on which names of students are placed who submitted plagiarized work.



(Hammaad Khalid)

Registration No: MCE241003

Acknowledgement

First and foremost, after Almighty Allah I would like to thank my father for bearing all the hardships and not letting me bear even a small amount of pain, for always standing at my back and for always being my strength. Then I would like to express my sincere and utmost gratitude to my supervisors Prof. Dr. Ishtiaq Hassan for providing me the opportunity to work with them. Their ability to read a student's limit and then maximizing it exponentially is truly amazing. Very few supervisors take this much pain to help their students to achieve their goals. They have always motivated me to be better and are a role model for me as a teacher. I am in their debt till the end of times.

(Hammaad Khalid)

Abstract

Digital Transformation has emerged as a critical enabler for improving productivity, efficiency, and sustainability in the construction industry. However, in Pakistan, where construction practices remain largely traditional and fragmented, the adoption of digital technologies is still limited and uneven. This gap contributes to persistent challenges such as project delays, cost overruns, inefficient coordination, and low overall performance. Despite increasing awareness of digital tools, there is limited empirical research that systematically examines the challenges, opportunities, and mitigation strategies associated with Digital Transformation in the local construction context. This study aims to identify, assess, and prioritize the key factors influencing Digital Transformation adoption in small- and medium-sized commercial construction projects in Islamabad, Pakistan, and to propose practical implementation guidelines. An extensive literature review was conducted to identify relevant factors, which were subsequently refined through expert validation using the Delphi technique involving experienced industry professionals. A structured questionnaire comprising factors grouped into three major categories challenges, opportunities, and mitigation strategies was developed and distributed among construction practitioners, resulting in 101 valid responses. The reliability of the questionnaire was confirmed using Cronbach's alpha ($\alpha = 0.859$), indicating strong internal consistency, while non-parametric statistical methods were adopted due to the non-normal distribution of the data. The Relative Importance Index (RII) method was employed to rank the identified factors, with values ranging approximately from 0.65 to 0.94, reflecting varying levels of influence on Digital Transformation adoption. The results indicate that human- and organization-related challenges dominate the overall rankings. The shortage of trained professionals in digital systems emerged as the most critical barrier (RII = 0.895), followed by lack of awareness of Digital Transformation benefits (RII = 0.889) and resistance to change among employees (RII = 0.877). In contrast, leadership gaps and policy-related issues were perceived as comparatively less influential. In terms of opportunities, performance-driven benefits ranked highest, with real-time project monitoring (RII = 0.901), improved collaboration (RII =

0.893), and enhanced decision-making through accurate digital data (RII = 0.889) identified as key drivers of adoption. Sustainability-related benefits, although recognized, received comparatively lower rankings. Regarding mitigation strategies, education- and capacity-building measures were identified as the most effective solutions, with the introduction of Digital Transformation courses (RII = 0.935), professional training programs (RII = 0.919), and awareness initiatives (RII = 0.909) emerging as top priorities. Based on these prioritized findings, the study proposes targeted and actionable recommendations for industry practitioners, policymakers, and academic institutions. These recommendations emphasize workforce development, awareness enhancement, phased implementation strategies, and institutional support to facilitate effective Digital Transformation adoption. The study provides an evidence-based framework to support the transition of Pakistan's construction industry toward improved efficiency, competitiveness, and sustainable development.

Contents

Author’s Declaration	iii
Plagiarism Undertaking	iv
Acknowledgement	v
Abstract	vi
List of Figures	xi
List of Tables	xii
Abbreviations	xiii
1 Introduction	1
1.1 Background	1
1.2 Research Motivation	5
1.3 Problem Statement	7
1.4 Research Questions	8
1.5 Objectives of the Study	8
1.6 Research Methodology	9
1.7 Research Scope	9
1.8 Study Limitations	10
1.9 Research Significance	11
1.10 Thesis Structure	11
2 Literature Review	13
2.1 General	13
2.2 Construction Industry as Backbone of a Country	16
2.3 Industrial Revolution	18
2.4 Conventional vs Digital Practices in Civil Engineering	21
2.4.1 Conventional Practices in Civil Engineering	21
2.4.2 Transition from Conventional to Digital Practices	22
2.4.3 Digital Practices	23
2.5 Phases of Digital Transformation Adoption	24
2.6 Digital Transformation in Developed and Developing Countries	29

2.6.1	Developed Countries	30
2.6.2	Developing Countries	31
2.7	Adoption of Digital Transformation	33
2.7.1	Barriers and Challenges in Adoption of Digital Transformation	33
2.7.2	Opportunities and Mitigation Strategies	35
3	Methodology	43
3.1	Background	43
3.2	Methodology Flowchart	44
3.2.1	Problem Identification and Literature Review	44
3.2.2	Research Objectives and Research Questions	45
3.2.3	Questionnaire Design	45
3.2.4	Pilot Survey and Reliability Testing	45
3.2.5	Main Survey Data Collection	45
3.2.6	Data Analysis Techniques	46
3.2.7	Results and Discussion	46
3.2.8	Conclusions and Recommendations	46
3.3	Research Design and Approach	46
3.3.1	Research Design	46
3.3.2	Research Approach	47
3.4	Questionnaire Development	47
3.4.1	Questionnaire Structure	47
3.4.2	Development of Technical Constructs	48
3.4.3	Item Formulation and Coding	48
3.4.4	Measurement Scale	48
3.5	Delphi Validation and Pilot Survey	48
3.5.1	Delphi Validation	49
3.5.2	Pilot Survey	49
3.6	Sampling Strategy and Sample Size	50
3.6.1	Target Population	50
3.6.2	Sample Strategy	50
3.6.3	Sample Size Determination	51
3.7	Data Collection Procedure	52
3.8	Data Analysis Techniques	52
3.8.1	Reliability Assessment	53
3.8.2	Normality Test	53
3.8.3	Relative Importance Index	53
4	Results and Discussion	55
4.1	General	55
4.2	Development of Questionnaire and Finalization	55
4.2.1	Questionnaire Coding	55
4.2.2	Delphi Process and Pilot Survey Analysis	56
4.2.2.1	Delphi Process	56
4.2.2.2	Pilot Survey-Demographic and Reliability	56

4.3	Main Survey	57
4.3.1	Sample Size	58
4.3.2	Demographic Data	58
4.3.3	Reliability Test	63
4.3.4	Normality Test Results	64
4.3.5	Relative Importance Index	69
4.3.6	Summary	72
5	Conclusion and Recommendations	74
5.1	General	74
5.2	Conclusion	74
5.3	Recommendations	76
5.4	Recommendations for Future Research	78
5.5	Guidelines for Effective D.T	78
	Bibliography	80
	Appendix A	89

List of Figures

1.1	Multi-Dimensional Change Process [5]	2
1.2	Methodology	9
2.1	Diagram of Construction 4.0 pillars illustrating digitization and industrialization concepts [17]	20
2.2	Conventional construction documentation workflow showing manual data flows and sequential activities [60]	21
2.3	Comparison of traditional and digital (BIM-enabled) construction workflows, illustrating centralized data processes vs. conventional fragmented processes [62]	24
2.4	Conceptual Adoption process phase wise [73]	28
2.5	Generic approach to digital adoption [67]	30
3.1	Methodology Flowchart	44
4.1	Respondents Organization Type	59
4.2	Respondents Profession	59
4.3	Respondents Profession	60
4.4	Respondents Experience	61
4.5	Respondents Qualification	61

List of Tables

2.1	Phases of Digital Transformation Adoption with Barriers and Mitigation Strategies Transformation phases [4],[7]	28
2.2	Summary of Challenges, Opportunities, and Mitigation Strategies for Digital Transformation Adoption in the Construction Industry [1]–[20], [76]– [77]	36
3.1	Likert Scale	49
3.2	Cronbach’s Alpha value table [77]	53
4.1	Questionnaire Coding	56
4.2	Respondents Work Experience Location	62
4.3	Tools Used	63
4.4	Table 4.4 Reliability Test Results	64
4.5	Normality Test Results	65
4.6	Kruskal Wallis Test	68
4.7	RII Test Results	69

Abbreviations

AI	Artificial Intelligence
AR	Augmented Reality
BIM	Building Information Modelling
CAD	Computer-Aided Design
DT	Digital Transformation
FM	Facility Management
GDP	Gross Domestic Product
IoT	Internet of Things
ML	Machine Learning
RII	Relative Importance Index
ROI	Return on Investment
SMEs	Small and Medium-Sized Enterprises
SPSS	Statistical Package for the Social Sciences
UAV	Unmanned Aerial Vehicle
VR	Virtual Reality

Chapter 1

Introduction

The construction industry plays a pivotal role in national development by contributing to infrastructure, employment, and economic stability. As one of the largest sectors globally, it significantly impacts GDP growth and industrial development. Over recent years, the need to improve productivity, reduce inefficiencies, and adopt modern technologies has become increasingly critical to meet growing urbanization and sustainability demands.

1.1 Background

The construction industry is a cornerstone of the global economy, responsible for creating the built environment that underpins societal function and economic activity. Globally, annual spending on building and construction activities approaches trillion of dollars, signifying its substantial contribution to economic stability and development [1]. Historically, however, the industry has been characterized by a paradox: while its output is fundamental to progress, its internal processes have been notoriously slow to evolve. For decades, construction has lagged behind sectors like finance, and automotive in adopting new technologies and improving productivity [2]. This resistance to change has been attributed to its fragmented nature, involving numerous stakeholders with often misaligned interests, a heavy reliance on manual labour, project-based workflows, and a pervasive culture of risk aversion [3], [4].

The advent of the Fourth Industrial Revolution (Industry 4.0) and the accelerating

pace of digital innovation have begun to disrupt this long-standing status quo. The concept of Digital Transformation (DT) has emerged as a critical imperative for the construction sector. DT transcends the mere digitization of paper-based processes; it represents a fundamental, organization-wide shift that leverages digital technologies to radically improve efficiency, decision-making, and value delivery across the entire project lifecycle—from pre-construction and design, through construction, to facility management and operation [5], [6]. It is a disruptive change process that integrates information, computing, communication, and connectivity technologies to create new or modify existing business processes, culture, and customer experiences [7].

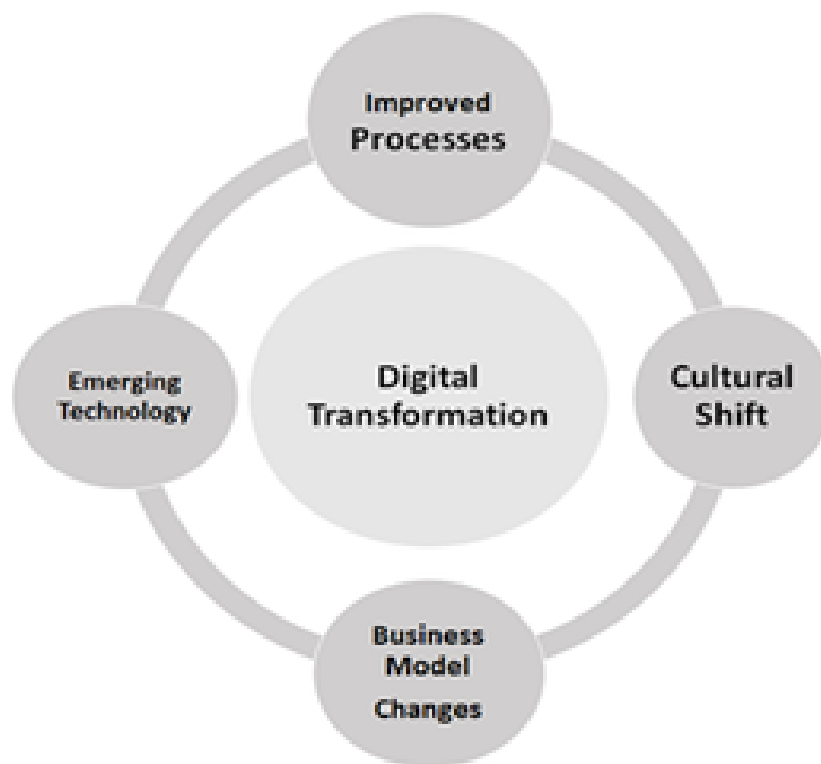


FIGURE 1.1: Multi-Dimensional Change Process [5]

Figure 1.1 illustrates Digital Transformation as a multidimensional change process rather than a purely technological upgrade. Emerging technologies act as enablers, but their value is realized through improved processes, organizational cultural shifts, and changes in business models. The framework emphasizes that successful Digital Transformation requires the simultaneous alignment of technology, people, processes, and strategic objectives, particularly in complex industries such as construction. The push for Digital Transformation is driven by a pressing need to address the

industry's perennial challenges. Studies consistently highlight issues such as low productivity growth, frequent cost and schedule overruns, safety concerns, and significant material waste [8]. Furthermore, increasing project complexity, tighter margins, and growing demands for sustainability and transparency from clients and regulators are forcing construction organizations to seek new ways of working [9]. Digital technologies offer a pathway to mitigate these challenges by enabling greater precision, enhanced collaboration, data-driven insights, and automated execution of routine or hazardous tasks. A wide array of digital technologies is now available and being implemented across the construction value chain. Building Information Modelling (BIM) stands as the most prominent and widely researched digital technology, serving as a collaborative process for generating and managing digital representations of physical and functional characteristics of places [10]. BIM acts as a central data repository and collaborative platform, facilitating improved visualization, clash detection, and information management from design through to operation. Beyond BIM, the technological landscape includes Internet of Things (IoT) sensors for real-time monitoring of sites, equipment, and structures; drones (Unmanned Aerial Vehicles) for surveying, progress monitoring, and inspection; robotics and automation for tasks like bricklaying, welding, and prefabrication; and 3D printing for producing building components and even entire structures [11], [12]. Digital Twins, defined as dynamic virtual replicas of physical assets that are updated with real-time data, are gaining traction for simulation, performance optimization, and predictive maintenance [13]. Furthermore, Artificial Intelligence (AI) and Machine Learning (ML) are being applied to analyse vast datasets for design optimization, risk prediction, safety monitoring, and supply chain management [14]. Supporting technologies like Augmented Reality (AR) and Virtual Reality (VR) enhance training, design review, and on-site guidance, while blockchain is explored for improving transparency and trust in contracts and supply chains [15].

The application of these technologies spans the three core phases of a building's lifecycle. In the pre-construction phase, digital tools assist in site analysis, generative design, cost estimation, and virtual prototyping, allowing stakeholders to identify and resolve issues before breaking ground [16]. During the construction phase, technologies enable real-time progress tracking, automated quality control,

resource and logistics optimization, and enhanced worker safety through wearables and computer vision [17]. In the facility management (FM) phase, Digital Transformation shifts maintenance from reactive to predictive and prescriptive, using IoT sensor data, BIM models, and AI analytics to optimize building performance, energy efficiency, and occupant comfort over the asset's entire operational life [18].

Despite the clear potential and increasing availability of these technologies, the construction industry's journey toward full-scale Digital Transformation remains in its early stages. The industry is widely recognized as a "late adopter" or the "least digitized" major sector, especially when compared to its counterparts [19]. This sluggish adoption is not due to a lack of available technology but is hampered by a complex web of interconnected barriers. These challenges can be broadly categorized into technological, organizational, economic, and regulatory domains.

From a technological and data perspective, significant hurdles exist. The fragmented nature of the industry leads to severe issues with data and information sharing between multiple stakeholders using different software platforms and data standards [20]. Closely related are challenges of data ownership, interoperability between systems, and cybersecurity risks as projects become more digitally connected [21].

Organizational and human-centric barriers are equally critical. There is often a deep-seated hesitation to adopt new ways of working, stemming from a lack of awareness, scepticism about return on investment, and comfort with traditional methods [22]. The lack of digital skills and competence across the workforce, from management to on-site labourers, presents a major obstacle [23]. Furthermore, successful implementation requires significant organizational and process changes, which many firms struggle to manage effectively. A key socio-technical barrier identified is the lack of control—a feeling that the success of digital tools depends too heavily on individual employees rather than on robust, managed processes [24].

Economic factors also play a decisive role. The high initial implementation cost of hardware, software, and training is a deterrent, particularly for small and medium-sized enterprises (SMEs) that operate on thin margins [25]. The perceived long return on investment (ROI) period and uncertainty about tangible benefits make financial decision-makers cautious. On a regulatory and contractual level, the industry grapples with a lack of standardized protocols and reference architectures

for new technologies. Legal and contractual uncertainties regarding liability and intellectual property in digital collaborations, along with stringent regulatory compliance requirements, create a complex environment for innovation [26]. To overcome these barriers and realize the benefits of Digital Transformation, a multi-faceted strategy is required. Research and industry practice point to several effective strategies. Training and upskilling the workforce is consistently ranked as a top priority to build the necessary digital competence and foster a culture of innovation [27].

Government intervention is crucial, not only in setting standards and policies but also in providing financial incentives, grants, and tax breaks to offset initial costs and de-risk early adoption, especially for SMEs [28]. Within organizations, strong leadership commitment and effective communication and change management are vital to align stakeholders, manage resistance, and ensure new technologies are integrated into core business processes [29]. Finally, fostering collaboration and digital partnering between contractors, technology providers, and clients can help pool resources, share knowledge, and develop integrated solutions [30].

In summary, the background of Digital Transformation in construction is defined by a powerful convergence of technological opportunity and existential necessity. While a suite of mature and emerging technologies promises to revolutionize how we design, build, and manage assets, the industry's path forward is obstructed by deep-rooted structural, cultural, and economic challenges. Moving beyond isolated pilot projects to industry-wide transformation will require a concerted effort that addresses not just the technology itself, but the holistic ecosystem of people, processes, and policies. This chapter sets the stage for a detailed exploration of these transformative technologies, the specific challenges they encounter, and the practical strategies needed to harness their potential for a more efficient, productive, and sustainable construction industry.

1.2 Research Motivation

The global construction industry is defined by a critical paradox: it is a fundamental driver of economic development, yet it remains encumbered by systemic

inefficiencies that curtail its productivity and performance [1]. Persistent issues such as project delays, budget overruns, and substantial material waste are well-documented, contrasting sharply with the increasing complexity of projects and stakeholder demands for sustainability and value [4]. Within this context, Digital Transformation emerges not as a mere trend but as an essential strategic response. The integration of digital technologies offers a demonstrable pathway to enhance precision, improve collaboration, and enable data-driven management across all phases of a building's lifecycle [1]. The necessity for this transformation is further amplified by an evolving regulatory and client environment that increasingly mandates demonstrable sustainability and digital project delivery, creating both a compliance imperative and a competitive advantage for early adopters [4]

However, the realization of this transformative potential is inconsistent and geographically varied. While pioneering firms and certain national industries have progressed in adoption, the sector's overall digitization maturity significantly lags behind comparable fields such as logistics [6]. This gap between technological possibility and widespread implementation constitutes the central impetus for this research. A detailed investigation is required to move beyond general advocacy and uncover the specific, actionable factors that determine successful digital adoption within the complex construction ecosystem. A core research driver is the need to critically examine how Digital Transformation generates value beyond operational efficiency. The strategic role of digitization in enabling sustainable innovation—such as optimizing resource flows, reducing environmental impact, and supporting circular economy models—is a compelling yet underexplored avenue [31]. Understanding the mechanisms that translate digital capabilities into measurable sustainability outcomes is crucial for aligning technological investment with global environmental imperatives.

The journey toward digital maturity is obstructed by a well-known yet complex array of barriers. These encompass high initial costs, skills shortages, organizational resistance, and fragmented data ecosystems [6]. A significant research challenge lies in advancing beyond generic barrier identification to develop a more nuanced understanding. This includes examining how the nature of these obstacles shifts with different technological paradigms and varying organizational contexts,

requiring tailored rather than one-size-fits-all mitigation strategies [32]. Ultimately, identifying barriers is insufficient without clear guidance for overcoming them. A pronounced deficit exists in practical, process-oriented frameworks that can steer organizations—particularly those with limited prior experience—through the multifaceted change management required for Digital Transformation [33]. This gap between problem diagnosis and solution deployment highlights a vital area for scholarly contribution.

Therefore, this thesis is motivated by the need to synthesize existing knowledge to address interconnected gaps in understanding: the strategic pathways linking digitization to sustainability, the contextual dynamics of adoption barriers, and the development of actionable implementation roadmaps. By consolidating insights on these pivotal issues, the research aims to provide a structured contribution to the discourse, supporting the construction industry's transition towards a more resilient, efficient, and digitally empowered future.

1.3 Problem Statement

There is need to find ways to upgrade the concepts of construction industry by adopting digital means and this upgradation is possible through exploration of challenges, opportunities and measures for its implementation in the construction industry of Pakistan [34]. This directive encapsulates the core imperative of this research. The Pakistani construction industry, like its global counterpart, grapples with entrenched inefficiencies including stagnant productivity, project delays, cost overruns, and resource waste. Digital Transformation presents a viable pathway for modernization, promising enhanced project delivery, improved sustainability, and greater competitiveness. However, the transition from traditional methods to digitally optimized processes is neither automatic nor straightforward. The successful integration of digital tools is contingent upon a clear understanding of the specific barriers that hinder adoption, the tangible opportunities these technologies create within the local context, and the actionable strategies required for effective implementation [35]. Presently, there is a lack of a consolidated, evidence-based framework that systematically addresses this triad of challenges, opportunities, and

implementation measures specifically tailored to the socio-economic, regulatory, and infrastructural realities of Pakistan's construction sector [36]. This gap impedes strategic decision-making for industry stakeholders and slows the pace of necessary technological adoption. Consequently, this thesis seeks to define and investigate this problem directly, providing a structured analysis to facilitate the industry's digital upgrade.

To systematically investigate this gap, the research is structured around specific guiding questions. These questions are designed to translate the broad problem into focused, actionable lines of inquiry.

1.4 Research Questions

- i What are the primary challenges and drivers influencing the adoption of digital technologies within the Pakistani construction industry?
- ii What implementation strategies and measures can effectively mitigate these challenges to accelerate Digital Transformation?
- iii What are the expert-validated critical success factors for implementing digital technologies in medium-sized commercial building projects in Islamabad?

1.5 Objectives of the Study

The primary aim of this research is to investigate the pathway for Digital Transformation within Pakistan's construction industry by empirically analysing expert perceptions of the key challenges, opportunities, and mitigation measures. To achieve this aim, the study is designed around the following specific objectives:

- i To investigate and analyse the multidimensional barriers—technological, economic, organizational, and human—that impede effective and widespread adoption
- ii To evaluate and prioritize the perceived opportunities arising from Digital Transformation by measuring expert consensus on their potential impact.

- iii To identify and assess the most effective mitigation strategies for overcoming adoption barriers by determining their expert-validated effectiveness.
- iv To analyse and rank the principal challenges hindering digital adoption in the Pakistani construction sector based on expert assessment of their severity.

By fulfilling these objectives through structured data analysis, this thesis will provide an evidence-based framework to guide stakeholders in Pakistan's construction industry towards strategic and effective digital implementation.

1.6 Research Methodology

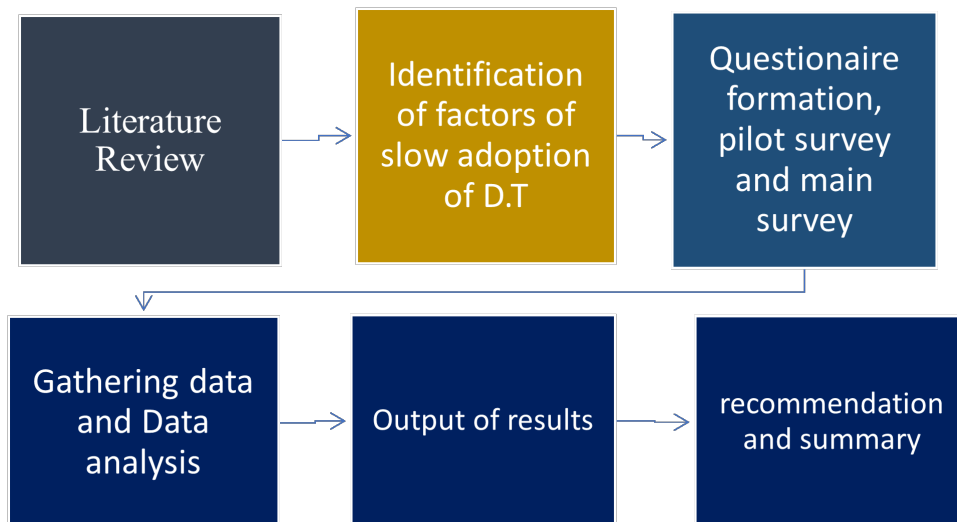


FIGURE 1.2: Methodology

1.7 Research Scope

This research is specifically scoped to investigate the Digital Transformation gap within Pakistan's construction industry. While digital technologies are increasingly adopted globally to enhance productivity and sustainability, their integration in Pakistan remains limited and inconsistent. The study focuses on identifying the underlying causes of this lag. Geographically, the empirical investigation is concentrated within the Islamabad region, targeting professionals involved in medium-sized commercial building projects. Methodologically, the scope is defined by a structured survey instrument designed to capture expert perceptions. This

involves a pilot survey for validation, followed by a main survey to collect and analyse data on three core dimensions: the severity of adoption challenges, the perceived value of digital opportunities, and the effectiveness of potential mitigation strategies. The research does not encompass a broad technological review or case studies from other regions. Its primary contribution is to provide an evidence-based, context-specific diagnosis of the barriers to digital adoption in Pakistan and to propose a prioritized set of actionable measures to accelerate implementation within the defined local context.

1.8 Study Limitations

This study acknowledges certain inherent limitations that define the boundaries of its findings and generalizability. First, the geographical scope is confined to the Islamabad region. While this provides focused insights into a major urban centre, the results may not be fully representative of the diverse socio-economic and infrastructural conditions found across Pakistan's other provinces or rural areas. Second, the research is specifically targeted at medium-sized commercial building projects. Consequently, the identified challenges, opportunities, and mitigation strategies are most directly applicable to this project typology and may not equally reflect the dynamics of large-scale infrastructure, residential, or industrial construction. Third, the analytical objective is the prioritization of key challenges and opportunities based on expert perception data. While this identifies critical areas for intervention, it does not involve the development or testing of detailed technical implementation protocols for specific digital tools. Finally, the reliance on survey data means the findings are contingent on the respondents' subjective perceptions and experiences, which may introduce bias, and the sample size constrains the depth of statistical analysis possible. These limitations are acknowledged to provide a clear context for interpreting the study's conclusions.

1.9 Research Significance

This research provides targeted, empirical insights to address the digital adoption gap in Pakistan's construction industry, offering direct value to key stakeholders. For industry practitioners, the study delivers actionable intelligence. By identifying and prioritizing the most critical barriers and valuable opportunities, it gives firms a clear roadmap to focus resources, reduce risk, and strategically guide their digital investments. For policymakers and academia, it supplies essential localized evidence. The findings translate global digitalization concepts into the specific Pakistani context, informing the development of relevant policies, incentives, and educational programs to tackle identified skill gaps and systemic challenges. Overall, the research moves the sectoral dialogue from general awareness to targeted action. It establishes an evidence-based foundation to help accelerate the industry's practical adoption of digital technologies, supporting improved productivity, sustainability, and competitiveness.

1.10 Thesis Structure

This thesis is organized into five chapters. The first chapter, Introduction, establishes the research foundation. It presents the background of Digital Transformation in the global and Pakistani construction industry, defines the research problem of low adoption, states the research aim and objectives, and outlines the significance and scope of the study.

The second chapter, Literature Review, provides a comprehensive analysis of existing knowledge. It reviews core digital technologies such as BIM, IoT, and AI, examines the documented benefits and opportunities they create, and synthesizes the key challenges and barriers to their adoption reported in international and regional contexts, establishing the theoretical framework for the investigation.

The third chapter, Research Methodology, details the study's design and execution. It explains the questionnaire development process, describes the pilot survey for validation, outlines the sampling strategy and data collection from experts in Islamabad, and specifies the statistical methods used for data analysis to address the research objectives.

The fourth chapter, Results and Analysis, presents and discusses the empirical findings. It reports the analyzed data on the perceived severity of challenges, the ranking of opportunities, and the assessed effectiveness of mitigation measures. The chapter provides a detailed discussion of these results, linking them back to the literature and interpreting their implications for the Pakistani construction context.

The fifth and final chapter, Conclusions and Recommendations, summarizes the research. It states the principal conclusions derived from the analysis, proposes practical recommendations for industry practitioners and policymakers to overcome adoption barriers, and suggests directions for future research to build upon this study's findings.

Chapter 2

Literature Review

2.1 General

The adoption of digital technologies within the construction industry has become an increasingly prominent topic in academic research, driven by persistent inefficiencies and the sector's critical role in economic development. Despite its substantial contribution to national economies, construction continues to exhibit comparatively low productivity growth and fragmented project delivery practices. As a result, a growing body of literature positions the adoption of digital technologies as a key mechanism for improving coordination, efficiency, and performance across construction projects and organizations [1]. Within existing research, digital adoption in construction is primarily discussed in relation to how firms implement, integrate, and utilize digital tools within established project and organizational environments. Rather than treating digitalization as a purely technical upgrade, scholars frequently examine adoption as a process influenced by organizational readiness, managerial capability, workforce competence, and inter-organizational collaboration. Systematic reviews indicate that successful adoption depends on the alignment between technological capabilities and the operational realities of construction firms, particularly within project-based and multi-stakeholder contexts [4]. A recurring observation in the literature is that, although awareness of digital technologies has increased, their adoption across the construction industry remains uneven and limited in scope. Many organizations adopt digital tools in a piecemeal manner, focusing on isolated applications rather than integrated solutions. This

fragmented adoption pattern has been widely reported across empirical studies and review-based research, leading scholars to characterize construction as a sector that lags behind other industries in terms of digital uptake and maturity [1]. The persistence of traditional work practices, combined with risk-averse decision-making, continues to constrain broader adoption efforts.

Research examining digital adoption highlights the multidimensional nature of the challenges faced by construction organizations. Adoption is not solely determined by the availability of technology but is strongly influenced by organizational structures, human factors, and contextual constraints. Studies focusing on implementation practices emphasize that firms often struggle to translate technological potential into operational benefits due to misalignment between digital tools and existing workflows. As a result, researchers stress the importance of structured implementation approaches that account for organizational capacity, employee engagement, and process adaptation [2]. The literature further indicates that motivations for adopting digital technologies in construction are closely linked to performance improvement and competitive positioning. Digital tools are commonly associated with enhanced information management, improved collaboration among project participants, and greater transparency across project stages. Reviews addressing sustainability-oriented adoption suggest that digital technologies can also support more efficient resource utilization and improved decision-making when integrated effectively into construction practices [8]. These perceived benefits continue to drive interest in digital adoption, even as implementation challenges persist.

At the same time, scholars consistently document a range of barriers that inhibit digital adoption in construction. Cost-related constraints, particularly high initial investment and uncertain returns, are frequently identified as major deterrents. These barriers are especially pronounced among small and medium-sized enterprises, which often lack the financial and technical resources required to implement digital tools at scale [25]. In addition to financial considerations, skills shortages and limited digital competence across the workforce are repeatedly cited as critical obstacles to adoption. Organizational resistance to change also features prominently in the adoption literature. Researchers note that construction firms often exhibit strong reliance on established practices, leading to hesitation in adopting unfamiliar

digital solutions. Studies grounded in organizational change theory emphasize that employee acceptance, managerial support, and clear communication are essential for overcoming resistance and sustaining adoption initiatives. Without these enabling conditions, digital tools are frequently underutilized or abandoned after initial implementation [29].

Another important theme in the literature is the influence of industry structure on digital adoption. Construction projects typically involve multiple stakeholders operating across fragmented contractual arrangements, which complicates information sharing and coordinated technology use. Scholars argue that this fragmentation limits the scalability of digital adoption and increases dependence on individual firms' capabilities rather than collective project-level integration [26]. As a result, adoption outcomes vary widely across projects and organizational contexts. The literature also highlights the growing research focus on identifying enablers and success factors that support effective digital adoption. Studies emphasize the importance of leadership commitment, targeted training programs, and incremental implementation strategies tailored to organizational capacity. Rather than advocating rapid or wholesale adoption, researchers suggest that gradual integration of digital tools, supported by continuous learning and process adjustment, is more likely to yield sustainable outcomes [2]. These findings underscore the need for adoption strategies that are both technically feasible and organizationally realistic. Overall, existing research provides a comprehensive foundation for understanding the adoption of digital technologies within the construction industry. The literature documents the motivations driving adoption, the persistent barriers that constrain implementation, and the organizational factors that influence success. However, it also demonstrates that adoption patterns are highly context-dependent, shaped by firm size, regional conditions, regulatory environments, and workforce characteristics [1]. This recognition has prompted calls for more localized and context-specific investigations that move beyond generalized observations.

Accordingly, this literature review synthesizes prior studies to establish a structured understanding of digital adoption in construction. It draws on existing research to outline prevailing adoption trends, summarize documented challenges, and present commonly cited enabling factors. By consolidating these perspectives,

the chapter provides a conceptual basis for examining digital optimization in construction and supports the subsequent exploration of challenges, opportunities, and implementation measures within the defined research context.

2.2 Construction Industry as Backbone of a Country

The construction industry is widely recognized in the academic literature as a fundamental pillar of national economic development. It plays a central role in shaping the physical environment through the delivery of buildings, transportation networks, utilities, and social infrastructure that support economic activity and societal well-being. As a capital-intensive sector, construction contributes directly to gross domestic product (GDP) while simultaneously stimulating demand across a wide range of upstream and downstream industries, including materials supply, professional services, and logistics [37]. Numerous studies have examined the relationship between construction activity and economic growth, consistently highlighting a strong and positive linkage. Construction investment has been shown to act as both a driver and an indicator of economic expansion, particularly in rapidly developing economies. Empirical analyses demonstrate that increased construction output is closely associated with growth in national income and improved economic performance, reinforcing the sector's role as a macroeconomic stabilizer during periods of development and urban expansion [38]. Beyond its contribution to GDP, the construction industry serves as a major source of employment, absorbing a significant share of the workforce across skill levels. The labour-intensive nature of construction enables it to generate large-scale employment opportunities, particularly in developing and transitional economies. Studies investigating causal relationships between construction activity, employment, and economic output confirm that growth in construction demand leads to corresponding increases in labour absorption and household income, thereby strengthening its socio-economic impact [39].

The construction sector also exerts substantial multiplier effects on national economies. Investment in construction projects triggers cascading economic activity

by stimulating material & equipment production, financial services, and technological support industries. Research focusing on multinational construction enterprises highlights the strategic economic role of construction firms in facilitating cross-border investment, infrastructure development, and knowledge transfer, further amplifying their contribution to national and regional economic systems [40]. In addition to its economic significance, the construction industry is critical to long-term development objectives. Infrastructure development underpins industrialization, urbanization, and improved quality of life by enabling access to housing, transportation, healthcare, and education. Longitudinal reviews of construction's role in development literature emphasize that sustained economic growth over the past several decades has been closely tied to the expansion and modernization of construction capacity, particularly in emerging economies undergoing structural transformation [38]. The interaction between construction activity and regulatory or institutional frameworks has also been explored in the literature. Studies examining construction standards and governance mechanisms suggest that well-developed construction systems contribute to economic efficiency and stability by improving project quality, safety, and productivity. In this context, construction is not only a reactive sector responding to economic growth but also an enabling mechanism that shapes development trajectories through improved built assets and infrastructure performance [41]. The contribution of the construction sector to national economic growth has also been empirically examined across different regional and development contexts. [42]. Environmental considerations further reinforce the strategic importance of the construction industry. As one of the largest consumers of natural resources and energy, construction significantly influences environmental quality and sustainability outcomes. Research examining the economic and environmental dimensions of construction activity highlights the sector's dual role as both a driver of growth and a source of environmental pressure, underscoring its central position in national sustainability agendas [37]. Several studies further highlight the bidirectional relationship between construction activity levels and broader macroeconomic performance indicators. [43].

Collectively, the literature establishes the construction industry as a backbone of national economies due to its direct contribution to economic output, employment

generation, infrastructure provision, and development facilitation. The role of construction standards and regulatory frameworks in shaping economic outcomes has also been emphasized in prior research [44]. Its extensive interconnections with other sectors magnify its economic influence, while its societal role positions it as a key enabler of long-term growth and stability. This foundational importance provides strong justification for continued scholarly and policy attention toward improving construction sector performance, efficiency, and resilience, particularly in the context of evolving technological and economic challenges [40].

2.3 Industrial Revolution

Industrial revolutions have historically reshaped production systems, labour structures, and technological capabilities across sectors, including construction. The construction industry has experienced these revolutions in a delayed and uneven manner due to its project-based nature, fragmented supply chains, and reliance on on-site manual labour. Nevertheless, each industrial revolution has left a distinct imprint on construction practices, gradually transforming methods, materials, and management approaches [45].

The First Industrial Revolution (Industry 1.0) introduced mechanization powered by water and steam energy, fundamentally altering construction materials and processes. The emergence of mechanized tools, standardized bricks, and early prefabrication concepts enabled larger-scale infrastructure such as railways, bridges, and factories. While construction remained largely craft-based, the period marked the beginning of mechanized assistance in material production and transportation, setting the foundation for industrialized construction activity [46].

The Second Industrial Revolution (Industry 2.0) brought mass production, electricity, and assembly-line principles, which significantly influenced construction through the large-scale manufacture of steel, cement, and reinforced concrete. Standardization of building components and improvements in transportation networks enabled rapid urbanization and expansion of public infrastructure. During this phase, construction increasingly supported national industrial growth by delivering factories, housing, and utilities required for expanding industrial economies [47].

The Third Industrial Revolution (Industry 3.0) introduced electronics, automation, and information technologies, marking a shift toward digital assistance in construction planning and management. Computer-aided design (CAD) and early project management software improved design accuracy and coordination. This period represented the transition from purely physical processes to digitally supported construction workflows, although digital integration remained largely isolated within individual project stages [48].

The Fourth Industrial Revolution (Industry 4.0) represents a paradigm shift characterized by cyber-physical systems, real-time data exchange, and intelligent automation. In construction, this transition has given rise to the concept of Construction 4.0, which adapts Industry 4.0 principles to the built environment. Technologies such as Building Information Modeling (BIM), the Internet of Things (IoT), artificial intelligence (AI), and digital twins enable interconnected planning, execution, and monitoring across the project lifecycle [45], [49]. Unlike earlier revolutions, Industry 4.0 emphasizes system integration rather than isolated technological adoption.

Research on Construction 4.0 highlights BIM as a central enabler that links digital models with construction activities, allowing real-time collaboration and data-driven decision-making. When combined with IoT-enabled sensing and analytics, construction processes become increasingly transparent and responsive, supporting productivity, quality, and sustainability objectives [50]. These developments position construction within broader smart city and infrastructure ecosystems rather than as a standalone production sector [51]. Recent studies also indicate that Industry 4.0 technologies are transforming construction management and quality assurance practices. Digital platforms enable integration of lean construction principles, automated inspection, and performance monitoring, enhancing control over complex projects. Advanced digital tools support predictive maintenance, safety monitoring, and lifecycle optimization, reflecting a gradual shift from reactive to proactive construction management approaches [52], [53].

Beyond Industry 4.0, emerging discourse has begun exploring Industry 5.0 and its implications for construction. This evolution emphasizes human-centric systems, resilience, and sustainability, positioning technology as a collaborative partner

rather than a replacement for human expertise. In construction, this perspective highlights the importance of integrating advanced digital systems with skilled labour, ethical considerations, and environmental responsibility [54]. Additional studies have examined Digital Transformation maturity models to assess organizational preparedness for large-scale technology adoption. [55].

Overall, the evolution of the construction industry across industrial revolutions reflects a gradual progression from mechanization to digital integration. Integration challenges across project phases and stakeholder groups have been identified as persistent barriers to Digital Transformation implementation [56]. While construction has historically lagged behind other industries in adopting revolutionary technologies, Industry 4.0 marks a critical inflection point where digital systems, data connectivity, and intelligent automation converge. The alignment of Digital Transformation initiatives with organizational governance and management structures has been highlighted as a key success factor [57]. Understanding this evolutionary trajectory provides essential context for examining contemporary Digital Transformation efforts within construction and sets the foundation for subsequent discussions on adoption challenges, opportunities, and implementation strategies. Framework-based evaluations further emphasize the importance of structured and policy-supported approaches for successful Digital Transformation in construction [58].



FIGURE 2.1: Diagram of Construction 4.0 pillars illustrating digitization and industrialization concepts [17]

Figure 2.1 illustrates the conceptual foundation of Construction 4.0, highlighting that it emerges from the integration of digitalization and industrialized construction processes. Digitalization enables data-driven planning, communication, and monitoring, while industrialization introduces standardization and automation. Together, these elements transform traditional construction practices into more efficient, scalable, and technologically integrated systems characteristic of Construction 4.0.

2.4 Conventional vs Digital Practices in Civil Engineering

Civil engineering practice has undergone a gradual transformation over time, moving from conventional, experience-driven methods toward digitally enabled and data-driven workflows. This evolution has not occurred abruptly; rather, it reflects a progressive shift in tools, processes, and professional practices influenced by advances in computing, automation, and information technologies. The literature consistently describes this transformation as a staged transition, where conventional practices coexist with emerging digital approaches before full digital integration becomes feasible [59].

2.4.1 Conventional Practices in Civil Engineering

Conventional civil engineering practices are characterized by manual and sequential workflows that rely heavily on professional experience, standardized codes, and paper-based or two-dimensional documentation. Traditionally, design and planning activities were conducted using hand-drawn drawings and later transitioned to basic computer-aided drafting (CAD) systems, which primarily served as digital replacements for manual drafting without fundamentally altering work processes [60].

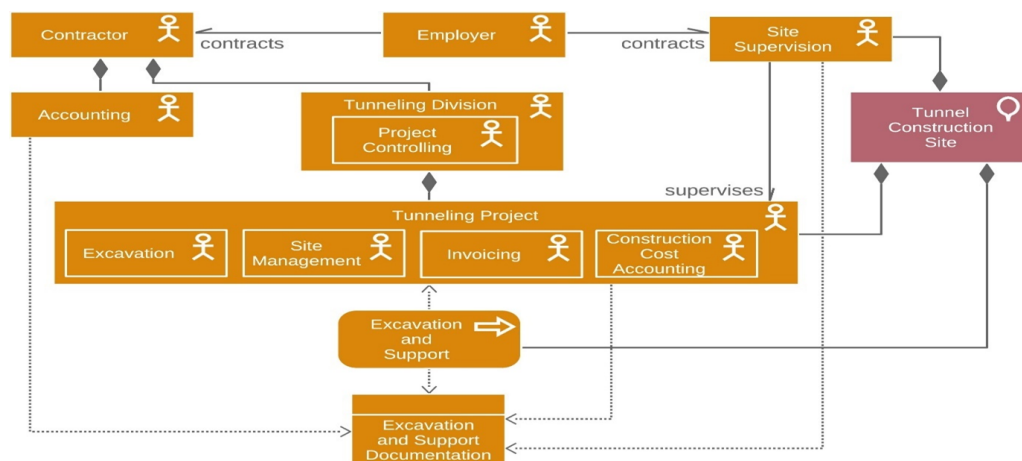


FIGURE 2.2: Conventional construction documentation workflow showing manual data flows and sequential activities [60]

Figure 2.2 illustrates a conventional project management and organizational structure commonly adopted in civil engineering projects such as tunnelling works. The workflow is characterized by a hierarchical and functionally segmented arrangement, where responsibilities such as excavation, site management, invoicing, and cost accounting operate as largely independent units. Information exchange between the contractor, employer, site supervision, and construction site are predominantly document-based and sequential, relying on manual reporting and formal documentation. This fragmented structure reflects traditional practice, where coordination is achieved through supervisory control rather than integrated, real-time data sharing [60]

In conventional practice, project delivery typically follows a linear sequence, where design, analysis, construction, and operation are treated as largely independent phases. Information exchange between stakeholders is often fragmented, leading to duplication of effort and limited coordination. Studies documenting traditional civil engineering practice emphasize the dominance of discipline-specific silos, where structural, geotechnical, and construction activities are managed separately, relying on static drawings and reports [61]. Despite these limitations, conventional practices have remained dominant for decades due to their familiarity, regulatory acceptance, and relatively low technological requirements. CAD-based drafting continues to be widely used in traditional settings, offering precision in geometric representation while lacking integrated data management and lifecycle capabilities [62].

2.4.2 Transition from Conventional to Digital Practices

The transition phase represents a hybrid period in which conventional methods coexist with emerging digital tools. During this phase, civil engineering firms began integrating software-based solutions to support design coordination, scheduling, and documentation, while still retaining many traditional workflows. This stage is marked by the gradual adoption of computer-based analysis tools, early project management software, and enhanced visualization techniques [63].

A significant aspect of this transition is the shift from CAD-centric drafting toward model-based approaches, where information richness and interoperability begin

to improve. Comparative studies between CAD and Building Information Modelling (BIM) highlight that while CAD focuses on geometric representation, BIM introduces object-based modelling and embedded data, enabling better coordination across project stages [62]. However, during the transition phase, BIM is often applied selectively rather than comprehensively, resulting in partial digital integration.

The literature also notes that this transitional stage is influenced by organizational readiness and technological maturity. Firms frequently adopt digital tools incrementally to complement existing practices rather than replacing them entirely, reflecting a cautious approach to change within the civil engineering profession [59].

2.4.3 Digital Practices

Digital practices in civil engineering represent a shift toward integrated, data-driven, and collaborative workflows that span the entire project lifecycle. At this stage, digital technologies are not merely supportive tools but core components of engineering practice. BIM serves as a central platform for integrating design, analysis, construction, and operation data, facilitating real-time collaboration among stakeholders [62].

Recent literature highlights the emergence of advanced digital technologies such as digital twins, automation systems, and intelligent data analytics as key elements of modern civil engineering practice. Digital twins enable the creation of dynamic virtual representations of physical assets, supporting monitoring, simulation, and performance optimization throughout infrastructure lifecycles [64], [65]. These technologies extend digital practices beyond design and construction into operation and maintenance phases.

Furthermore, Digital Transformation frameworks emphasize the role of integrated digital environments in supporting sustainability and decision-making within the built environment. Studies examining digital practices in civil engineering indicate that data-driven approaches enhance transparency, improve resource efficiency, and support long-term infrastructure resilience [66]. The increasing convergence of automation, digital modelling, and intelligent systems reflects a broader reorientation

of civil engineering practice toward digitally enabled delivery models [59]. Overall, the literature demonstrates that civil engineering practices have evolved through identifiable stages, from conventional manual methods to hybrid transitional approaches and, ultimately, to fully digital practices. Understanding this progression provides essential context for examining how Digital Transformation influences contemporary civil engineering workflows and sets the foundation for subsequent discussions on adoption strategies and implementation challenges.

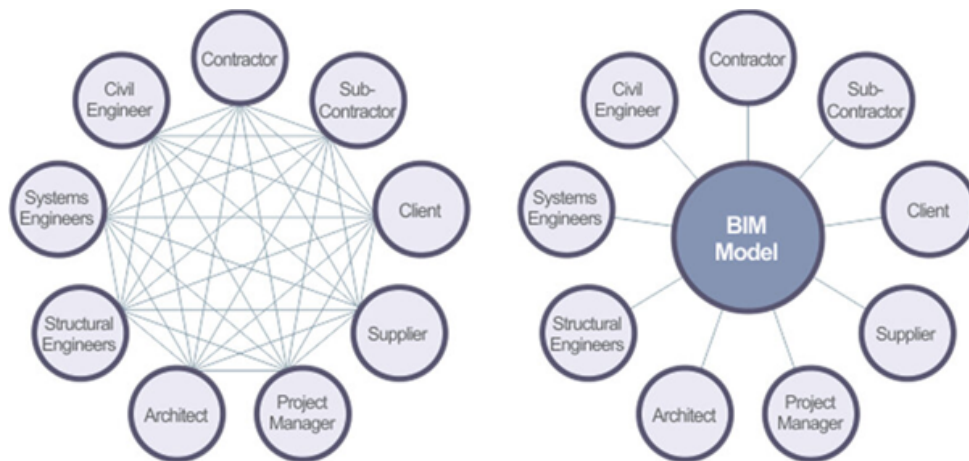


FIGURE 2.3: Comparison of traditional and digital (BIM-enabled) construction workflows, illustrating centralized data processes vs. conventional fragmented processes [62]

This figure contrasts traditional construction collaboration with a BIM-enabled collaboration model. In conventional practice, information exchange occurs through fragmented, peer-to-peer communication, leading to data duplication, coordination gaps, and inefficiencies. In contrast, the BIM-based model establishes a centralized information repository, enabling all stakeholders to access, share, and update project data consistently, thereby improving coordination, transparency, and decision-making across the project lifecycle [62].

2.5 Phases of Digital Transformation Adoption

Digital Transformation in the construction industry is widely recognized as a staged and evolutionary process rather than an instantaneous technological shift. The literature emphasizes that successful Digital Transformation unfolds through

sequential phases that reflect increasing levels of organizational readiness, technological integration, and strategic alignment. These phases collectively describe how construction organizations progress from limited digital awareness to fully integrated, data-driven operating models [67]. The initial phase of Digital Transformation is commonly characterized by digital awareness and experimentation. At this stage, organizations recognize the potential value of digital technologies but apply them in isolated or pilot-based initiatives. Digital tools such as BIM or basic data platforms are adopted on a limited scale, often driven by individual projects rather than organizational strategy. This phase is marked by fragmented implementation and a lack of standardized processes, reflecting an exploratory approach to digitalization [67], [68]. As organizations gain experience, they enter a digital readiness and integration phase, where digital initiatives become more structured and coordinated. During this phase, construction firms focus on integrating digital tools across project functions and stakeholders. Governance mechanisms, data standards, and interoperability frameworks begin to emerge, enabling better coordination between design, construction, and supply chain activities. Research highlights the importance of integrated governance models in supporting this transition, as they align technological deployment with organizational structures and decision-making processes [69].

The subsequent phase involves operational digitalization and system integration, where digital technologies are embedded within core project and organizational workflows. BIM platforms evolve into shared data environments, while emerging technologies such as blockchain and digital twins are introduced to enhance transparency, traceability, and lifecycle management. Studies emphasize that this phase is characterized by increased automation, real-time data exchange, and cross-organizational integration across the construction lifecycle [68], [70]. In more advanced stages, organizations progress toward strategic Digital Transformation and optimization. At this level, digital technologies support predictive analytics, intelligent decision-making, and continuous performance improvement. Digital twins and semantic data models enable simulation, optimization, and proactive asset management, shifting construction organizations from reactive project delivery toward value-driven lifecycle management. This phase reflects a mature alignment

between digital capabilities, organizational strategy, and long-term performance objectives [71].

The final phase of Digital Transformation is commonly described as digital maturity, where digital systems are fully embedded within organizational culture, governance structures, and business models. At this stage, digitalization is no longer treated as a technical initiative but as a strategic capability that shapes decision-making, operational resilience, and long-term competitiveness. Construction firms operating at this level leverage interconnected digital ecosystems to support innovation, cross-project learning, and coordinated transformation at both organizational and industry scales. Policy-oriented studies emphasize that digitally mature organizations are better equipped to align internal strategies with external regulatory frameworks, sustainability targets, and evolving market conditions, enabling more adaptive and resilient transformation pathways [72]. In parallel, advanced digital constructs such as semantic digital twins and integrated data environments strengthen maturity by enabling continuous system feedback, performance optimization, and knowledge-driven governance across complex construction networks [73].

Overall, the literature demonstrates that Digital Transformation in construction follows a progressive, multi-phase trajectory. Each phase builds upon the capabilities developed in earlier stages, requiring not only technological investment but also organizational alignment, governance structures, and strategic intent. Understanding these phases provides a structured foundation for analysing how construction organizations navigate Digital Transformation and informs subsequent discussions on barriers, opportunities, and implementation strategies.

Table?? Phases of Digital Transformation Adoption with Barriers and Mitigation Strategies Transformation phases [4],[7]

Phase	Key Activities	Barriers	Opportunities / Mitigation Strategies
Digitization	Converting manual and paper-based data into digital formats; storing project information electronically; implementing basic software for documentation	Limited access to technology, resistance to change, lack of digital awareness, reliance on traditional methods, inconsistent data entry	Awareness campaigns, simple training programs, use of affordable digital tools, gradual digitization of core workflows

Digitalization Using BIM, IoT sensors, project management software, and cloud platforms to improve coordination and planning; integrating design and construction data Poor system integration, lack of interoperability, high software costs, limited technical skills, cultural resistance, fragmented data management Leadership engagement, structured training, phased implementation, establishing data standards, encouraging interdepartmental collaboration

Digital Transformation Full integration of digital systems across design, construction, and operation; data-driven decision-making; adoption of AI, Digital Twins, predictive analytics, and advanced monitoring tools High investment requirements, low organizational digital maturity, lack of clear policies, cybersecurity concerns, insufficient skill development Strategic roadmaps, government support and incentives, continuous monitoring and optimization, cross-functional teams, policy frameworks, leveraging pilot projects to scale adoption

This table 2.1 presents a structured view of the progressive stages of digital evolution in the construction industry, distinguishing clearly between digitization, digitalization, and Digital Transformation. Digitization represents the foundational stage, focusing on the conversion of manual and paper-based information into digital formats, which primarily improves data accessibility and record management but offers limited process integration. As organizations advance to digitalization, digital tools such as BIM, IoT-enabled sensing, and project management platforms are employed to enhance coordination, planning, and information flow across project functions, although challenges related to interoperability, skills, and organizational culture often persist. The final stage, Digital Transformation, reflects a comprehensive integration of digital technologies across the entire project lifecycle, enabling data-driven decision-making, advanced analytics, and intelligent systems such as digital twins and AI. At this level, digitalization extends beyond operational improvement to strategic and organizational change, requiring strong leadership, supportive policies, and sustained capability development to fully realize long-term value.

TABLE 2.1: Phases of Digital Transformation Adoption with Barriers and Mitigation Strategies Transformation phases [4],[7]

Phase	Key Activities	Barriers	Opportunities / Mitigation Strategies
Digitization	Converting manual and paper-based data into digital formats; storing project information electronically; implementing basic software for documentation	Limited access to technology, resistance to change, lack of digital awareness, reliance on traditional methods, inconsistent data entry	Awareness campaigns, simple training programs, use of affordable digital tools, gradual digitization of core workflows
Digitalization	Using BIM, IoT sensors, project management software, and cloud platforms to improve coordination and planning; integrating design and construction data	Poor system integration, lack of interoperability, high software costs, limited technical skills, cultural resistance, fragmented data management	Leadership engagement, structured training, phased implementation, establishing data standards, encouraging interdepartmental collaboration
Digital Transformation	Full integration of digital systems across design, construction, and operation; data-driven decision-making; adoption of AI, Digital Twins, predictive analytics, and advanced monitoring tools	High investment requirements, low organizational digital maturity, lack of clear policies, cybersecurity concerns, insufficient skill development	Strategic roadmaps, government support and incentives, continuous monitoring and optimization, cross-functional teams, policy frameworks, leveraging pilot projects to scale adoption

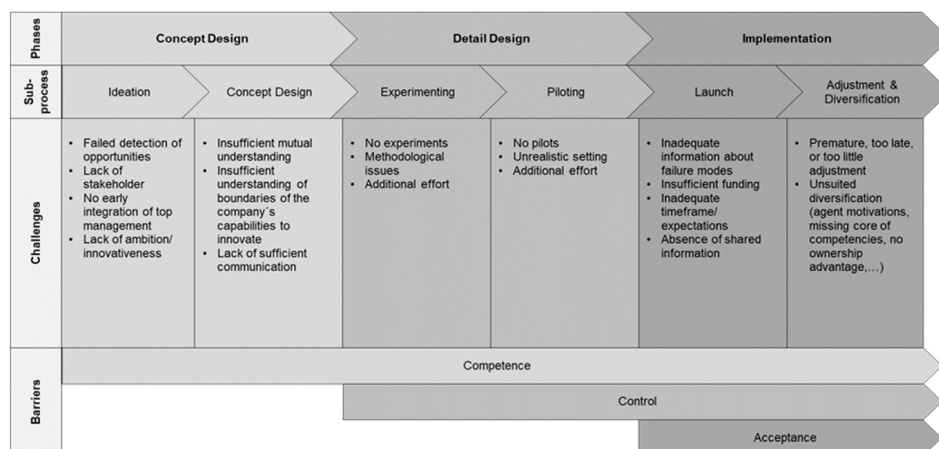


FIGURE 2.4: Conceptual Adoption process phase wise [73]

The figure 2.4 illustrates a phased conceptual model for digital innovation management in construction, outlining critical junctures and failure modes. It delineates three primary phases: Concept Design, where issues like insufficient funding, unrealistic settings, and methodological flaws can derail initial ideation and experimentation; Conclusion, where strategic failures such as lack of stakeholder integration, inadequate communication, and misaligned ambition prevent successful project finalization; and Compliance & Control, which ensures adherence to standards and acceptance [73]. This framework systematically maps the points at which innovation efforts commonly falter, emphasizing the need for structured governance throughout the transformation lifecycle.

2.6 Digital Transformation in Developed and Developing Countries

Digital Transformation in the construction industry does not progress uniformly across the globe. Instead, it reflects broader national differences in digital readiness, institutional capacity, economic resources, and technological infrastructure. The literature consistently emphasizes that while the core principles of Digital Transformation are similar worldwide, the pace, depth, and scope of implementation vary significantly between developing and developed countries. These variations shape how Digital Transformation is conceptualized, operationalized, and sustained within construction sectors across different economic contexts [67].

At a macro level, global assessments of digital development indicate substantial disparities in digital maturity between countries, influenced by factors such as connectivity, digital skills, innovation ecosystems, and governance frameworks. Such disparities directly affect the construction industry, which relies heavily on coordinated digital infrastructure, skilled human capital, and supportive policy environments to achieve meaningful transformation [74], [75]. Understanding these contextual differences is essential for interpreting adoption patterns and setting realistic expectations for Digital Transformation outcomes in construction.

2.6.1 Developed Countries

In developing countries, Digital Transformation in construction is typically characterized by incremental and uneven progress, with adoption often limited to specific tools or project phases rather than organization-wide integration. The literature indicates that digital initiatives in these contexts are frequently driven by external pressures such as client requirements, international partnerships, or pilot projects, rather than by comprehensive national or organizational digital strategies [67]. BIM adoption in developing countries often remains at a basic or intermediate level, primarily supporting visualization, clash detection, or documentation rather than full lifecycle integration. Digital tools are commonly applied at the design or planning stages, while construction execution and facility management continue to rely on conventional methods. Studies highlight that fragmented workflows, limited interoperability, and inconsistent data standards restrict the ability of firms to scale digital solutions beyond isolated applications [67]. Institutional and economic factors play a critical role in shaping Digital Transformation trajectories in developing countries. Limited access to advanced digital infrastructure, high software and hardware costs, and shortages of skilled professionals constrain the depth of transformation achievable by construction organizations. In many cases, Digital Transformation initiatives remain dependent on individual champions or short-term projects, making them vulnerable to discontinuation once external support diminishes [74].



FIGURE 2.5: Generic approach to digital adoption [67]

This figure 2.5 outlines the key enablers for successful Digital Transformation in

the construction industry. Government policies and financial incentives create an enabling regulatory and economic environment, while pilot projects allow organizations to test and validate digital solutions with reduced risk. Effective integration across project phases, supported by continuous training and skill development, ensures that digital initiatives are embedded into routine practices rather than remaining isolated implementations [67].

From a national perspective, uneven digital development further amplifies sectoral challenges. Countries with lower levels of digital readiness often lack coherent policy frameworks, standardized regulations, and coordinated digital roadmaps for the construction sector. As a result, Digital Transformation efforts tend to be reactive and fragmented, with limited alignment between industry, academia, and government institutions [75]. Despite these constraints, the literature also notes gradual progress, particularly in urban centres and large infrastructure projects, where exposure to global best practices accelerates digital learning and experimentation. Digital Transformation in developing countries can be described as project-driven, selective, and transitional, reflecting broader socio-economic and institutional limitations. While the foundations for transformation are increasingly visible, achieving sustained and integrated digital maturity remains a long-term challenge in these contexts [67].

2.6.2 Developing Countries

In contrast, developed countries generally exhibit more advanced and integrated Digital Transformation within the construction industry. Digital Transformation in these contexts is often embedded within national innovation strategies, supported by robust digital infrastructure, skilled workforces, and mature regulatory environments. The literature describes a shift from isolated digitalization efforts toward coordinated, ecosystem-level transformation across the construction life-cycle [67]. BIM adoption in developed countries typically extends beyond design coordination to encompass construction planning, asset management, and operational optimization. Digital platforms are increasingly integrated with supply chains, enabling real-time data exchange, traceability, and collaboration among stakeholders. Emerging technologies such as digital twins, advanced analytics, and

automated monitoring systems are deployed to support predictive decision-making and lifecycle performance management [70], [71].

Policy support and governance frameworks play a decisive role in enabling Digital Transformation in developed countries. Studies emphasize that clear national standards, mandatory BIM requirements, and long-term digital roadmaps provide stability and direction for industry-wide adoption. These frameworks facilitate interoperability, data governance, and alignment between public and private stakeholders, allowing construction organizations to scale digital initiatives with reduced uncertainty [72]. Digital maturity in developed countries is further reinforced by strong innovation ecosystems that link industry, academia, and technology providers. Continuous professional development, research collaboration, and public investment in digital infrastructure contribute to sustained capability building. Comparative assessments of digital development consistently rank developed countries higher in terms of readiness, network connectivity, and innovation capacity, which directly translates into deeper and more resilient Digital Transformation within construction sectors [75].

At the organizational level, Digital Transformation in developed countries increasingly influences business models, project delivery methods, and strategic decision-making. Construction firms leverage integrated digital environments to enhance productivity, sustainability, and resilience, moving beyond efficiency gains toward long-term value creation. As a result, Digital Transformation is treated not as a technological upgrade but as a core strategic asset that shapes competitive positioning and industry evolution [73].

In summary, the literature reveals a clear contrast between developing and developed countries in terms of Digital Transformation maturity within the construction industry. While developing countries experience gradual, project-based, and uneven transformation, developed countries demonstrate more comprehensive, policy-supported, and ecosystem-driven digital integration. This global disparity provides essential context for understanding adoption challenges and informs the subsequent examination of barriers, opportunities, and mitigation strategies in Digital Transformation.

2.7 Adoption of Digital Transformation

The adoption of Digital Transformation in construction represents the sector's systematic integration of advanced technologies, data-centric processes, and new collaborative models to achieve fundamental improvements in performance [66]. This process is a strategic response to critical drivers, including demands for greater productivity, stringent sustainability goals, and enhanced project predictability [67]. Adoption, therefore, is not merely about implementing software but about managing a complex organizational and technical shift that disrupts long-standing industry conventions [68]. This transition creates a distinct phase where traditional and digital practices coexist, presenting both significant opportunities and formidable challenges. A clear understanding of this hybrid landscape is essential for effective navigation. The path forward requires two complementary analyses.

First, a detailed comparison between conventional and emerging digital practices is necessary to identify the precise points of operational change and potential conflict [69]. Second, a strategic assessment of the resulting opportunities and the barriers that can impede them is required to develop effective mitigation pathways [70]. The following subsections provide this structured analysis to inform successful implementation strategies.

2.7.1 Barriers and Challenges in Adoption of Digital Transformation

A prominent challenge to Digital Transformation adoption in the construction industry is the high initial cost of implementation, including expenses related to software acquisition, hardware infrastructure, system integration, and workforce training. Many construction organizations, particularly small and medium-sized enterprises, operate under tight financial constraints, making long-term digital investment difficult to justify amid uncertain returns. The literature repeatedly identifies cost-related concerns as a primary reason for delayed or partial adoption of digital technologies [25]. Another widely reported barrier is the lack of digital skills and technical expertise within the construction workforce. Digital Transformation

requires competencies in data management, modelling, analytics, and system integration, which are often absent in traditionally trained construction professionals. Skills shortages are evident across managerial, technical, and site-operational levels, limiting organizations' ability to implement and sustain advanced digital systems effectively [27].

Organizational resistance to change further constrains adoption. Construction firms often exhibit strong reliance on established practices, informal knowledge transfer, and experience-based decision-making. Digital Transformation challenges existing power structures and workflows, leading to apprehension among both management and operational staff. Studies emphasize that resistance is particularly pronounced when digital initiatives are introduced without clear communication, leadership commitment, or alignment with organizational objectives [3]. From a technological perspective, interoperability and data integration challenges remain persistent obstacles. Construction projects typically involve multiple stakeholders using diverse digital platforms, resulting in fragmented data environments. The absence of standardized data protocols and integration frameworks limits seamless information exchange and undermines collaboration across project phases, reducing the effectiveness of Digital Transformation initiatives [9]. Institutional and regulatory barriers also play a significant role. The absence of clear national digital construction policies, standards, and regulatory guidance creates uncertainty for organizations considering digital investment. In many contexts, unclear legal frameworks related to data ownership, liability, and cybersecurity discourage organizations from fully integrating digital systems into core operations [14].

Finally, limited digital infrastructure and connectivity, particularly in developing contexts, restricts the scalability of Digital Transformation. Inadequate internet access, unreliable power supply, and uneven technological ecosystems constrain the use of cloud-based platforms, real-time monitoring systems, and advanced analytics. These infrastructural limitations contribute to fragmented and project-specific adoption rather than organization-wide transformation [74]. Collectively, these challenges illustrate that Digital Transformation adoption in construction is constrained by a combination of financial, human, organizational, technological, and institutional factors, reinforcing the need for holistic and context-sensitive

adoption strategies.

2.7.2 Opportunities and Mitigation Strategies

Despite the challenges identified, the literature highlights substantial opportunities and mitigation strategies that can support effective Digital Transformation adoption in the construction industry. A recurring theme is the importance of strong leadership and strategic vision. Organizations that articulate clear digital roadmaps and demonstrate top-management commitment are more likely to align digital initiatives with long-term business goals and overcome resistance to change [3]. Capacity building through targeted training and continuous professional development is consistently identified as a critical mitigation strategy. Investment in digital skills enhances workforce competence, improves confidence in technology use, and supports cultural change within organizations. Studies indicate that training initiatives are particularly effective when they address both technical skills and managerial understanding of digital value creation [27]. A practical mitigation approach emphasized in the literature is phased and incremental implementation. Rather than pursuing full-scale Digital Transformation immediately, organizations can introduce digital technologies through pilot projects and modular adoption strategies. This approach allows firms to manage risk, assess performance outcomes, and build internal support before scaling digital systems across projects and departments [11].

At the institutional level, policy support and government intervention represent significant opportunities for accelerating adoption. National digital construction strategies, standardized BIM mandates, financial incentives, and public-private partnerships reduce uncertainty and encourage broader industry participation. Evidence from policy-driven digitalization initiatives demonstrates that supportive regulatory environments play a decisive role in sustaining long-term Digital Transformation [72]. Digital Transformation also offers opportunities to address broader industry challenges related to productivity, sustainability, and safety. Integrated digital systems enable improved coordination, data-driven decision-making, predictive maintenance, and lifecycle performance optimization. Advanced technologies such as digital twins and AI-driven analytics support proactive risk management,

TABLE 2.2: Summary of Challenges, Opportunities, and Mitigation Strategies for Digital Transformation Adoption in the Construction Industry [1]–[20], [76]– [77]

Literature Source	Key Challenges Identified	Opportunities Enabled by Digital Transformation	Mitigation / Implementation Strategies
Digital Transformation of the Construction Industry: A Review	Slow adoption due to high costs, skills shortages, and organizational resistance	Improved productivity, sustainability, and collaboration	Awareness initiatives, workforce training, and standardization of digital technologies
Challenges and Strategies for the Adoption of Smart Technologies in the Construction Industry	Limited financial resources, lack of technical skills, and fragmented implementation	Automation, efficiency improvement, and enhanced project delivery	Policy support, structured training programs, and phased adoption strategies
Implementation of Digital Technologies in Construction Companies	Organizational resistance, lack of interoperability, and unclear digital vision	Enhanced data sharing and cross-functional coordination	Clear digital roadmaps, leadership commitment, and change management
Digitalization as a Strategic Means of Achieving Sustainable Efficiencies	Limited awareness of digital value and fragmented data environments	Sustainable resource use and waste reduction	Development of digital sustainability frameworks and data integration standards

Continued on next page...

Literature Source	Key Challenges Identified	Opportunities Enabled by Digital Transformation	Mitigation / Implementation Strategies
Introduction to Digital Transformation in the Construction Industry	Cultural inertia and absence of coherent policy guidance	Improved competitiveness and data-driven decision-making	Policy frameworks and cross-sector collaboration mechanisms
Enhancing Digital Transformation in Architecture and Construction	Cybersecurity concerns and resistance to organizational change	Innovation, collaborative workflows, and data-driven design	Digital governance structures and structured implementation strategies
Generative AI in the Construction Industry	Data reliability concerns, ethical issues, and skills gaps	Design optimization, efficiency, and advanced simulation	Ethical guidelines, controlled deployment, and pilot testing
Potentials of Digital Technology Practices at Managerial Level	Limited top-management support and strategic alignment	Positive managerial perception of digital value	Executive engagement and targeted leadership training
Impact of Industry 4.0 Platforms on Construction 4.0	System integration and interoperability challenges	Automation and real-time data analytics	Alignment of digital frameworks and interoperability standards
Reinventing Construction: A Route to Higher Productivity	Fragmented workflows and inefficient traditional processes	Productivity improvement and cost reduction	Process re-engineering and adoption of lean digital practices

Continued on next page...

Literature Source	Key Challenges Identified	Opportunities Enabled by Digital Transformation	Mitigation / Implementation Strategies
From BIM to Digital Twin	Complexity of multi-system integration	Predictive maintenance and lifecycle transparency	Unified BIM–IoT frameworks and continuous monitoring
Construction 4.0 in Narrow and Broad Sense	Low technological readiness and skills gaps	Smarter construction processes	Gradual transition planning and institutional support
BIM Implementation Barriers in Pakistan	High costs, limited awareness, and regulatory gaps	Cost control, efficiency, and sustainability	National digital policies and technical capacity building
Digitalization Drivers and Barriers in Pakistan	Weak policy support and lack of standards	Transparency, productivity, and economic growth	Public–private partnerships and regulatory frameworks
Digital Twin-Enabled BIM–IoT Frameworks	Technical complexity and limited expertise	Energy efficiency and real-time optimization	Data-driven frameworks and advanced analytics
World Bank Construction Sector Insights	Infrastructure deficits and institutional constraints	Employment generation and economic development	Government-led infrastructure and digital investment programs
Digital Construction Technologies and SDGs	Cost barriers and data interoperability issues	Environmental sustainability and carbon reduction	Adoption of green digital technologies

Continued on next page...

Literature Source	Key Challenges Identified	Opportunities Enabled by Digital Transformation	Mitigation / Implementation Strategies
Construction 4.0 and Sustainable Practices	Digital literacy gaps	Lifecycle performance improvement	Workforce training and policy alignment
Artificial Intelligence in Construction Management	Data trust issues and high implementation costs	Automation, safety improvement, and predictive planning	Stepwise AI adoption strategies
Digital Transformation in Smart Construction	Skills shortages and lack of standardization	Innovation and collaborative delivery	Education initiatives and cross-sector innovation
Intelligent Data-Driven Methods in Construction Projects	Poor data quality, lack of trust in predictive outputs, and limited computational expertise	Improved forecasting accuracy, proactive risk identification, and enhanced decision support	Data quality management frameworks, gradual integration of intelligent analytics, and validation through pilot projects
Advanced Computational Decision-Support Systems in Construction	Resistance to algorithm-based decision-making and lack of transparency in analytical models	Faster and more informed project planning and control	Human-in-the-loop approaches, explainable analytics, and managerial training

Continued on next page...

Literature Source	Key Challenges Identified	Opportunities Enabled by Digital Transformation	Mitigation / Implementation Strategies
Machine Learning Applications for Construction Safety and Planning	Limited availability of historical datasets and integration challenges with existing systems	Enhanced safety monitoring, early hazard detection, and improved site management	Structured data collection practices and incremental deployment alongside traditional methods
Data-Driven Scheduling and Cost Prediction in Construction	Uncertainty in model reliability and limited technical skills	Improved schedule predictability and cost control	Stepwise implementation, benchmarking against traditional estimates, and workforce upskilling
Intelligent Analytics for Sustainable Construction Management	Complexity of integrating sustainability metrics and computational tools	Optimized resource use, reduced waste, and improved environmental performance	Standardized sustainability indicators and integration with existing project management platforms
Advanced Computational Methods for Construction Risk Management	Limited awareness and scepticism toward predictive risk models	Early risk identification and proactive mitigation	Awareness initiatives, scenario-based testing, and decision-support integration
Data-Centric Digital Transformation Frameworks	Fragmented data environments and organizational silos	Integrated project information and lifecycle transparency	Establishment of centralized data environments and interoperability standards

Continued on next page...

Literature Source	Key Challenges Identified	Opportunities Enabled by Digital Transformation	Mitigation / Implementation Strategies
Intelligent Monitoring and Performance Optimization Systems	High implementation costs and infrastructure dependency	Real-time performance tracking and lifecycle optimization	Phased deployment and selective adoption in high-impact project areas
Computational Intelligence in Construction Decision-Making	Skills gap and lack of confidence in automated insights	Enhanced managerial decision-making and strategic planning	Executive training, controlled system deployment, and performance audits
Advanced Analytics for Construction Productivity Enhancement	Cultural resistance and uncertainty about benefits	Productivity improvement and operational efficiency	Change management strategies and demonstration through pilot case applications

energy efficiency, and environmental performance, strengthening the overall value proposition of Digital Transformation [15].

Finally, the literature emphasizes the role of collaborative ecosystems involving industry, academia, and technology providers. Knowledge sharing, research collaboration, and innovation networks support the diffusion of best practices and reduce duplication of effort. Countries and organizations embedded within strong innovation ecosystems demonstrate higher digital maturity and greater resilience in overcoming adoption barriers [75]. In summary, while Digital Transformation adoption in construction is hindered by multiple interrelated challenges, the literature indicates that these barriers can be mitigated through strategic leadership, skills development, phased implementation, supportive policy frameworks, and collaborative ecosystems. These opportunities provide a structured pathway for construction organizations to transition from fragmented digital initiatives toward sustained and integrated Digital Transformation. To complement the preceding discussion, 2.2 provides a comparative synthesis of key barriers, opportunities, and mitigation measures identified in selected studies

Chapter 3

Methodology

3.1 Background

This research adopts an empirical methodology to investigate the adoption of Digital Transformation within the construction industry, with particular emphasis on identifying challenges, opportunities, and mitigation strategies. Given the multi-faceted nature of Digital Transformation—encompassing technical, organizational, and human-related factors—a systematic approach is required to capture industry-wide perceptions in a measurable and comparable manner. The study focuses on construction professionals involved in small- and medium-sized commercial projects in Islamabad, where the implementation of Digital Transformation remains limited and uneven. In this context, a questionnaire-based survey was selected as the primary data collection method, as it enables the collection of standardized responses from a diverse group of practitioners while facilitating quantitative assessment of key adoption-related factors.

To ensure that the research instrument reflects practical industry conditions rather than purely theoretical considerations, the questionnaire was refined through expert input prior to full-scale deployment. This validation process enhances the clarity, relevance, and applicability of the survey items, thereby strengthening the methodological rigor of the empirical investigation. The adopted methodological approach provides a structured framework for assessing the current state of Digital Transformation adoption in the construction industry. It supports objective evaluation of practitioner perceptions and enables evidence-based analysis aligned with

the research objectives, forming a coherent foundation for the subsequent stages of data collection and analysis

3.2 Methodology Flowchart

A flowchart is constructed to visually understand the methodology that was used to conduct this research. The flowchart indicates the step wise process that was followed throughout this study.

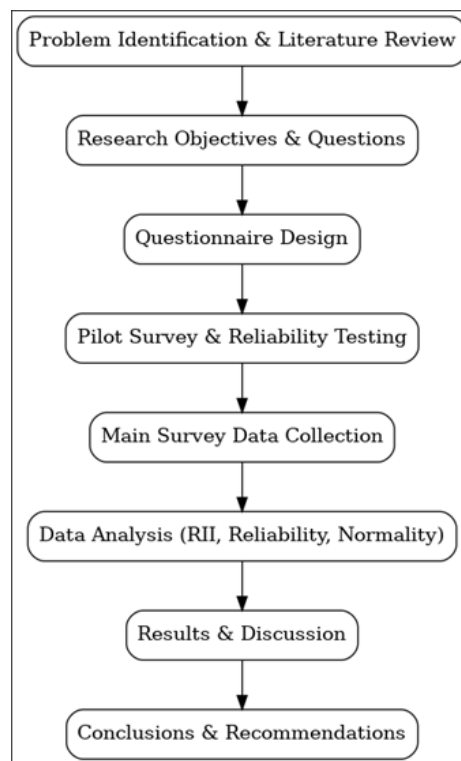


FIGURE 3.1: Methodology Flowchart

3.2.1 Problem Identification and Literature Review

This step involves identifying the research problem related to Digital Transformation adoption in the construction industry and reviewing relevant literature to understand existing knowledge, gaps, and contextual issues. The review provides a theoretical foundation for defining the study focus and research direction.

3.2.2 Research Objectives and Research Questions

Based on the identified research problem and literature review, clear research objectives and research questions are formulated. These objectives guide the scope of the study and define the key aspects of Digital Transformation examined in the research.

3.2.3 Questionnaire Design

A structured questionnaire was developed to systematically collect expert opinions on the challenges, opportunities, and mitigation strategies related to Digital Transformation in the construction industry. The questionnaire items were initially derived from an extensive literature review and then refined through the Delphi technique, where multiple rounds of expert feedback were used to validate, modify, and finalize the relevant factors. This process ensured that the selected items are not only literature-based but also practically relevant and expert-validated. Furthermore, the questionnaire was aligned with the research objectives, and a Likert scale was adopted to quantitatively capture expert responses for analysis.

3.2.4 Pilot Survey and Reliability Testing

A pilot survey was conducted to evaluate the clarity, relevance, and structure of the questionnaire. Expert feedback from the pilot phase helped in refining ambiguous or unclear questions. Additionally, reliability testing was performed using statistical measures such as Cronbach's Alpha to assess the internal consistency of the questionnaire. The results confirmed that the instrument was reliable and suitable for the main survey, ensuring the accuracy and credibility of the collected data.

3.2.5 Main Survey Data Collection

The refined questionnaire is distributed to construction professionals involved in small- and medium-sized commercial building projects in Islamabad. Responses collected during the main survey form the primary dataset for subsequent analysis.

3.2.6 Data Analysis Techniques

The collected data are analysed using appropriate statistical techniques, including reliability testing, normality assessment, and Relative Importance Index (RII) analysis. These methods are used to prioritise factors influencing Digital Transformation adoption.

3.2.7 Results and Discussion

The analysed results are presented and discussed to highlight key challenges, opportunities, and mitigation strategies identified through RII ranking. The discussion interprets the findings in relation to the study objectives and research context.

3.2.8 Conclusions and Recommendations

Based on the results of the study, conclusions are drawn regarding Digital Transformation adoption in the defined research scope. Practical recommendations are then proposed to support effective implementation within the local construction industry.

3.3 Research Design and Approach

3.3.1 Research Design

This study employs a cross-sectional survey research design, in which data are collected from respondents at a single point in time. The purpose of this design is to capture the current state of Digital Transformation adoption within the construction industry, particularly with respect to practitioner perceptions of challenges, opportunities, and mitigation strategies. A cross-sectional design is appropriate for this research because Digital Transformation adoption in construction is context-dependent and varies across organizations and projects. The design allows for systematic comparison of responses across different professional roles and organizational settings without requiring longitudinal tracking, which is beyond the scope of the present study.

3.3.2 Research Approach

The research follows a quantitative-dominant approach, as the primary objective is to measure, compare, and prioritize factors influencing Digital Transformation adoption using structured survey data. Quantitative methods enable the conversion of expert perceptions into numerical form, facilitating objective analysis, ranking, and interpretation of key factors. Quantitative analysis supports the study's focus on identifying the relative significance of adoption-related challenges, opportunities, and mitigation measures. This approach ensures consistency in data interpretation and allows findings to be presented in a form suitable for comparison and decision-making within the construction industry.

3.4 Questionnaire Development

The questionnaire was developed as the primary research instrument for this study to systematically capture construction professionals' perceptions regarding the adoption of Digital Transformation. The development process was guided by the research objectives and focused on producing an instrument that is conceptually clear, practically relevant, and suitable for quantitative analysis. Particular attention was given to logical structure, clarity of wording, and consistency in measurement to ensure that responses could be meaningfully compared and analysed.

3.4.1 Questionnaire Structure

The questionnaire was structured into two main sections: demographic information and technical assessment items. The demographic section was designed to capture background characteristics of respondents, such as professional role, experience level, and organizational context. This information supports contextual interpretation of responses and enables comparative assessment across different groups of construction professionals. The technical section formed the core of the questionnaire and was developed to directly address the objectives of the study. It comprised a series of statements designed to evaluate key aspects of Digital Transformation adoption in the construction industry.

3.4.2 Development of Technical Constructs

To ensure conceptual organization and analytical clarity, the technical assessment items were grouped into three primary constructs: challenges, opportunities, and mitigation strategies related to Digital Transformation adoption. These constructs represent distinct dimensions of the adoption process while remaining interconnected in practice. Structuring the questionnaire around these constructs enables systematic evaluation of practitioner perceptions and supports subsequent comparison and prioritization of factors within and across each category.

3.4.3 Item Formulation and Coding

Questionnaire items were formulated to reflect practical conditions and commonly encountered issues within construction projects, rather than abstract or purely theoretical concepts. Each item was designed to address a single issue to minimize ambiguity and ensure consistent interpretation by respondents from diverse professional backgrounds, including consultants, contractors, and engineers.

3.4.4 Measurement Scale

The questionnaire items were measured using a five-point Likert-type scale, which is widely applied in construction management and empirical research to capture respondents' perceptions and levels of agreement in a structured and quantifiable manner. The Likert-type scale enables subjective judgments to be expressed numerically, facilitating comparison and subsequent statistical analysis of responses [6].

A uniform measurement scale was applied across all technical items to ensure consistency in response interpretation. The adopted response categories and their corresponding numerical values are presented in Table 3.1.

3.5 Delphi Validation and Pilot Survey

Prior to full-scale data collection, the questionnaire underwent a structured validation process to ensure clarity, relevance, and practical applicability. Given the

TABLE 3.1: Likert Scale

Response Category	Score
Strongly Disagree	1
Disagree	2
Neutral	3
Agree	4
Strongly Agree	5

applied nature of the study and the industry-specific context of Digital Transformation in construction, expert input was incorporated to refine the questionnaire and enhance its suitability for empirical investigation.

3.5.1 Delphi Validation

The Delphi technique was employed as a systematic expert consultation method to validate the content of the questionnaire. A panel of construction professionals with experience in digital technologies and project delivery was invited to review the preliminary version of the questionnaire. The experts evaluated the questionnaire items with respect to clarity, relevance, completeness, and alignment with real-world construction practices. Feedback from the expert panel was collected iteratively and used to refine the questionnaire items. Ambiguous wording was clarified, overlapping items were adjusted, and minor modifications were made to improve consistency and interpretability. The Delphi process was used strictly as a validation mechanism rather than as a standalone qualitative research method.

3.5.2 Pilot Survey

Following expert validation, a pilot study was conducted to test the refined questionnaire under practical conditions. The pilot survey was administered to a small group of construction professional's representative of the study's target population. The purpose of the pilot study was to assess the questionnaire's usability, response clarity, and overall structure prior to large-scale deployment. The pilot study enabled identification of any remaining issues related to question sequencing, response interpretation, or completion time. Based on the pilot feedback, minor adjustments were made to optimize the questionnaire for the main survey. No

substantive changes to the underlying constructs were required, indicating that the instrument was suitably designed for full-scale data collection.

3.6 Sampling Strategy and Sample Size

To thoroughly investigate the adoption and impact of Digital Transformation in the construction industry, a structured survey methodology was employed. The process included expert validation, pilot testing, and the main survey to ensure reliability, clarity, and comprehensiveness.

3.6.1 Target Population

The target population for this study comprises construction industry professionals involved in small- and medium-sized commercial building projects within the Islamabad region. This population includes consultants, contractors, engineers, architects, and client representatives who are directly engaged in planning, execution, and management activities and who possess practical exposure to construction project delivery and related decision-making processes. Islamabad was selected as the study area due to its concentration of ongoing commercial construction activity and the presence of organizations operating at varying levels of digital maturity. Restricting the population to a defined geographic area and project type ensures contextual consistency and supports meaningful interpretation of practitioner perceptions.

3.6.2 Sample Strategy

A purposive sampling strategy was adopted for this study. Respondents were selected based on their professional involvement in construction projects and their relevance to activities associated with digital technologies or project management practices. This approach is appropriate for perception-based empirical research, where informed professional judgment and experience are essential for obtaining meaningful and reliable responses. Efforts were made to include respondents from different professional roles within the construction industry to capture diverse perspectives on Digital Transformation adoption. Although probabilistic sampling

was not employed, the adopted strategy ensured that participants were suitably qualified to address the research objectives.

3.6.3 Sample Size Determination

The required sample size for this study was determined using Yamane's (1967) formula for finite populations, which is commonly applied in survey-based research to estimate an appropriate sample size based on population size and an acceptable margin of error. The formula is expressed as:

$$n = \frac{N}{(1 + N(e)^2)} \quad (3.1)$$

Where,

n = required sample size

N = population size

e = margin of error (level of precision)

In this study, a margin of error of 5% (e = 0.05) was adopted, corresponding to a 95% confidence level, which is widely accepted in empirical research. Based on the defined study scope and the number of construction professionals realistically accessible within small- and medium-sized commercial projects in Islamabad, the population size was estimated to be approximately 125. This estimate represents a conservative and contextually reasonable approximation of the accessible population rather than an exact census value.

Substituting these values into Yamane's formula:

$$n = \frac{125}{(1 + 125(0.05)^2)} \quad (3.2)$$

Accordingly, a minimum sample size of 94 respondents was considered adequate for the study, providing a balance between statistical reliability and practical feasibility within the defined research context.

3.7 Data Collection Procedure

Data collection for this study was carried out using the finalized questionnaire following completion of the pilot study and expert validation process. The refined questionnaire was administered to construction professionals involved in small- and medium-sized commercial projects within the Islamabad region, in line with the defined sampling strategy.

The questionnaire was distributed using a combination of online and in-person approaches to maximize response reach and participation. Online distribution was conducted through professional communication channels, including email and messaging platforms, while in-person distribution was undertaken where direct access to respondents was feasible. This mixed distribution approach helped accommodate varying respondent preferences and availability.

Prior to participation, respondents were informed about the purpose of the study and assured that their responses would be used solely for academic research. Participation was voluntary, and respondents were encouraged to provide honest and unbiased responses based on their professional experience. To maintain confidentiality, no personally identifiable information was collected, and all responses were treated anonymously.

The data collection process was conducted over a defined time period to ensure consistency in responses and to allow adequate time for follow-up where necessary. Upon completion of the data collection phase, the responses were reviewed for completeness and suitability prior to data coding and analysis.

3.8 Data Analysis Techniques

The collected questionnaire data were analysed using a structured quantitative approach aligned with the research objectives. Prior to advanced analysis, responses were screened for completeness and suitability.

Descriptive statistics, including frequencies, percentages, mean values, and standard deviations, were used to summarise respondent characteristics and to provide an initial understanding of overall response patterns. To support appropriate analysis

and interpretation, data normality assessment and factor prioritisation techniques were applied as described in the following subsections.

3.8.1 Reliability Assessment

The internal consistency of the questionnaire was evaluated using Cronbach's alpha. Reliability analysis was performed for each construct, and the results were interpreted based on standard threshold values, as presented in Table 3.2.

TABLE 3.2: Cronbach's Alpha value table [77]

Cronbach's alpha (α)	Remark
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Weak
$0.6 > \alpha \geq 0.5$	Unacceptable

3.8.2 Normality Test

Normality testing was conducted to examine whether the distribution of the collected Likert-scale data was suitable for subsequent statistical analysis. The assessment of normality involved evaluation of skewness and kurtosis values, where values within the range of -1 to $+1$ were considered indicative of an approximately normal distribution. In addition, graphical methods, including histograms and normal Q-Q plots, were examined to visually assess data distribution characteristics. To further support the normality assessment, formal statistical tests, including the Shapiro-Wilk test and the Kolmogorov-Smirnov test, were applied. The combined use of numerical indicators, graphical inspection, and statistical tests provided a robust basis for evaluating the distributional properties of the data and informed the selection and interpretation of subsequent analytical techniques.

3.8.3 Relative Importance Index

The Relative Importance Index (RII) method was employed to analyse and rank the identified challenges, opportunities, and mitigation strategies related to Digital Transformation adoption. RII is widely used for analysing Likert-scale survey data

and enables comparison of the relative significance of individual items based on respondents' collective perceptions [78].

The RII was calculated using the following formula:

$$RII = \frac{\sum W}{A \times N} \quad (3.3)$$

where:

W = weight assigned to each item by respondents

A = highest possible scale value

N = total number of respondents

The calculated RII values range between 0 and 1, with higher values indicating greater perceived importance. Based on these values, items within each construct were ranked to identify the most critical challenges, opportunities, and mitigation strategies influencing Digital Transformation adoption in the construction industry.

Chapter 4

Results and Discussion

4.1 General

This chapter presents the results and analysis of the data collected through the questionnaire survey conducted to investigate the challenges, opportunities, and mitigation strategies associated with Digital Transformation in the construction industry. Prior to administering the main survey, a pilot study was undertaken to evaluate the clarity, consistency, and reliability of the research instrument. The pilot survey served as a validation step to ensure that the questionnaire was suitable for large-scale data collection and statistical analysis. The pilot data were analysed using the Statistical Package for the Social Sciences (SPSS). Demographic survey and reliability test were conducted to assess the internal consistency of the questionnaire and the distributional characteristics of the collected responses. The findings from the pilot survey provided assurance regarding the robustness of the instrument and informed its final deployment in the main survey.

4.2 Development of Questionnaire and Finalization

4.2.1 Questionnaire Coding

After identifying the relevant factors related to Digital Transformation adoption in the construction industry, the questionnaire items were systematically grouped into

three main categories: challenges, opportunities, and mitigation strategies. Each category represents a distinct dimension of Digital Transformation as perceived by construction professionals. To ensure clarity and consistency during data analysis, a coding system was applied to all questionnaire items. This coding structure facilitated efficient data handling, analysis, and interpretation of results. The categorized factors and their corresponding codes are presented in Table 4.1.

TABLE 4.1: Questionnaire Coding

Sr. No	Categories	Alphabetical Codes	Number of Factors
1	Challenges	CH	16
2	Opportunities	OP	14
3	Mitigation Strategies	MIT	14

4.2.2 Delphi Process and Pilot Survey Analysis

4.2.2.1 Delphi Process

To finalize the questionnaire, the Delphi technique was adopted as a structured expert validation process. For this purpose, the preliminary version of the questionnaire was reviewed by eight construction industry professionals with relevant experience in digital technologies and project delivery. The experts were requested to evaluate the questionnaire in terms of clarity, relevance, and practical applicability. Based on their feedback, several modifications were suggested, including refinement of wording and improvement in the organization of certain items. After careful consideration of the experts' recommendations, the proposed changes were incorporated to enhance the overall quality, clarity, and reliability of the questionnaire before its final deployment.

4.2.2.2 Pilot Survey-Demographic and Reliability

In the pilot survey, respondents belonged to different organizational backgrounds within the construction industry. The majority of participants were consultants, indicating strong representation from professionals involved in design coordination and advisory roles. Contractors also formed a significant portion of the pilot sample, while client representation was comparatively limited.

The professional background of the respondents reflects a diverse mix of roles within the construction industry. Designers constitute the largest proportion of participants, followed by civil engineers who primarily serve in project management roles. Contractors represent a smaller share of the sample, indicating comparatively lower participation from execution-focused professionals in the pilot phase.

Respondents exhibited a balanced distribution of professional experience levels. The largest proportions fall within the 5–10 years and 10–15 years experience categories, while a smaller group possesses more than 20 years of industry experience. This distribution indicates that the pilot sample includes both mid-career and highly experienced professionals.

All respondents participating in the pilot survey possess a master's-level academic qualification. This indicates a highly educated pilot sample, ensuring informed and professional evaluation of the questionnaire during the validation stage.

Respondents reported professional experience across multiple project locations, reflecting diverse geographical exposure within the construction industry. The highest representation is observed in federal and Khyber Pakhtunkhwa regions, followed by Punjab and Baluchistan, while limited experience is reported in Sindh and international projects. This distribution indicates that the pilot respondents possess exposure to varied regional construction environments.

The distribution of software usage indicates varying levels of exposure to digital technologies among pilot respondents. Building Information Modeling (BIM) tools are used by all participants, reflecting strong familiarity with foundational digital systems, while artificial intelligence-based tools show moderate usage. Internet of Things (IoT) applications are least represented, indicating limited practical exposure during the pilot phase.

Pilot survey showed the reliability value of 0.730 which is greater than 0.7 that showed questionnaire's suitability for main survey.

4.3 Main Survey

Following the completion of the pilot study, the refined questionnaire was administered in the main survey to capture responses from a broader sample of construction

industry professionals involved in small- and medium-sized commercial building projects in Islamabad. The main survey data form the primary empirical basis for this study and are used to examine industry perceptions of Digital Transformation adoption across three dimensions: challenges, opportunities, and mitigation strategies. The analysis presented in the subsequent sections is based on the aggregated responses obtained from the main survey and reflects practitioner assessments of the relative importance of these factors within the local construction context.

4.3.1 Sample Size

A total of 125 questionnaires were distributed to construction professionals through WhatsApp and in-person survey methods. Out of these, 109 responses were received, resulting in a response rate of 87.2%. Based on the sample size calculation using Equation 3.1 (presented in Chapter 3), the minimum number of responses required for this study was 94. Therefore, the number of responses obtained exceeded the minimum requirement. Subsequently, responses from participants with less than five years of professional experience were excluded. In addition, invalid and inconsistent responses were removed during the data screening process. After applying these criteria, a total of 101 valid responses were retained and used for the final data analysis.

4.3.2 Demographic Data

This section presents the demographic profile of respondents who participated in the main survey, focusing on characteristics relevant to Digital Transformation in the construction industry. It summarizes respondents' organizational affiliation, academic qualifications, and years of professional experience to assess the diversity of professional backgrounds. The analysis also considers the provinces in which respondents have worked, providing insight into their geographical exposure within the national construction sector. In addition, the types of software used in their professional practice are examined to reflect their level of technological engagement. Together, these variables help evaluate the representativeness of the sample. The demographic results are presented graphically and discussed individually.

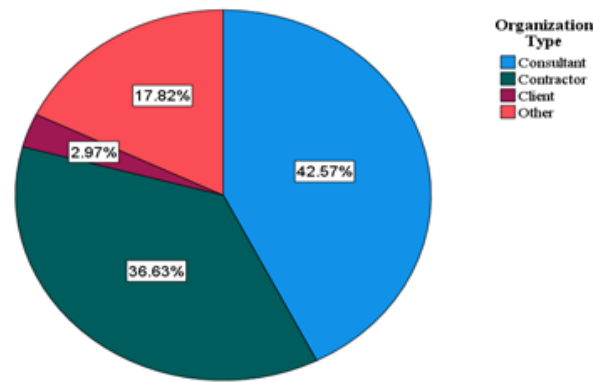


FIGURE 4.1: Respondents Organization Type

Figure 4.1 shows organizational affiliation, the majority of respondents were associated with consultancy firms, accounting for 42.57% of the total sample. Contractors represented the second-largest group, comprising 36.63% of respondents, indicating substantial participation from professionals involved in construction execution and site-level decision-making. Respondents representing client organizations constituted 2.97% of the sample, reflecting limited direct client participation in the survey. The remaining 17.82% of respondents were classified under other organizational categories, including suppliers, developers, and professionals operating in multiple or independent roles. Consultancy-based respondents were primarily involved in design coordination, project management, and advisory functions, while contractor-affiliated respondents were engaged in construction planning, execution, and on-site management activities. Participants categorized under other organizational types often reported mixed responsibilities across technical, managerial, and support roles.

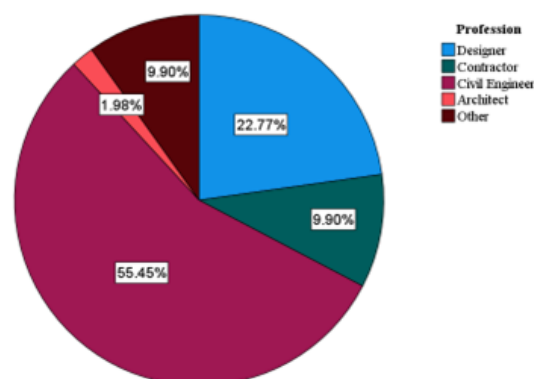


FIGURE 4.2: Respondents Profession

Figure 4.2 illustrates the professional distribution of respondents participating in the survey. Civil engineers constitute the largest proportion of the sample at 55.45% (project manager, general manager, site engineers, project engineers, resident engineer, assistant resident engineer), indicating strong representation from core construction management and site-based roles. Designers account for 22.77% of respondents, reflecting involvement from planning and design-oriented professionals. Contractors represent 9.90%, highlighting participation from execution-focused stakeholders, while respondents categorized as “Other” also comprise 9.90%, capturing roles not explicitly defined within the main categories. Architects form the smallest group at 1.98%. Overall, the distribution suggests a respondent pool largely grounded in engineering and project execution functions, which is relevant for assessing Digital Transformation adoption in the construction industry.

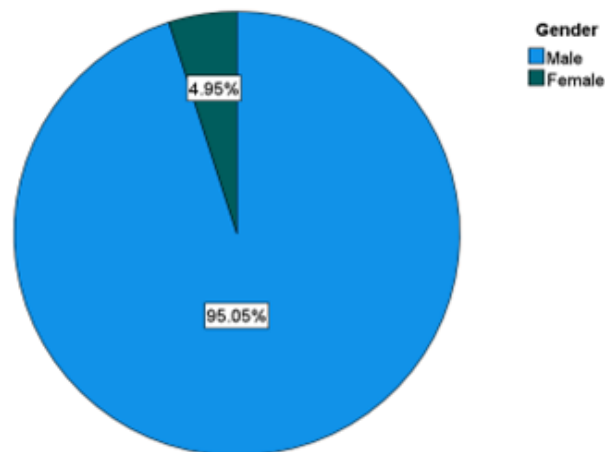


FIGURE 4.3: Respondents Profession

Figure 4.3 shows the gender distribution of respondents indicates a predominantly male participation, with males comprising 95.0% ($n = 96$) of the total sample, while females represent only 5.0% ($n = 5$). This imbalance closely reflects the existing workforce structure of the construction industry, which is traditionally male-dominated, particularly in technical, managerial, and site-based roles. Since this study focuses on Digital Transformation adoption within construction organizations, the dominance of male respondents suggests that the findings largely capture perspectives from those who are most actively involved in decision-making, project execution, and technology implementation. Although female representation is limited, the sample remains contextually appropriate for the industry under

investigation. However, this skewed distribution should be acknowledged as a limitation, as gender-diverse perspectives on technology adoption may not be fully represented.

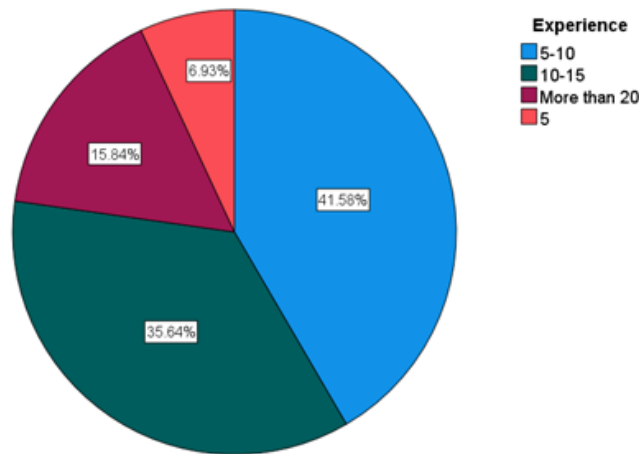


FIGURE 4.4: Respondents Experience

The table presents the distribution of respondents based on their professional experience in the construction industry. The largest proportion of respondents falls within the 5–10 years of experience category, accounting for 41.6% ($n = 42$) of the sample, followed by those with 10–15 years of experience at 35.6% ($n = 36$). Together, these two groups represent over three-quarters of the respondents, indicating that the majority possess substantial mid-level to senior professional experience. Respondents with more than 20 years of experience constitute 15.8% ($n = 16$), providing perspectives from highly experienced professionals with long-term industry exposure. A smaller proportion of respondents, 6.9% ($n = 7$), have less than 5 years of experience, representing early-career professionals.

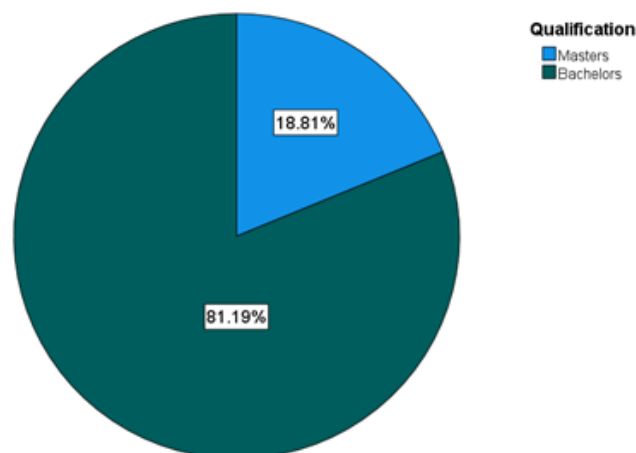


FIGURE 4.5: Respondents Qualification

The figure 4.5 illustrates the academic qualification profile of the survey respondents. The majority of participants hold a bachelor's degree, accounting for 81.2% ($n = 82$) of the total sample, while 18.8% ($n = 19$) possess a master's degree. This distribution reflects the typical educational structure of the construction industry, where most professionals enter practice with an undergraduate qualification and gain expertise through field experience. In relation to this thesis, the dominance of bachelor-qualified respondents suggests that the findings primarily represent operational and practice-oriented perspectives on Digital Transformation. At the same time, the inclusion of respondents with master's-level education contributes higher-level analytical and managerial viewpoints, which are relevant for understanding strategic decision-making and technology adoption within construction organizations.

TABLE 4.2: Respondents Work Experience Location

Project Location		Responses	
		N	Percent
	Federal	69	31.5%
	Punjab	44	20.1%
	Sindh	9	4.1%
	KPK	35	16.0%
	Baluchistan	10	4.6%
	Kashmir	10	4.6%
	Gilgit Baltistan	3	1.4%
	International	39	17.8%

The table 4.2 summarizes the distribution of respondents' project experience across different locations. The highest proportion of projects is reported at the federal level (31.5%), followed by Punjab (20.1%) and Khyber Pakhtunkhwa (16.0%), indicating concentration in major construction regions. International project experience accounts for 17.8%, reflecting exposure beyond the domestic construction environment. Sindh, Baluchistan, Kashmir, and Gilgit Baltistan show comparatively lower representation, together accounting for a smaller share of project locations.

The table 4.3 presents the frequency distribution of digital tools used by respondents in their professional practice. The most frequently reported category is

TABLE 4.3: Tools Used

Tools Used		Responses	
		N	Percent
Tools Used	BIM	58	35.6%
	AI	27	16.6%
	IoT	12	7.4%
	Others	66	40.5%

“Other”, accounting for 40.5% of responses, indicating that respondents extensively use conventional and specialized construction tool beyond the core Digital Transformation technologies defined in the study. This category includes widely used tools such as ETABS, Primavera, and others for structural analysis, project scheduling, planning, and cost management, which remain integral to everyday construction operations. Building Information Modelling (BIM) tools constitute 35.6% of responses, reflecting a relatively strong level of adoption compared to other advanced technologies. Artificial intelligence-based tools account for 16.6% of responses, suggesting emerging awareness and limited practical usage within the industry. Internet of Things (IoT) tools represent the smallest share at 7.4%, indicating that real-time monitoring and sensor-based systems are still in the early stages of adoption. In the context of this thesis, these results suggest that while foundational digital tools and traditional engineering software are well embedded in practice, the adoption of advanced Digital Transformation technologies remains uneven and at a developing stage within the construction industry.

4.3.3 Reliability Test

The reliability test is conducted to examine the internal consistency of the measurement items used to assess the core research variables. It ensures that the questionnaire items reliably measure the same underlying constructs related to Digital Transformation in the construction industry. Establishing acceptable reliability is essential before proceeding to further statistical analysis, as it enhances the credibility and stability of the results. The following subsection presents and discusses the reliability test outcomes based on the collected data.

The reliability analysis in table 4.4 shows a Cronbach’s Alpha value of 0.859 for the

TABLE 4.4: Table 4.4 Reliability Test Results

Reliability Statistics	
Cronbach's Alpha	N of Items
0.859	44

44 measurement items used in the study. This value indicates excellent internal consistency, suggesting that the items are highly reliable and measure the underlying constructs effectively. A Cronbach's Alpha above the commonly accepted threshold confirms the stability and coherence of the questionnaire. Therefore, the scale is considered reliable and suitable for subsequent statistical analyses.

4.3.4 Normality Test Results

The normality test is performed to examine the distribution characteristics of the collected data before conducting further analysis. Assessing normality helps determine the appropriateness of the statistical techniques applied in the study. This step ensures that the interpretation of results is methodologically sound and based on valid statistical assumptions. The following subsection presents the normality test results and their implications for the analysis.

Table 4.5 presents the results of the normality assessment conducted for all challenge (CH), opportunity (OP), and mitigation strategy (MIT) variables using the Kolmogorov–Smirnov and Shapiro–Wilk tests. The purpose of this analysis was to examine the distributional characteristics of the questionnaire responses prior to further statistical analysis.

The results show that the significance values (Sig.) for both normality tests are less than 0.05 for all variables. This indicates that the response distributions deviate from normality across all challenge, opportunity, and mitigation items. Such distribution patterns are commonly observed in perception-based survey data collected using Likert-type scales, where responses are ordinal in nature and tend to cluster around particular levels of agreement.

The presence of non-normal distributions supports the use of non-parametric and index-based analytical techniques for subsequent analysis.

TABLE 4.5: Normality Test Results

Factors	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
CH_1	0.345	101	0.000	0.670	101	0.000
CH_2	0.334	101	0.000	0.805	101	0.000
CH_3	0.376	101	0.000	0.688	101	0.000
CH_4	0.365	101	0.000	0.725	101	0.000
CH_5	0.313	101	0.000	0.733	101	0.000
CH_6	0.331	101	0.000	0.724	101	0.000
CH_7	0.366	101	0.000	0.633	101	0.000
CH_8	0.334	101	0.000	0.721	101	0.000
CH_9	0.335	101	0.000	0.759	101	0.000
CH_10	0.278	101	0.000	0.860	101	0.000
CH_11	0.285	101	0.000	0.796	101	0.000
CH_12	0.261	101	0.000	0.858	101	0.000
CH_13	0.330	101	0.000	0.767	101	0.000
CH_14	0.364	101	0.000	0.718	101	0.000
CH_15	0.339	101	0.000	0.740	101	0.000
CH_16	0.295	101	0.000	0.764	101	0.000
OP_1	0.353	101	0.000	0.609	101	0.000
OP_2	0.347	101	0.000	0.707	101	0.000
OP_3	0.337	101	0.000	0.759	101	0.000
OP_4	0.326	101	0.000	0.676	101	0.000
OP_5	0.336	101	0.000	0.657	101	0.000
OP_6	0.243	101	0.000	0.873	101	0.000
OP_7	0.241	101	0.000	0.814	101	0.000
OP_8	0.309	101	0.000	0.645	101	0.000
OP_9	0.390	101	0.000	0.692	101	0.000
OP_10	0.328	101	0.000	0.687	101	0.000
OP_11	0.336	101	0.000	0.729	101	0.000

Continued on next page...

Factors	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
OP_12	0.321	101	0.000	0.733	101	0.000
OP_13	0.307	101	0.000	0.702	101	0.000
OP_14	0.292	101	0.000	0.707	101	0.000
MIT_1	0.391	101	0.000	0.668	101	0.000
MIT_2	0.331	101	0.000	0.673	101	0.000
MIT_3	0.407	101	0.000	0.646	101	0.000
MIT_4	0.458	101	0.000	0.559	101	0.000
MIT_5	0.347	101	0.000	0.634	101	0.000
MIT_6	0.307	101	0.000	0.693	101	0.000
MIT_7	0.304	101	0.000	0.803	101	0.000
MIT_8	0.329	101	0.000	0.727	101	0.000
MIT_9	0.261	101	0.000	0.794	101	0.000
MIT_10	0.306	101	0.000	0.678	101	0.000
MIT_11	0.308	101	0.000	0.751	101	0.000
MIT_12	0.267	101	0.000	0.861	101	0.000
MIT_13	0.282	101	0.000	0.850	101	0.000
MIT_14	0.523	101	0.000	0.379	101	0.000

a. Lilliefors Significance Correction

Table 4.6 shows the results of the Kruskal-Wallis's test conducted to examine variations in respondents' perceptions across different groups for the challenge (CH), opportunity (OP), and mitigation strategy (MIT) factors related to Digital Transformation in the construction industry. Within the challenge category, a total of sixteen factors were analysed, of which two factors (CH_2 and CH_13) exhibited statistically significant differences across respondent groups, while the remaining fourteen challenge factors showed consistent perceptions. For the opportunity category, fourteen factors were tested, and only one factor (OP_3) demonstrated significant variation, whereas thirteen opportunity-related factors retained uniform responses. In the mitigation strategy category, fourteen factors were examined, among which three factors (MIT_7, MIT_12, and MIT_13) showed statistically

significant differences, while eleven mitigation-related factors reflected consistent agreement across respondent groups. Overall, the results indicate a strong level of consensus among construction professionals regarding most aspects of Digital Transformation, suggesting that perceptions of key challenges, benefits, and implementation measures are largely shared across different professional roles and experience levels. The limited number of factors exhibiting significant variation highlights specific areas where organizational context, exposure, and responsibility influence perceptions. The rejection of CH_2 suggests that leadership-related challenges are experienced differently across organizations, likely due to variations in managerial commitment, strategic vision, and digital maturity. Similarly, the rejection of CH_13 reflects differing financial capacities and investment priorities, where organizations with limited resources may perceive digital tools and their maintenance costs as a greater burden than firms with stronger technological infrastructure. In the opportunity category, the rejection of OP_3 indicates uneven exposure to digital safety technologies, with respondents who have experienced technology-enabled safety management recognizing its benefits more strongly than those relying on conventional practices. For mitigation strategies, the rejection of MIT_7 emphasizes variability in leadership engagement across organizations, reinforcing the critical role of leadership commitment in Digital Transformation success. The rejection of MIT_12 suggests divergent views regarding the role of digital standards, potentially influenced by tensions between short-term project delivery pressures and long-term governance requirements. Lastly, the rejection of MIT_13 highlights differences in organizational communication practices, where structured communication strategies may be more prevalent in digitally mature organizations compared to those with informal or fragmented change management processes. Collectively, these findings indicate that while there is broad agreement on Digital Transformation in the construction industry, variations arise primarily in areas linked to leadership, financial investment, safety implementation, governance, and communication, underscoring the need for targeted and context-sensitive Digital Transformation strategies.

TABLE 4.6: Kruskal Wallis Test

Factors	Sig. ^{a,b}	Decision	Factors	Sig. ^{a,b}	Decision
Challenges					
CH_1	0.058	Retain the null hypothesis.	CH_9	0.584	
CH_2	0.008	Reject the null hypothesis.	CH_10	0.565	Retain the null hypothesis.
CH_3	0.067		CH_11	0.361	
CH_4	0.241		CH_12	0.062	
CH_5	0.362	Retain the null hypothesis.	CH_13	0.038	Reject the null hypothesis.
CH_6	0.616		CH_14	0.780	
CH_7	0.656		CH_15	0.763	Retain the null hypothesis.
CH_8	0.066		CH_16	0.500	
Opportunities					
OP_1	0.363	Retain the null hypothesis.	OP_8	0.597	
OP_2	0.523		OP_9	0.327	
OP_3	0.007	Reject the null hypothesis.	OP_10	0.869	Retain the null hypothesis.
OP_4	0.453		OP_11	0.484	
OP_5	0.921	Retain the null hypothesis.	OP_12	0.686	
OP_6	0.938		OP_13	0.693	
OP_7	0.407		OP_14	0.737	
Mitigation					
MIT_1	0.522		MIT_8	0.030	
MIT_2	0.570		MIT_9	0.163	Retain the null hypothesis.

Continued on next page...

Factors	Sig. ^{a,b}	Decision	Factors	Sig. ^{a,b}	Decision
MIT_3	0.138	Retain the null hypothesis.	MIT_10	0.078	
MIT_4	0.286		MIT_11	0.234	
MIT_5	0.192		MIT_12	0.014	Reject the null hypothesis.
MIT_6	0.903		MIT_13	0.088	
MIT_7	0.028	Reject the null hypothesis.	MIT_14	0.411	Retain the null hypothesis.

a. The significance level is .050.

b. Asymptotic significance is displayed.

4.3.5 Relative Importance Index

The Relative Importance Index (RII) is used to rank factors based on their relative significance as perceived by the respondents. It provides a systematic and quantitative approach to prioritize variables by converting Likert-scale responses into comparable index values. Higher RII values indicate greater perceived importance of a factor within the study context. The following table presents the RII results, which are later discussed in detail to explain their implications for Digital Transformation in the construction industry.

TABLE 4.7: RII Test Results

Coding	RII	Category Wise Ranking	Coding	RII	Category Wise Ranking
Challenges					
CH_1	0.832	6	CH_9	0.832	6
CH_2	0.768	14	CH_10	0.701	15
CH_3	0.794	10	CH_11	0.826	8
CH_4	0.782	13	CH_12	0.783	12
CH_5	0.877	3	CH_13	0.800	9
CH_6	0.830	7	CH_14	0.855	4

CH_7	0.889	2	CH_15	0.790	11
CH_8	0.895	1	CH_16	0.846	5
Opportunities					
OP_1	0.869	5	OP_8	0.859	7
OP_2	0.875	4	OP_9	0.853	9
OP_3	0.796	13	OP_10	0.865	6
OP_4	0.846	11	OP_11	0.893	2
OP_5	0.901	1	OP_12	0.889	3
OP_6	0.752	14	OP_13	0.848	10
OP_7	0.836	12	OP_14	0.855	8
Mitigation Strategies					
MIT_1	0.919	2	MIT_8	0.883	6
MIT_2	0.897	5	MIT_9	0.851	10
MIT_3	0.909	3	MIT_10	0.853	9
MIT_4	0.935	1	MIT_11	0.865	8
MIT_5	0.907	4	MIT_12	0.657	14
MIT_6	0.869	7	MIT_13	0.741	13
MIT_7	0.752	12	MIT_14	0.824	11

The Relative Importance Index results shown in table 4.7 for the challenge-related factors reveal clear prioritization of the barriers influencing Digital Transformation adoption in the construction industry. Among all challenge factors, CH_8 (shortage of trained professionals in digital systems) ranked first, indicating that the lack of skilled human resources is perceived as the most critical obstacle. This highlights the industry's limited digital competence and reinforces concerns regarding insufficient technical expertise required to implement and manage digital technologies effectively. Closely following this, CH_7 (lack of awareness about Digital Transformation benefits) ranked second, emphasizing that limited understanding of the value and practical advantages of digital tools continues to restrict adoption. The high ranking of CH_5 (resistance to change among employees) further reflects the cultural inertia prevalent in construction organizations, where reliance on traditional practices remains dominant. Financial and client-related challenges also appear prominently.

CH_14 (clients are not willing to pay for digital solutions) ranked fourth, indicating that cost sensitivity and limited client-driven demand for digital deliverables hinder investment decisions. CH_16 (Digital Transformation improves coordination and management), despite being a positive statement, ranked fifth, suggesting variability in how practitioners perceive the realized benefits of digital systems. Infrastructure and operational readiness factors such as CH_1 (lack of digital literacy due to high costs) and CH_6 (lack of digital infrastructure) occupy mid-level rankings, indicating that while important, they are perceived as secondary to human and organizational barriers. Lower-ranked factors, including CH_10 (security and privacy concerns) and CH_2 (leadership gaps), suggest comparatively less perceived severity within the studied context. This does not imply irrelevance but indicates that respondents view skill shortages, awareness, and resistance as more immediate barriers than governance or cybersecurity concerns. Overall, the RII results demonstrate that human-centric and cultural challenges dominate the Digital Transformation landscape in the construction industry.

The RII analysis of opportunity-related factors highlights strong consensus on the value that Digital Transformation can deliver to construction projects. The highest-ranked opportunity, OP_5 (Digital Transformation allows projects to monitor themselves), reflects strong confidence in automation and real-time monitoring capabilities enabled by digital technologies. This suggests growing recognition of the potential for reduced manual supervision and improved project control. Similarly, OP_11 (improved collaboration between teams) and OP_12 (support for long-term maintenance and asset management) ranked second and third, respectively, emphasizing the perceived benefits of integrated data environments and lifecycle-based digital approaches. Productivity and performance-related benefits also ranked highly. OP_2 (reduction in project delays and cost overruns) and OP_1 (productivity gains) indicate that practitioners associate Digital Transformation with improved efficiency and project predictability. Design-related benefits, represented by OP_10 (improved design quality through BIM integration), further reinforce the role of digital tools in enhancing technical outcomes. Sustainability-focused opportunities, such as OP_6 (green and sustainable construction), ranked relatively lower, suggesting that environmental benefits are acknowledged but may

not yet be a primary driver of adoption in practice. Lower-ranked opportunities, including OP_6 and OP_3, reflect limited exposure or measurable impact of advanced applications such as sustainability analytics and digital safety systems. Overall, the opportunity rankings demonstrate that practitioners prioritize operational efficiency, monitoring, and collaboration benefits over longer-term or indirect outcomes, indicating a pragmatic and performance-driven perception of Digital Transformation.

The mitigation strategy rankings provide insight into the measures perceived as most effective for overcoming Digital Transformation barriers. The highest-ranked strategy, MIT_4 (universities and training institutions should introduce Digital Transformation courses), underscores the central role of education and skill development in enabling digital adoption. This finding aligns with the top-ranked challenge related to skills shortages, highlighting a clear linkage between barriers and mitigation priorities. Closely following this, MIT_1 (standardized digital processes across the industry) and MIT_3 (public-private collaboration) reflect strong support for structural and institutional support mechanisms. Leadership and governance also emerge as critical enablers. MIT_5 (clear digital standards and data protocols) and MIT_2 (government incentives and policies) ranked highly, indicating recognition of the importance of regulatory clarity and financial support. MIT_8 (pilot projects before full-scale adoption) also received strong ranking, suggesting that respondents favour incremental and risk-managed implementation approaches rather than immediate large-scale transformation. Lower-ranked mitigation strategies, such as MIT_12 (ignoring digital standards) and MIT_13 (communication strategies), indicate limited support for informal or unstructured approaches to digital change. The low ranking of MIT_7 (leadership commitment), despite its acknowledged importance, suggests that leadership is viewed as necessary but insufficient without parallel investments in skills, standards, and institutional frameworks.

4.3.6 Summary

The analysis of results indicates that the most significant challenges affecting the adoption of Digital Transformation in small and medium sized commercial construction projects in Islamabad are primarily human-related. Factors such as

shortage of skilled professionals, lack of awareness regarding digital benefits, and resistance to change emerged as the most critical barriers, reflecting a considerable gap in industry readiness. In addition to these, financial constraints and limited organizational support were also identified as contributing challenges, although with comparatively lower influence. On the other hand, the analysis of opportunities highlights that Digital Transformation is largely perceived as a means to enhance project performance. Key benefits such as improved efficiency through real-time monitoring, better stakeholder coordination, and data-driven decision-making were ranked highest, indicating a strong inclination towards operational improvements. While additional benefits such as risk management, sustainability, and reduction in rework were recognized, they were considered less influential in driving adoption. Furthermore, the evaluation of mitigation strategies suggests that education- and awareness-based measures are perceived as the most effective approaches to overcoming existing barriers. The introduction of digital-related academic courses, professional training programs, and awareness initiatives were ranked highest, emphasizing the importance of capacity building. In contrast, institutional and policy-level strategies, including phased implementation and development of standardized guidelines, were viewed as supportive measures with relatively lower immediate impact.

Chapter 5

Conclusion and Recommendations

5.1 General

This chapter presents the conclusions drawn from the empirical findings of the study and outlines practical recommendations based on the analysed results. The conclusions are derived from the prioritised challenges, opportunities, and mitigation strategies identified through Relative Importance Index (RII) analysis, within the defined scope of small- and medium-sized commercial construction projects in Islamabad, Pakistan. The chapter synthesizes the key findings to provide clear insights into Digital Transformation adoption and proposes context-specific recommendations aimed at supporting effective implementation within the local construction industry.

5.2 Conclusion

The findings indicate that the most critical challenges hindering Digital Transformation adoption are concentrated among the highest-ranked factors. CH_8 (Shortage of trained professionals capable of using digital tools) ranked first, recording an RII of 0.895, followed by CH_7 (Lack of awareness regarding the benefits of Digital Transformation) ranked second with an RII score of 0.889, and CH_5 (Resistance to change among employees) ranked third, achieving an RII value of 0.877. These

results collectively demonstrate that skill limitations, limited understanding of digital value, and behavioural resistance form the dominant barriers to digital adoption in small- and medium-sized commercial construction projects in Islamabad. Together, these factors reflect a fundamental readiness gap that restricts the effective integration of digital practices across construction organizations.

The remaining challenges, although ranked lower, further reinforce the complexity of Digital Transformation adoption. CH_3 (High initial investment required for digital tools) was ranked tenth with an RII score of 0.794, while CH_2 (Lack of top management support) ranked fourteenth, reflecting an RII of 0.768, and CH_10 (Unavailability of standardized digital procedures) ranked fifteenth with an RII index of 0.701. These factors indicate that financial limitations and weak institutional commitment continue to act as secondary constraints, complementing the dominant barriers identified earlier. This combination suggests that organizational and resource-related issues persist alongside human-related challenges, collectively slowing digital transition efforts.

In terms of opportunities, the highest-ranked factors highlight the strong performance-driven motivation for Digital Transformation adoption. OP_5 (Improved project efficiency through real-time monitoring) ranked first, attaining an RII score of 0.901, followed by OP_11 (Enhanced coordination among project stakeholders) ranked second with an RII of 0.893, and OP_12 (Improved decision-making through accurate digital data) ranked third, achieving an RII value of 0.889. These findings confirm that practitioners primarily associate Digital Transformation with improved control, coordination, and informed decision-making in commercial construction projects. This reflects a clear emphasis on operational efficiency and project execution benefits as primary drivers of digital adoption.

Opportunities ranked at mid and lower levels further illustrate the extended benefits of digital adoption. OP_3 (Improved risk identification during project execution) ranked thirteenth, registering an RII score of 0.796, while OP_6 (Support for sustainable construction practices) ranked fourteenth with an RII of 0.752, and OP_7 (Reduction in rework through digital coordination) ranked twelfth, recording an RII value of 0.836. Although comparatively lower in ranking, these opportunities suggest that broader operational and sustainability-related benefits

are acknowledged but remain secondary to immediate performance gains. This indicates that long-term and indirect advantages of Digital Transformation are not yet central to adoption decisions.

The mitigation strategies analysis reveals that education- and system-driven measures are perceived as the most effective solutions. MIT_4 (Introducing Digital Transformation courses in academic curricula) achieved the highest rank, registering an RII of 0.935, followed by MIT_1 (Professional training programs for digital tools) ranked second with an RII score of 0.919, and MIT_3 (Awareness programs highlighting digital benefits) ranked third, reflecting an RII value of 0.909. These results indicate that strengthening knowledge, skills, and awareness is viewed as the most impactful pathway for overcoming Digital Transformation barriers. This underscores the central role of capacity building in enabling effective digital adoption within the construction sector.

Lower-ranked mitigation strategies emphasize gradual and institutional support mechanisms. MIT_6 (Phased implementation of digital systems) ranked seventh with an RII of 0.869, while MIT_7 (Encouraging collaboration between academia and industry) ranked twelfth, recording an RII score of 0.752, and MIT_12 (Development of national digital construction guidelines) ranked fourteenth with an RII value of 0.657. These findings suggest that although structural and policy-level interventions are recognized, they are considered less immediately influential compared to education- and training-based strategies. This implies that such measures are perceived as supportive rather than primary drivers of Digital Transformation at the current stage.

5.3 Recommendations

Based on the findings of this study, the following recommendations are proposed to support effective and sustainable Digital Transformation adoption within small- and medium-sized commercial construction projects in Islamabad, Pakistan.

1. Strengthen digital capacity through education and professional development in Digital Transformation adoption should begin with strengthening human capacity across the construction industry. Academic institutions should

integrate digital construction concepts into civil engineering and construction management curricula, while construction firms should prioritize continuous professional training to enhance digital competencies among their workforce. This approach directly addresses the skills gap identified as a primary barrier to adoption.

2. Promote awareness and cultural acceptance of digital practices within construction organizations should be achieved through internal workshops, knowledge-sharing sessions, and pilot demonstrations. Improving understanding of how digital tools enhance efficiency, coordination, and decision-making can reduce resistance to change and encourage broader acceptance among professionals and management.
3. Adopt a phased and practical approach to digital implementation by construction firms should focus on introducing digital tools gradually, beginning with applications that support project monitoring, coordination, and documentation. This incremental approach allows organizations to manage financial constraints, minimize operational disruption, and support progressive adaptation to digital workflows.
4. Enhance client engagement and demand for digital deliverables in commercial construction projects should involve engaging clients early in the project lifecycle and informing them of the long-term value of digital practices. Increased awareness of benefits such as improved transparency, reduced rework, and better project control can encourage clients to support digital adoption.
5. Support Digital Transformation through institutional and policy initiatives should involve government agencies and regulatory bodies introducing training programs, incentives, and supportive regulatory frameworks. Integrating digital practices into construction approval processes and professional accreditation can further promote consistent adoption across the industry.
6. Encourage collaboration between industry and academia should be prioritized to align academic knowledge with practical industry needs. Such collaboration

can support innovation, improve workforce readiness, and contribute to the long-term sustainability of Digital Transformation initiatives within the construction sector.

5.4 Recommendations for Future Research

Future research may extend this study by examining Digital Transformation adoption across other urban centres in Pakistan to compare regional differences in challenges and opportunities. Longitudinal studies could provide insight into how adoption patterns evolve within Islamabad as digital maturity increases over time. Additionally, qualitative or mixed-method approaches may be employed to explore organizational change processes, leadership roles, and behavioural dynamics influencing Digital Transformation outcomes in commercial construction projects.

5.5 Guidelines for Effective D.T

Digital Transformation is the need of the hour for the construction industry, not only to cope with the evolving global construction environment but also to digitally upgrade and modernize construction practices in Pakistan. In this regard, the following guidelines are proposed as minimum requirements to support effective Digital Transformation adoption within the local construction industry.

1. Digital tools should be made a fundamental component of professional education so that future construction professionals develop adequate knowledge and familiarity with digital systems before entering the industry, enabling them to meet the demands of modern construction practices.
2. The government should actively facilitate Digital Transformation adoption by providing structured training programs through technical institutions and professional forums, and by incorporating Digital Transformation requirements into construction-related policies, standards, and accreditation frameworks.

3. Construction organizations should adopt Digital Transformation in a phased and systematic manner, beginning with basic digital applications for project monitoring, coordination, and documentation, to ensure smooth transition and minimize resistance within organizations.
4. Industry stakeholders should be encouraged to standardize digital practices and workflows, including the use of common digital platforms and protocols, to improve coordination, data consistency, and information sharing across project teams.
5. Continuous collaboration between academia, industry, and regulatory bodies should be promoted to ensure that digital knowledge, skills development, and practical implementation remain aligned with the evolving needs of the construction sector in Pakistan.

Bibliography

- [1] K. K. Najji, M. Gunduz, F. H. Alhenzab, H. Al-Hababi, and A. H. Al-Qahtani, “A systematic review of the digital transformation of the building construction industry,” *IEEE Access*, vol. 12, pp. 31461–31487, 2024.
- [2] P. Schnell, P. Haag, and H. C. Jünger, “Implementation of digital technologies in construction companies: Establishing a holistic process which addresses current barriers,” *Businesses*, vol. 3, no. 1, pp. 1–18, 2023.
- [3] B. G. Hwang, J. Ngo, and J. Z. K. Teo, “Challenges and strategies for the adoption of smart technologies in the construction industry: The case of singapore,” *Journal of Management in Engineering*, vol. 38, no. 1, 2022.
- [4] M. A. Musarat, N. Hameed, M. Altaf, W. S. Alaloul, M. A. Salaheen, and A. M. Alawag, “Digital transformation of the construction industry: A review,” in *Proceedings of the International Conference on Decision Aid Sciences and Application (DASA)*, (Sakheer, Bahrain), pp. 897–902, 2021.
- [5] A. M. Pettigrew, R. W. Woodman, and K. S. Cameron, *Studying Organizational Change and Development: Challenges for Future Research*, vol. 44. Academy of Management, 2001.
- [6] O. Samuelson and L. Stehn, “Digital transformation in construction – a review,” *Journal of Information Technology in Construction*, vol. 28, pp. 385–404, 2023.
- [7] A. Khoshkenar, M. B. Hatoum, N. Zahin, J. Aquino, H. Nassereddine, and E. N. Farsangi, “Introduction to digital transformation in the construction industry,” in *Digital Transformation in the Construction Industry*, pp. 3–24, 2025.

-
- [8] M.-I. Mahraz, L. Benabbou, and A. Berrado, "A systematic literature review of digital transformation," in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, (Toronto, ON, Canada), 2019.
- [9] B. Nikmehr, M. R. Hosseini, I. Martek, E. K. Zavadskas, and J. Antucheviciene, "Digitalization as a strategic means of achieving sustainable efficiencies in construction management: A critical review," *Sustainability*, vol. 13, no. 9, p. 5040, 2021.
- [10] V. Nyvlt and K. Kubecka, "Challenges and opportunities of digitization in the construction industry," in *Proceedings of the SWS International Scientific Conference on Social Sciences*, vol. 10, pp. 1–11, 2023.
- [11] S. E. N. Lau, R. Zakaria, E. Aminudin, C. C. Saar, A. Yusof, and C. M. F. H. C. Wahid, "A review of application building information modeling (bim) during pre-construction stage: Retrospective and future directions," in *IOP Conference Series: Earth and Environmental Science*, vol. 143, p. 012050, 2018.
- [12] P. Ghimire, K. Kim, and M. Acharya, "Generative ai in the construction industry: Opportunities & challenges," *arXiv preprint arXiv:2310.04427*, 2023.
- [13] Z. Li, "Digital technologies for construction sustainability: Status quo, challenges, and future prospects," *npj Materials Sustainability*, 2024.
- [14] P. Schnell, "Digital twins in construction: Architecture, applications, trends and challenges," *Buildings*, vol. 14, no. 9, 2024.
- [15] J. Huang, "A review of digital twin technologies for enhanced sustainability in the construction industry," *Buildings*, 2024.
- [16] X. Liu, "Bim, iot, and gis integration in construction resource monitoring," *Automation in Construction*, 2025.

-
- [17] N.-H. Tran and N.-T. Ngo, “Potential applications of digital twin and bim technology in construction industry,” *University of Danang Journal of Science and Technology*, pp. 106–112, 2025.
- [18] K. El Ammari and A. Hammad, “Remote interactive collaboration in facilities management using bim-based mixed reality,” *Automation in Construction*, vol. 107, p. 102940, 2019.
- [19] C. Biagini, “From bim to digital twin: Iot data integration in building maintenance,” *Journal of Information Technology in Construction*, vol. 29, pp. 251–271, 2024.
- [20] Deutsche Telekom AG, “Corporate communications baugewerbe 2020/2021—digitalisierungsindex.” <https://www.digitalisierungsindex.de/>, 2021.
- [21] X. Zhao *et al.*, “Extended reality for safe and effective construction management: State-of-the-art, challenges, and future directions,” *Buildings*, vol. 13, no. 1, p. 155, 2023.
- [22] S. Ahmad, “Applications of digital technologies in promoting sustainable construction practices: A literature review,” *Sustainability*, 2025.
- [23] B. R. K. Mantha and B. G. de Soto, “Cyber security challenges and vulnerability assessment in the construction industry,” in *Proceedings of the Creative Construction Conference*, 2019.
- [24] J. Sorce and R. R. A. Issa, “Extended technology acceptance model (tam) for adoption of information and communications technology (ict) in the u.s. construction industry,” *Journal of Information Technology in Construction*, vol. 26, pp. 227–248, 2021.
- [25] D. O. Aghimien, C. O. Aigbavboa, and A. E. Oke, “Critical success factors for digital partnering of construction organisations—a delphi study,” *Engineering, Construction and Architectural Management*, 2020.

- [26] F. J. Neyer, J. Felber, and C. Gebhardt, "Entwicklung und validierung einer kurzskala zur erfassung von technikbereitschaft," *Diagnostica*, vol. 58, no. 2, pp. 87–99, 2012.
- [27] A. Bajpai and S. C. Misra, "Barriers to implementing digitalization in the indian construction industry," *International Journal of Quality & Reliability Management*, vol. 39, no. 10, pp. 2438–2464, 2021.
- [28] T. D. Oesterreich and F. Teuteberg, "Understanding the implications of digitisation and automation in the context of industry 4.0: A triangulation approach and elements of a research agenda for the construction industry," *Computers in Industry*, vol. 83, pp. 121–139, 2016.
- [29] L. Li, "Reskilling and upskilling the future-ready workforce for industry 4.0 and beyond," *Information Systems Frontiers*, 2022.
- [30] A. E. Oke, D. O. Aghimien, C. O. Aigbavboa, and N. Koloko, "Challenges of digital collaboration in the south african construction industry," in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, (Bandung, Indonesia), pp. 2472–2482, 2018.
- [31] B. C. Lines and P. K. R. Vardireddy, "Drivers of organizational change within the aec industry: Linking change management practices with successful change adoption," *Journal of Management in Engineering*, vol. 33, no. 6, p. 04017031, 2017.
- [32] D. O. Aghimien, C. O. Aigbavboa, A. E. Oke, and W. D. Thwala, "Digitalization of construction organisations—a case for digital partnering," *International Journal of Construction Management*, pp. 1–10, 2020.
- [33] L. Li, Z. Yi, F. Jiang, S. Zhang, and J. Zhou, "Exploring the mechanism of digital transformation empowering green innovation in construction enterprises," *Developments in the Built Environment*, vol. 15, p. 100199, 2023.
- [34] K. Shoukat, M. Jian, M. Umar, H. Kalsoom, W. Sijjad, S. H. Atta, and A. Ullah, "Use of digital transformation and artificial intelligence strategies

- for pharmaceutical industry in pakistan: Applications and challenges,” *Artif. Intell. Health*, vol. 1, no. 1, p. 1486, 2023.
- [35] M. U. Mehmood, N. Iftikhar, A. U. R. Bhatti, *et al.*, “Digital transformation in pakistan’s public schools: Opportunities and challenges for sdg-4,” *Journal of Applied Linguistics and TESOL (JALT)*, vol. 8, no. 3, pp. 1669–1687, 2025.
- [36] O. Khan, *Overcoming Barriers to Digital Transformation in Pakistan’s Public Sector: A Change Management Perspective*. PhD thesis, University of Wales Trinity Saint David, 2025.
- [37] M. Sadeghi, A. Mahmoudi, and X. Deng, “Adopting distributed ledger technology for the sustainable construction industry: evaluating the barriers using ordinal priority approach,” *Environmental Science and Pollution Research*, vol. 29, no. 7, pp. 10495–10520, 2021.
- [38] Y. Liu, M. Habibnezhad, and H. Jebelli, “Brainwave-driven human-robot collaboration in construction,” *Automation in Construction*, vol. 124, p. 103556, 2021.
- [39] T. Rakha and A. Gorodetsky, “Review of unmanned aerial system (uas) applications in the built environment: Towards automated building inspection procedures using drones,” *Automation in Construction*, vol. 93, pp. 252–264, 2018.
- [40] H. Xue and S. J. Zhang, “Relationships between engineering construction standards and economic growth in the construction industry: The case of china’s construction industry,” *KSCE Journal of Civil Engineering*, vol. 22, no. 5, pp. 1606–1613, 2018.
- [41] S. Zhu, Z. Quan, S. Gao, W. Wang, B. Aslam, and J. Jiang, “How does the construction industry affect economic growth and environmental quality in china?,” *Clean Technologies and Environmental Policy*, vol. 27, no. 11, pp. 7093–7106, 2025.

- [42] D. T. H. Giang and L. S. Pheng, "Role of construction in economic development: Review of key concepts in the past 40 years," *Habitat International*, vol. 35, no. 1, pp. 118–125, 2011.
- [43] Y. H. Chiang, L. Tao, and F. K. W. Wong, "Causal relationship between construction activities, employment and gdp: The case of hong kong," *Habitat International*, vol. 46, pp. 1–12, 2015.
- [44] R. Zhu, X. Hu, V. Li, and C. Liu, "Investigating economic roles of multinational construction industries: A super-efficiency dea approach," *Applied Economics*, vol. 53, no. 41, pp. 4810–4822, 2021.
- [45] C. J. Turner, J. Oyekan, L. Stergioulas, and D. Griffin, "Utilizing industry 4.0 on the construction site: Challenges and opportunities," *IEEE Transactions on Industrial Informatics*, vol. 17, no. 2, pp. 746–756, 2021.
- [46] A. L. C. Ciribini, S. M. Ventura, and M. Paneroni, "Implementation of an interoperable process to optimise design and construction phases of a residential building: A bim pilot project," *Automation in Construction*, vol. 71, pp. 62–73, 2016.
- [47] S. Zhang and L. Yao, "A study on coordination relationship of construction industry and economic growth in shaanxi province," in *Proceedings of the 19th International Conference on Industrial Engineering and Engineering Management*, (Berlin, Germany), pp. 11–19, 2013.
- [48] C. J. Turner, J. Oyekan, L. Stergioulas, and D. Griffin, "Utilizing industry 4.0 on the construction site: Challenges and opportunities," *IEEE Transactions on Industrial Informatics*, vol. 17, no. 2, pp. 746–756, 2021.
- [49] A. Abasova and E. Mamedov, "Analysis of modern development trends in the construction sector," *Economic Transport Complex*, vol. 45, p. 184, 2025.
- [50] Y. Chen, D. Huang, Z. Liu, M. Osmani, and P. Demian, "Construction 4.0, industry 4.0, and bim for sustainable building development within the smart city," *Sustainability*, vol. 14, no. 16, p. 10028, 2022.

-
- [51] G. Mahajan, “Swift rising pattern of new emerging construction technology trends in the construction industry,” *International Journal of Innovative Technology and Exploring Engineering*, vol. 11, no. 11, pp. 55–64, 2022.
- [52] C. Botton, L. Rivest, O. Ghnaya, and M. Chouchen, “What is at the root of construction 4.0: A systematic review of the recent research effort,” *Archives of Computational Methods in Engineering*, vol. 28, no. 4, pp. 2331–2350, 2020.
- [53] T. Honcharenko *et al.*, “Digital transformation of the construction design based on bim and iot,” in *Proceedings of ITTAP*, pp. 267–279, 2021.
- [54] A. Lekan *et al.*, “Construction 4.0 application: Industry 4.0, iot and lean construction tools’ application in quality management,” *Buildings*, vol. 12, no. 10, p. 1557, 2022.
- [55] T. D. Moshood *et al.*, “Infrastructure digital twin technology: A new paradigm for future construction industry,” *Technology in Society*, vol. 77, p. 102519, 2024.
- [56] H. Shafei *et al.*, “Construction 4.0 technologies and decision-making: A systematic review and gap analysis,” *Buildings*, vol. 12, no. 12, p. 2206, 2022.
- [57] M. A. Musarat *et al.*, “A review on the way forward in construction through industrial revolution 5.0,” *Sustainability*, vol. 15, no. 18, p. 13862, 2023.
- [58] M. Sajjad *et al.*, “Evaluation of the success of industry 4.0 digitalization practices for sustainable construction management,” *Buildings*, vol. 13, no. 7, p. 1668, 2023.
- [59] M. Xu, J. M. David, and S. H. Kim, “The fourth industrial revolution: Opportunities and challenges,” *International Journal of Financial Research*, vol. 9, no. 2, p. 90, 2018.
- [60] C. Chute and T. French, “Introducing care 4.0: An integrated care paradigm built on industry 4.0 capabilities,” *International Journal of Environmental Research and Public Health*, vol. 16, no. 12, p. 2247, 2019.

- [61] J. Zhong, “Research on the collaborative mechanism of construction automation and civil engineering technology under the background of digital transformation,” *Applied Computational Engineering*, vol. 167, no. 1, pp. 144–150, 2025.
- [62] D. Beadman, “Civil engineering practice,” *Proceedings of the Institution of Civil Engineers – Geotechnical Engineering*, vol. 156, no. 1, pp. 59–60, 2003.
- [63] B. B. Das, S. V. Nanukuttan, A. K. Patnaik, and N. S. Panandikar, *Recent Trends in Civil Engineering*. Singapore: Springer, 2021.
- [64] Z. Liu, “Comparison and analysis of advantages and disadvantages between bim and cad in civil drafting software,” *Applied Computational Engineering*, vol. 62, no. 1, pp. 192–197, 2024.
- [65] T. Wayne *et al.*, “Evaluation of digital’s role in sustainable built environment,” *Pertanika Journal of Science and Technology*, vol. 31, no. 3, pp. 1335–1351, 2023.
- [66] M. Wang, M. Ashour, A. Mahdiyar, and S. Sabri, “Opportunities and threats of adopting digital twin in construction projects: A review,” *Buildings*, vol. 14, no. 8, p. 2349, 2024.
- [67] T. A. Adebisi, N. A. Ajenifuja, and R. Zhang, “Digital twins and civil engineering phases: Reorienting adoption strategies,” *Journal of Computing and Information Science in Engineering*, vol. 24, no. 10, 2024.
- [68] O. Samuelson and L. Stehn, “Digital transformation in construction – a review,” *Journal of Information Technology in Construction*, vol. 28, pp. 385–404, 2023.
- [69] Y. Celik, I. Petri, and Y. Rezgui, “Integrating bim and blockchain across construction lifecycle and supply chains,” *Computers in Industry*, vol. 148, p. 103886, 2023.
- [70] Z. Liu, R. Ding, Z. Gong, and O. Ejohwomu, “Fostering digitalization of construction projects through integration: A conceptual project governance model,” *Buildings*, vol. 13, no. 3, p. 825, 2023.

-
- [71] C. Boje, A. Guerriero, S. Kubicki, and Y. Rezgui, "Towards a semantic construction digital twin: Directions for future research," *Automation in Construction*, vol. 114, p. 103179, 2020.
- [72] H. Li *et al.*, "Systematic identification of the influencing factors for the digital transformation of the construction industry based on lda-dematel-anp," *Buildings*, vol. 12, no. 9, p. 1409, 2022.
- [73] J. Zhang *et al.*, "A new framework to evaluate and optimize digital transformation policies in the construction industry: A china case study," *Journal of Building Engineering*, vol. 70, p. 106388, 2023.
- [74] C. Boje, A. Guerriero, S. Kubicki, and Y. Rezgui, "Towards a semantic construction digital twin: Directions for future research," *Automation in Construction*, vol. 114, p. 103179, 2020.
- [75] V. Shymanska, O. Bakulina, and T. Momont, "Development of digital transformation of countries of the world on a global dimension," *Eastern Europe: Economy, Business and Management*, vol. 4, no. 41, 2023.
- [76] Z. Bánhidi and I. Dobos, "Measuring digital development: ranking using data envelopment analysis (dea) and network readiness index (nri)," *Central European Journal of Operations Research*, 2024.
- [77] J. A. Gliem and R. R. Gliem, "Calculating, interpreting, and reporting cronbach's alpha reliability coefficient for likert-type scales," in *Midwest Research-to-Practice Conference in Adult, Continuing, and Community Education*, (Columbus, OH, USA), 2003.
- [78] M. S. Singh, D. Tejaswini, R. Narwade, and K. Nagarajan, "Factors affecting the labour productivity of brickwork and analyzing them using rii method," *International Journal of Advanced Technology and Engineering Exploration*, vol. 6, no. 54, pp. 143–151, 2019.

Appendix A

CHALLENGES

CODE	Questions	1	2	3	4	5
CH-1	Due to high costs, there is lack of digital literacy					
CH-2	Leaderships gaps hinder DDigital Transformation					
CH-3	Stakeholders are aware of DT					
CH-4	Most organizations already have everything they need for full Digital Transformation					
CH-5	Resistance to change among employees delays DT implementation.					
CH-6	The construction industry lacks the required digital infrastructure.					
CH-7	Lack of awareness about DT benefits limits its adoption.					
CH-8	There is a shortage of trained professionals in digital systems.					
CH-9	Poor internet connectivity and IT infrastructure cause difficulties.					
CH-10	There is a no of clear national or industry-level digital policies.					
CH-11	Security and privacy concerns discourage digital adoption.					
CH-12	Construction companies depend heavily on manual methods.					

CODE	Questions	1	2	3	4	5
CH-13	Data sharing demands integration between departments					
CH-14	Digital tools are expensive and require frequent updates.					
CH-15	Clients are not willing to pay for digital solutions.					
CH-16	Time and project pressures make firms avoid new technology.					

OPPORTUNITIES

CODE	Questions	1	2	3	4	5
OP-1	Digital Transformation offers improved coordination and management					
OP-2	DT results in productivity gains					
OP-3	Adoption of DT reduces project delays and cost overruns.					
OP-4	DT leads to better safety management at construction sites.					
OP-5	DT contributes to client's higher satisfaction through improved quality.					
OP-6	DT allows projects to monitor themselves without any human involvement.					
OP-7	DT supports green and sustainable construction					
OP-8	DT increases project transparency and accountability.					
OP-9	DT helps in predicting risks and improving safety.					
OP-10	DT improves material management and reduces waste.					
OP-11	DT improves design quality through BIM integration.					

CODE	Questions	1	2	3	4	5
OP-12	Adoption of DT makes collaboration between teams more effective.					
OP-13	DT supports long-term maintenance and asset management.					
OP-14	DT helps track progress through data and digital dashboards.					

MITIGATION

CODE	Description	1	2	3	4	5
MIT-1	Awareness & Training programs are needed to improve digital skills.					
MIT-2	Standardized digital processes should be developed across the industry.					
MIT-3	Government incentives and policies should include mandatory DT requirements.					
MIT-4	Collaboration between public and private sectors is necessary for DT success.					
MIT-5	Universities and training institutions should introduce courses on DT.					
MIT-6	Clear digital standards and data protocols must be established.					
MIT-7	Construction policies should not include mandatory digital requirements.					
MIT-8	Leadership commitment is essential for successful DT adoption.					
MIT-9	Firms should start with pilot projects before full-scale adoption.					
MIT-10	Continuous monitoring and feedback improve DT implementation.					

CODE	Description	1	2	3	4	5
MIT-11	Collaboration with technology providers supports effective use of tools.					
MIT-12	Digital performance indicators should be included in project evaluation.					
MIT-13	Digital standards should be ignored because they slow down project work					
MIT-14	Clear communication strategies should guide digital change in organizations.					