CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Enhancing the Adoption of Digital Technologies in Building Projects of Islamabad

by

Mohsin Aziz

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in the

Faculty of Engineering
Department of Civil Engineering

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This work is dedicated to the most precious blessings of my life - ***my Beloved Family.*** *You are my strength and my greatest source of love. Thank you for always standing by my side, supporting me through every challenge, and encouraging me to move forward. Your love and presence have always been a beacon of happiness and inspiration for me.*

CERTIFICATE OF APPROVAL

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Abstract

The construction industry in Pakistan faces persistent challenges such as inefficiencies, cost overruns, project delays, and quality management. Globally, the adoption of digital technologies such as Building Information Modeling (BIM), Internet of Things (IoT), and Artificial Intelligence (AI) has revolutionized construction practices by improving project outcomes, streamlining processes, and enhancing sustainability. However, Pakistan's construction sector, particularly in building projects, has been slow to embrace these transformative technologies. Hence a need was felt to identify the factors that influence the adoption of digitization in Pakistan's construction sector- particularly in urban centres like Islamabad. Although there is a significant research on the barriers and drivers to adoption of specific digital technologies in Pakistan, such as BIM, however a noticeable gap exists in understanding how to holistically Foster / Enhance the Digital Ecosystem in Pakistan's Construction Sector. To conduct the study, comprehensive literature review followed by online surveys (from industry professionals of twin cities) were conducted. 129 responses were received, yielding a remarkable 78.18% response rate. PESTEL framework was used to categorise the factors into Political, Economic, Social, Technological, Environmental and Legal dimensions. Based on recent studies from 2021 to 2025, a total of 41 factors were identified which were shortlisted to 27 using Delphi method. Relative relevance index (RII) was used to further rank the factors. The results indicated that across all PESTEL factors, environmental factors (average RII = 0.726) are the most influential drivers for fostering a digital ecosystem underscoring the importance of aligning digital adoption with Sustainable Development Goals (SDGs). Social factors and Technological factors follow closely, highlighting the critical role of stakeholders perception & awareness, and the skill gaps. Political factors suggested the government support required to enhance the digitisation drive. Keeping in view the findings of the study, a framework has been proposed which outlines actionable recommendations across the five dimensions of PESTEL analysis. This study will contribute to body of knowledge by offering key insights into the interplay of various factors which influence adoption of digital ecosystem in construction sector of developing countries like Pakistan.

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Abbreviations and Symbols

AEC	Architecture Engineering and Construction
AHP	Analytical Hierarchy Process
AR	Augmented Reality
BIM	Building Information Modelling
CQM	Construction Quality Management
CV	Computer Vision
DT	Digital Technologies
FCEM	Fuzzy Comprehensive Evaluation Method
IoT	Internet Of Things
MCDM	Multi Criteria Decision Making
PESTEL	Political Economic Social Technology Environment Legal
RII	Relative Importance Index
SMEs	Small and Medium Sized Enterprises
SDGs	Sustainable Development Goals
VR	Virtual Reality

Chapter 1

Introduction

1.1 Background

The Fourth Industrial Revolution (4IR), characterized by the integration of digital technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), Big Data, and Building Information Modeling (BIM), is transforming industries worldwide [1]. These technologies are driving efficiency, sustainability, and innovation across sectors, from manufacturing to healthcare. However, the construction industry, despite its critical role in economic development, has been slow to adopt these advancements [2]. The sector continues to rely heavily on traditional methods, which are often inefficient, costly, and prone to errors [3]. This reluctance to embrace digital transformation is attributed to the industry's inherent fragmented nature and the ”3D challenges: Dangerous, Difficult, and Dirty” that make innovation adoption particularly challenging [4].

The construction sector of Islamabad, specifically the building projects have not yet embraced the digital technologies in a wholesome manner. The inherent issues like quality management, disputes between stakeholders and cost over runs are the result of its reliance on traditional methods which are marred by inefficiencies. While some of the common digital technologies like BIM are being used in building projects, however, on the whole the applicability of various other technologies like IoT for quality management, Blockchain for contract management, cloud computing for data acquisition and planning etc remains non existent. The sector remains plagued by inefficiencies, including delays, cost overruns, and poor project management, which are exacerbated by the reliance on outdated practices [5]. While the global construction industry is gradually moving toward digitization, Pakistan's building construction sector faces unique impediments that hinder its ability to fully embrace this new paradigm. These barriers include lack of technical skills, limited awareness of digital tools, financial constraints, and inadequate infrastructure [6]. Additionally, the absence of a supportive regulatory framework and the resistance to change among stakeholders further complicate the adoption process [7].

The concept of a digital ecosystema interconnected network of stakeholders, technologies, and processesoffers a promising solution to these challenges. A digital ecosystem can streamline workflows, enhance collaboration, and improve decision-making through real-time data sharing and advanced analytics [8]. However, fostering such an ecosystem requires a holistic approach that addresses both technological and non-technological barriers. For Pakistan's construction industry, this entails not only investing in digital tools but also building the capacity of stakeholders, raising awareness, and creating an enabling environment for innovation [9].

Given the transformative potential of digital technologies, there is an urgent need to identify the factors that influence the adoption of digitization as a complete ecosystem in Pakistan's construction sector. Understanding these factors can provide valuable insights for policymakers, industry leaders, and researchers to develop strategies that facilitate the transition toward a more efficient, sustainable, and competitive construction industry. This study aims to bridge this gap by exploring the challenges and opportunities associated with fostering a digital ecosystem in Pakistan's construction sector, thereby contributing to the broader discourse on digital transformation in developing economies.

1.2 Research Motivation

The construction industry in Pakistan faces persistent challenges such as inefficiencies, cost overruns, project delays, and quality management. Globally, the adoption of digital technologies such as Building Information Modeling (BIM), Internet of Things (IoT), and Artificial Intelligence (AI) has revolutionized construction practices by improving project outcomes, streamlining processes, and enhancing sustainability. However, Pakistan's construction sector, particularly in building projects, has been slow to embrace these transformative technologies, resulting in a significant gap between local practices and global advancements. This gap presents a unique opportunity to explore how digital technologies can address the longstanding issues plaguing the industry and drive a much needed modernization effort. The motivation for this research stems from the increasing global emphasis on digital transformation in construction and the pressing need for Pakistan to catch up with international trends. By fostering a digital ecosystem, Pakistan's construction industry can enhance its competitiveness, efficiency, and sustainability, ultimately contributing to the country's economic development and aligning with the goals of the Fourth Industrial Revolution. This study aims to bridge the gap between traditional practices and digital innovation, providing actionable insights for stakeholders to navigate the challenges and opportunities of digital adoption.

1.3 Problem Statement

The rapid growth of cities like Islamabad has created an ever increasing requirement of buildings to be constructed in minimum time and in a cost effective manner. Alongside, there is also an enhanced focus on sustainability aspects to be followed for long term effects. Resultantly, there is a requirement for efficient, high-quality, and sustainable construction practices to keep pace with urbanization. However, Pakistan's construction industry continues to face significant challenges, including inefficiencies, cost overruns, delays, and poor quality management. These issues are pronounced due to reliance of building construction on traditional methods. Despite numerous advantages, the modern digital tools have not yet been incorporated into the building construction practices in Pakistan. Around the world, the construction sector has embraced digital technologies such as Building Information Modeling (BIM), the Internet of Things (IoT), and Artificial Intelligence (AI) etc to tackle similar problems, resulting in improved productivity, cost savings, and sustainability. Yet, in Pakistan, the adoption of these technologies remains extremely limited. For example, only 11% of the industry uses BIM, highlighting a stark gap between global advancements and local practices [10].

This disconnect raises critical questions about why Pakistan's construction sector lags behind in adopting digital tools and how these technologies can be leveraged to address the industry's persistent challenges. The existing studies focus on barriers related to certain common technologies like BIM, however, there is a noticeable gap in understanding how to holistically enhance the digital ecosystem in Pakistans construction sector. Hence, there is a need to explore the current state of digital adoption, identify the factors influencing digitisation with a view to develop practical strategies to foster an ecosystem in construction sector. By doing so, this research seeks to pave the way for a more efficient, sustainable and competitive construction industry capable of meeting the demands of rapidly growing urban centers like Islamabad.

1.4 Research Objectives

The objectives of this research work are:

- To identify key factors affecting adoption of digital technologies in Pakistan's building construction projects.
- To evaluate the identified factors using Analytic Hierarchy Process (AHP) to determine their interrelationship and relative ranking.
- To suggest a framework for the implementation of digital technologies in building construction projects of Pakistan for enhancing efficiency, sustainability & quality.

1.5 Research Significance

This research is novel due to the reason that it focuses on addressing the specific factors influencing adoption of digitisation in the context of Pakistan's rapidly growing urban construction sector, particularly in a major city like Islamabad. Although there is significant research on adoption of specific digital technologies in Pakistan, such as Building Information Modeling (BIM), however a noticeable gap exists in understanding how to holistically foster the digital ecosystem in Pakistan's construction sector, specially in building projects. This study aims to fill this gap by assessing the current use of these technologies in Pakistan, while identifying the factors contributing to present adoption level, thereby suggesting framework for its adoption for driving positive changes towards efficiency, sustainability and quality.

1.6 Scope of Work

The research was restricted to only the Building Projects being executed in Islamabad and Rawalpindi region, as this area is a national capital and a hub of major developmental activites and a yardstick for urbanisation in Pakistan. All efforts were nade to keep the sample size as versatile and as large as possible from maximum professionals related to Architecture, Construction & Engineering (AEC) industry related to building construction to obtain more accurate results.

1.7 Study Limitations

Since the scope of this study entailed building projects of Islamabad region, certain limitations were applied during the research. Firstly, due to time constraints, the research relied mainly on online surveys conducted through Google Sheets for primary data collection, whereas, the secondary data was collected through a systematic literature review. The data was gathered from conculting construction industry professionals related to Islamabad and Rawalpindi region only. Scope of the study was limited to building projects and other types of projects like highways and infrastructure were omitted. Only the registered professional enlisted with PEC and with adequate qualification credentials were contacted to get pertinent results. Shortlisting of factors was carried out through a closed group of highly experienced professionals using Delphi method. With respect to the sample size, the only source available was PEC website which did not have exact data on total registered construction professionals, specifically located in Islamabad region; therefore convenient sampling technique was used.

1.8 Brief Methodology

Methodology of this research is illustrated in Figure 1.1 below:

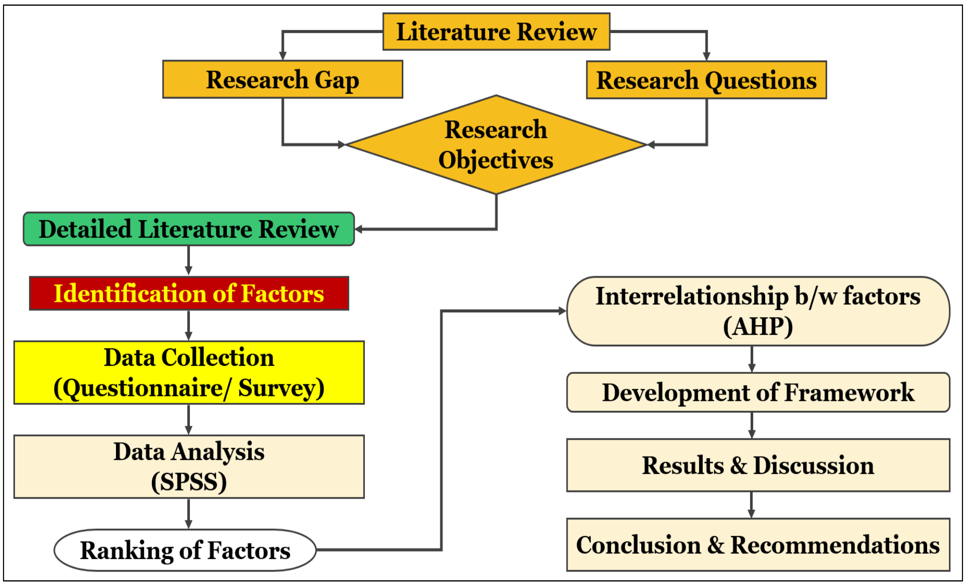

FIGURE 1.1: Brief Methodology

1.9 Thesis Structure

There are five chapters in this thesis.

Chapter 1 highlights the background and motivation behind this study i.e. the need for digital transformation in building projects of a major city like Islamabad. The chapter also briefly describes the scope and methodology of this research.

Chapter 2 elaborates a comprehensive literature review of various digital technologies and their applications in construction industry and the factors which affect the adoption of digital technologies worldwide.

Chapter 3 discusses the detailed research methodology of this research including the research design, data gathering & analysis techniques as well as framework formulation method which leads towards the results.

Chapter 4 includes the statistics, specific tests & their analysis, followed by the results.

Chapter 5 summarizes the study through pertinent conclusions from the study and suggested framework for fostering digital ecosystem in Pakistan's construction sector.

Chapter 2

Literature Review

2.1 Introduction

The construction industry plays a vital role in Pakistan's economy, contributing significantly to its GDP [11]. The construction industry is a vital component of Pakistan's economy, significantly contributing to employment, infrastructure development, and overall economic growth. The construction sector is the second largest industry in Pakistan, following agriculture, contributing approximately 3 to 8 percent to the GDP [12]. The industry is crucial for providing essential infrastructure, which supports other economic activities and enhances living standards. Construction projects are instrumental in promoting social and economic development, acting as drivers of growth and investment opportunities. The sector is labor-intensive, providing substantial employment opportunities, particularly for migrant and unskilled workers, making it second only to agriculture in job creation [13]. However, the construction industry in Pakistan heavily relies on traditional methods, which are characterized by manual, labor-intensive practices that often hinder efficiency and sustainability. Current practices are predominantly manual and document-centric, leading to slow progress and inefficiency [14].

Digital technologies have revolutionized the business field, offering significant opportunities for small and medium-sized enterprises (SMEs) to enhance sustainability and value creation [15]. The adoption of digital ecosystems in construction projects offers significant benefits, including increased operational efficiency, productivity, and speed of task execution [16]. Digital ecosystems, comprising technologies such as Building Information Modeling (BIM), cloud platforms, Big Data, Artificial Intelligence (AI), Machine Learning (ML), Block Chain and Internet of Things (IoT) enable real-time management of project lifecycles and are crucial for achieving digital transformation in the construction industry [17]. Digital technologies facilitate better resource management, improve communication among stakeholders, and enable data-driven decision-making, ultimately leading to more successful project outcomes.

Hence, there is a need to establish an understanding of what constitutes a digital ecosystem in the construction industry while exploring its key components & technologies, review the global trends and identify a key factors influencing the adoption of digital technologies using the PESTLE framework.

2.2 Digital Technologies in the Construction Industry

2.2.1 Digital Ecosystems

An ecosystem is the interaction between components or actors in within the system [18]. It is the interaction of whole components surrounding the ecosystem. A digital ecosystem is a complex network of interconnected digital platforms, technologies, and stakeholders that collaborate to create value and facilitate innovation. It encompasses various components that work together to enhance business operations and consumer experiences. A “digital ecosystem” is a network of interconnected digital platforms, technologies, data, and people, where various entities like businesses, customers, and partners interact and collaborate to create a larger, more valuable digital offering, often exceeding what a single company could achieve alone [19]. The key components of a digital eosystem include digital platforms, technological infrastructure, stakeholders, data & information and norms & standards. Digital platforms are central to the ecosystem, that enable interactions among users, businesses, and technologies, facilitating collaboration and innovation. Technological Infrastructure includes cloud computing, big data analytics, and the Internet of Things, which support the functionality and scalability of the ecosystem. Stakeholders are the various actors, such as businesses, consumers, and regulatory bodies, play crucial roles in the ecosystem, contributing to value creation and governance. Data and Information formulate a unified digital space that encompasses data sharing and management is essential for informed decision-making and operational efficiency. Norms and Standards are the Established rules and guidelines govern interactions within the ecosystem, ensuring security, trust, and compliance [20].

2.2.2 Benefits of Digital Technologies in Construction

Digital technologies offer numerous benefits to the construction industry, including increased operational efficiency, productivity, and speed of task execution [21]. These technologies, including Building Information Modeling (BIM), artificial intelligence, and the Internet of Things (IoT), facilitate improved communication and coordination among stakeholders, leading to better project outcomes.

2.2.2.1 Enhanced Design and Collaboration

Digital tools enable high-quality and faster preparation of designs, significantly improving project timelines. Improved information exchange and management foster better collaboration among project participants, reducing misunderstandings and errors [22].

2.2.2.2 Cost Efficiency and Productivity

Digital technologies contribute to cost savings through optimized resource allocation and reduced project delays. The implementation of digital construction methods can lead to increased productivity by streamlining processes and enhancing data management [23].

2.2.2.3 Improved Operations Efficiency

The primary benefits that digital technologies have the most influence on are communication, operational efficiency and market intelligence. The encouraging relationships that enable the use of digital technologies should be promoted between technology providers and construction companies [24]. This improves the overall workflows and reduces friction during decision making processes.

2.2.2.4 Sustainability and Environmental Impact

The adoption of digital solutions supports sustainable practices by enabling precise project planning and execution, which minimizes waste. Technologies like digital twins and 3D modeling enhance the ability to create smart, efficient urban environments, aligning with sustainability goals [25].

2.2.2.5 Enhanced Quality Management

Digital technologies facilitate efficient information processing, which supports quality planning and control in construction projects. This leads to improved management of quality information throughout the construction lifecycle [26]. A framework for DT application construction quality management (CQM) is illustrated in figure 2.1.

2.2.2.6 Improved Communication and Collaboration

Technologies like Building Information Modeling (BIM) eliminate information barriers between different stakeholders, enhancing coordination and collaboration among architects, engineers, and construction teams [26].

2.2.2.7 Real-time Monitoring and Data Analysis

The Internet of Things (IoT) enables real-time monitoring of construction processes, allowing for immediate data collection and analysis, which can lead to timely decision-making and preventive maintenance [26].

2.2.2.8 Automated Quality Assessment

Digitalization has positively impacted various aspects of construction, including smart construction, energy optimization, and sustainable environments. Computer Vision (CV) technologies can automate the identification of construction activities and assess site productivity, leading to more efficient quality control processes [27].

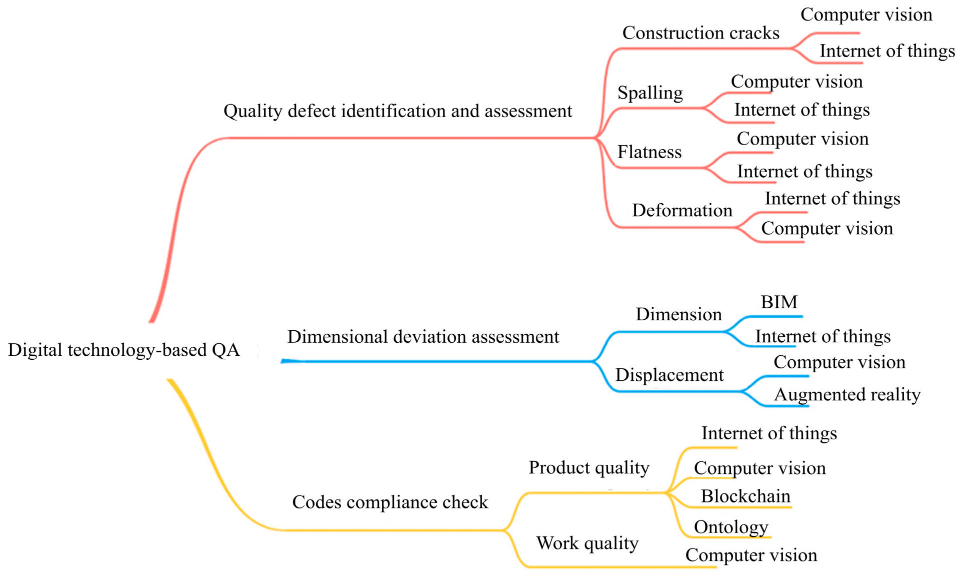

FIGURE 2.1: Framework of digital technology application in CQM [26].

2.2.3 Global Trends & Applications of Digital Technology in Construction

Digital technologies have significantly transformed the construction industry, leading to various global applications that enhance efficiency, safety, and collaboration. A map of DT application in AEC industry is illustrated in figure 2.2. Based on a research of around 4000 articles, Brozovsky et al have illustrated a Sankey Diagram depicting publications related to emerging technologies in various countries as shown in Figure 2.3. Souza et al have identified 21 technologies and grouped into five sets according to their similarities and applications in construction industry as illustrated in Figure 2.4. Some of the key applications of digital technologies in construction are described as under:

2.2.3.1 Building Information Modeling (BIM):

BIM is central to the digitalization of construction, facilitating better planning, design, and management of construction projects. It allows for the creation of detailed virtual models of buildings, which can simulate construction projects in a

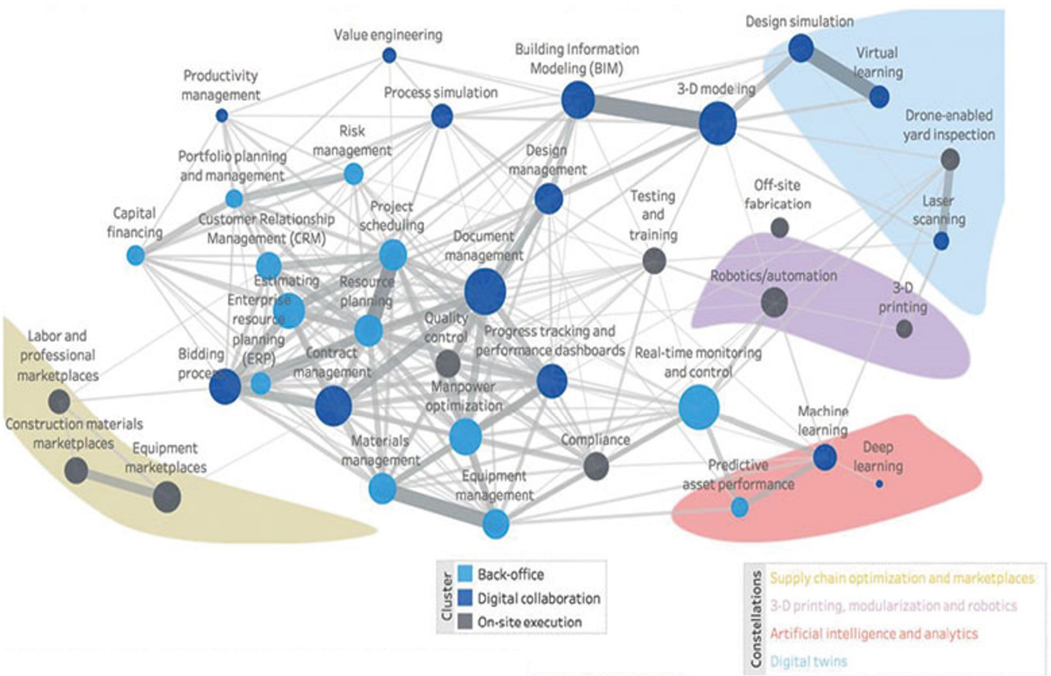

FIGURE 2.2: Mapping of DTs in the AEC industry [40]

controlled environment. This aids in design, procurement, and construction activities. It integrates with other technologies like virtual reality (VR) and augmented reality (AR) to improve visual representation and simulation of construction processes, enhancing stakeholder engagement and decision-making [28].

2.2.3.2 Digital Twins:

Digital twins (DTs) are emerging as powerful tools in construction, offering real-time monitoring, simulation, and decision-making capabilities beyond traditional Building Information Modeling (BIM). It enables real-time monitoring and optimization throughout the construction lifecycle, addressing challenges like data integration and security [29].

2.2.3.3 Automation and Robotics:

Automation and robotics in construction are gaining traction globally, offering solutions to labor shortages, safety concerns, and productivity challenges. The integration of automation and robotics in construction processes is reshaping traditional roles [30]. New positions such as digital fabrication management and programming are emerging, reflecting the need for skilled professionals who can operate and manage these technologies. [31].

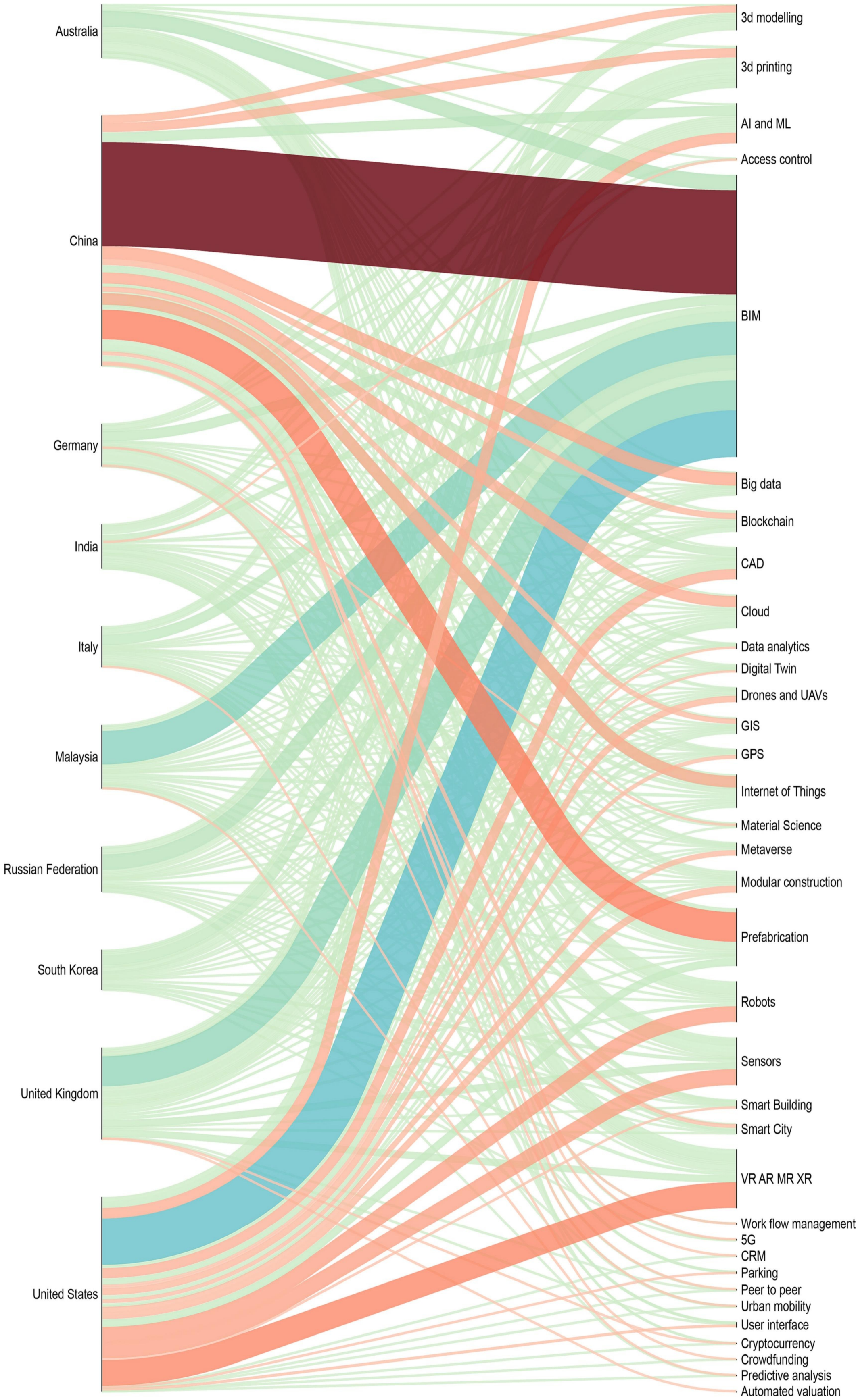

FIGURE 2.3: Sankey diagram linking the ten countries with the most publications to technologies [41]

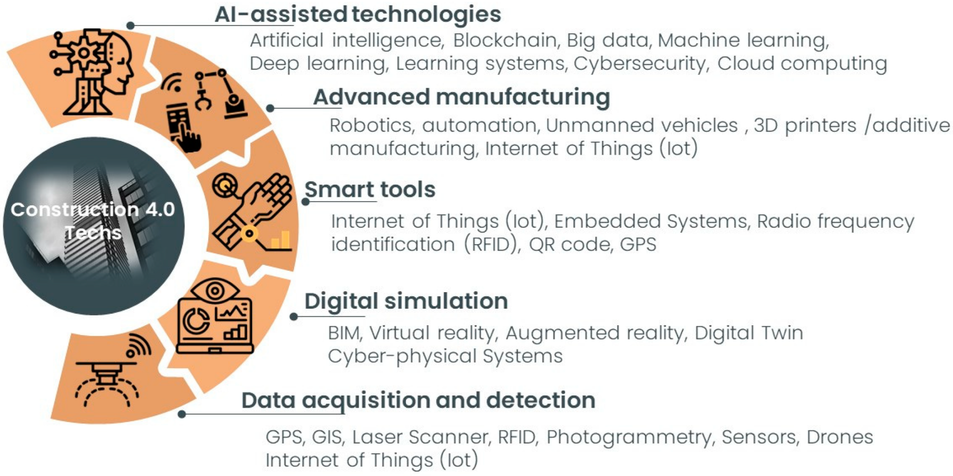

FIGURE 2.4: Construction 4.0 technology groups [42]

2.2.3.4 UAV (Unmanned Aerial Vehicles):

Unmanned Aerial Vehicles (UAVs) or drones are revolutionizing the construction industry by enhancing safety, efficiency, and accuracy . They are widely used for monitoring, inspection, surveying, and architectural design [32]. Drones can increase productivity by up to 60% and reduce worker exposure to dangerous tasks [33].

2.2.3.5 Data Collection Technologies:

Technologies like laser scanning, Geographic Information Systems (GIS), and the Internet of Things (IoT) are crucial for data collection in construction. They offer significant potential for improving project management and cost control. For instance, IoT sensors provide real-time data, enhancing efficiency in areas such as supply chain logistics, site management, and safety monitoring [34]. Similiarly, applications of IoT also include mobile computing for site management, UAVs for progress monitoring, and RFID for safety management [35].

2.2.3.6 Artificial Intelligence (AI):

Artificial Intelligence (AI) is revolutionizing the construction industry by addressing key challenges and enhancing various processes. AI applications in construction span design and planning, construction execution, and building management [36].

AI is utilized for data mining and transforming raw data into actionable information, which aids in risk assessment and project management. Machine learning, computer vision, and natural language processing are prominent technologies being utilized [37].

2.2.3.7 Cybersecurity and Blockchain:

As digital technologies proliferate, ensuring data security becomes paramount. The construction industry is adopting blockchain technology for secure transactions and data integrity, which is vital for maintaining trust among stakeholders [37]. Blockchain technology offers significant potential for enhancing various aspects of the construction industry. Its applications include streamlining project management, improving contract administration, and enhancing transparency in payment processes. In construction contract management, blockchain can address issues related to information sharing, payment processes, and supply chain traceability [38].

2.2.3.8 Enhanced Labor Safety:

The digital transformation in construction is expected to improve labor safety by predicting risk situations and enabling better safety protocols through data analysis and simulation technologies. Digital technologies are increasingly being explored to enhance construction safety, with focus of research on various technologies, including sensors, wireless systems, artificial intelligence and machine learning [39].

2.3 Factors Affecting Adoption of Digital Technologies

A systematic literature review was carried out to identify the various factors influencing adoption of digital technologies in construction. Only the research papers dating from 2021 to 2025 were included in the search and older papers were excluded. Search engines Google Scholar and Semantic Scholar were used for the research. Key word Construction Management was used in conjunction with BIM, IoT, Blockchain, Big Data, Cloud Computing to conduct the search. Only W and X category journals were used while other categories were discarded. Based on the above, total 15 papers were shortlisted and a total of 115 factors were identified as presented in the table 2.1.

2.4 Tools and Methods to Address factors Influencing Digitisation

When analyzing complex systems or decision-making processes, it's crucial to understand the relative importance of different factors. Numerous methods for assessing and analyzing the relative significance index (RII) values of the factors have been approved by the majority of scholars. Factor Analysis is one of the techniques that helps identify underlying factors or dimensions that explain the correlations among a set of observed variables, which helps to reduce the dimensionality of the data and identify the most important factors [43]. To determine the impact values of the identified factors, a questionnaire survey was conducted using an analysis and components identified from prior research. Relative relevance index (RII) was used to further rank the factors. Utilizing a Fuzzy Evaluation approach to assess both the frequency and degree of impact of all factors through the application of the Relative Importance Index (RII) formula [44].

Through a questionnaire survey, the method entailed soliciting bids on criteria and categorizing them accordingly. The influence of the identified factors was evaluated using a rating scale ranging from 1 to 5, with data collection and analysis conducted using SPSS software. A comprehensive analysis of all parameters was conducted, and a ordinal scale was employed to conduct the survey. All factors' rankings and significance levels were established by the use of the (RII) method. A survey using an application was used to determine each factor's effect levels. These factors, identified through literature review and the survey, were then prioritized based on their computed impact values. Initially, the total sum of all elements

Table 2.1: Factors Influencing Adoption of DTs in Construction

Serial	Author	Year	Title of Paper	Factors
1	Yang, X et al	2025	Evaluation of Construction Worker Perceptions of Wearable Proximity Sensors during the COVID-19 Pandemic	. Social Influences - Perceived Risks - Privacy Concerns - Perception Of Usefulness
2	Kussl, S et al	2025	Change Must Come from within: Study of Digital Transformation in Construction Client Organizations	. Organization's Readiness To Embrace Change - Innovation Management - Business Transformation - Data Precedence - Change Leadership - Digital Governance
3	Swallow, M et al	2025	Investigating the implementation of immersive technologies within on-site construction safety processes	. On-Site Safety Aspects - Risk Assessment - Lack Of Engagement From Senior Leadership - Limited Investment - Need For Digital Expertise - Fear Of Complacency
4	Alwashah, Z et al	2024	Challenges to adopt digital construction technologies in the Jordanian construction industry	. Status Quo Industry Standards - Lack of Client Interest - Lack of Financial Need/-Drive - Technical Barriers - Environmental Barriers - Social Dimensions - Organizational Characteristics
5	Chen, X. et al	2024	A multivariate regression analysis of barriers to digital technologies adoption in the construction industry	. Slow Technology Adoption - Fragmented Sector - Skill Set Requirements - Focus on Education - Collaboration with Industry - Geographic Disparities - Research Gaps - Emerging Technologies - Supply Chains
6	Brozovsky, J. et al	2024	Digital technologies in architecture, engineering, and construction	. Cost Pressures - Lack Of Models And Data - Uncertain Economic Returns - Senior Management Support - Expected Outcomes From Clients - Financial Subsidies - Limited IT Infrastructure - Collaboration Between Public-Private Sectors - Conservative Organizational Cultures

Serial	Author	Year	Title of Paper	Factors
7	Aghimien, D. et al	2024	Determinants of cloud computing deployment in South African construction organisations using structural equation modelling and machine learning technique	. Cost-effectiveness - Availability - Compatibility - Client Demand - Competitors' Pressure - Trust In Cloud Service Providers
8	Liu, H. et al	2023	Blockchain technology toward smart construction: Review and future directions	. Return On Investment - Practitioners Training - Industry Readiness - Integration With Project Delivery Systems - Technology Fusion
9	Musarat, M. et al	2023	A review on the way forward in construction through industrial revolution	. Resilience - Human-centricity - Economic Efficiency - Sustainable Development - Shortage Of Technical Skills - Investment-hesitancy Among Investors - Security And Cultural Concerns - Unavailability Of Data
10	Statsenko, L. et al	2023	Construction 4.0 technologies and applications: A systematic literature review of trends and potential areas for development	. Efficient Energy Usage - Prefabricated Construction - Sustainability - Safety And Environmental Management - Indoor Occupant Comfort - Efficient Asset Utilisation
11	Malik, M. S.	2023	Digital Transformation in Construction Industry in India	. Recognition of Digital Transformation Benefits - Improved Efficiency & Productivity - Cost Reduction - Lack of Awareness - High Implementation Costs - Resistance to Change
12	Na, S. et al	2022	Acceptance model of artificial intelligence (AI)-based technologies in construction firms	. Relative Advantage - Conformance - Technology Complexity - Corporate Size - Project Range - Management Support - HR Scale - Competitive Advantage
13	Aghimien, D. et al	2022	Latent institutional environment factors influencing construction digitalization in South Africa	. Legislation and Regulation - Pressure from Clients and Competitors

Serial	Author	Year	Title of Paper	Factors
14	Orze, B. et al	2022	Digitization in the design and construction industryremote work in the context of sustainability	. Working Time Savings - Work Comfort and Safety - Environmental Sustainability - Legal Aspects - Difficult Cooperation with Clients
15	Lekan, A. et al	2022	Disruptive technological innovations in construction field	. Organizational Induced Factors - Professional Composition Oriented Factors - Construction Industry Induced Factors - Internet of Things Factors
16	Hwang, B. et al	2022	Challenges and strategies for the adoption of smart technologies in the construction industry	. Organizational Culture - Leadership Support - Training and Skills Development - Cost and Financial Considerations - Technological Infrastructure - Regulatory Environment - Collaboration and Communication - Market Competition
17	Khudzari, F. et al	2021	Factors Affecting the Adoption of Emerging Technologies in the Malaysian Construction Industry	. Management Support - Training and Skills - Organizational Culture - Project Complexity - Market Competition - Regulatory Environment - Economic Conditions - Client Demand - Technological Readiness
18	Teisserenc, B. et al	2021	Adoption of blockchain technology through digital twins in the construction industry 4.0	. Technological Challenges - Regulatory and Compliance Issues - Economic Factors - Social Factors - Environmental and Legal Factors - Security Concerns
19	Bademosi, F. et al	2021	Factors influencing adoption and integration of construction robotics and automation technology in the US	. Technological Readiness - Cost Considerations - Workforce Skills and Training - Management Support - Regulatory Environment - Market Competition - Perceived Benefits

was calculated using the average method, followed by determining the percentage values [45].

Serial	Author	Year	Title of Paper	Factors
20	Yevu, S. et al	2021	Evaluation model for influences of driving forces for electronic procurement systems application in Ghanaian construction projects	. Environment-related Aspects - Process Optimization

2.4.1 PESTLE Framework

The PESTLE framework is a strategic analysis tool that evaluates the macro-environmental factors affecting an organization, encompassing Political, Economic, Social, Technological, Legal, and Environmental dimensions. This framework aids in understanding external influences that can impact decision-making and strategic planning across various sectors [46]. PESTLE provides a structured approach to assess multiple external factors simultaneously, ensuring a well-rounded understanding of the environment [47]. By analyzing the external environment, organisation can identify potential opportunities for innovation, growth, and expansion and make informed decisions [48]. PESTLE analysis can reveal emerging technologies that can improve construction efficiency or new government regulations that create demand for sustainable building practices [49]. The framework offers several advantages over traditional methods like SWOT analysis as it provides a more comprehensive understanding of external forces, facilitates ongoing trend scanning, and helps develop robust strategies aligned with dynamic macro-environmental conditions [50]. This framework is mostly used in strategic decision making in industries, politics and governmental domains.

2.4.2 Analytical Hierarchy Process

One of the primary tasks performed by the organisations is to adopt a strategy to foster digital culture. The project's performance will suffer in the absence of a suitable and precise process for choosing the best strategy. It is therefore recommended that organisations adopt the multicriteria decision-making (MCDM) process. One technique for MCDM is the analytic hierarchy process (AHP). But AHP can only be used in decision-making that is hierarchical [51]. Analytic hierarchy process (AHP) is a strategic approach decision assistance system. Its main component is the pairwise assessment of all available options with respect to each evaluation criterion. These comparisons' outcomes are stored in a matrix with reciprocal symmetrical entries. A nine-step verbal scale was employed, in the expert's judgment, to preserve the response's symmetry. Selecting the appropriate tender has a significant impact on contractors' reputation, financial standing, and desire for success [52]. Several decision-making techniques, such as TOPSIS, ENTROPY, and ELECTRE, are available; however, the analytical hierarchy process (AHP) has been employed in this study. More than any other instrument for decision-making, AHP is easy to use and effective. It is frequently used to choose and prioritize tasks. In the last stage, options are to be assessed using the most suitable assessment criteria. After that, the AHP approach was applied to create an assessment model and assess the index by including previously gathered score weights [53].

2.4.3 AHP-FCE Approach

In order to establish the value of an assessment objective using a membership matrix and factor weights, Zadeh originally suggested the Fuzzy Comprehensive assessment (FCE) approach, which was derived from fuzzy set theory [54]. With a variety of properties, an imprecise border, and challenges in providing a fair interpretation and overall assessment, fuzzy sets employ fuzzy relation composite theory [54]. AHP-FCE approach-based framework for factor evaluation is shown in figure 2.5.

The standard AHP tchnique is unable to accurately capture the knowledge of decision makers, despite the fact that this is its intended purpose. To address this issue, the fuzzy AHP technique is frequently utilized in the literature. Based on fuzzy sets theory, the membership function determines whether a given element is a member of the fuzzy AHP (or FAHP) model. A membership function that ranges from zero to one can be used to define the values of fuzzy decision variables. The fuzzy decision variable can vary from fully true to false, and the membership function specifies the degree of truth and completely false. When the language factors utilized in the decision-making process are common, this technique is more acceptable [56]. This technique addresses the vagueness or subjectivity in the

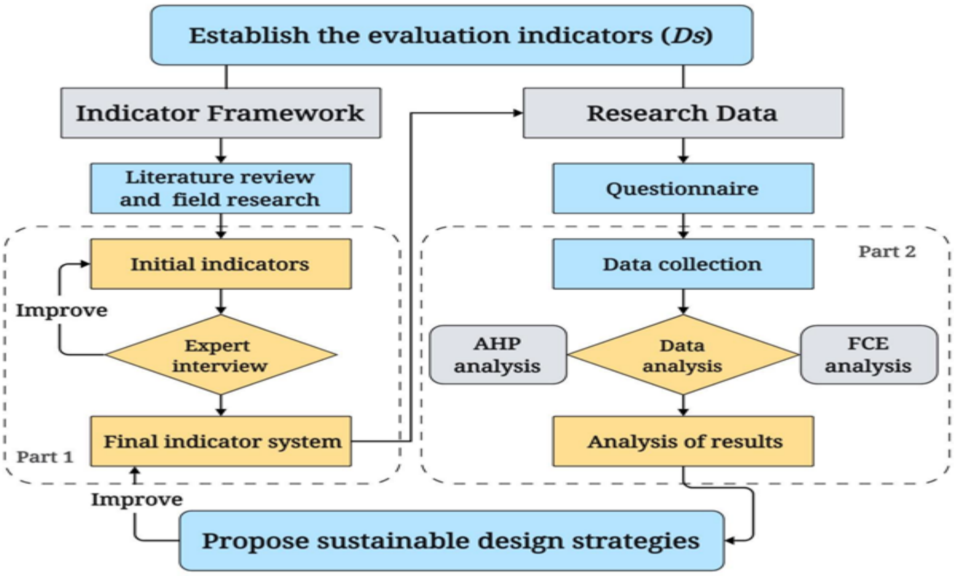

Figure 2.5: Research method process [55]

people's perceptions and provides a way to quantify their opinions, so that the most important factors can be weighed and ranked accordingly.

2.5 Research Gap

Although there is significant research on the barriers and drivers to adoption of specific digital technologies, such as Building Information Modeling (BIM), specifically in context of Pakistan, however a noticeable gap exists in understanding how to holistically enhance the digital ecosystem in Pakistan's construction sector. The existing literature predominantly focuses on the adoption challenges and benefits of individual technologies, such as financial constraints, technical skill requirements, and organizational readiness. For instance, a study by Asaad et al [57] focuses only on opportunities and challenges in implementation of BIM in developing countries. Likewise, study by Rahimian et al [58] examines only the barriers related to adoption of IoT-Based Technologies in Green Buildings only. There is a lack of research focusing on wholesome integration of digital systems in building construction, specifically Pakistan. Moreover, a comprehensive framework addressing the interplay between political, economic, social, technological, legal, and environmental factors in fostering a unified digital ecosystem is largely absent. Specifically, there is limited research exploring strategies tailored to the unique challenges of Pakistan's construction sector, such as low investment in digital expertise, organizational resistance to change, and inadequate collaboration between public and private stakeholders. Addressing this gap is critical for developing context-specific solutions that enhance efficiency, sustainability, and innovation within the industry.

2.6 Summary

The literature review provides a comprehensive theoretical foundation and examines global applications of digital technologies within the construction industry, emphasizing their impact on efficiency and sustainability. Core technologies, including Building Information Modeling (BIM), Digital Twins, Automation, and the Internet of Things (IoT), are explored for their role in enhancing project management, safety, and data-driven decision-making processes. The review also identifies factors influencing the adoption of digital technologies, categorized using the PESTLE framework, which encompasses political, economic, social, technological, legal, and environmental dimensions. While existing research provides valuable insights into individual technologies and associated barriers, the review highlights a critical gap in the holistic development of a digital ecosystem tailored to the unique challenges of Pakistan's construction sector. Addressing this gap is essential for formulating strategies that promote innovation, operational efficiency, and sustainability in the industry.

Chapter 3

Research Methodology

3.1 Introduction

This chapter outlines the methodological framework adopted for the study. The research employs a structured approach to investigate the factors influencing the adoption of digital technologies in construction projects in Pakistan, utilizing the PESTEL framework. A quantitative research method was adopted to achieve the aim of the study using a questionnaire survey designed to assess the impact of political, economic, social, technological, environmental, and legal factors [59]. The Delphi technique was utilized to refine the questionnaire based on expert input, ensuring its relevance and clarity. A total of 129 questionnaires were retrieved from respondents in the Islamabad region. The respondents included project managers, construction managers, quantity surveyors, designers, engineers and diploma holders. Data analysis was performed using the Analytic Hierarchy Process (AHP) and statistical tools (SPSS) to derive meaningful insights. The detailed methodology used in the study is described in the subsequent sections.

3.2 PESTLE Framework

PESTLE framework was used to categorise the factors as it is an effective analysis tool to evaluate the macro-environmental factors, encompassing Political, Economic, Social, Technological, Legal, and Environmental dimensions. This framework aids in understanding external influences that can impact decision-making and strategic planning across various sectors. PESTLE provides a structured approach to assess multiple external factors simultaneously, ensuring a well-rounded understanding of the environment [46]. The framework offers several advantages over traditional methods like SWOT analysis as it provides a more comprehensive understanding of external forces, facilitates ongoing trend scanning, and helps develop robust strategies aligned with dynamic macro-environmental conditions [50].

3.3 Research Design

This studys theoretical foundation is based on a systematic literature review to identify key factors affecting adoption of digital technologies in building construction projects globally as well as in developing countries. A descriptive and survey-based research design was employed to collect and analyze data systematically [60]. Data was gathered using structured questionnaires distributed to contractors, project managers, and other professionals at various construction sites of Islamabad. The Delphi technique was employed to refine the questionnaire, ensuring that it accurately captured the most significant factors identified in the literature. The collected data was analyzed using statistical method (SPSS) and the identified factors were evaluated using Analytic Hierarchy Process (AHP) to determine their interrelationship and relative ranking, enabling a quantitative assessment of the PESTEL factors. The findings were then analysed to draw conclusions and provide actionable recommendations in the form of a framework for the implementation of digital technologies in building construction projects of Pakistan for enhancing efficiency, sustainability and quality. A schematic representation of the methodology employed in this study is illustrated in Figure 3.1.

3.3.1 Preliminary Investigation

A thorough examination of existing literature and exploratory investigations were conducted. Initially, the aim was to gain insight into the factors affecting digitisation across different countries and their implications on construction projects. Subsequently, the problem statement and research objectives were formulated following an analysis of the literature review.

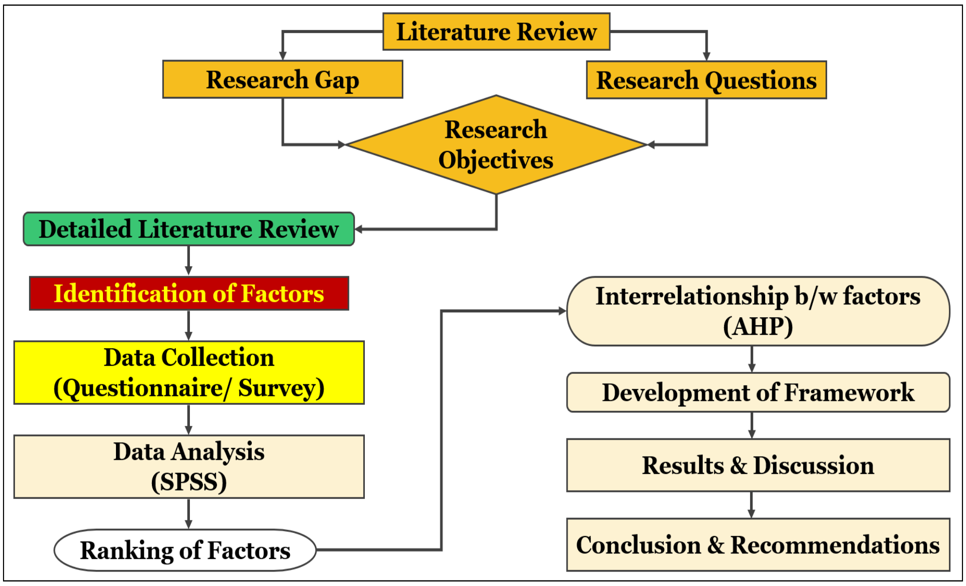

FIGURE 3.1: Schematic Diagram of Method Used

3.3.1.1 Primary Data

In order to identify the elements influencing digitisation, questionnaires and other considerations are employed as key data collection tools.

3.3.1.2 Secondary Data

To ensure that the research concerns were well grasped, a comprehensive literature review was carried out at the beginning of this thesis. Through academic literature, journal publications, and conference proceedings, secondary data was gathered.

3.3.2 Literature Study

A comprehensive and systematic analysis of the previous literature was done to determine the variables influencing digitization in construction. The method is also known as systematic literature review or SLR. Various factors affecting the adoption of digital technologies in construction were identified. The factors which had impact on digitsation globally were extracted from leading publications in developed as well as developing countries. 115 factors were initially identified after compiling the pertinent research articles, publications, journals and other publications. These elements were examined in more detail and shortlisted to 41 factors based on commonalities and further divided into different areas of research based on PESTLE framework.

3.3.3 Questionnaire Design

The questionnaire was generated after applying Delphi technique as it took place in two rounds based upon experts panel. 41 shorlisted factors were further reduced to 27 key factors, pertinent to Pakistans industry (described in Appendix 1).

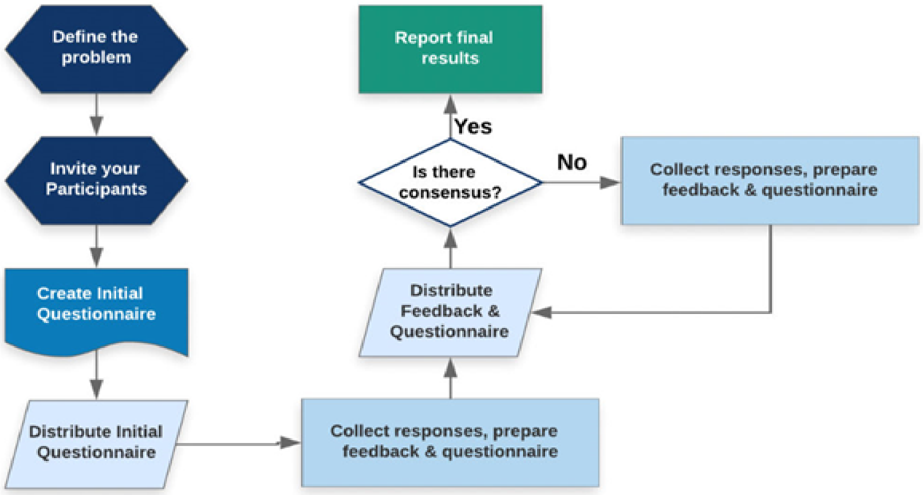

FIGURE 3.2: Delphi Technique Process [61]

After the literature review analysis, the Delphi approach was used to design a questionnaire survey for data collection. The Delphi method is an official communication strategy or procedure that was first created as a thorough and predictive method using a panel of experts, researchers, and professionals. Feedback is usually obtained through focus groups and the Delphi technique [62]. Formal group approach and the Delphi method are commonly employed for gathering feedback. However, the Delphi method offers structured discussions, indirect interactions, and quantifiable written feedback, rendering the process more thorough, clear, and effective compared to alternative approaches [63].

The field study involved several industry specialists who provided valuable comments on the identification of significant criteria and questionnaire creation. The identified factors were narrowed down based on input from industry specialists and added to a questionnaire to collect further data.

After extensive consultations with experts and collecting input from professionals in the field, a concise set of developed variables were chosen. These variables were used to construct a questionnaire, which included a list of 27 shorlisted factors (described in Appendix 2).

A Likert scale was employed to evaluate the answers. The matching criteria listed below were put into practice., shown in table 3.1 [64].

Table 3.1: Impact Scale (Likert Scale)

Descriptive Range	**Range**
Very Low	1
Low	2
Moderate	3
High	4
Very High	5

3.3.4 Data Acquisition

Following the development of the questionnaire, a survey was administered. Professionals, site managers, and key stakeholders from various governmental and commercial entities in Islamabad were invited to participate and provide their responses to the questionnaire.

3.4 Data Analysis

Following data collection from specialists in the construction business, the statistical package for the social sciences (SPSS) was used to evaluate the collected data. The gathered information was scrutinized, as explained below:

3.4.1 Tools for Data Analysis

The abbreviation SPSS, offers versatility for a range of mathematical tasks and is known for its user-friendly interface. This mathematical tool encompasses both parametric and non-parametric analyses, covering comparative and correlational mathematical investigations [65].

Examining the distribution pattern of the results was crucial post reliability analysis. Utilizing statistical data, SPSS has the capability to generate reports, graphs, charts, descriptive visuals, and complex mathematical analyses [66].

SPSS possesses the ability to analyze data, interpret it effectively, and provide solutions for intricate research challenges. With the aid of advanced statistical algorithms, SPSS can efficiently handle large and intricate datasets [67].

3.4.2 Reliability Test

A crucial test which confirms the accuracy, stability and dependability of the results is the reliability test [67]. Cronbachs alpha is used in analysis of the reliability. Its score above 0.7 indicates that the data gathered can be reliably evaluated for additional research, which is considered appropriate and acceptable [68]. The data sets are generally utilized in statistical investigations [69].

3.4.3 Normality Test

The widely recognized and dependable Shapiro-Wilk's W-test (1965) is employed for assessing normality. This test, commonly referred to as the normality test, is frequently utilized to determine if the collected data adheres to a normal distribution. A significance value exceeding 0.05 suggests that the data follows a regular distribution (parametric data), whereas a value below 0.05 indicates non-normal distribution (non-parametric data).

3.4.4 Parametric and Non-parametric

The generated data (using SPSS) does not conform to the hypothesis of the test, one can opt for either parametric or non-parametric tests. Parametric tests are suitable for data with consistent patterns and a generally normal distribution, particularly when each group's distribution varies linearly. Conversely, nonparametric tests are utilized for data that lacks linearity, exhibits no specific distribution, and is measured on an ordinal or ranked scale. Non-parametric tests indicate non-normal data distribution, while parametric tests suggest normal distribution.

Non-parametric tests are typically preferred when data does not adhere to a normal distribution [70].

The hypothesis for assessing normality is as follows:

- Null Hypothesis (H0): The data exhibit a normal distribution if the p-value is greater than the alpha threshold.
- Alternative Hypothesis (H1): The data deviate from a normal distribution if the p-value is less than the alpha threshold.

3.4.4.1 Kruskal Wallis Test

The Kruskal-Wallis test is a nonparametric method used to determine if sample data comes from a single distribution. It can be extended to compare more than two samples, which is beneficial compared to the Wilcoxon and Mann-Whitney tests that only handle two samples. Importantly, the Kruskal-Wallis test does not assume normality [71].

In the Kruskal-Wallis test, each individual's score is ranked, with the lowest score receiving a rank of 1, the next lowest a rank of 2, and so forth. When dealing with non-parametric data, this test is recommended; however, for better outcomes with parametric data, one-way ANOVA is preferred [72].

This test is a commonly used non-parametric method for comparing multiple independent samples. It assesses whether these samples are derived from the same distribution. A significance value above 0.05 suggests that all respondents share a similar viewpoint [73].

As deduced from previous studies, the null and alternative hypotheses for this test,in terms of their significance value are described as follows:

- Null Hypothesis (Ho): If $p >$ alpha level, it indicates that all medians are equal (indicating a similar perception);this means that all correspondents do not have similiar perceptions accross various categories of experience, knowledge etc.
- Null Hypothesis (Ho): If $p <$ alpha level, it indicates that all medians are equal (indicating a similar perception).

3.5 Framework Development Using AHP

The (AHP) was initially introduced by Saaty. AHP is a technique designed to address challenging and ambiguous problems. It serves as a valuable tool for managing complex decision-making processes by assisting in the formulation and evaluation of criteria, analyzing gathered data, and advancing decision-making methodologies.

1. Apply the analytic hierarchy process (AHP) to develop a hierarchical structure.
2. Determine the (RII).
3. Build the pairwise matrix and analyze the comparisons between the pairs.
4. Assess the level of consistency in the pattern.

3.5.1 Develop a Hierarchical Framework

In the AHP, the initial step involves constructing the decision problem hierarchy. There are no rigid guidelines for hierarchy creation. AHP facilitates the organization of intricate judgments into a hierarchical structure, specifically tailored to tackle challenging problems across multiple levels. The top priority represents the objective, the middle levels denote criteria, and the bottom level signifies the goal [74].

The hierarchical structure in this study consists of the goal ,criteria and index layer, which break down the complex process of determining index weight. This structure is designed based on the qualities of the MCDM problem and the overarching objective [75].

3.5.2 Relative Importance Index

It is utilized in the research involved identifying and ranking factors. Each factor's significance was determined by averaging the values provided by respondents in the dataset. Consequently, the relative relevance index (RII) of each item was assessed based on the intensity level chosen by respondents. The RII for each element was computed by converting the ranking scale into a relative ranking scale. Equation (3.1) was employed to calculate the RII.

$$RII = \sum \frac{W}{A} \times N \tag{3.1}$$

$\sum W$ represents the weights given by respondents to each element, ranging from 1 to 5 on a scale.

A denotes the maximum factor value, equivalent to five on the Likert scale.

N indicates the entire number of responders.

3.5.3 Pair-Wise Comparison Evaluation

In the AHP process, a (P) is created to limit the weights for each criterion. This involves comparing each criterion with every other criterion. A real (m x m) matrix is denoted by the matrix (P), where'm' stands for the number of criteria for assessment. Every value in matrix (P), represented by the notation a_{ij}, shows the significance of the ith criterion is in relation to the jth criterion. When the ith criterion has a greater value than the jth criterion, it is regarded as more significant; conversely, when the value is lower, it is considered less significant. When two criteria are equally significant, the value of aij is 1 [76].

According to Amin Bakhsh et al., Saaty recommends utilizing a specific numerical scale for pairwise comparisons, as depicted in Table 3.2. This numerical scale assists decision-makers in assessing the severity of judgments and offers results within a arithmetical outline for analysis.

The steps listed below are suggested to calculate the pairwise comparison matrix:

1. A pairwise comparison matrix (P) is generated to assess criteria.
2. Equation (3.2) is applied to compute each entry ij in the normalized matrix (P norm).

$$\bar{\alpha}_{ij} = \frac{a_{ij}}{\sum_{k=1}^{m} a_{kj}} \tag{3.2}$$

$\sum_{k=1}^{m} a_{kj}$= The total score is assigned to each column of the matrix (P) = αij denoted by αij, which represents the entries in the normalized matrix (P). Equation (3.3) is employed to determine the weights of the criteria after normalization, wherein each value is divided by the sum of all values obtained.

TABLE 3.2: Scale of pair wise comparison

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally
3	Moderate importance	Personal opinion and experience clearly prefer one activity over another.
5	Essential or strong importance	One activity is clearly preferred over another by experience and self-evaluation.
7	Very strong importance	A component is heavily preferred, and its practical domination is proven.
9	Extreme importance	The factor that prioritizes one activity over another is the strongest affirmation there is.
2,4,6,8	Values that lie between two consecutive judgements	An assessment falls between two levels.

$$W = \frac{\sum_{k=1}^{m} \bar{\alpha}_{ik}}{n} \tag{3.3}$$

$\sum_{k=1}^{m} \bar{\alpha}_{ik}$=The entire amount score of each row in the normalized matrix (Pnorm) equals the number of elements, denoted as 'n'.

Eigen values (λ_{max}) calculation by equation (3.4).

$$\sum_{k=1}^{m} \alpha_{kj} \times W \tag{3.4}$$

$\sum_{k=1}^{m} \alpha_{kj}$ =Total sum score of matrix (P)

W= Standards weight

3.5.4 Evaluate the Consistency Patterns

Verifying the decisions made in each level can be done with the use of the Analytic level Process (AHP). Although it is generally accepted that an inconsistency ratio of 10% or less is desirable, certain circumstances may call for a larger figure to be approved or accepted. The λ is a validation parameter in AHP.

1. Calculate the consistency index for each medium using equation 3.5:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{3.5}$$

   Consistency Index, or CI Biggest eigenvalue (λ_{max}) = total number of components(n).

2. Equation (3.6) is then used to get the consistency ratio:

$$CR = \frac{CI}{RI} \tag{3.6}$$

   CR= Consistency Ratio

   RI= Random Index

   Thomas Saaty established random consistency index scores are presented in Table 3.3.

According to Saaty (2012), for matrices sized 3 by 3 or 4 by 4 good range 0.05 of CR. For larger matrix exceeding size 5, the acceptable range is 0.08, and for matrices even larger, it's 0.1. Matrix internal analysis is considered appropriate or indicates a high level of consistency in the comparative decisions presented if the CR score is equal to or less than the specified value [77].

3.6 Framework Evaluation Method

To pinpoint the factors affecting digitisation in the construction industry, a combination of AHP and evaluation techniques is employed. Determining these factors becomes challenging or impossible using a single set of explicitly stated management criteria [78].

To tackle this issue of fuzzy complexity, Zadeh introduced fuzzy sets in 1965, laying the groundwork for utilizing FCEM. The synthesis theory of fuzzy relations is employed in the evaluation approach to assess variables with fuzzy boundaries. This approach offers a comprehensive identification of goals considering multiple factors. It involves establishing a factor set U and a decision set V, where V represents a scale ranging from very low to very high (i =(1,2,3,4,5)), while U denotes the factors (j = (1,2,3,...n)).

3.6.1 First Level Fuzzy Comprehensive Evaluation

FCEM involves lines comprising membership vectors and index weight vectors. The membership matrix Bi is computed by multiplying each factor of the fuzzy relation matrix ”R” by the local weight of each sub-criteria, as determined by the analytic hierarchy process (AHP). Equation (3.7) is utilized to calculate the membership matrix Bi, also known as the first-level comprehensive assessment matrix.

$$B_i = W' \times R \tag{3.7}$$

W’= Local weight

R= Fuzzy relation matrix

3.6.2 Second Level Fuzzy Comprehensive Evaluation

Comparable to the initial fuzzy assessment, the assessment results of all first-class fuzzy comprehensive evaluations are incorporated into the medium of the second level FCEM. To generate the comprehensive assessment matrix, the factors local weight is multiplied by the R, resulting in the second-level fuzzy comprehensive assessment matrix [79]. The R’ for each comment is depicted by the Bi. Equation (3.8) can be utilized to calculate the second-level FCEM.

$$B_i = W \times R \tag{3.8}$$

W = weight of factors

R = Evaluation index containing first level assessment

Following the acquisition of the second FCE matrix (B), it was noted that which factor is in accordance with the notion of maximum membership grade. The various impacts are defined in Table 3.3.

Table 3.3: Description of different impacts

Types of Impact	**Meaning**
Very Low,	The likelihood of impact is low, and even if it occurs, the resulting loss would be minimal but significant
Low	There is little chance of an impact, and if it did occur, there would be little loss
Moderate	There is a moderate chance of an impact, and this impact would result in a loss overall
High	There is a significant chance of effect, and this impact would result in significant loss
Very High	There is a higher chance of impact, which would result in more loss

3.7 Summary

This chapter provides a detailed overview of the research methods utilized in this project. It outlines the strategies employed to evaluate the factors influencing adoption of digital ecosystem in Pakistan's construction sector. Through literature analysis, key factors affecting the digitisation were identified. The Delphi technique was then utilized to ascertain whether these factors identified by experts were relevant to Pakistan's development projects. To rank these elements based on their importance, a questionnaire survey was conducted to assess their influence. Numerous tests were conducted to confirm the consistency of the data, understand its nature, and gauge respondents' perceptions. Additionally, this chapter discusses the (MCDM), the (AHP), and the determination of local weights for factors in the (FCEM). These techniques evaluate the severity of final decisions in the matrix, the reliability of the matrix, and its consistency. Towards the conclusion, the AHP-FCE method a combination of quantitative and qualitative approaches is introduced. This method aims to assess the project's level and identify the factors influencing bid evaluations for construction projects.

Chapter 4

Results and Analysis

4.1 Introduction

The information gathered from 126 respondents who are actively involved in Pakistan's construction business is presented in this chapter, with an emphasis on developing a digital ecosystem within the sector. Using strong analytical tools, the analysis explores the elements impacting digital adoption and ecosystem development in order to extract valuable insights. The results are presented in an efficient manner using tables and charts. This study's main goal is to evaluate the crucial elements promoting or impeding the growth of a digital ecosystem in Pakistan's construction industry. In keeping with the objectives of the study, the responses have been methodically arranged into a number of subject headings. The results are presented in depth in this chapter, which serves as the foundation for the introduction, findings, interpretations, and conclusions of the thesis.

4.2 Sample Size and Response Rate

The sample size of this research was 126 which is deemed appropriate as determined by Conroy (2021), which states that a sample size of 100 is often considered a minimum for meaningful results, as a Rule of thumb. The study iterates that if the population size 5000 or larger, then a sample size of 96 to 98 would yield results within 10 percent margin error which is good enough to infer the results. Since the population of construction professional within Islamabad is around 5000, therefore, the sample size i.e. 126 is deemed suitable for our evaluation. 129 of the 165 questionnaires that were sent out were returned, yielding a remarkable 78.18% response rate. A typical questionnaire study in information systems receives between 136 and 374 respondents, with a median of 217. Response rates typically range from 16.5% to 50%, with a median of 27.8% (Lund, 2023). Out of total 165 questionnaires distributed to various field practitioners and experts, 129 responses were received (response rate 78.18%) which is acceptable 3 responses discarded due to diploma qualification. A good survey should aim for at least a 40% response rate and a margin of error of 5% or less (Story & Tait, 2019).

4.3 Demographic Characteristics of the Respondents

Fig 4.1 shows that the majority of respondents held a Bachelor's degree (50.8%), followed by those with a Master's degree (45.2%). A smaller proportion reported being Diploma holders (2.4%) or having a Ph.D. (1.6%). This highlights a predominantly well-educated workforce.

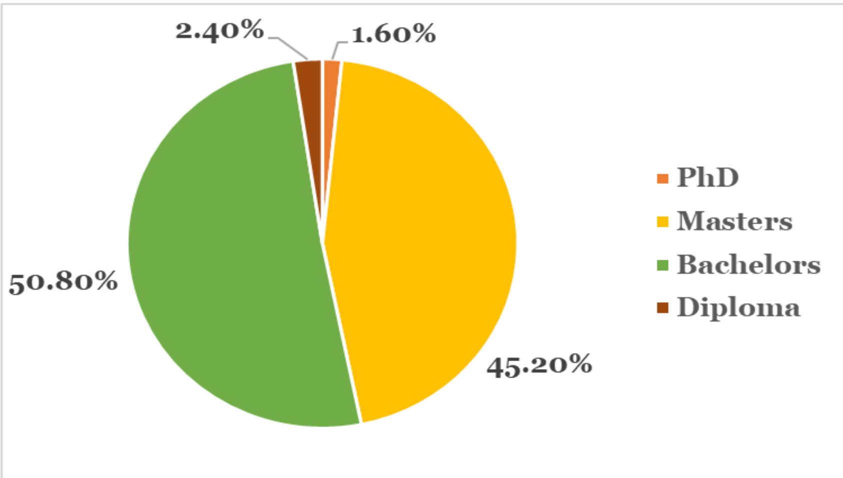

FIGURE 4.1: Education Distribution

A significant proportion of respondents (34.9%) had 1 to 4 years of experience, indicating a younger demographic. Others had 10 to 14 years (25.4%) or 5 to 9 years of experience (24.6%). A smaller percentage had 15 to 19 years (8.7%) or 20+ years (6.3%), suggesting a balanced mix of early-career and experienced professionals.

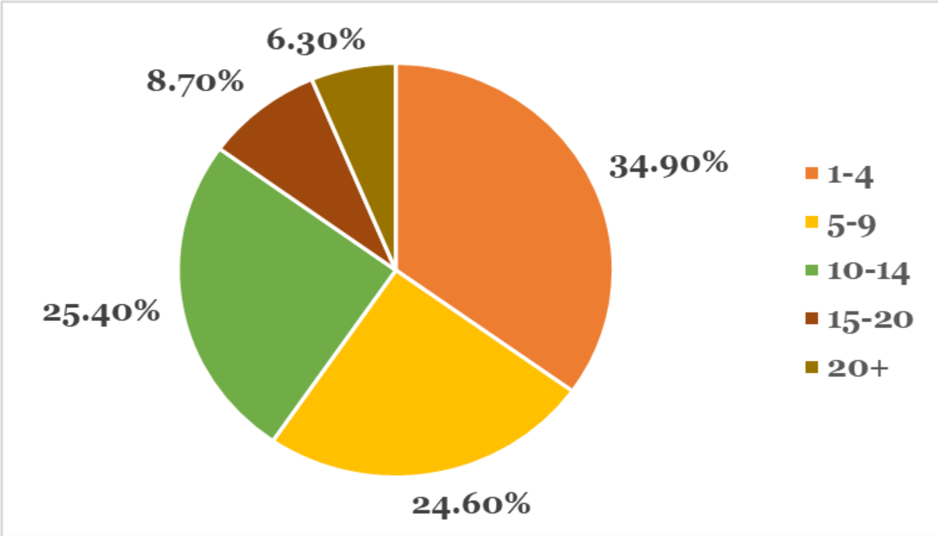

FIGURE 4.2: Experience Distribution

Most respondents were associated with contractors (42.9%), while others represented clients (17.5%), consultants (17.5%), and supervisors (9.5%). A minority (12.7%) were categorized as "other."

The most common role was that of a project/construction manager (45.2%), followed by site engineers (20.6%). Other positions included planning engineers (9.5%), resident engineers (4.0%), and other roles (20.6%).

Half of the respondents (50.0%) were engaged in infrastructural projects. Residential projects accounted for 28.6%, while smaller proportions were involved in non-residential projects (4.8%), social amenities (4.8%), and other types of projects (11.9%).

4.4 Descriptive Statistics

The descriptive statistics provide an overview of the central tendencies and variability in the data, offering insights into factors influencing the digital ecosystem in Pakistan's construction sector.

The mean scores of variables ranged from 2.47 (Government subsidies or incentives) to 4.33 (Perception of benefits), indicating varying levels of agreement or prevalence. Among the political factors, policy support (M = 3.02, SD = 1.09) showed moderate support, while Government subsidies or incentives (M = 2.47, SD = 1.30) received relatively low scores, suggesting that financial backing remains insufficient. Compliance with existing standards (M = 2.77, SD = 1.04) and policy incentives for environmental goals (M = 2.94, SD = 1.07) also reflected moderate agreement.

Economic factors showed notable trends, with clients' demand for digitization receiving a high mean score (M = 3.65, SD = 0.70), indicating strong market pressure for digital adoption. Conversely, resource allocation for digitization (M = 2.75, SD = 1.04) and availability of financial incentives (M = 2.65, SD = 1.15) were perceived as relatively low, emphasizing resource constraints. The role of market competition due to digitization was significant (M = 3.84, SD = 0.99), highlighting competitive pressures driving adoption.

Social factors such as awareness of digital technology (M = 3.61, SD = 0.93) and perception of benefits (M = 4.33, SD = 0.87) were positively rated, suggesting a high level of understanding and acknowledgment of the advantages of digital transformation. However, barriers like stakeholders' lack of interest (M = 3.87, SD = 0.80) and resistance to change (M = 3.15, SD = 1.07) were moderately high, indicating social resistance within the sector.

Technological factors revealed a moderate present level of adoption (M = 2.93, SD = 1.17) and availability of infrastructure (M = 3.05, SD = 1.06). Efforts to improve skills were rated low (efforts to enhance skillsets: M = 2.56, SD = 1.08), although willingness to acquire digital skills was high (M = 4.13, SD = 0.92).

Environmental factors related to sustainability showed promising trends, with achievement of SDGs (M = 4.01, SD = 0.83) and alignment with SDGs (M = 3.47, SD = 1.09) scoring positively. This suggests an increasing focus on aligning digital initiatives with environmental goals.

Overall, the data reveals a mix of opportunities and challenges. High scores in areas like perception of benefits and clients' demand indicate strong drivers for digital transformation. However, barriers such as lack of government support, resource allocation, and social resistance highlight areas needing intervention to foster a robust digital ecosystem.

Here is a graphical representation of the descriptive analysis, showing the mean values of each variable with error bars representing the standard deviation. This visualization highlights the variability and central tendency of each factor.

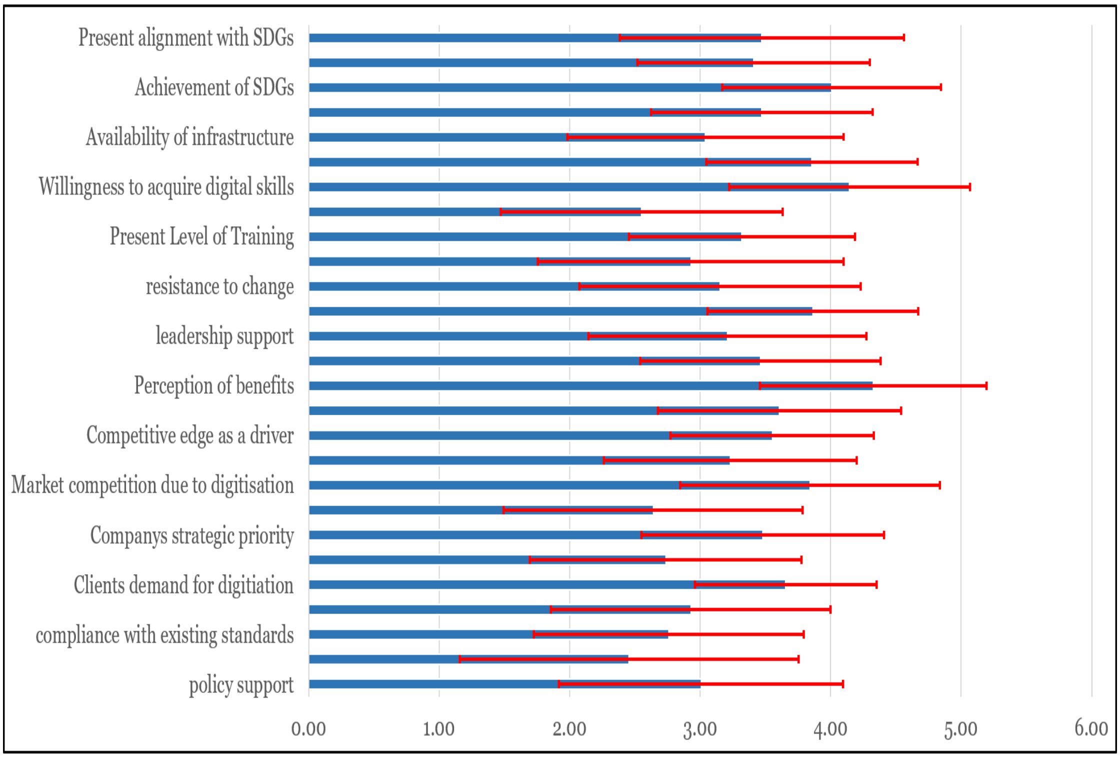

FIGURE 4.3: Descriptive Analysis of Variables

4.5 Reliability of the Research

The notion of data reliability is employed to evaluate the caliber of research. It illustrates how well a procedure or test captures an idea.

4.5.1 Reliability of the Questionnaire

The reliability of the questionnaire was checked by employing Cronbach's alpha test. The most popular way to test internal constancy is with Cronbach's alpha which is typically employed when a survey or questionnaire has multiple Likert items that together form a scale and one wishes to ascertain the reliability of the scale. The higher values of Cronbach Alpha results (approaching 1) indicate more reliability of the survey.

4.5.2 Reliability Analysis

The reliability analysis of the scale, which includes 27 items, yielded a Cronbach's Alpha value of 0.839, with a similar value of 0.837 based on standardized items. This indicates a high level of internal consistency among the items. Table 4.1 illustrates the reliability statistics: According to widely accepted thresholds for

TABLE 4.1: Reliability Statistics

Cronbach's Alpha	**Cronbach's Alpha Based on Standardized Items**	**Number of Items**
0.839	0.837	27

Cronbach's Alpha:

- Values above 0.8 are considered good, indicating that the items measure the same underlying construct effectively.
- The high reliability score suggests that the scale is suitable for assessing the intended factors related to fostering a digital ecosystem.

These results demonstrate that the items in the scale are reliable and consistent, supporting their use in further analyses, such as factor analysis or regression modeling.

4.6 Factor's Coding

Finding and defining a link between concepts is the process of coding. The process of indexing or classifying the data to create a framework of theme concepts is called coding. This makes it convenient which analysis the relative impportance and formulating a heirarchy between factors. There are five PESTEL factors in this study as described earlier, namely Political, Economic, Social, Technology and Environment. Tentative factors coding includes the following for convenience of use: each is denoted by (P, E, S, T, EN), and all factors have 27 sub-factors, which are all denoted by P= (P1, P2, P3,..., E1, E2,) correspondingly.

4.7 Normality Test

The results of the normality tests, including the Kolmogorov-Smirnov and Shapiro-Wilk tests, indicate that none of the variables exhibit a normal distribution. For the Kolmogorov-Smirnov test, all variables produced significant p-values ($p < .001$) with test statistics ranging from .170 (e.g., Present level of adoption) to .343 (e.g., Awareness to digital tech), suggesting varying degrees of deviation from normality as noted by Kim and Park. Similarly, the Shapiro-Wilk test results were significant for all variables ($p < .001$), with statistics ranging from .700 (e.g., Perception of benefits, showing the greatest deviation) to .915 (e.g., Present level of adoption, showing the least deviation).

These findings indicate that the data do not conform to the assumption of normality, which is a requirement for parametric tests. This means that all correspondents do not have similiar perceptions related to a question, accross various categories of experience, qualifiifications etc. As a result, non-parametric tests, such as the Mann-Whitney U test or Kruskal-Wallis test, are recommended for analyzing group differences. Table 4.2 summarizing the normality test results:

Table 4.2: Normality Results

Variable	**Kolmogorov-Smirnov Statistic**	**Kolmogorov-Smirnov Sig. (p)**	**Shapiro-Wilk Statistic**	**Shapiro-Wilk Sig. (p)**
Policy Support	0.225	0	0.853	0
Govt Subsidies or Incentives	0.221	0	0.843	0
Compliance with Existing Standards	0.224	0	0.905	0
Policy Incentives for Environmental Goals	0.201	0	0.912	0
Clients' Demand for Digitization	0.259	0	0.794	0

Variable	Kolmogorov-Smirnov Statistic	Kolmogorov-Smirnov Sig. (p)	Shapiro-Wilk Statistic	Shapiro-Wilk Sig. (p)
Resource Allocation for Digitization	0.192	0	0.91	0
Company's Strategic Priority	0.264	0	0.879	0
Availability of Financial Incentives	0.192	0	0.896	0
Market Competition Due to Digitization	0.204	0	0.856	0
Cost Effect Barrier	0.195	0	0.904	0
Competitive Edge as a Driver	0.302	0	0.828	0
Awareness to Digital Tech	0.343	0	0.795	0
Perception of Benefits	0.276	0	0.7	0
Willingness for Digitization	0.288	0	0.857	0
Leadership Support	0.201	0	0.911	0
Stakeholders' Lack of Interest	0.287	0	0.846	0
Resistance to Change	0.244	0	0.884	0
Present Level of Adoption	0.17	0	0.915	0

Variable	**Kolmogorov-Smirnov Statistic**	**Kolmogorov-Smirnov Sig. (p)**	**Shapiro-Wilk Statistic**	**Shapiro-Wilk Sig. (p)**
Present Level of Training	0.256	0	0.868	0
Efforts to Enhance Skillsets	0.181	0	0.904	0
Willingness to Acquire Digital Skills	0.263	0	0.804	0
Lack of Expertise	0.339	0	0.8	0
Availability of Infrastructure	0.205	0	0.912	0
Compatibility with Existing Systems	0.277	0	0.841	0
Achievement of SDGs	0.28	0	0.822	0
SDGs as a Driver	0.219	0	0.876	0
Present Alignment with SDGs	0.22	0	0.883	0

This table presents the Kolmogorov-Smirnov and Shapiro-Wilk test results for normality, highlighting that all variables significantly deviate from a normal distribution ($p < .001$).

4.8 Kruskal Wallis Test

4.8.1 Level of Education

The Kruskal-Wallis H test was conducted to examine differences in various factors related to fostering a digital ecosystem across levels of education (Bachelor's, Master's, Diploma, and Ph.D.). The results revealed that for most factors, the null hypothesis of equal medians was retained, indicating no statistically significant differences across education levels. However, significant differences were found for the following factors:

1. **Policy Incentives for Environmental Goals:** The test yielded a statistically significant result, $H(3) = 8.247,p = 0.047H(3) = 8.247, p = 0.047H(3) = 8.247,p = 0.047$, suggesting differences in perceptions based on education levels.

2. **Clients' Demand for Digitization:** A significant result was obtained, $H(3) = 10.462,p = 0.015H(3) = 10.462, p = 0.015H(3) = 10.462,p = 0.015$, indicating that educational background influences perceptions of client demand for digitization.

3. **Resistance to Change:** Differences were significant, $H(3) = 10.932,p = 0.012H(3) = 10.932, p = 0.012H(3) = 10.932,p = 0.012$, reflecting varying levels of resistance to change among educational groups.

4. **Present Alignment with SDGs:** The analysis revealed significant differences, $H(3) = 9.553,p = 0.049H(3) = 9.553, p = 0.049H(3) = 9.553,p = 0.049$, suggesting that education impacts perceptions of alignment with Sustainable Development Goals (SDGs).

For other factors, such as policy support, availability of financial incentives, and awareness of digital technology, no significant differences were found ($p>0.05p > 0.05p>0.05$), indicating consistent perceptions across education levels.

The results highlight that education levels influence perceptions of certain factors critical to fostering a digital ecosystem, particularly regarding policy incentives, client demand, resistance to change, and alignment with SDGs. These findings suggest that targeted strategies may be required for different educational groups to effectively address these areas.

4.8.2 Experience

The Kruskal-Wallis H test was conducted to examine differences in various factors across levels of experience in the construction sector. The results indicate that for most factors, the null hypothesis of equal medians across experience categories was retained, suggesting no statistically significant differences. However, significant differences were found for the following factors:

1. **Government Subsidies or Incentives:** The test revealed a significant difference, H(3)=11.019,p=.039H(3) = 11.019, p = .039H(3)=11.019,p=.039, indicating variations in perceptions of government subsidies based on experience levels.

2. **Market Competition due to Digitization:** Significant differences were observed, H(3)=9.735,p=.044H(3) = 9.735, p = .044H(3)=9.735,p=.044, suggesting that experience influences how respondents perceive competition driven by digitization.

3. **Efforts to Enhance Skillsets:** The analysis yielded significant results, H(3)=11.221,p=.030H(3) = 11.221, p = .030H(3)=11.221,p=.030, reflecting differences in the perceived efforts to enhance skills across experience groups.

For other factors, such as policy support, clients' demand for digitization, and resistance to change, no significant differences were found (p>.05p > .05p>.05), suggesting that perceptions of these factors are consistent across different levels of experience.

The significant results for government subsidies, competition due to digitization, and skill enhancement efforts suggest that targeted strategies may be required to address these areas for individuals at different levels of experience. For example, less experienced individuals may perceive fewer subsidies or lower competition, requiring tailored initiatives to engage them in digital transformation.

4.8.3 Type of Organisation

The Kruskal-Wallis H test was conducted to evaluate differences in various factors influencing the digital ecosystem across different categories of organization types (e.g., contractors, consultants, clients, etc.). For most factors, the null hypothesis of equal medians was retained, suggesting no significant differences across organization types. However, significant differences were identified in the following factors:

1. **Willingness for Digitization:** The test revealed significant differences, H(3)=9.334,p=.025H(3) = 9.334, p = .025H(3)=9.334,p=.025, suggesting that organizational type influences willingness to adopt digital practices.

2. **Leadership Support:** Significant differences were observed, H(3) = 11.483,p = .009H(3) = 11.483, p = .009H(3)=11.483,p=.009, indicating that perceptions of leadership support vary across organization types.

3. **Present Alignment with SDGs:** The results were significant, H(3) = 8.347,p =.040H(3) = 8.347, p = .040H(3)=8.347,p=.040, reflecting differing perceptions of how well organizations align with Sustainable Development Goals (SDGs).

4. **SDGs as a Driver:** Differences were also significant, H(3)=8.445,p=.038H(3) = 8.445, p = .038H(3)=8.445,p=.038, suggesting that the role of SDGs as a motivator for digitization varies by organization type.

For other factors, such as policy support, clients' demand for digitization, and efforts to enhance skillsets, no significant differences were observed (p$>$.05p $>$ .05p$>$.05), indicating consistent perceptions across organization types.

These findings highlight that organizational type significantly influences certain key factors, such as leadership support, willingness for digitization, and alignment with SDGs. These results suggest that tailored strategies may be necessary to engage different types of organizations effectively in the digital transformation process. For example, contractors may require additional incentives to align with SDGs, while clients may need more leadership-driven initiatives to encourage digitization.

Table 4.3 summarizes Kruskal-Wallis test results across the three categories (Education, Experience, and Organization Type):

Notes: Significant Results: Only factors with $p \leq 0.05$ are reported.

4.9 Framework Development Using AHP

The analytic hierarchy process (AHP) is what the multi-criteria decision technique is the AHP is a multicriteria policymaking technique that is comparatively

TABLE 4.3: Summary of Significant Kruskal-Wallis Test Results with significant differences.

Factor	**Sig. (p-value)**	**Category**	**Interpretation**
Policy Incentives for Environmental Goals	0.047	Education	Significant differences across education levels.
Clients' Demand for Digitization	0.015	Education	Significant differences across education levels.
Resistance to Change	0.012	Education	Significant differences across education levels.
Present Alignment with SDGs	0.049	Education	Significant differences across education levels.
Govt Subsidies or Incentives	0.039	Experience	Significant differences across experience levels.
Market Competition Due to Digitization	0.044	Experience	Significant differences across experience levels.
Efforts to Enhance Skillsets	0.03	Experience	Significant differences across experience levels.
Willingness for Digitization	0.025	Organization Type	Significant differences across organization types.
Leadership Support	0.009	Organization Type	Significant differences across organization types.
Present Alignment with SDGs	0.04	Organization Type	Significant differences across organization types.
SDGs as a Driver	0.038	Organization Type	Significant differences across organization types.

straightforward, yet technically efficient. When tackling a complex problem, it is helpful for decision makers to apply a simple hierarchy and conduct an organized, multi-criteria analysis of both quantitative and qualitative evidence.

4.9.1 Hierarchical Framework of Factors

The hierarchical structure of factors is depicted in Figure 4.4. Level 3 is index layer (sub criteria) having 27 factors affecting digitisation in construction sector. The index framework in this research is titled the target layer. It consists of five levels of factors labelled the criterion layer. Coding C = (P, E, S, T, EN) is referred to the criteria layer for evaluation ease, while P = (P1,P2,P3,.......,E1, E2,..) is written in the coding.

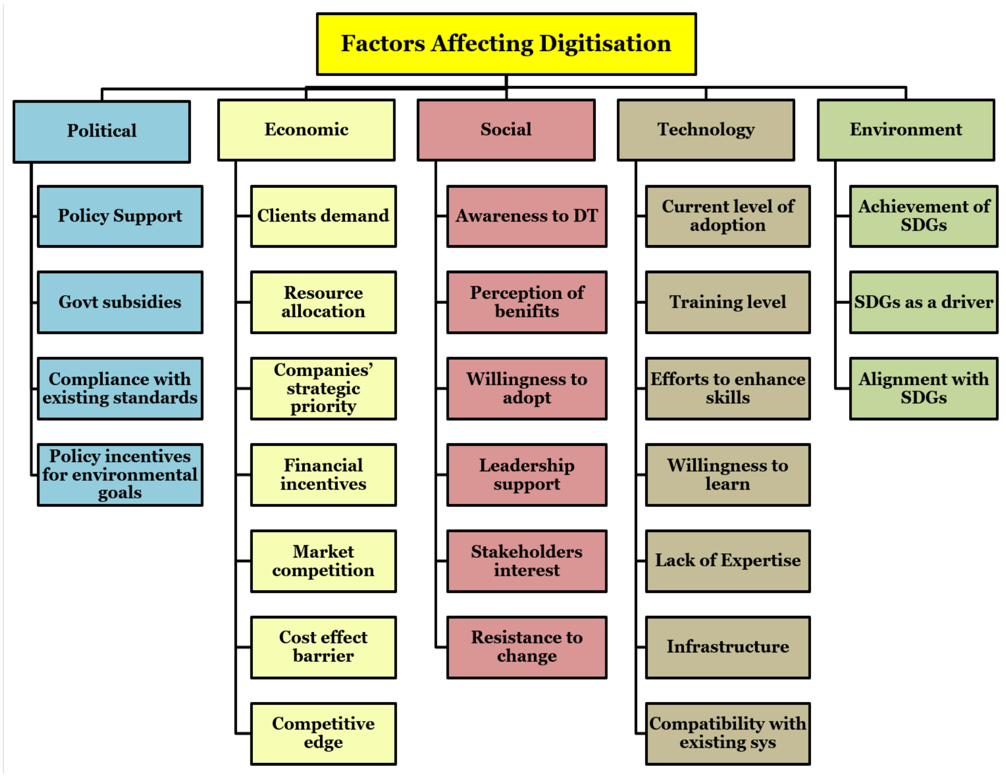

FIGURE 4.4: Hierarchical structure of factors

4.9.2 Relative Importance Index

Data was gathered by a questionnaire survey using the five-point Likert scale. As previously stated, it is composed of five PESTEL components, each of which has been further divided into 27 sub-components. RII values were evaluated to identify the ranks and effect level. Each 5 factors RI value was determined by taking mean of subfactors of each portion.

Table 4.5 shows the results for political factors which indicate that policy support (RII = 0.603) is the most significant driver for fostering a digital ecosystem in Pakistan's construction sector. This highlights the need for government initiatives and frameworks that actively promote digitization. Policy incentives for environmental goals (RII = 0.587) also play a crucial role, reflecting the importance of aligning digitization efforts with sustainability objectives. Compliance with existing standards (RII = 0.554) ranks third, suggesting that adherence to current regulations is moderately influential but does not drive adoption as strongly as policy-related initiatives. Finally, government subsidies or incentives (RII = 0.494) rank the lowest, indicating that direct financial interventions are perceived as the least impactful political factor.

Table 4.4: Results for Political Factors

Factor	**Code**	**RII**	**Ranking**
Policy Support	P1	0.603	1
Policy Incentives for Environmental Goals	P4	0.587	2
Compliance with Existing Standards	P3	0.554	3
Government Subsidies or Incentives	P2	0.494	4
Average	-	0.56	-

The results for economic factors highlight that market competition due to digitization (RII = 0.768) is the most significant driver of digital ecosystem adoption in Pakistan's construction sector. This finding suggests that competitive pressures are compelling companies to embrace digitization to maintain relevance and gain a market edge. Similarly, clients' demand for digitization (RII = 0.730) and the pursuit of a competitive edge (RII = 0.711) are key motivators, reflecting the influence of external market forces and client expectations on digital transformation initiatives. Company's strategic priority (RII = 0.697) ranks fourth, emphasizing the internal prioritization of digitization by businesses. In contrast, cost-effect barriers (RII = 0.648) and resource allocation for digitization (RII = 0.549) indicate that financial constraints remain significant obstacles. The availability of financial incentives (RII = 0.530) ranks the lowest, underscoring a lack of supportive funding mechanisms to facilitate digital adoption.

The results for social factors indicate that perception of benefits (RII = 0.865) is the most influential factor driving the adoption of a digital ecosystem in Pakistan's construction sector. This finding underscores the importance of clearly communicating the tangible advantages of digitization to stakeholders. Stakeholders' lack of interest (RII = 0.773) ranks second, suggesting that overcoming apathy and engaging stakeholders effectively is critical for fostering adoption. Awareness of digital technology (RII = 0.722) ranks third, highlighting the role of knowledge

Table 4.5: Results for Economic Factors

Factor	**Code**	**RII**	**Ranking**
Market Competition Due to Digitization	E5	0.768	1
Clients' Demand for Digitization	E1	0.73	2
Competitive Edge as a Driver	E7	0.711	3
Company's Strategic Priority	E3	0.697	4
Cost Effect Barrier	E6	0.648	5
Resource Allocation for Digitization	E2	0.549	6
Availability of Financial Incentives	E4	0.53	7
Average	-	0.662	-

and education in driving digital transformation. Meanwhile, willingness for digitization (RII = 0.694) reflects moderate readiness to adopt digital solutions. Leadership support (RII = 0.641) and resistance to change (RII = 0.630) are ranked lower, indicating that while these are barriers, they are less significant compared to perception, awareness, and stakeholder engagement.

Table 4.6: Results for Social Factors

Factor	**Code**	**RII**	**Ranking**
Perception of Benefits	S2	0.865	1
Stakeholders' Lack of Interest	S5	0.773	2
Awareness of Digital Technology	S1	0.722	3
Willingness for Digitization	S3	0.694	4
Leadership Support	S4	0.641	5
Resistance to Change	S6	0.63	6
Average	-	0.721	-

The results for technological factors reveal that willingness to acquire digital skills (RII = 0.827) is the most significant enabler of digital ecosystem adoption in Pakistan's construction sector. This finding reflects a high level of readiness and interest among stakeholders to embrace digital transformation. Lack of expertise (RII = 0.771) ranks second, suggesting that while willingness exists, there is a notable skills gap that must be addressed through targeted interventions. Compatibility with existing systems (RII = 0.695) and the present level of training (RII = 0.665) are moderately influential, indicating that efforts to enhance system integration and provide training are essential for successful digitization. Lower-ranked factors include availability of infrastructure (RII = 0.610) and the present level of adoption (RII = 0.586), indicating that infrastructure readiness and current adoption rates are perceived as limiting factors. The least influential factor is efforts to enhance skillsets (RII = 0.513), highlighting a gap in structured initiatives to build digital competencies. The results for environmental factors highlight the critical

Table 4.7: Results for Technological Factors

Factor	**Code**	**RII**	**Ranking**
Willingness to Acquire Digital Skills	T4	0.827	1
Lack of Expertise	T5	0.771	2
Compatibility with Existing Systems	T7	0.695	3
Present Level of Training	T2	0.665	4
Availability of Infrastructure	T6	0.61	5
Present Level of Adoption	T1	0.586	6
Efforts to Enhance Skillsets	T3	0.513	7
Average	-	0.667	-

role of sustainability in fostering a digital ecosystem in Pakistan's construction sector. Achievement of Sustainable Development Goals (SDGs) (RII = 0.802) is identified as the most significant environmental driver, reflecting the strong alignment between digitization initiatives and broader sustainability objectives. This suggests that stakeholders recognize the value of digital technologies in contributing to environmental and social goals. Present alignment with SDGs (RII = 0.694) ranks second, indicating that while current practices contribute moderately to sustainability goals, there is significant room for improvement. SDGs as a driver (RII = 0.683) ranks third, suggesting that while SDGs are recognized as a motivating factor, they are not as influential as their practical achievement.

Table 4.8: Results for Environmental Factors

Factor	**Code**	**RII**	**Ranking**
Achievement of SDGs	EN1	0.802	1
Present Alignment with SDGs	EN3	0.694	2
SDGs as a Driver	EN2	0.683	3
Average	-	0.726	-

4.9.3 Summarised RII

The summarized results across all PESTE factors indicate that environmental factors (average RII = 0.726) are the most influential drivers for fostering a digital ecosystem in Pakistan's construction sector. This underscores the growing importance of aligning digital adoption with sustainability goals, particularly in achieving Sustainable Development Goals (SDGs). Social factors (average RII = 0.721) follow closely, highlighting the critical role of stakeholder awareness, perception of benefits, and engagement in driving adoption. Technological factors (average RII = 0.667) and economic factors (average RII = 0.662) are also significant but indicate areas where challenges such as skill gaps, infrastructure limitations, and financial constraints need to be addressed. Political factors (average RII = 0.560) rank the lowest, suggesting that policy interventions and government support are perceived as less influential in the current context.

Overall, the results emphasize that fostering a digital ecosystem requires a holistic approach. While environmental and social considerations are key motivators, addressing technological and economic barriers and enhancing political support will be critical to accelerating digital transformation in the construction sector.

Table 4.9: Summarized Overall Results for Each PESTE Factor

Category	**Average RII**	**Ranking**
Environmental	0.726	1
Social	0.721	2
Economic	0.662	3
Technological	0.667	4
Political	0.56	5

4.9.4 Pair-wise Comparison Matrix

Following the achievement of the (RII) values for each component and sub-factor, the native masses of each factor and sub-factor were determined. The pair-wise comparison matrix was then built , Table 4.10 displays the local weights of each factor and subfactor:

Environmental factors (0.23) and social factors (0.22) contribute the most to fostering a digital ecosystem in Pakistan's construction sector. Their significant influence reflects the importance of sustainability goals and societal perceptions. Technological (0.19) and economic factors (0.19) are equally influential, indicating a need to address infrastructure and financial barriers. Political factors (0.17) have

Table 4.10: Local Weights

Factor	**Weight**	**Indicator**	**Local Weight**
Political	0.1677791	P1	0.2695
		P2	0.2206
		P3	0.2475
		P4	0.2624
Economic	0.1984682	E1	0.1576
		E2	0.1185
		E3	0.1504
		E4	0.1144
		E5	0.1658
		E6	0.1398
		E7	0.1535
Social	0.2161693	S1	0.167
		S2	0.2
		S3	0.1604
		S4	0.1483
		S5	0.1787
		S6	0.1457
Technical	0.199907	T1	0.126
		T2	0.143
		T3	0.11
		T4	0.177
		T5	0.165
		T6	0.131
		T7	0.149
Environment	0.2176765	E1	0.368
		E2	0.313
		E3	0.319

the least weight, highlighting a lower perceived impact of government policies and incentives.

4.9.5 Consistency

After collecting the local weights, it was crucial to verify the consistency of the pair-wise comparisons matrix. The number of criteria was the same as the greatest eigenvalue of the comparison matrix. Although a 10% or less inconsistency ratio is generally seen as desirable, certain circumstances may call for the acceptance or approval of a greater amount. Table 4.11 displays the λ max computation for each criterion and index.

TABLE 4.11: λ_{max} for each criterion and index

	λ_{max}	**CI**	**CR**	**Consistency**
P	5	0	0	Yes
E	7	0	0	Yes
S	6	0	0	Yes
T	7	0	0	Yes
EN	3	0	0	Yes

The consistency analysis for the PESTE factors reveals that all pairwise comparisons exhibit high consistency, as evidenced by the Consistency Ratio (CR) values being well below the threshold of 0.1 for all factors. The calculated λ max values align with the number of sub-factors in each category, confirming the internal consistency of the comparison matrices. The consistency analysis for the PESTE factors reveals that all pairwise comparisons exhibit high consistency, as evidenced by the Consistency Ratio (CR) values being well below the threshold of 0.1 for all factors. The calculated λ_{max} values align with the number of sub-factors in each category, confirming the internal consistency of the comparison matrices.

4.10 Framework Evaluation Method

The Fuzzy Comprehensive Evaluation Method (FCEM) is a quantitative tool that incorporates fuzzy logic to evaluate complex systems or frameworks. This method is particularly useful when dealing with subjective judgments and uncertain data, such as stakeholder opinions or qualitative criteria. Fuzzy mathematics' membership degree theory serves as the foundation for the fuzzy comprehensive evaluation method (FCEM). Before constructing the first level fuzzy relation matrix R, ascertain the factor set "u" and deciding or assessment grade "v".

4.10.1 First Level FCEM

Using the membership grade [Rij = n / N] and incidence-based in the first level complete evaluation matrix, the R was created. The membership grade idea in fuzzy mathematics serves as the cornerstone of the fuzzy comprehensive evaluation method . When applied in tandem with the professional grading system, FCEM closely considers the evaluation criteria and generates outcomes that are true to life. The membership matrix Bi was obtained by multiplying each factor of the fuzzy relation matrix R by the local weight of each sub-criteria, which was established using the analytic hierarchy approach.

The data presents a breakdown of factors and their relative influences within a fuzzy relationship matrix. Each PESTE factor (Political, Economic, Social, Technological, Environmental) is associated with sub-factors, each scored by respondents on a scale from 1 to 5. These scores are converted into relative importance indices (RIIs), probability values, and local weights. Using these components, the first-level comprehensive fuzzy equation (Bi_ii) is calculated for each sub-factor.

The Bi_ii values represent the first-level fuzzy comprehensive evaluation scores for each sub-factor under the Political dimension. These values reflect how responses are distributed across the five categories (from 5 = Very Important to 1 = Not Important). Policy Support (P1) and Compliance with Existing Standards (P3) both show relatively balanced scores, with a moderate concentration in 3 and 4 response categories. This indicates that while these factors are seen as important, stakeholders do not perceive them as overwhelmingly influential. Government Subsidies/Incentives (P2) has a noticeable increase in 1 responses (Bi_ii = 0.077), suggesting that stakeholders are more skeptical about the impact of financial incentives, perhaps viewing them as less effective compared to other political measures. Policy Incentives for Environmental Goals (P4) stands out with higher values in the 3 (Bi_ii = 0.100) and 4 (Bi_ii = 0.050) response categories. This indicates that aligning digital policies with environmental goals is seen as a promising but not dominant driver.

The Bi_ii values for the Economic factor reveal varying levels of importance placed on different economic drivers. Client Demand (E1) and Market Competition (E5) stand out with relatively higher scores for "4" (Bi_ii = 0.073 for E1, Bi_ii = 0.057 for E5) and "5" (Bi_ii = 0.016 for E1, Bi_ii = 0.049 for E5) responses. This indicates that external pressures such as customer expectations and competitive dynamics are seen as strong motivators for digitization. Resource Allocation (E2) and Financial Incentives (E4) have more moderate scores across the board, with noticeable values in "3" (Bi_ii = 0.042 for E2, Bi_ii = 0.027 for E4) and "2" (Bi_ii = 0.033 for both), suggesting stakeholders view these factors as relevant but not

TABLE 4.12: Bi_ii Values for Political Factor and Sub-Factors

Sub-Factor	**Bi_ii for "5" Responses**	**Bi_ii for "4" Responses**	**Bi_ii for "3" Responses**	**Bi_ii for "2" Responses**	**Bi_ii for "1" Responses**
Policy Support (P1)	0.006	0.103	0.088	0.034	0.039
Govt Subsidies/Incentives (P2)	0.007	0.06	0.04	0.037	0.077
Compliance with Standards (P3)	0.01	0.047	0.1	0.057	0.033
Policy Incentives (P4)	0.023	0.05	0.1	0.067	0.023

overwhelmingly influential. Company Strategy (E3) and Competitive Edge (E7) show moderate importance as well, reflecting a balanced perception of internal organizational priorities and the value of staying ahead in the market. Cost Barrier (E6) shows a relatively even distribution across "3" (Bi_ii = 0.052), "4" (Bi_ii = 0.044), and "5" (Bi_ii = 0.012) categories. This indicates that while cost is a known barrier, it is not seen as insurmountable and is weighed similarly to other economic factors.

TABLE 4.13: Bi_ii Values for Economic Factor and Sub-Factors

Sub-Factor	**Bi_ii for "5" Responses**	**Bi_ii for "4" Responses**	**Bi_ii for "3" Responses**	**Bi_ii for "2" Responses**	**Bi_ii for "1" Responses**
Client Demand (E1)	0.016	0.073	0.068	0	0.001
Resource Allocation (E2)	0.005	0.024	0.042	0.033	0.015
Company Strategy (E3)	0.016	0.068	0.044	0.019	0.004
Financial Incentives (E4)	0.004	0.029	0.027	0.033	0.022
Market Competition (E5)	0.049	0.057	0.049	0.005	0.005
Cost Barrier (E6)	0.012	0.044	0.052	0.027	0.004

The Bi_ii values for the Social factor demonstrate varying degrees of importance placed on each sub-factor. Perception of Benefits (S2) shows the strongest influence, with the highest scores for "5" (Bi_ii = 0.098) and "4" (Bi_ii = 0.081) responses. This suggests that stakeholders clearly recognize the advantages of digitization and see it as a significant motivator. Stakeholders' Lack of Interest (S5) also has relatively high scores in "5" (Bi_ii = 0.035) and "4" (Bi_ii = 0.094) responses, indicating that overcoming disengagement is crucial for driving adoption. Awareness of Digital Technology (S1) and Willingness for Digitization (S3) receive moderate values, reflecting a need for further promotion and support to raise awareness and readiness. Leadership Support (S4) and Resistance to Change (S6) show lower scores overall, but still indicate that leadership buy-in and resistance are areas that need attention. Resistance to change, while not the most critical barrier, still requires strategic interventions to ensure smooth transitions.

TABLE 4.14: Bi_ii Values for Social Factor and Sub-Factors

Sub-Factor	**Bi_ii for "5" Responses**	**Bi_ii for "4" Responses**	**Bi_ii for "3" Responses**	**Bi_ii for "2" Responses**	**Bi_ii for "1" Responses**
Awareness of Digital Tech (S1)	0.016	0.098	0.033	0.012	0.008
Perception of Benefits (S2)	0.098	0.081	0.014	0	0.006
Willingness for Digitization (S3)	0.013	0.079	0.045	0.019	0.005
Leadership Support (S4)	0.019	0.036	0.058	0.027	0.008
Stakeholders' Lack of Interest (S5)	0.035	0.094	0.041	0.007	0.001
Resistance to Change (S6)	0.013	0.042	0.062	0.013	0.016

The Bi_ii values for the Technology factor show a diverse range of importance placed on various sub-factors. Willingness to Acquire Digital Skills (T4) stands out as a strong driver, with higher values for "5" (Bi_ii = 0.077) and "4" (Bi_ii = 0.055) responses. This indicates that stakeholders are ready and motivated to build digital competencies. Lack of Expertise (T5) also emerges as an influential factor, with a high "4" score (Bi_ii = 0.100). This highlights that addressing skill gaps is perceived as critical to advancing technological adoption. Present Level of Training (T2) and Compatibility with Existing Systems (T7) show moderate importance, with noticeable "4" (Bi_ii = 0.061 for T2, 0.072 for T7) and "3" (Bi_ii = 0.049 for T2, 0.052 for T7) scores. These results suggest that while training and compatibility are important, they are not seen as the primary barriers. Efforts to Enhance Skillsets (T3) and Availability of Infrastructure (T6) receive relatively lower scores, suggesting these factors are not as pressing, though still relevant. Present Level of Adoption (T1) has the lowest overall scores, indicating that current adoption levels are seen more as a baseline than as a significant influence on future actions.

TABLE 4.15: Bi_ii Values for Technology Factor and Sub-Factors

Sub-Factor	**Bi_ii for "5" Responses**	**Bi_ii for "4" Responses**	**Bi_ii for "3" Responses**	**Bi_ii for "2" Responses**	**Bi_ii for "1" Responses**
Present Level of Adoption (T1)	0.014	0.025	0.039	0.034	0.014
Present Level of Training (T2)	0.007	0.061	0.049	0.024	0.002
Efforts to Enhance Skillsets (T3)	0.004	0.017	0.037	0.031	0.021
Willingness to Acquire Digital Skills (T4)	0.077	0.055	0.039	0.003	0.003
Lack of Expertise (T5)	0.028	0.1	0.028	0.008	0.003
Availability of Infrastructure (T6)	0.01	0.033	0.051	0.025	0.011
Compatibility with Existing Systems (T7)	0.009	0.072	0.052	0.011	0.005

The Bi_ii values for the Environmental factor indicate that stakeholders place a relatively high importance on achieving Sustainable Development Goals (SDGs) as a motivator for fostering digitization. Achievement of SDGs (EN1) is seen as the most influential, with the highest values for "5" (Bi_ii = 0.102) and "4" (Bi_ii = 0.187). This demonstrates that aligning digital adoption efforts with broader sustainability goals is a top priority. SDGs as a Driver (EN2) shows a moderate distribution across "3" (Bi_ii = 0.127), "4" (Bi_ii = 0.122), and "5" (Bi_ii = 0.027) responses. While still important, it is not as dominant as the direct achievement of SDGs. Present Alignment with SDGs (EN3) has the highest value for "3" (Bi_ii = 0.134) responses, indicating that stakeholders acknowledge the need for better alignment but do not yet view current practices as a strong driver of digital ecosystem adoption.

TABLE 4.16: Bi_ii Values for Environmental Factor and Sub-Factors

Sub-Factor	**Bi_ii for "5" Responses**	**Bi_ii for "4" Responses**	**Bi_ii for "3" Responses**	**Bi_ii for "2" Responses**	**Bi_ii for "1" Responses**
Achievement of SDGs (EN1)	0.102	0.187	0.064	0.009	0.006
SDGs as a Driver (EN2)	0.027	0.122	0.127	0.027	0.01
Present Alignment with SDGs (EN3)	0.068	0.073	0.134	0.025	0.018

4.10.2 Second Level Fuzzy Comprehensive Evaluation Matrix

The factor's native weight was multiplied by R' to generate the FCEM. The R' of every remark is represented by the full evaluation matrix Bi. To assess variables without distinct bounds, the evaluation approach applies the synthesis theory of fuzzy relations. It provides a detailed goal identification within the framework of several elements. Following the acquisition of the first level fuzzy comprehensive assessment matrix, (R0) i.e Second-level fuzzy relation matrix was created and is displayed in the table 4.17.

The second level fuzzy comprehensive evaluation matrix B was produced by multiplying the local weight of the criteria layer components as determined by AHP by the second level fuzzy relation matrix (Ro). It is shown in table below. The second level fuzzy relationship matrix confirms that environmental and social factors are seen as the most important dimensions driving the adoption of a digital ecosystem in Pakistan's construction sector. In contrast, political and economic

TABLE 4.17: Results from the Second-Level Fuzzy Relationship Matrix

PESTE Factor	Frequency of "5" Responses	Frequency of "4" Responses	Frequency of "3" Responses	Frequency of "2" Responses	Frequency of "1" Responses	Local Weight	Rank
Political (P)	0.046	0.259	0.328	0.195	0.172	0.168	5
Economic (E)	0.111	0.375	0.334	0.126	0.054	0.198	4
Social (S)	0.194	0.43	0.253	0.078	0.045	0.216	2
Technological (T)	0.15	0.362	0.294	0.135	0.059	0.2	3
Environmental (EN)	0.198	0.382	0.325	0.061	0.033	0.218	1

factors carry relatively lower weights, reflecting their secondary role in stakeholder considerations. This ranking emphasizes the need for strategies that align technological advancements and financial incentives with sustainability goals and societal engagement.

TABLE 4.18: Results for Second-Level Fuzzy Comprehensive Evaluation Matrix

PESTE Factor	Bi_ii for "5" Responses	Bi_ii for "4" Responses	Bi_ii for "3" Responses	Bi_ii for "2" Responses	Bi_ii for "1" Responses
Political (P)	0.008	0.044	0.055	0.033	0.029
Economic (E)	0.022	0.074	0.066	0.025	0.011
Social (S)	0.042	0.093	0.055	0.017	0.01
Technological (T)	0.03	0.072	0.059	0.027	0.012
Environmental (EN)	0.043	0.083	0.071	0.013	0.007
Total (B Value)	0.145	0.366	0.306	0.115	0.068

The second-level fuzzy comprehensive evaluation matrix provides the Bi_ii values for each PESTE factor based on stakeholder responses across five categories. These values represent the weighted impact of each factor at this level of analysis.

- **Highest Weight Categories:** The majority of the responses were in 4 and 5 category, with the "4" responses (0.366) carry the most weight overall, indicating that stakeholders largely see the factors as important but not necessarily critical. This aligns with previous findings where most factors were considered moderately to highly influential.

- **Lower Weight Categories:** The "1" (0.068) and "2" (0.115) responses carry the least weight, showing that relatively few respondents perceive the PESTE factors as unimportant. This confirms that all factors hold some relevance in driving digital ecosystem adoption.
- **Environmental (EN) and Social (S) Factors:** These two factors have higher contributions in "5" and "4" response categories compared to other factors, reinforcing their importance in the digital transformation landscape. Their combined high scores reflect a consensus on the significance of sustainability and societal considerations.

4.11 Summary

This chapter provides a detailed analysis of the findings and discussion. A summary was provided of the respondents' demographics and response rate. The present study employed three distinct tests to evaluate the dependability and perception levels of the participants: the statistical data reliability test, the normalcy test, and the Kruskal Wallis test. For ease of comprehension, each identified factor was referenced together with a code. The construction industry's digitisation factors were arranged in this chapter using an analytical hierarchy technique to evaluate each factor's relative importance in resolving the main issue. Thus, grade level was assessed for the project utilizing the AHP-FCE approach. This contributed to the development of the hierarchical framework.

Chapter 5

Conclusions and Recommendations

5.1 Conclusions of the Study

This study's primary goal was to examine the factors influencing adoption of digital technologies and fostering a digital ecosystem in Pakistan's construction sector. The identified factors were categorized into five PESTEL dimensions i.e., Political, Economic, Social, Technological & Environmental and further analyzed using statistical techniques such as the Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation Method (FCEM). Data was collected from 126 respondents, yielding an exceptional response rate of 78.18%, surpassing the threshold of 70% recommended by Ashley and Boyd for reliability. The reliability of the survey was also confirmed using Cronbach's Alpha, which produced a value of 0.839, indicating a high level of internal consistency. The mean scores of variables ranged from 2.47 (Government subsidies or incentives) to 4.33 (Perception of benefits), reflecting varying levels of agreement among respondents. Environmental factors had the highest average RII (0.726), followed by Social (0.721), Technological (0.667), Economic (0.662), and Political (0.560), highlighting the importance of sustainability and stakeholder engagement in driving digital transformation. The average Relative Importance Index (RII) values highlight the following:

1. **Environmental Factors (Average RII = 0.726):** These factors emerged as the most significant, with the "Achievement of Sustainable Development

Goals (SDGs)" scoring the highest RII (0.802). This indicates strong alignment between digital adoption and sustainability objectives.

2. **Social Factors (Average RII = 0.721):** Key social drivers include "Perception of Benefits" (RII = 0.865) and "Stakeholders' Lack of Interest" (RII = 0.773), emphasizing the importance of effectively communicating the advantages of digital transformation and engaging stakeholders.

3. **Technological Factors (Average RII = 0.667):** "Willingness to Acquire Digital Skills" (RII = 0.827) reflects stakeholders' readiness to embrace change, while "Lack of Expertise" (RII = 0.771) highlights the need for skill development programs.

4. **Economic Factors (Average RII = 0.662):** Market dynamics, such as "Market Competition Due to Digitization" (RII = 0.768) and "Clients' Demand for Digitization" (RII = 0.730), are critical motivators, although "Resource Allocation for Digitization" (RII = 0.549) and "Availability of Financial Incentives" (RII = 0.530) remain challenges.

5. **Political Factors (Average RII = 0.560):** "Policy Support" (RII = 0.603) and "Policy Incentives for Environmental Goals" (RII = 0.587) were the top political drivers, underscoring the role of government frameworks in fostering digitization.

The statistical tools employed ensured robust findings. The Kolmogorov-Smirnov and Shapiro-Wilk tests confirmed non-normal data distribution, necessitating non-parametric methods such as the Kruskal-Wallis test. These tests revealed significant differences in perceptions based on education levels, experience, and organizational types, particularly regarding policy incentives, client demand, and alignment with SDGs.

The study's hierarchical and fuzzy evaluation frameworks ranked environmental and social dimensions as the most impactful drivers of digital transformation, with political and economic factors playing supplementary roles. These insights suggest that targeted strategies, such as enhancing sustainability integration, engaging stakeholders, bridging skill gaps, and providing financial incentives, are critical for fostering a comprehensive digital ecosystem in Pakistan's construction sector.

These findings are visualized in the summarized RII table:

TABLE 5.1: Summarized RII table

Category	**Average RII**	**Ranking**
Environmental	0.726	1
Social	0.721	2
Technological	0.667	3
Economic	0.662	4
Political	0.56	5

5.2 Recommendations - Framework for Fostering a Digital Ecosystem in Pakistan's Construction Sector

Keeping in view the findings of this study, a framework is proposed which outlines actionable recommendations across five dimensions of PESTEL analysis. Each dimension is supported by targeted strategies to overcome barriers and leverage opportunities for digital transformation. The framework describing key strategies and expected outcomes is illustrated in figure 5.1.

5.2.1 Policy and Governance (Political)

- A federal level committee should be formed under auspices of Pakistan Engineering Council (PEC) to develop and implement comprehensive digitalization policies that align with sustainability objectives (e.g., policy incentives for environmental goals; RII = 0.587).
- Ministry of finance should aim to increase government subsidies, tax rebates, and low-interest loans to encourage investment in digital technologies (RII = 0.494).
- Pakistan Standards and Quality Control Authority (PSQCA) should establish national standards and compliance mechanisms for digital technologies to ensure uniformity and quality control (RII = 0.554).

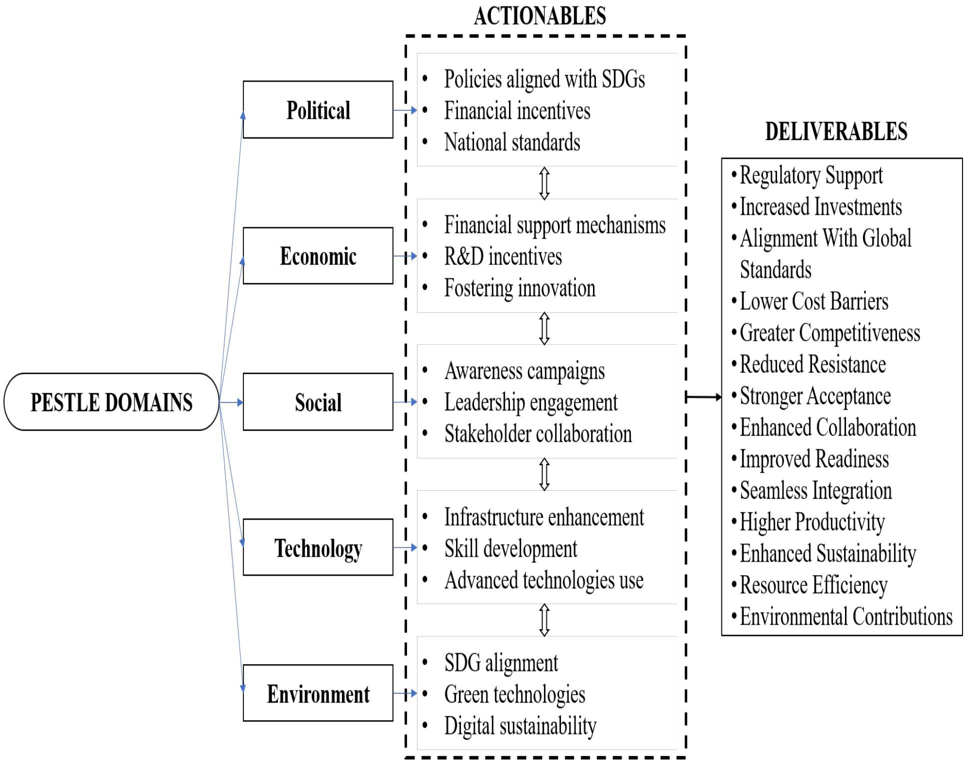

FIGURE 5.1: Framework for Fostering Digital Ecosystem in Pakistan's Construction

5.2.2 Stakeholder Engagement (Social)

- National and Provincial Building Control Authorities should launch awareness campaigns through electronic, print and social media to highlight the benefits of digital adoption and address resistance to change.

- National Higher Educational as well as Vocational Education policy should encompass measures so as to build leadership capacity to advocate for digital transformation within organizations (RII = 0.641). SECP can also play its role in this regard.

- One window forumns should be launched to facilitate stakeholders to share success stories and best practices, fostering collaboration. In this regards, Expo or seminars should be regularly conducted country wide.

5.2.3 Technological Advancement (Technological)

- Enhance digital infrastructure and ensure compatibility of new technologies with existing systems (RII = 0.695).

- Focus of skill development by TEVTA should incorporate digital skillsets in construction industry apart from other fields and formulate a comprehensive program to close the expertise gap.
- Promote the adoption of cutting-edge technologies, including Building Information Modeling (BIM), IoT, and digital twins, to improve project management and efficiency.

5.2.4 Economic Incentives (Economic)

- National Economic Council should formulate strategy to provide financial support mechanisms, such as grants and subsidies, to offset high implementation costs as well as import subsidies in digital construction tools.
- Promote competitive advantages through market-driven innovation and digital adoption (RII = 0.768).
- Incentivize firms to allocate resources for research and development in digital technologies (RII = 0.549).

5.2.5 Sustainability Integration (Environmental)

- National & Provincial Building Control Authorities should implement strict measure to align all construction with Sustainable Development Goals through digital initiatives.
- Promotion of environmentally friendly practices, such as 3D printing and prefabrication, to reduce waste and enhance energy efficiency can not be understated specially under the prevailing climate change threats.
- Integrate digital technologies to improve resource management and urban planning for sustainable construction.

5.3 Future Recommendations

Overall, this research highlights the multifaceted nature of digital ecosystem adoption and provides a foundation for strategic interventions tailored to Pakistan's unique construction landscape. Future efforts should prioritize aligning initiatives with sustainability goals, enhancing stakeholder engagement, and addressing technological and financial barriers to drive industry-wide digital transformation. Future efforts should focus on finding how digital initiatives in construction can be aligned with sustainability goals, how can digital technologies enhance stakeholder engagement in Pakistans construction sector to ease dispute resolution, how value management be achieved through digital transformation in construction, how digital technologies can improve the contract management in Pakistan and how can country wise digital transformation be achieved in highway and infrastructure projects of Pakistan.

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Appendix-1: Shortlisted Factors

Appendix-1

Inclusion Status through Delphi Method for Initial 41 Factors

Ser	Factors	Inclusion Status							
		1	2	3	4	5	6	7	Total
1.	Policy support for digitization		✓	✓	✓		✓	✓	5
2.	Govt Subsidies & Incentives	✓		✓			✓	✓	4
3.	Existing standards & regulations	✓		✓	✓	✓	✓	✓	6
4.	Clients Demand for Digitization	✓		✓	✓	✓	✓		5
5.	Resource Allocation for digitization	✓		✓	✓	✓	✓	✓	6
6.	Companies' Strategic Priority	✓		✓	✓	✓	✓		5
7.	Availability of Financial Incentives			✓	✓		✓	✓	4
8.	Market Competition due to digitization		✓		✓	✓	✓	✓	5
9.	Cost Effect Barrier		✓	✓	✓		✓	✓	5
10.	Competitive Edge as a drivers for digitization				✓	✓	✓		3
11.	Awareness with Digitization in Construction		✓	✓	✓	✓	✓		5
12.	Perception of positive outcomes of digitization		✓	✓	✓			✓	4
13.	Willingness towards Technology Adoption		✓	✓	✓		✓		4
14.	Leadership Support				✓	✓	✓	✓	4
15.	Stakeholders interest	✓	✓	✓	✓		✓	✓	6
16.	Resistance to Change	✓	✓	✓	✓			✓	5
17.	Present Level of Adoption	✓	✓	✓	✓	✓	✓		6
18.	Present Level of Training		✓	✓			✓	✓	4
19.	Efforts to enhance skillsets	✓	✓					✓	3
20.	Willingness to acquire digital skills	✓	✓		✓	✓			4
21.	Lack of expertise		✓	✓	✓	✓	✓	✓	6
22.	Availability of requisite infrastructure	✓	✓	✓	✓	✓	✓		6
23.	compatibility of digital tools with existing systems	✓	✓	✓	✓	✓			5
24.	Perception of achievement of sustainability goals			✓	✓	✓		✓	4
25.	sustainability being a driver for adoption		✓						1
26.	Present alignment with sustainability goals				✓		✓	✓	3
27.	Public-Private Collaboration			✓	✓				2
28.	Cost and Financial Considerations		✓		✓		✓	✓	4

29.	Return on Investment and Cost Effectiveness		✓		✓		✓	✓	4
30.	Technological Infrastructure and Readiness		✓			✓			2
31.	Environmental and Sustainability Factors	✓	✓		✓			✓	4
32.	Security and Legal Concerns			✓					1
33.	Market and Competition						✓		1
34.	Technological Challenges and Complexity		✓						1
35.	Regulatory and Compliance Issues		✓					✓	2
36.	Project Complexity			✓		✓		✓	3
37.	HR and Organizational Support		✓						1
38.	Industry Factors and Induced Barriers		✓					✓	2
39.	Client Cooperation Challenges	✓		✓					2
40.	Technological Fusion and Integration	✓						✓	2
41.	Process Optimization			✓				✓	2

SHORLISTED 27 FACTORS CATEGORISED INTO PESTEL FRAMEWORK

	POLITICAL
1.	Policy support for digitization
2.	Govt Subsidies & Incentives
3.	Existing standards & regulations
4.	Policy incentives for sustainability goals
	ECONOMIC
1.	Clients Demand for Digitization
2.	Resource Allocation for digitization
3.	Companies' Strategic Priority
4.	Availability of Financial Incentives
5.	Market Competition due to digitization
6.	Cost Effect Barrier
7.	Competitive Edge as a drivers for digitization
	SOCIAL
1.	Awareness with Digitization in Construction
2.	Perception of positive outcomes of digitization
3.	Willingness towards Technology Adoption
4.	Leadership Support
5.	Stakeholders interest
6.	Resistance to Change
	TECHNOLOGY
1.	Present Level of Adoption
2.	Present Level of Training
3.	Efforts to enhance skillsets
4.	Willingness to acquire digital skills
5.	Lack of expertise
6.	Availability of requisite infrastructure

7.	compatibility of digital tools with existing systems
	ENVIRONMENT
8.	Perception of achievement of sustainability goals
9.	sustainability being a driver for adoption
10.	Present alignment with sustainability goals

Appendix-2: Questionnaire

Appendix 2

QUESTIONNAIRES

Question	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**
Demographics					
What is your level of education?	Masters	Bachelors	PhD	Diploma Holder	
State the number of years of experience you have in the construction industry?	0-5	6-10	11-15	16-20	20+
What is the Type of your current organization?	Client	Contractor	Consultant	Supervisor	Other
State your position in the organization?	Construction/ Project Manager	Site Engineer	Other	Planning Engineer	Resident Engineer
Type of projects currently being under taken by your organization?	Infrastructural	Residential	Non-Residential	Social Amenities	Other

POLITICAL					
Do you think there's adequate policy support and incentives for technology innovation in Islamabad?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Are you aware of any subsidies or incentives for digital technology implementation?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Does compliance with status quo standards & regulations hinder the adoption of digital technologies?	Never	Rarely	Sometimes	Often	Always
Are there government incentives for using digital technologies to meet environmental goals?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

ECONOMIC					
How frequently do clients demand or prefer firms that utilize advanced digital technologies in their projects?	Never	Rarely	Sometimes	Often	Always
Does your management allocate sufficient resources for digital tools?	Never	Rarely	Sometimes	Often	Always

Are digital technologies a strategic priority in your organization's long-term goals?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Are there financial incentives available for using digital tools in your projects?	Never	Rarely	Occasionally	Often	Frequently
How would you rate the role of digital technologies in enhancing market competitiveness? *(Scale: 1 = Minimal, 5 = Significant)*	1	2	3	4	5
How often do budget constraints delay technology adoption?	Never	Rarely	Occasionally	Often	Frequently
Do competitors' use of digital tools influence your organization's adoption strategies?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

SOCIAL					
Are you familiar with various digital technologies in construction industry like BIM, drones, PM softwares?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Do you think digital technologies can enhance the construction efficiency in your organisation?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Does your company actively promote digital technology adoption?	Never	Rarely	Occasionally	Often	Frequently
How supportive is the leadership in implementing new technologies?	1	2	3	4	5
Do you think there is a lack of interest among project stakeholders towards adoption of digital tools?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Do you encounter resistance from employees during the implementation of digital tools?	Never	Rarely	Occasionally	Often	Frequently

TECHNOLOGY					
What is the level of adoption of digital technologies in your organisation?	1	2	3	4	5
Do employees have adequate technical skills for technology adoption?	Not at all	To a small extent	To a moderate extent	To a large extent	To a very large extent
Does your organization provide workshops or training sessions for new technologies?	Never	Rarely	Occasionally	Often	Frequently
How willing are you to learn new digital tools?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Do you believe a lack of technical expertise hinders technology adoption?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Is your organization equipped with the necessary infrastructure for digital technologies adoption?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Are the available digital tools compatible with your current systems?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

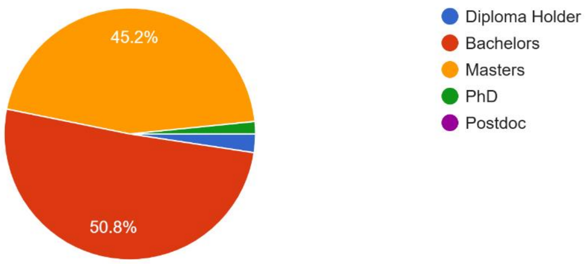
ENVIRONMENT					
Do you think digital technologies contribute significantly to achieving sustainability goals in your projects?	Not at all	To a small extent	To a moderate extent	To a large extent	To a very large extent
Are environmental considerations a driving factor for adopting digital tools?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
How would you rate the alignment of digital technologies with your sustainability objectives? (Scale: 1 = Poor, 5 = Excellent)	1	2	3	4	5

Appendix-3: Response Demographics

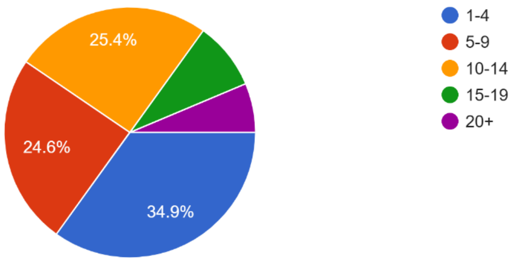
Appendix 3

Response demographics

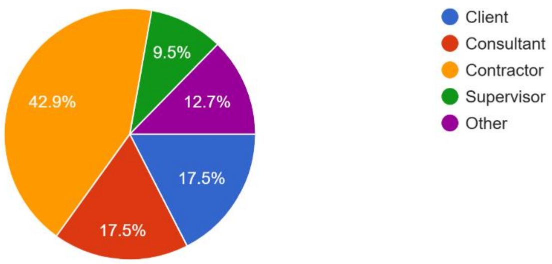
What is your level of education?
126 responses



State the number of years of experience you have in the construction industry?
126 responses

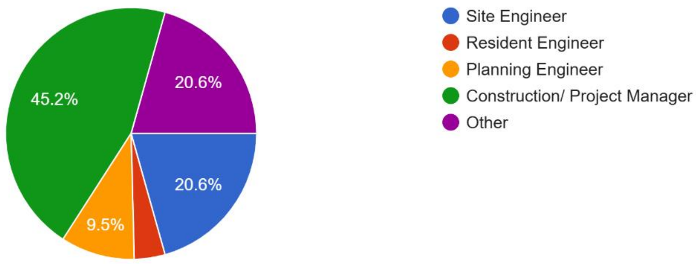


What is the Type of your current organization?
126 responses



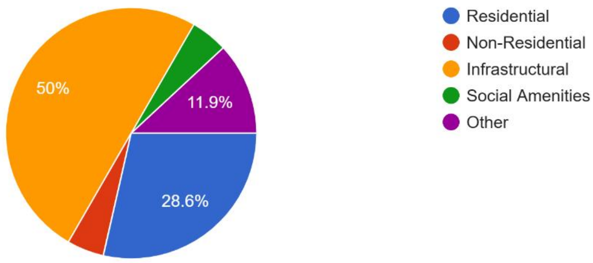
State your position in the organization?

126 responses



Type of projects currently being under taken by your organization?

126 responses



Appendix-4: Descriptive Statistics

APPENDIX 4

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
policy support	126	1	5	3.02	1.088
Govt subsidies or incentives	126	1	5	2.47	1.300
compliance with existing standards	126	1	5	2.77	1.037
Policy incentives for environmental goals	126	1	5	2.94	1.071
Clients demand for digitiation	126	1	5	3.65	0.696
Resource allocation for digitization	126	1	5	2.75	1.043
Companys strategic priority	126	1	5	3.48	0.927
Availability of financial incentives	126	1	5	2.65	1.148
Market competition due to digitisation	125	1	5	3.84	0.995
Cost Effect Barrier	126	1	5	3.24	0.967
Competitive edge as a driver	126	1	5	3.56	0.775
Awareness to digital tech	126	1	5	3.61	0.929
Perception of benefits	126	1	5	4.33	0.866
Willingness for Digitisation	126	1	5	3.47	0.918
leadership support	126	1	5	3.21	1.061
stakeholders lack of interest	126	1	5	3.87	0.804
resistance to change	126	1	5	3.15	1.074
Present level of adoption	126	1	5	2.93	1.167
Present Level of Training	126	1	5	3.33	0.866
Efforts to enhance skillsets	126	1	5	2.56	1.084
Willingness to acquire digital skills	126	1	5	4.13	0.924
lack of expertise	126	1	5	3.86	0.807
Availability of infrastructure	126	1	5	3.05	1.057
compatibility with existing systems	126	1	5	3.48	0.846
Achievement of SDGs	126	1	5	4.01	0.834
SDGs as a driver	126	1	5	3.41	0.888
Present alignment with SDGs	126	1	5	3.47	1.086
Valid N (listwise)	125				

Appendix-5: Normality and Reliability

Appendix 5

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
policy support	0.225	125	0.000	0.853	125	0.000
Govt subsidies or incentives	0.221	125	0.000	0.843	125	0.000
compliance with existing standards	0.224	125	0.000	0.905	125	0.000
Policy incentives for environmental goals	0.201	125	0.000	0.912	125	0.000
Clients demand for digitiation	0.259	125	0.000	0.794	125	0.000
Resource allocation for digitization	0.192	125	0.000	0.910	125	0.000
Companys strategic priority	0.264	125	0.000	0.879	125	0.000
Availability of financial incentives	0.192	125	0.000	0.896	125	0.000
Market competition due to digitisation	0.204	125	0.000	0.856	125	0.000
Cost Effect Barrier	0.195	125	0.000	0.904	125	0.000
Competitive edge as a driver	0.302	125	0.000	0.828	125	0.000
Awareness to digital tech	0.343	125	0.000	0.795	125	0.000
Perception of benefits	0.276	125	0.000	0.700	125	0.000
Willingness for Digitisation	0.288	125	0.000	0.857	125	0.000
leadership support	0.201	125	0.000	0.911	125	0.000
stakeholders lack of interest	0.287	125	0.000	0.846	125	0.000
resistance to change	0.244	125	0.000	0.884	125	0.000
Present level of adoption	0.170	125	0.000	0.915	125	0.000
Present Level of Training	0.256	125	0.000	0.868	125	0.000
Efforts to enhance skillsets	0.181	125	0.000	0.904	125	0.000
Willingness to acquire digital skills	0.263	125	0.000	0.804	125	0.000
lack of expertise	0.339	125	0.000	0.800	125	0.000
Availability of infrastructure	0.205	125	0.000	0.912	125	0.000
compatibility with existing systems	0.277	125	0.000	0.841	125	0.000
Achievement of SDGs	0.280	125	0.000	0.822	125	0.000
SDGs as a driver	0.219	125	0.000	0.876	125	0.000
Present alignment with SDGs	0.220	125	0.000	0.883	125	0.000

a. Lilliefors Significance Correction

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.839	0.837	27

Case Processing Summary

		N	%
Cases	Valid	125	99.2
	Excluded[a]	1	0.8
	Total	126	100.0

a. Listwise deletion based on all variables in the procedure.

Appendix-6: Kruskall Wallis Test

Appendix 6

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of policy support is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.103	Retain the null hypothesis.
2	The distribution of Govt subsidies or incentives is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.008	Reject the null hypothesis.
3	The distribution of compliance with existing standards is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.511	Retain the null hypothesis.
4	The distribution of Policy incentives for environmental goals is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.063	Retain the null hypothesis.
5	The distribution of Clients demand for digitiation is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.970	Retain the null hypothesis.
6	The distribution of Resource allocation for digitization is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.291	Retain the null hypothesis.
7	The distribution of Companys strategic priority is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.381	Retain the null hypothesis.
8	The distribution of Availability of financial incentives is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.646	Retain the null hypothesis.
9	The distribution of Market competition due to digitisation is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.035	Reject the null hypothesis.
10	The distribution of Cost Effect Barrier is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.858	Retain the null hypothesis.
11	The distribution of Competitive edge as a driver is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.608	Retain the null hypothesis.
12	The distribution of Awareness to digital tech is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.319	Retain the null hypothesis.
13	The distribution of Perception of benefits is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.581	Retain the null hypothesis.
14	The distribution of Willingness for Digitisation is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.248	Retain the null hypothesis.
15	The distribution of leadership support is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.752	Retain the null hypothesis.
16	The distribution of stakeholders lack of interest is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.649	Retain the null hypothesis.
17	The distribution of resistance to change is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.378	Retain the null hypothesis.
18	The distribution of Present level of adoption is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.195	Retain the null hypothesis.
19	The distribution of Present Level of Training is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.569	Retain the null hypothesis.
20	The distribution of Efforts to enhance skillsets is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.030	Reject the null hypothesis.
21	The distribution of Willingness to acquire digital skills is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.588	Retain the null hypothesis.
22	The distribution of lack of expertise is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.324	Retain the null hypothesis.
23	The distribution of Availability of infrastructure is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.417	Retain the null hypothesis.
24	The distribution of compatibility with existing systems is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.269	Retain the null hypothesis.
25	The distribution of Achievement of SDGs is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.519	Retain the null hypothesis.
26	The distribution of SDGs as a driver is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.217	Retain the null hypothesis.
27	The distribution of Present alignment with SDGs is the same across categories of experience.	Independent-Samples Kruskal-Wallis Test	.477	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of policy support is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.767	Retain the null hypothesis.
2	The distribution of Govt subsidies or incentives is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.409	Retain the null hypothesis.
3	The distribution of compliance with existing standards is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.425	Retain the null hypothesis.
4	The distribution of Policy incentives for environmental goals is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.133	Retain the null hypothesis.
5	The distribution of Clients demand for digitiation is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.610	Retain the null hypothesis.
6	The distribution of Resource allocation for digitization is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.148	Retain the null hypothesis.
7	The distribution of Companys strategic priority is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.688	Retain the null hypothesis.
8	The distribution of Availability of financial incentives is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.707	Retain the null hypothesis.
9	The distribution of Market competition due to digitisation is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.635	Retain the null hypothesis.
10	The distribution of Cost Effect Barrier is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.797	Retain the null hypothesis.
11	The distribution of Competitive edge as a driver is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.651	Retain the null hypothesis.
12	The distribution of Awareness to digital tech is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.625	Retain the null hypothesis.
13	The distribution of Perception of benefits is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.683	Retain the null hypothesis.
14	The distribution of Willingness for Digitisation is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.288	Retain the null hypothesis.
15	The distribution of leadership support is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.691	Retain the null hypothesis.
16	The distribution of stakeholders lack of interest is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.804	Retain the null hypothesis.
17	The distribution of resistance to change is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.012	Reject the null hypothesis.
18	The distribution of Present level of adoption is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.307	Retain the null hypothesis.
19	The distribution of Present Level of Training is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.393	Retain the null hypothesis.
20	The distribution of Efforts to enhance skillsets is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.114	Retain the null hypothesis.
21	The distribution of Willingness to acquire digital skills is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.310	Retain the null hypothesis.
22	The distribution of lack of expertise is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.574	Retain the null hypothesis.
23	The distribution of Availability of infrastructure is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.272	Retain the null hypothesis.
24	The distribution of compatibility with existing systems is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.467	Retain the null hypothesis.
25	The distribution of Achievement of SDGs is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.270	Retain the null hypothesis.
26	The distribution of SDGs as a driver is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.067	Retain the null hypothesis.
27	The distribution of Present alignment with SDGs is the same across categories of education.	Independent-Samples Kruskal-Wallis Test	.162	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of policy support is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.262	Retain the null hypothesis.
2	The distribution of Govt subsidies or incentives is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.004	Reject the null hypothesis.
3	The distribution of compliance with existing standards is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.274	Retain the null hypothesis.
4	The distribution of Policy incentives for environmental goals is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.002	Reject the null hypothesis.
5	The distribution of Clients demand for digitiation is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.984	Retain the null hypothesis.
6	The distribution of Resource allocation for digitization is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.156	Retain the null hypothesis.
7	The distribution of Companys strategic priority is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.013	Reject the null hypothesis.
8	The distribution of Availability of financial incentives is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.029	Reject the null hypothesis.
9	The distribution of Market competition due to digitisation is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.161	Retain the null hypothesis.
10	The distribution of Cost Effect Barrier is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.759	Retain the null hypothesis.
11	The distribution of Competitive edge as a driver is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.255	Retain the null hypothesis.
12	The distribution of Awareness to digital tech is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.613	Retain the null hypothesis.
13	The distribution of Perception of benefits is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.366	Retain the null hypothesis.
14	The distribution of Willingness for Digitisation is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.464	Retain the null hypothesis.
15	The distribution of leadership support is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.567	Retain the null hypothesis.
16	The distribution of stakeholders lack of interest is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.615	Retain the null hypothesis.
17	The distribution of resistance to change is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.718	Retain the null hypothesis.
18	The distribution of Present level of adoption is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.144	Retain the null hypothesis.
19	The distribution of Present Level of Training is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.193	Retain the null hypothesis.
20	The distribution of Efforts to enhance skillsets is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.285	Retain the null hypothesis.
21	The distribution of Willingness to acquire digital skills is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.750	Retain the null hypothesis.
22	The distribution of lack of expertise is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.014	Reject the null hypothesis.
23	The distribution of Availability of infrastructure is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.111	Retain the null hypothesis.
24	The distribution of compatibility with existing systems is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.018	Reject the null hypothesis.
25	The distribution of Achievement of SDGs is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.170	Retain the null hypothesis.
26	The distribution of SDGs as a driver is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.139	Retain the null hypothesis.
27	The distribution of Present alignment with SDGs is the same across categories of position.	Independent-Samples Kruskal-Wallis Test	.338	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of policy support is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.352	Retain the null hypothesis.
2	The distribution of Govt subsidies or incentives is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.383	Retain the null hypothesis.
3	The distribution of compliance with existing standards is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.155	Retain the null hypothesis.
4	The distribution of Policy incentives for environmental goals is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.493	Retain the null hypothesis.
5	The distribution of Clients demand for digitiation is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.493	Retain the null hypothesis.
6	The distribution of Resource allocation for digitization is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.365	Retain the null hypothesis.
7	The distribution of Companys strategic priority is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.529	Retain the null hypothesis.
8	The distribution of Availability of financial incentives is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.833	Retain the null hypothesis.
9	The distribution of Market competition due to digitisation is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.229	Retain the null hypothesis.
10	The distribution of Cost Effect Barrier is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.088	Retain the null hypothesis.
11	The distribution of Competitive edge as a driver is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.231	Retain the null hypothesis.
12	The distribution of Awareness to digital tech is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.010	Reject the null hypothesis.
13	The distribution of Perception of benefits is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.343	Retain the null hypothesis.
14	The distribution of Willingness for Digitisation is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.997	Retain the null hypothesis.
15	The distribution of leadership support is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.683	Retain the null hypothesis.
16	The distribution of stakeholders lack of interest is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.085	Retain the null hypothesis.
17	The distribution of resistance to change is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.586	Retain the null hypothesis.
18	The distribution of Present level of adoption is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.600	Retain the null hypothesis.
19	The distribution of Present Level of Training is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.373	Retain the null hypothesis.
20	The distribution of Efforts to enhance skillsets is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.358	Retain the null hypothesis.
21	The distribution of Willingness to acquire digital skills is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.817	Retain the null hypothesis.
22	The distribution of lack of expertise is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.052	Retain the null hypothesis.
23	The distribution of Availability of infrastructure is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.817	Retain the null hypothesis.
24	The distribution of compatibility with existing systems is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.667	Retain the null hypothesis.
25	The distribution of Achievement of SDGs is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.007	Reject the null hypothesis.
26	The distribution of SDGs as a driver is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.157	Retain the null hypothesis.
27	The distribution of Present alignment with SDGs is the same across categories of Type of projects.	Independent-Samples Kruskal-Wallis Test	.009	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of policy support is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.469	Retain the null hypothesis.
2	The distribution of Govt subsidies or incentives is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.550	Retain the null hypothesis.
3	The distribution of compliance with existing standards is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.522	Retain the null hypothesis.
4	The distribution of Policy incentives for environmental goals is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.743	Retain the null hypothesis.
5	The distribution of Clients demand for digitiation is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.866	Retain the null hypothesis.
6	The distribution of Resource allocation for digitization is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.394	Retain the null hypothesis.
7	The distribution of Companys strategic priority is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.063	Retain the null hypothesis.
8	The distribution of Availability of financial incentives is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.193	Retain the null hypothesis.
9	The distribution of Market competition due to digitisation is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.081	Retain the null hypothesis.
10	The distribution of Cost Effect Barrier is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.085	Retain the null hypothesis.
11	The distribution of Competitive edge as a driver is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.353	Retain the null hypothesis.
12	The distribution of Awareness to digital tech is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.082	Retain the null hypothesis.
13	The distribution of Perception of benefits is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.793	Retain the null hypothesis.
14	The distribution of Willingness for Digitisation is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.021	Reject the null hypothesis.
15	The distribution of leadership support is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.004	Reject the null hypothesis.
16	The distribution of stakeholders lack of interest is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.394	Retain the null hypothesis.
17	The distribution of resistance to change is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.955	Retain the null hypothesis.
18	The distribution of Present level of adoption is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.255	Retain the null hypothesis.
19	The distribution of Present Level of Training is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.256	Retain the null hypothesis.
20	The distribution of Efforts to enhance skillsets is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.581	Retain the null hypothesis.
21	The distribution of Willingness to acquire digital skills is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.165	Retain the null hypothesis.
22	The distribution of lack of expertise is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.492	Retain the null hypothesis.
23	The distribution of Availability of infrastructure is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.083	Retain the null hypothesis.
24	The distribution of compatibility with existing systems is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.254	Retain the null hypothesis.
25	The distribution of Achievement of SDGs is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.093	Retain the null hypothesis.
26	The distribution of SDGs as a driver is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.738	Retain the null hypothesis.
27	The distribution of Present alignment with SDGs is the same across categories of organization type.	Independent-Samples Kruskal-Wallis Test	.017	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Appendix-7: Relative Importance Index

Appendix 7

RELATIVE IMPORTANCE INDEX (RII)

PESTE Factor	Factors	Code	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Total respondents (N)	Weighted total	RII	Ranking
Political	policy support	P1	3	48	41	16	18	126	380	0.603	1
Political	Govt subsidies or incentives	P2	4	34	23	21	44	126	311	0.494	4
Political	compliance with existing standards	P3	5	24	51	29	17	126	349	0.554	3
Political	Policy incentives for environmental goals	P4	11	24	48	32	11	126	370	0.587	2
					Average					0.560	
ECONOMIC	Clients demand for digitiation	E1	13	58	54	0	1	126	460	0.730	2
ECONOMIC	Resource allocation for digitization	E2	5	25	45	35	16	126	346	0.549	6
ECONOMIC	Companys strategic priority	E3	13	57	37	16	3	126	439	0.697	4
ECONOMIC	Availability of financial incentives	E4	4	32	30	36	24	126	334	0.530	7
ECONOMIC	Market competition due to digitisation	E5	37	43	37	4	4	125	480	0.768	1
ECONOMIC	Cost Effect Barrier	E6	11	40	47	24	4	126	408	0.648	5
ECONOMIC	Competitive edge as a driver	E7	8	66	42	8	2	126	448	0.711	3
					Average					0.662	
SOCIAL	Awareness to digital tech	S1	12	74	25	9	6	126	455	0.722	3
SOCIAL	Perception of benefits	S2	62	51	9	0	4	126	545	0.865	1
SOCIAL	Willingness for Digitisation	S3	10	62	35	15	4	126	437	0.694	4
SOCIAL	leadership support	S4	16	31	49	23	7	126	404	0.641	5
SOCIAL	stakeholders lack of interest	S5	25	66	29	5	1	126	487	0.773	2
SOCIAL	resistance to change	S6	11	36	54	11	14	126	397	0.630	6
					Average					0.721	
TECHNOLOGY	Present level of adoption	T1	14	25	39	34	14	126	369	0.586	6
TECHNOLOGY	Present Level of Training	T2	6	54	43	21	2	126	419	0.665	4
TECHNOLOGY	Efforts to enhance skillsets	T3	5	19	42	36	24	126	323	0.513	7
TECHNOLOGY	Willingness to acquire digital skills	T4	55	39	28	2	2	126	521	0.827	1
TECHNOLOGY	lack of expertise	T5	21	76	21	6	2	126	486	0.771	2
TECHNOLOGY	Availability of infrastructure	T6	10	32	49	24	11	126	384	0.610	5
TECHNOLOGY	compatibility with existing systems	T7	8	61	44	9	4	126	438	0.695	3
					Average					0.667	
ENVIRONMENT	Achievement of SDGs	EN1	35	64	22	3	2	126	505	0.802	1
ENVIRONMENT	SDGs as a driver	EN2	11	49	51	11	4	126	430	0.683	3
ENVIRONMENT	Present alignment with SDGs	EN3	27	29	53	10	7	126	437	0.694	2
						Average				0.726	

Appendix-8: Pair Wise Comparative Evaluation Matrix

Appendix 8

PAIR WISE COPARATIVE EVALUATION MATRIX

		Alternatives				
		0.560	0.662	0.721	0.667	0.726
		P	E	S	T	EN
0.560	P	1	0.8453701	0.7761468	0.839285714	0.7707726
0.662	E	1.1829139	1	0.9181148	0.992802721	0.9117576
0.721	S	1.2884161	1.0891884	1	1.081349206	0.9930758
0.667	T	1.1914894	1.0072495	0.9247706	1	0.9183673
0.726	EN	1.2973995	1.0967827	1.0069725	1.088888889	1
	SUM	5.9602188	5.0385907	4.6260047	5.002326531	4.5939733

	Normalize Matrix (Alternatives)						
	P	E	S	T	EN	**AVG-Weight**	
P	0.16777907	0.1677791	0.1677791	0.1677791	0.167779074	**0.1677791**	5
E	0.1984682	0.1984682	0.1984682	0.1984682	0.198468196	**0.1984682**	4
S	0.21616926	0.2161693	0.2161693	0.2161693	0.216169256	**0.2161693**	2
T	0.19990698	0.199907	0.199907	0.199907	0.199906982	**0.199907**	3
EN	0.21767649	0.2176765	0.2176765	0.2176765	0.217676492	**0.2176765**	1
Weight	1	1	1	1	1		

	Weight	**Sum**	**Answer**	
P	0.1678	5.960	1	
E	0.1985	5.039	1	
S	0.2162	4.626	1	
T	0.1999	5.002	1	
EN	0.2177	4.594	1	
		λ max	5	
		CI	0.00	
		CR	0.0000	<0.1 OK

Appendix-9: Fuzzy Comprehensive Evaluation Matrix

Appendix 9

Fuzzy Comprehensive Evaluation Matrix

(R-1) First Level Fuzzy matrix (N*i*/N)					Probability	Local Weight	**First level*Local weight (R-1)**				
0.024	0.381	0.325	0.127	0.143	1.000	0.270	0.006	0.103	0.088	0.034	0.039
0.032	0.270	0.183	0.167	0.349	1.000	0.221	0.007	0.060	0.040	0.037	0.077
0.040	0.190	0.405	0.230	0.135	1.000	0.248	0.010	0.047	0.100	0.057	0.033
0.087	0.190	0.381	0.254	0.087	1.000	0.262	0.023	0.050	0.100	0.067	0.023
							0.046	0.259	0.328	0.195	0.172
0.103	0.460	0.429	0.000	0.008	1.000	0.158	0.016	0.073	0.068	0.000	0.001
0.040	0.198	0.357	0.278	0.127	1.000	0.119	0.005	0.024	0.042	0.033	0.015
0.103	0.452	0.294	0.127	0.024	1.000	0.150	0.016	0.068	0.044	0.019	0.004
0.032	0.254	0.238	0.286	0.190	1.000	0.114	0.004	0.029	0.027	0.033	0.022
0.296	0.344	0.296	0.032	0.032	1.000	0.166	0.049	0.057	0.049	0.005	0.005
0.087	0.317	0.373	0.190	0.032	1.000	0.140	0.012	0.044	0.052	0.027	0.004
0.063	0.524	0.333	0.063	0.016	1.000	0.153	0.010	0.080	0.051	0.010	0.002
							0.111	0.375	0.334	0.126	0.054
0.095	0.587	0.198	0.071	0.048	1.000	0.167	0.016	0.098	0.033	0.012	0.008
0.492	0.405	0.071	0.000	0.032	1.000	0.200	0.098	0.081	0.014	0.000	0.006
0.079	0.492	0.278	0.119	0.032	1.000	0.160	0.013	0.079	0.045	0.019	0.005
0.127	0.246	0.389	0.183	0.056	1.000	0.148	0.019	0.036	0.058	0.027	0.008
0.198	0.524	0.230	0.040	0.008	1.000	0.179	0.035	0.094	0.041	0.007	0.001
0.087	0.286	0.429	0.087	0.111	1.000	0.146	0.013	0.042	0.062	0.013	0.016
							0.194	0.430	0.253	0.078	0.045
0.111	0.198	0.310	0.270	0.111	1.000	0.126	0.014	0.025	0.039	0.034	0.014
0.048	0.429	0.341	0.167	0.016	1.000	0.143	0.007	0.061	0.049	0.024	0.002
0.040	0.151	0.333	0.286	0.190	1.000	0.110	0.004	0.017	0.037	0.031	0.021
0.437	0.310	0.222	0.016	0.016	1.000	0.177	0.077	0.055	0.039	0.003	0.003
0.167	0.603	0.167	0.048	0.016	1.000	0.165	0.028	0.100	0.028	0.008	0.003
0.079	0.254	0.389	0.190	0.087	1.000	0.131	0.010	0.033	0.051	0.025	0.011
0.063	0.484	0.349	0.071	0.032	1.000	0.149	0.009	0.072	0.052	0.011	0.005
							0.150	0.362	0.294	0.135	0.059
0.278	0.508	0.175	0.024	0.016	1.000	0.368	0.102	0.187	0.064	0.009	0.006
0.087	0.389	0.405	0.087	0.032	1.000	0.313	0.027	0.122	0.127	0.027	0.010
0.214	0.230	0.421	0.079	0.056	1.000	0.319	0.068	0.073	0.134	0.025	0.018
							0.198	0.382	0.325	0.061	0.033

Appendix-10: Seconf Level Fuzzy Evaluation Matrix

Appendix 10

SECOND LEVEL FUZZY COMPREHENSIVE EVALUATION MATRIX

Second level fuzzy relation matrix named (R')							
	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Local Weight	Rank
P	0.046	0.259	0.328	0.195	0.172	0.168	5.000
E	0.111	0.375	0.334	0.126	0.054	0.198	4.000
S	0.194	0.430	0.253	0.078	0.045	0.216	2.000
T	0.150	0.362	0.294	0.135	0.059	0.200	3.000
EN	0.198	0.382	0.325	0.061	0.033	0.218	1.000

	Frequency of "5" responses	Frequency of "4" responses	Frequency of "3" responses	Frequency of "2" responses	Frequency of "1" responses	Local Weight	Rank
P	0.008	0.044	0.055	0.033	0.029	0.168	5.000
E	0.022	0.074	0.066	0.025	0.011	0.198	4.000
S	0.042	0.093	0.055	0.017	0.010	0.216	2.000
T	0.030	0.072	0.059	0.027	0.012	0.200	3.000
EN	0.043	0.083	0.071	0.013	0.007	0.218	1.000
B Value	0.145	0.366	0.306	0.115	0.068		
	3	1	2	4	5		

	100	75	40	15	5	score	
Total Score	14.476485	27.482443	12.220502	1.7245337	0.3416056	56.245569	
							rank
P	4.6149949	19.448666	13.124395	2.9189463	0.8591411	40.966	5
E	11.112888	28.122017	13.346278	1.8959278	0.2692938	54.746	4
S	19.404689	32.223023	10.127508	1.1683705	0.2261686	63.150	1
T	14.982183	27.180313	11.754238	2.0282232	0.2935158	56.238	3
EN	19.785737	28.661235	13.004072	0.9210572	0.167436	62.540	2
		Rank is ok,Same as RII,AHP					