DIGITAL TWINS IN THE CONSTRUCTION INDUSTRY: CURRENT STATUS, CHALLENGES AND WAY FORWARD

DEPARTMENT OF CIVIL ENGINEERING

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BACHELOR'S THESIS

DIGITAL TWINS IN THE CONSTRUCTION INDUSTRY:

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DEDICATION

"To our parents, the unwavering pillars of support, and to our teachers, the guiding light through ever challenge belief in us has fueled our success and shaped our journey."

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Certificate

This is to certify that the work presented in this project thesis on **"Digital Twin in the Construction Industry: Current Status, Challenges, And Way Forward"** is entirely written by the following students themselves under the supervision of Engr. Syed Abdullah Shah Hashmi

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ABBREVIATIONS

AE: Assistant Engineer

AEC: Architecture, Engineering, and Construction

AI: Artificial Intelligence

Arch: Architect

B&W: Buildings and Works

BIM Building Information Modelling

CEO: Chief Executive Officer

DT: Digital Twin

HVAC: Heating, Ventilation, and Air Conditioning

IDB: Irrigation Department Balochistan

IE: Interior Engineer

IoT: Internet of Things

MC: Municipal Corporation

NASA: National Aeronautics and Space Administration

NHA: National Highway Authority

NLC: National Logistic Cell

P&DDB: Planning & Development Department Balochistan

PHEB: Public Health Engineering Balochistan

PLM Product Lifecycle Management

PLM: Product Lifecycle Management

QDA: Quetta Development Authority

QOS: Quality of Service

SDO: Sub-Divisional Officer

SE: Site EngineerSPHERE: Service Platform to Host and share Residential data

SPSS: Statistical Package for Social Sciences

WAPDA: Water & Power Development Authority

WD: Works & Services Department

XEN: Executive Engineer

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ABSTRACT

In the construction industry, digital twins function as digital replica of actual buildings, infrastructure, or projects. DTs acquire real-time data from many platforms and sensors to improve project analysis, simulation, and monitoring procedures. This thesis explores the environment, obstacles, and opportunities related to the adoption of digital twin (DT) technology in Pakistan's building sector. The study uses network and density visualization techniques with VOS viewer, combined with statistical analysis tools like SPSS and MS Excel, and a questionnaire-based survey. The results show that there is currently a low rate of adoption, along with poor professional knowledge, a lack of legislative regulations that are favorable, and a limited understanding of DT concepts. The challenges that have been identified include gaps in knowledge, concerns about privacy, technological shortcomings, legislative limits, organizational obstacles, financial constraints, data integrity issues, and interoperability constraints. The thesis summarizes with suggestions for overcoming these obstacles, including the promotion of cost-effective methods, training programs, regulatory authority cooperation, strategic technology investments, transparent data ownership frameworks, and the development of an innovative environment. In terms of the future, the report sees a bright future for DT in Pakistan's construction industry, provided that the government takes the initiative to enact laws and conduct research projects that will hasten the technology's development and implementation. Digital twins are positioned as key players in changing industry standards as a result of this technological advancement, which could have implications for supporting environmental sustainability in the construction sector.

CHAPTER 1 INTRODUCTION

1.1 Background

One of the key industries requiring many precise and accurate data is construction. Data must be readily available, accurate, complete, timely, and presented in an understandable manner (xu et al., 2014) [1]. From conceptual planning to decommissioning, a building project generates a lot of data. The success of the construction project depends on the management of information flow and the ability to analyze the vast amount of data and extract insightful knowledge (bilal et al., 2016) [2].

Information management is essential to the lifecycle of a building project, according to academics (onyegiri and nwachukwu, 2011) [3]. Information creation, transmission, and interpretation are all included in this, as are the occasions when building, maintaining, reusing, and eventually recycling the project call for it. Despite the fact that information is crucial for the whole project lifecycle, research has focused on information management during design and construction. These phases barely account for 30 to 40 percent of the project's total cost, despite their significance (jiang, 2013) [4].

Despite the construction industry's reputation for being cautious about potential technological advancements and applications, over the past few decades, the industry has made significant strides to improve information management through the use of building information modelling (BIM) (nassereddine et al., 2019). [5]. Building information modeling (BIM) has been one of the most important and cutting-edge tools for more than ten years. It has been shown to improve key stakeholder collaboration and communication, approach building design holistically, increase productivity, enhance overall product quality, decrease industry fragmentation, and increase industry efficiency (succar, 2009; schweigkofler et al., 2018) [6].

The phrase "digital twin" was first used in 2002 by dr. Michael grieves, a professor at the university of michigan, in his paper "conceptual ideal for product lifecycle management (PLM)" (grieves and vickers, 2016) [7]. Every system is composed of two systems, according to the PLM concept, which includes every aspect of the digital twin: a virtual system that stores all of the data related to the physical system and a physical system, or the actual space that has always been. Information can flow between virtual and physical systems due to this connectivity (grieves and vickers, 2016) [8].

For the Apollo program, the national aeronautics and space administration (NASA) deployed the first digital twin in 2010. To enable mirroring or twinning of the real space vehicle's state during the trip, at least two identical space vehicles were built (campos-ferreira et al., 2019; schleich et al., 2017).[9]. Nasa defined the term "digital twin" in its first formal definition as "an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or systems that uses the best available physical model, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin" (schleich et al., 2017)[10].

On the other hand, the digital twin is used to monitor the physical asset and improve its operational efficiency by looking at real-time information. For example, facility managers may do what-if analysis using the building's digital twin for operation and maintenance, which would ultimately lower energy consumption and improve resident comfort (khajavi et al., 2019)[11]. Architects can collect data for the operation and maintenance phase of a facility using a digital twin, then save it in a database for use in other projects (qi and tao, 2018)[12].

As a means of overcoming its poor track record of digitization, the construction industry began to see digital twins as a critical enabler for its digital transformation (brilakis et al., 2019)[13]. However, technology receives the least amount of study in the fields of architecture, engineering, and construction (AEC) (ammar and nassereddine, 2022)[14].

After the concept of "digital twins" was introduced to the construction industry, a number of studies described the applications of digital twins in the built environment and investigated how technology could enhance worker proficiency, facilitate more efficient facility management, increase worker productivity, health, and safety, and reduce operating and construction costs (bolton et al., 2018; evans et al., 2020; akanmu et al., 2021)[15]. The researchers continued by saying that by tracking and diagnosing an asset's condition and enabling predictive maintenance, digital twins maximize asset performance. They do this by combining data from several sources, such as historical records, sensor data, and simulation results (yitmen et al., 2021).[16].

1.2 Research justification

There are various reasons to use digital twins in building projects, since they have become more and more common in the construction industry in recent years. Digital twins provide extremely detailed, real-time viewing of building projects. Enhancing understanding of complex designs and structures can help project stakeholders make well-informed decisions. Digital twins facilitate better collaboration and communication across project teams by providing a centralized platform for exchanging and accessing project data. This might lead to fewer miscommunications and better teamwork. Digital twins help with complex simulations and analyses, which allows for improved design and planning. This might lead to improved construction methods, more efficient use of resources, and overall improved project performance. Digital twins provide a framework for comprehensive project lifecycle management. Over a structure's complete life, from design and building to operation and maintenance, the digital twin may be updated and used, fostering sustainability and long-term efficiency.

1.3 Aim of the study

The objective of this research is to evaluate the existing state of affairs, identify obstacles, and provide novel approaches for the successful integration of digital twin technology within the construction sector.

1.4 Objective of the study

Three goals are established in order to fulfill the study's purpose.

- To determine the obstacles to DT implementation in the building sector.
- To establish the path ahead for DT in the Pakistan construction sector.
- To determine DT's present construction status.

1.5 Scope of the Study

Public sector departments including NHA, B&W, Irrigation, Local Government, B&R Department, QDA, MC offices, etc. would be the sources of the data.

1.6 Significance of the study

This research promotes innovation in the construction industry by examining the transformative potential of digital twin technology and offering insights that can spur industry-wide improvement. The study's conclusions provide insightful knowledge on how digital twins could enhance stakeholder, decision-maker, and project manager collaboration, visualization, and management in general.

1.7 Thesis structure:

Five chapters make up the structure of this thesis.

Chapter 1: this chapter provides an overview of the study, issue description, goals, importance of the research, and scope of work.

Chapter 2: this chapter provides a thorough analysis of the literature.

Chapter 3: the research introduction, research design, study area, data collecting, delivery of the questionnaire, and data analysis technique are all covered in this chapter.

Chapter 4: in this chapter, the participants in the questionnaire survey are described, the questionnaire replies are analyzed, and recommendations for solutions are discussed.

Chapter 5: in this chapter, the entire investigation is summed up together with its key conclusions and worthwhile results. It also makes reference of the suggestions.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

With the introduction of Industry 4.0, the construction sector—a major force behind the growth of the world economy—faces a revolutionary wave. Historically, this sector has been resistant to technological advancements because of its size and complexity. The Digital Twin (DT) becomes a major player, bridging the digital and physical worlds with ease and offering substantial advantages and real-time information. In the construction industry, where productivity is critical, DT promises to transform established methods. According to recent literature, there is a growing interest in understanding and using DT in a variety of industries, including the building, road, and irrigation construction. For efficient navigation, it is essential to comprehend the state of DT in construction both globally and in Pakistan. The goal of the literature review is to provide a thorough summary of the state of DT now, its difficulties, and its future directions. It examines numerous DT kinds, their ramifications, and suggested approaches to overcome obstacles through the examination of research and applications. The effective deployment of digital transformation in Pakistan's construction sector would be guided by global landscape insights. The evaluation prioritizes uniqueness in content and sets the stage for a thorough investigation of DT's potential, obstacles, and role in reshaping the construction sector.

2.2 Digital Twin

Using digital twin (DT) technology, a physical item may be dynamically represented digitally. In order to guarantee the best results, this representation is continuously adjusted to changes in the physical environment or processes (Parris et al, 2016). [17].The process of creating a virtual model based on data analysis of a real object results in the formation of a Digital Twin (DT). This architecture allows for easy monitoring by keeping a synchronized link with the physical item (GAVS, 2017) [18]. Via the virtual model, the Digital Twin (DT) provides the ability to monitor and control the state of actual things. It has the ability to increase productivity, extend life, and lower running costs for a tangible object. This is done by building a platform that supports a proactive and predictive maintenance cycle (Liu et al, 2018) [19].

2.2.1 History

Within the context of Digital Twins (DT), the term "twin" was first used in the aerospace industry, most famously in relation to NASA's Apollo program in the 1960s, as NASA Technology Roadmaps describe (Shafto et al. 2010; Negri et al. 2017; Boschert et al, 2018)[20]. As part of the NASA program, two spacecraft were built, one of which was dubbed "the twin" and placed on Earth to replicate the movements and capabilities of the spacecraft that was really participating in the mission (Boschert et al, 2018; Zhuang et al, 2018).[21]. The twin was identified as a prototype that faithfully replicated the spacecraft's in-flight activities. (2015) Rosen et al. [22]. However, it's important to remember that the "twin" in this historical period symbolized a physical system (Zhuang et al., 2018)[23]. The term 'twin' did not include the digital component during this time. When Michael Grieves first presented the idea in his product lifecycle management (PLM) course in 2003, he came up with the term "digital twin"

(Grieves, 2014)[24]. PLM unifies several business processes pertaining to the creation, modification, and application of data in order to support a product's lifetime at every stage, from design and manufacture to use, upkeep, and, in the end, recycling and disposal (Schroeder et al., 2016)[25].

2.2.2 Definitions

In his product lifecycle management course, Michael Grieves provided the first explanation of the term "digital twin," referring to it as an information mirroring model (Grieves, 2005)[26]. (Thereafter, Boschert and Rosen 2016) offered a more concise definition, saying that the Digital Twin is made up of all relevant functional and physical data taken from a system or product. The focus of this description is on data sharing and the algorithms that control how virtual and physical models behave[27]. Although brief, it ignores the components and purpose of DT data in favor of concentrating solely on it. The concept of DT was expanded by (Lui et al. 2018), who defined it as a dynamic model that replicates a real asset or system. Using real-time data and information, this model continually adapts to operational changes, making it possible to anticipate future states for the corresponding physical item. According to Madni et al. (2019), DT serves as a virtual representation of a physical system's performance, maintenance, and health status data, going beyond just being a virtual prototype. Updates to this representation are made continuously while the physical system is in use[28].

2.2.3 Types Of Digital Twins In The Construction Industry

After reading through several study articles, the sorts of digital twins that were found were as follows. Delgado and Oyedele (2021) examined the differences between the BIM and digital twin ideas, highlighting the fact that both are essential for meeting the various demands of the industry. In order to give a more thorough insight, the study went deeper into the relationship between BIM and digital twin in the construction industry[29]. Building information modeling (BIM) to digital twins was thoroughly examined by deng et al. (2021), who also developed a five-level framework to describe this transition. Within this structure,

Level 1 refers to the only use of BIM for conceptual design and scheduling of building projects.

Level 2 uses integrated simulations in conjunction with BIM for facility management, operation, and estimating.

Level 3 involves integrating internet of things (IoT) technology with BIM to provide real-time tracking and visualization.

Level 4 demonstrates a more advanced BIM and artificial intelligence (AL) combination for data-driven forecasts and decision-making. The perfect digital twin, which enables control feedback, optimization, and seamless integration, represents level 5, the pinnacle, [30].

Furthermore, Atkins, an engineering and design company, unveiled a digital twin maturity spectrum that has six components on a logarithmic scale that represents increasing interconnection and complexity (evans et al., 2020)[31]. The creation of an asset's digital twin is a dynamic process that may be applied at any point in the asset's lifespan, as stated in their paper. Data gathering and reality capture are the first steps, represented by element 0. The gathered information is then employed to create 2d systems or 3d models, which make up element 1, which is frequently used to create the as-built model. Element 2 is created by combining data from element 1—such as design requirements, material specifications, inspection reports, and asset management information enhanced with building information modeling (BIM) data—with a static dataset. Project planning, maintenance, operation, and decommissioning are among the functions fulfilled by element 2. Real-time data updates are enabled by the integration of sensors and internet of things (IoT) technology, resulting in a continuous data flow from the physical asset to the digital asset—identified as element 3. Element 3 is used to forecast asset performance and facilitate decision-making. Elevated complexity is represented by the last two aspects, elements 4 and 5, which include autonomous operation and maintenance aided by sophisticated algorithms and artificial intelligence, as well as bidirectional integration and communication between the physical and digital assets.

2.3 Construction Industry and Digital Twin

Using simulations to anticipate building state and execute preventative maintenance, digital twins provide a flexible method. These simulations cover a wide range of topics, including emergency situations, 4d building models, energy and heat consumption calculations, and user comfort projections. Furthermore, by utilizing ground data, machine learning techniques may be used to target particular factors, such as occupant comfort. The significance of digital twins in facilitating data-driven decision-making is emphasized by the authors. Decisions on how to proceed with construction, the building's existing condition, and projections of future results—like energy consumption and occupant thermal comfort—are all influenced by real-time data collecting.

Researchers presented the "sphere" digital twin platform (service platform to host and exchange residential data) in a different study. The seamless integration of data among people, construction stakeholders, municipal administration, and urban developers is facilitated by this platform. The platform's main goal is to improve the evaluation of residential buildings' performance, construction, and design. By optimizing residential building energy performance and design, the created platform hopes to lower carbon dioxide emissions and have a positive environmental impact (alonso et al., 2019)[32]. The suggested paradigm facilitated data exchange across stakeholders and allowed the integration of data from numerous sources. A further use of digital twins was to assess the structural soundness of particular milanese cathedral elements. This was accomplished by precisely modeling the building in three dimensions and examining how the system responded in different scenarios (angjeliu et al., 2020)[33].

2.3.1 Building Construction Sector

A few studies have looked at the real-world uses of digital twins in construction, with an emphasis on anomaly detection and real-time asset monitoring. Sensors are used by digital twin systems to measure Quality of Service (QOS) in HVAC systems and track important assets such pump vibration frequency (Lu et al., 2020; Xie et al., 2020)[34]. In addition to integrating data from several sources, the suggested architecture makes it easier for stakeholders to share data easily. Another use is using an accurate 3D model to assess the structural integrity of particular Cathedral of Milan components while analyzing the system's reaction to various scenarios (Angjeliu et al., 2020)[35]. Researchers were able to comprehend past structural element failures in the building and put preemptive maintenance plans in place for the future thanks to the produced Digital Twin model. Furthermore, they investigated Digital Twin frameworks that used virtual reality, machine learning, wearable sensors, and VIVE Trackers to teach construction workers how to create a posture training environment that can reduce musculoskeletal injuries (Akanmu et al., 2020)[36].

2.3.2 Road Construction Sector

Using digital twins of real transportation assets to enhance planning, building, and maintenance procedures is known as the integration of digital twins in the transportation sector of the construction industry. This integration allows for ongoing observation, evaluation, and commenting as well as projecting future results with reference to transportation performance. Furthermore, by providing real-time data for informed decisions on the status of transportation development and projected future transportation performance, digital twins help data-driven decision-making (Zhang et al., 2013)[37]. Traffic Management and Optimization: Digital twins help to improve traffic management tactics and facilitate infrastructure development by simulating and analyzing traffic flow, congestion patterns, and transportation network performance. (Akanmu and others, 2013)[38]. Real-time monitoring, resilience, and infrastructure maintenance are made possible by digital twins for a variety of transportation infrastructure elements, including roads, bridges, and tunnels. This makes it possible to evaluate the structural health, forecast maintenance requirements, and improve the resilience of the infrastructure as a whole. In 2013. Grolinger et al.[39]. Connected Transportation Planning with IoT and Emergency Response Support: In the transportation industry, digital twins are combined with IoT devices and sensor technologies to create a digital model of the whole transportation network that is smoothly connected. Data gathering on vehicle movements, environmental conditions, and infrastructure performance is made easier by this connection. Furthermore, by modeling events like accidents or natural disasters, digital twins aid in emergency response planning by facilitating the evaluation of their effects on transportation networks and the creation of successful reaction plans (Kan and Anumba, 2019)[40].

2.3.3 Irrigation Construction Sector.

Improving Water Flow and System Efficiency via Simulation: Digital twins are used to model water flow in irrigation systems, allowing for better water distribution, pressure management, and system efficiency overall. This helps to advance agricultural methods.

(Akanmu and others, 2013)[41]. Using Sensor Integration for Real-time Monitoring and Predictive Maintenance: Digital twins track soil moisture, weather, and water use in real time by integrating sensors. Decision-making and automated irrigation system control are supported by these data. Furthermore, predictive maintenance evaluates data in real-time to avert malfunctions and improve infrastructure dependability (Grieves and Vickers, 2017).[41]

2.4 Current Status of the Digital Twin in the Construction Industry Worldwide

The digital twin environment in the construction industry is rapidly changing on a worldwide scale, as seen by the increased interest and acceptance in recent times. Digital twins are an essential tool for improving project results and reducing costs. They are used to support planning, building, and maintenance processes. The following references (G. T. Dottin and S. L. Lee, "Digital twin technology in the construction industry: An overview") provide insightful information on the current state of digital twins globally. Automation in Construction: A Systematic Review (2021) In light of the worldwide obstacles that the construction sector must contend with, such as decreased output and a labor scarcity, there is a growing need to complete projects effectively and within allocated budgets and schedules[42]. Simultaneously, increasing emphasis is being placed on achieving project owners' expectations and adding value. Organizations and executives throughout the world are forced to make important choices in light of these industry-wide problems, which emphasizes the vital need for access to comprehensive and trustworthy data (Ammar and Dadi, 2021)[43].

2.5 Current Status of the Digital Twin in the Construction Industry of Pakistan

Since no study, articles have been produced about the role of the digital twin in Pakistan's building. Therefore, there is not a literature study accessible on the state of digital twins in Pakistan right now. This paper's understanding of this field was exclusively derived from study employing a questionnaire survey.

2.6 Challenges in the Implementation of Digital Twin in the Construction Industry

Getting about in the world of digital twins for building means overcoming a number of obstacles. First of all, there are complexities involved in understanding, preparing, and effectively using the necessary data for the creation and maintenance of digital twins in building projects. Second, maintaining a two-way interaction between the digital and physical realms is a problem when integrating physical assets with their corresponding digital representations. Thirdly, there are obstacles in the way of fully utilizing digital twins' predictive power and real-time monitoring capacity, especially when it comes to tackling particular construction difficulties like temperature fluctuations during the pouring of concrete. Another difficulty is getting different stakeholders engaged in building projects to work together effectively. To overcome this, digital twins must be optimized to improve communication and decision-making. Lastly, resource restrictions, including limits in experience, resources, and technical infrastructure, create challenges to the effective installation and maintenance of digital twins in the construction sector (Ammar, et al, 2022)[44].

Table 1: Challenges

S.NO	CHALLENGES
1	**Issues with Data comprehension, Preparation, and Usage:** This issue relates to the challenges with data comprehension, preparation, and utilization in digital twin technology. Data quality, dependability, ownership, communication delay, sensing, sharing, interoperability, and storage are some of the topics it covers.
2	**Inadequate comprehension of the idea, which might cause problems with adoption:** This problem, which is connected to the last one, is that people may be discouraged from embracing the technology due to a vague and poorly understood notion of the digital twin.
3	**Technical Complexity:** Managing models and data is only one of the many intricate and technically demanding processes involved in putting digital twin technology into practice.
4	**Compatibility and standardization:** One major obstacle to the adoption of digital twin technology in the construction sector is the absence of compatibility and standardization across various software and hardware systems.
5	**Expense and complexity:** Especially for small and medium-sized businesses, the expense and complexity of integrating digital twin technology in the construction sector can be a major hurdle.
6	**Knowledge and skill gap:** Using digital twin technology in the construction sector calls for certain knowledge and skills that may not be widely available in the sector.
7	**Legal and regulatory obstacles:** The deployment of digital twin technology in the construction sector may confront legal and regulatory challenges, primarily relating to data ownership, responsibility, and intellectual property rights.
8	**Cooperation and Communication:** Two of the biggest obstacles to successfully using digital twins in the construction industry are improving stakeholder cooperation and communication as well as guaranteeing efficient information sharing between real and virtual components.
9	**Sluggish Technological Development:** The building sector has been hesitant to implement Digital Twins because of the technology's sluggish development.

10	**Complex Production and Procurement processes:** Using digital twin technology is hampered by the complex production and procurement processes seen in the building sector.

2.7 Way Forward For Digital Twin in Pakistan's Construction Industry

This research study investigates the possible benefits and challenges associated with implementing digital twin technology within the construction sector. Benefits including better project management, better decision-making, lower costs, more efficiency, and safety are highlighted. Notwithstanding, many obstacles are noted, including the demand for highly qualified staff, infrastructural needs, data protection concerns, and significant expenditures in technology.

Within the construction business, decision-making, information management, and project management might all benefit from this seamless integration. Furthermore, there's a requirement for utilizing cutting-edge technologies like virtual reality, artificial intelligence, and the Internet of Things to bring innovative service techniques in the building industry. One of the most promising digital technology platforms, Digital Twin enables bi-directional integration at any time by enabling the virtual representation of physical asset conditions as data. Digital twins facilitate this integration, which has the potential to improve information flow and operational efficiency in building procedures (Ozturk, G. B., 2019).

2.8 Sustainability

However, digital twin technology has the potential to help to sustainability in the construction sector by enhancing project management, decreasing waste, and increasing efficiency. By optimizing the building design and construction processes, digital twin technology, for instance, can lower the quantity of energy and materials needed. Furthermore, by monitoring and improving building efficiency, digital twin technology can lower energy use and greenhouse gas emissions. At el, 2022, Madubuike But it's crucial to remember that putting digital twin technology into practice itself takes a lot of energy and resources, and the infrastructure and data centers needed to support it may have a big negative impact on the environment. As a result, it is critical to take into account the digital twin technology's entire environmental impact and to make sure that it is applied responsibly (Madubuike, et al., 2022). The relevance and attention given to the sustainability of digital twin technology in the building sector is growing. The study article addresses the use of digital twin technology in assessing the sustainability of buildings and railway station structures, even if it does not specifically address the sustainability component. It is essential to recognize that evaluating the sustainability of digital twins in the construction industry requires taking into account a variety of factors, including resource efficiency, long-term economic viability, and environmental effect. With its potential to reduce waste and resource consumption, improve energy use, and facilitate predictive maintenance, digital twin technology is a promising tool for promoting sustainability in the construction industry.(Liu Mengnan, al., 2020) The potential of digital twins to improve resource efficiency, reduce waste, and maximize energy use in building operations and construction holds great promise for promoting sustainability. Digital twins also have a positive effect on the economy by helping to save costs, manage assets more effectively, and optimize building processes through improved monitoring and predictive analytics. In consequence, these financial advantages have positive effects on encouraging sustainable practices in the building sector. Digital twins have social benefits in addition to environmental and financial ones. They improve safety protocols, encourage stakeholder engagement, and improve project management in general. These developments underscore the comprehensive influence of digital twin technology by promoting safer and more socially conscious building methods.(R. Khallaf and others, 2022).

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction:

The research approach used for this study is thoroughly explained in this chapter. Through a combination of literature study, bibliometric analysis, and VOSviewer author and co-author connection discovery, the current state, Challenges, and future trends of digital twins in the construction sector were evaluated. A questionnaire was also created and distributed, and SPSS was used to evaluate the information acquired. Within the public and commercial sectors of the construction industry, professionals and specialists with a variety of backgrounds were the target audience for the study.

3.2 The Research Design:

The design of this study is mixed-method. A qualitative technique is used to identify possible obstacles in the use of Digital Twins (DT) in building projects. The qualitative data helps formulate corrective measures for the future implementation of DTs in the construction sector, in addition to improving comprehension of the research aims.

Skilled participants from the construction industry have access to a standardized questionnaire survey during the quantitative phase. This study collects information on the present state of digital technology (DT) in the construction industry as well as evaluates challenges and potential prospects for the technology going forward. Furthermore, author and co-author relationships are investigated using VOSviewer, a bibliometric analysis tool, which offers insights into the academic environment related to digital twins.

3.3 Data Collection:

The sources from which the data was gathered are covered below.

3.3.1 Primary Data:

Primary data was gathered for this particular project from experts and interested parties in Pakistan's governmental engineering departments. Information was gathered through the distribution of questionnaires, and this primary data played a major role in the research's analysis and results. A literature research was also done in order to collect secondary data for the investigation. To augment the original data, many sources were employed, such as books, research papers, the Internet, construction management magazines, and engineering periodicals.

3.3.2 Secondary Data:

To find linked papers, a VOS viewer bibliometric analysis was performed by searching the project title in the Publish or Perish software. After that, Mendeley was used to retrieve the pertinent research articles and turn them into RIS files for VOS viewer examination. The goal of this strategy was to investigate the network visualization and density of relevant field research.

3.4 Questionnaire Design:

After a comprehensive assessment of the literature, a well-designed questionnaire with 10 items for each target group was developed for data collection. The questionnaire was divided into two sections: the first asked questions about the demographics of the respondents, and the second utilized a 5-point Likert scale to ask questions about the study aims. In order to guarantee clarity and remove any ambiguity, the questionnaire was revised several times in cooperation with the project supervisor and academic specialists. The completed questionnaire was utilized in structured interviews after being accepted by the project manager. Google Forms was used to transform it into an electronic version for online surveys.

3.5 Questionnaire Administration:

Engineering and contractor specialists with years of experience and knowledge in their respective fields were among the construction professionals to whom the questionnaires were distributed. Google Forms enabled the online survey, and both online and offline approaches were used. Social media posts and emails were used to distribute links to the surveys. Both in-person and online contacts improved the replies received over the almost two-week-long data gathering procedure.

3.6 Method for Data Analysis:

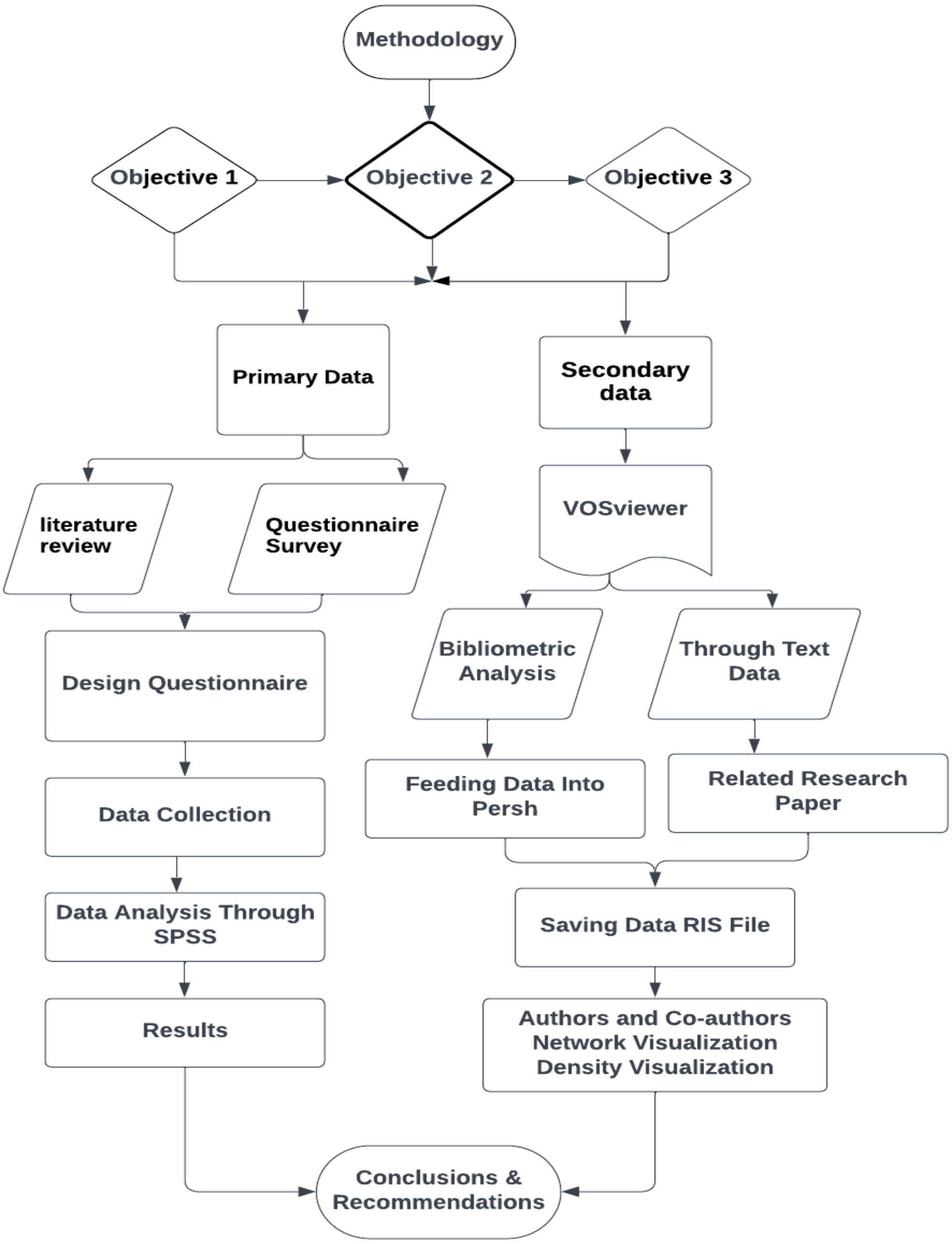
After the phase of data collecting was over, data analysis was conducted using both qualitative and quantitative approaches. Utilizing Microsoft Excel and the Statistical Package for Social Sciences (SPSS-22) application, data collected from the surveys was examined. The average means of the variables were used to rank them, and Chapter four of the thesis goes into great depth on the analysis's findings.

3.6.1: Framework for Data Collection and Analysis:

Traversing the Research Terrain

Examine the detailed flow charts below to comprehend the methodical process used to collect and analyze primary and secondary data using a combination of qualitative and quantitative techniques.

Flow Chart


Methodology
Objective 1
Objective 2
Objective 3
Primary Data
Secondary data
literature review
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VOSviewer
Design Questionnaire
Bibliometric Analysis
Through Text Data
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Related Research Paper
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CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction:

This chapter goes into great depth on the statistical analysis that was done on the data gathered from the questionnaire surveys as well as the study's conclusions. This chapter also provides graphs, charts, and tables to comment on the demographics of respondents from the questionnaire and the aims of the research project. The research study's findings and analysis are presented objectively in the following manner.

4.2 Data Analysis through SPSS

4.2.1 Objective 1:

In order to accomplish the first study goal, a questionnaire survey was carried out. The survey was divided into two sections: one asked questions about demographics and the other asked questions about present situation. A total of 110 questionnaires were issued to professionals in the construction business, of which 40 were completed and returned. The questionnaire had 10 items..

4.2.1.1 Demographics of Respondents:

Out of the 40 replies, 24 came from public or government agencies, 14 from businesses in the private sector, and 2 from other sources. The respondents were employed by various government agencies in Balochistan, including the Works & Services Department, PHE (Public Health Engineering), Irrigation Department, WAPDA (Water & Power Development Authority), NLC (National Logistic Cell), NHA (National Highway Authority), Municipal Corporation, Balochistan Local Government, P & DD (Planning & Development Department), and private consultancies and firms.

The participants had diverse professional roles; almost sixteen (16) were XEN, nine were SDOs, one was a CEO, two were contractors, seven were assistant engineers, two were architects, one was an interior designer, and two were site engineers.

Of the respondents, 17 stated they had less than five years of experience managing construction projects, 13 said they had five to ten years, six said they had eleven to fifteen years, three said they had sixteen to twenty years, and one said they had more than twenty years of experience in the field.

Figure 1: Questionnaire distribution

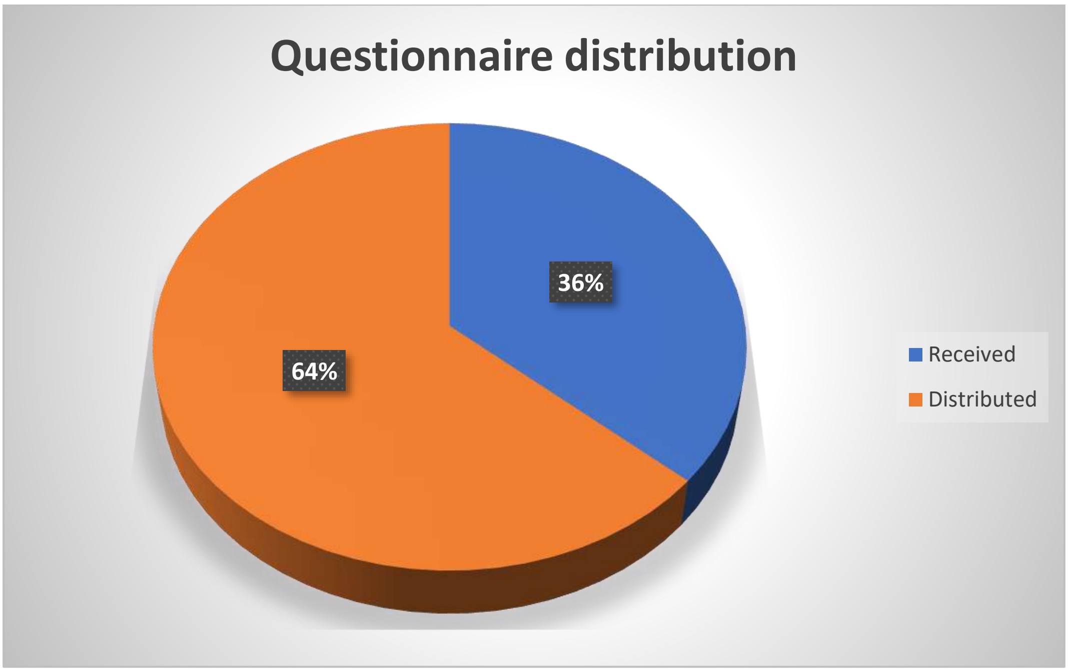


Figure 2: Designation of respondents

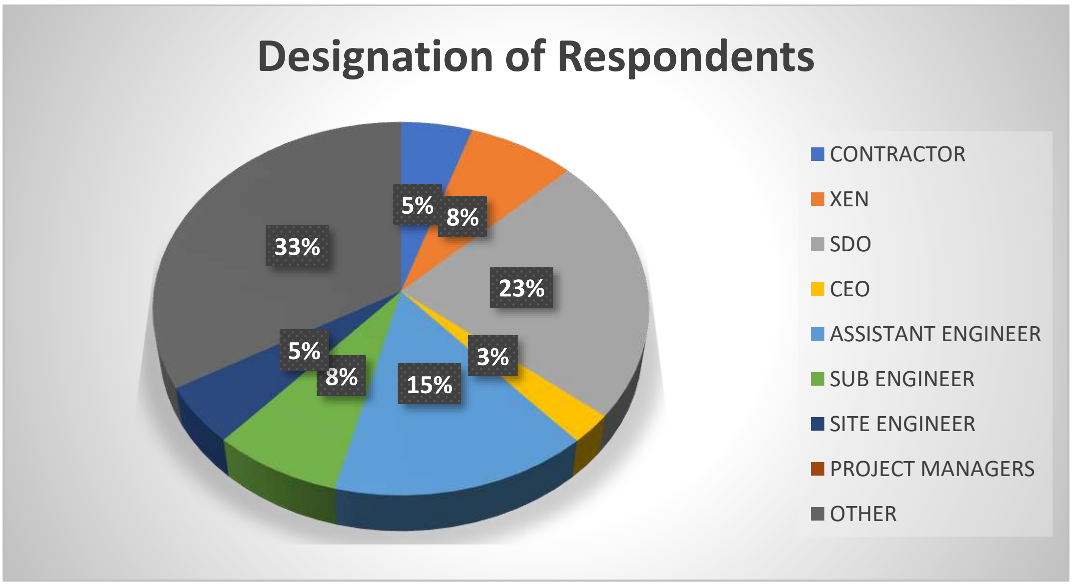


Figure 3: Qualification of respondents

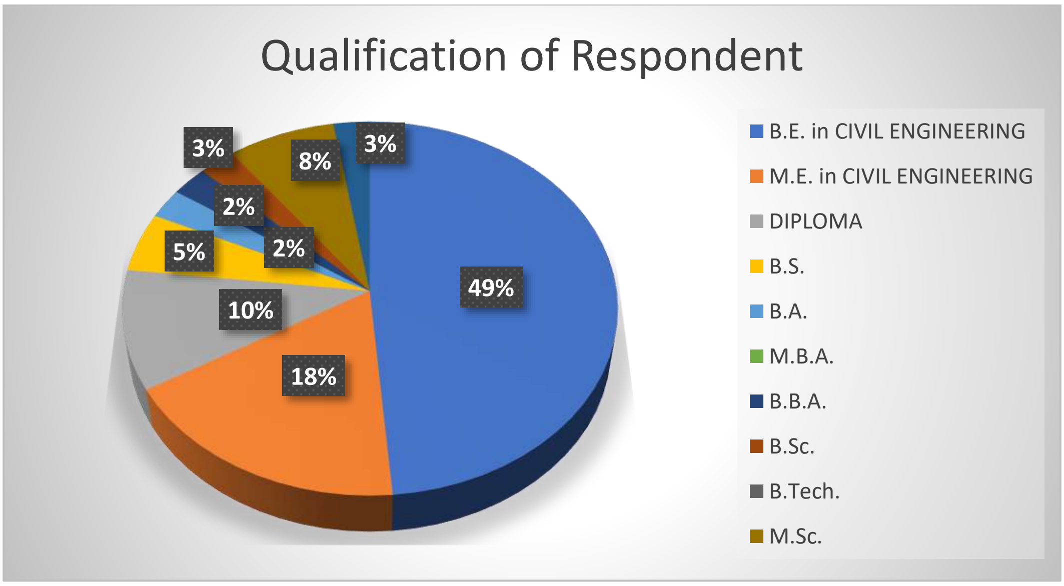


Figure 4: Experience of respondents

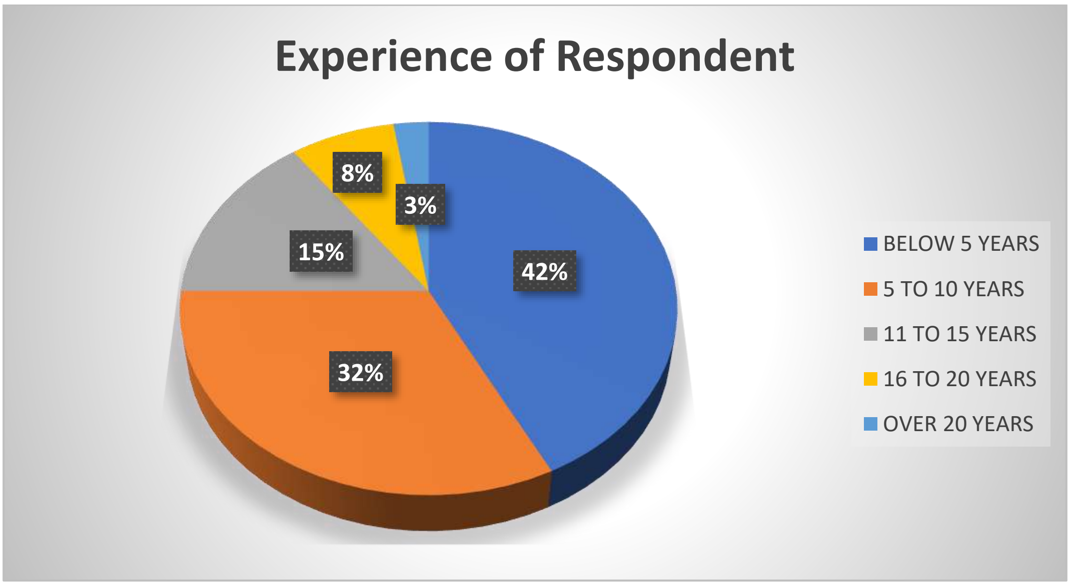
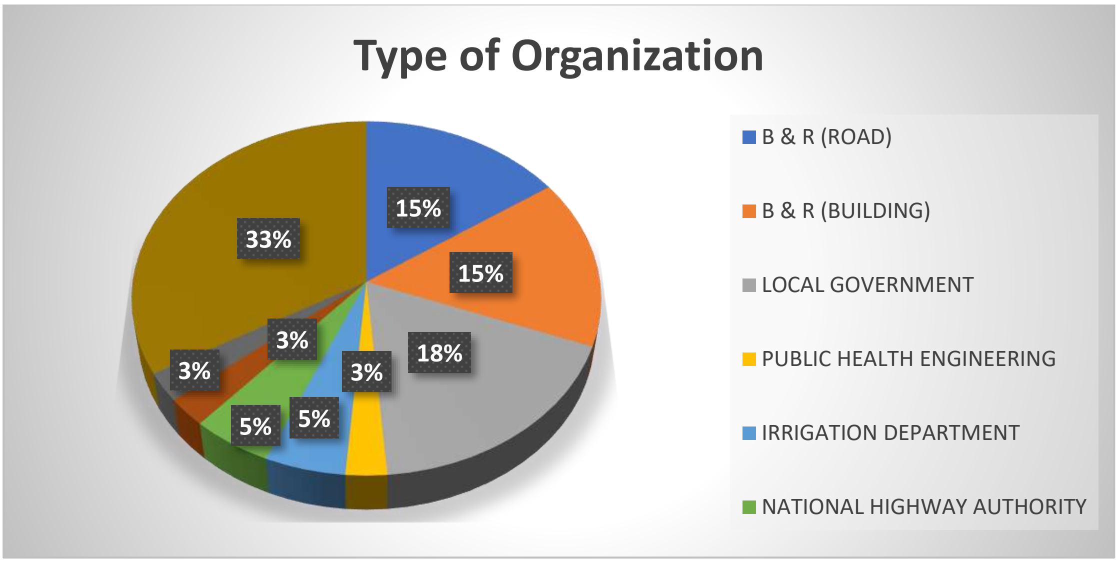


Figure 5: Type of organizations



4.2.1.2 Results and Discussions:

Ten questions on the Current Status of DT in the construction sector were created and circulated as part of a questionnaire to find out more. MS Excel was used to do further analysis on the mean scale questions after SPSS software was used for the original analysis. The entire SPSS program findings, displayed in tabular, pie chart, and bar chart formats using MS Excel.

Table 2: Questions regarding the Current Status of Digital Twin

Sr. No.	**Questions regarding the Current Status of DT in the Construction Industry of Pakistan**	Mean	Ranking
1	Regular Use of DT in Construction	2.770	1
2	Utilization of DT in Building projects	2.691	2
3	Use of DT in the building as is normal procedure	2.580	3
4	DT uses results advantages	2.400	4
5	Positive impact on cost and time due to DT	2.160	5
6	Govt. policies encourage DT use	2.145	6
7	DT implemented in notable projects	2.102	7
8	Education and training are advancing DT use	2.003	8
9	DT is not used due to Challenges	1.999	9
10	DT improves stakeholder collaboration	1.897	10

Figure 6: Percent of responses regarding Current Status of Digital Twin

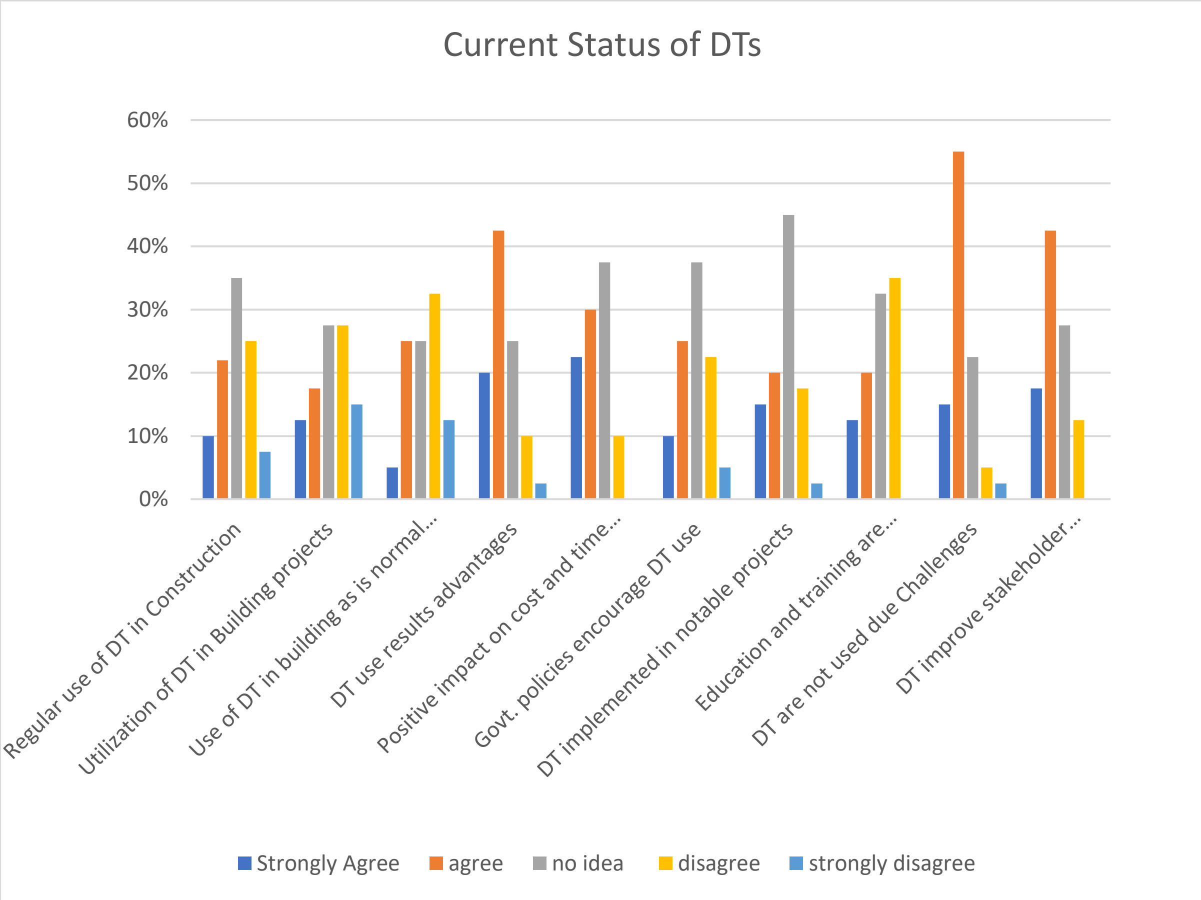


Figure 7: Ranking of questions regarding Current Status

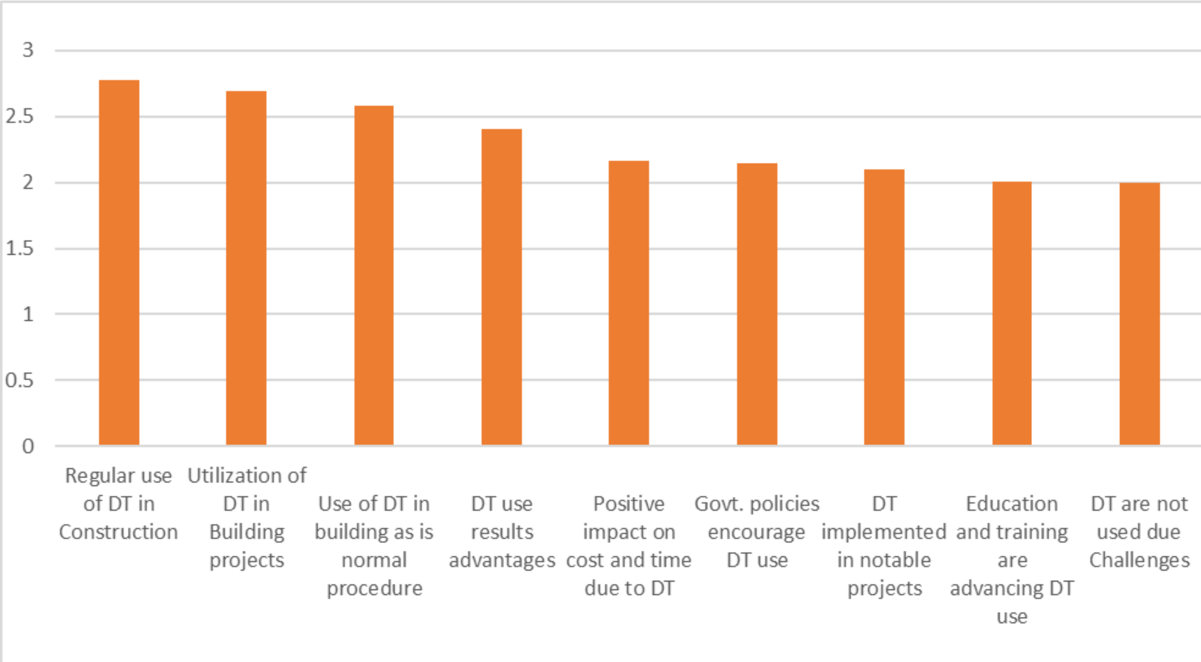
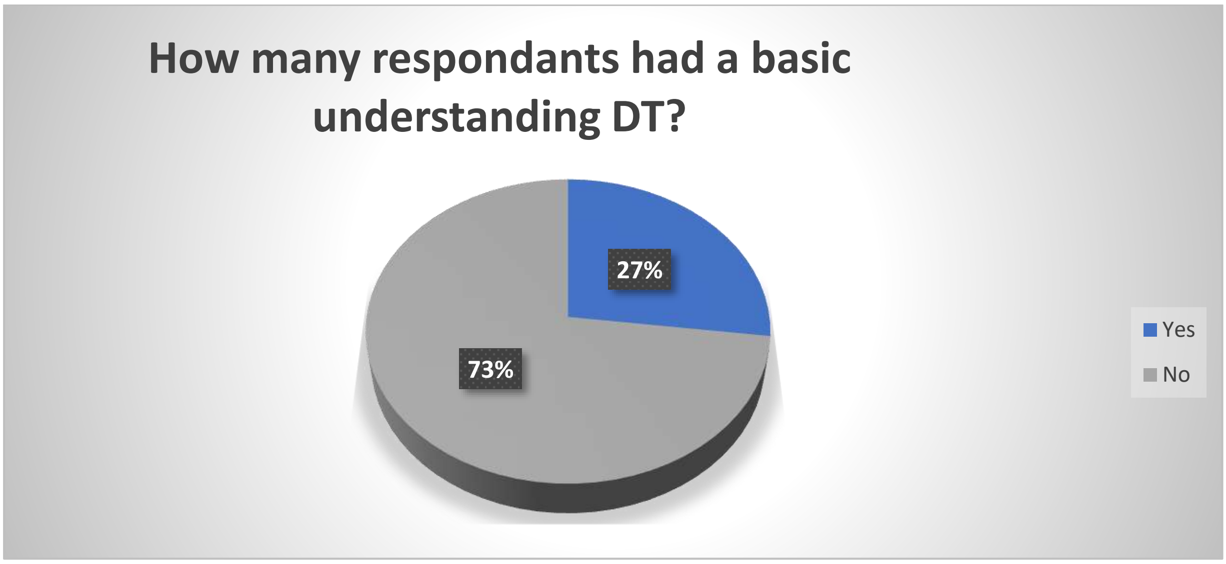


Figure 8: Basic understanding of Digital Twin among respondents



4.2.2 Objective 2:

In order to accomplish the second study goal, a questionnaire survey was administered. The survey was divided into two sections: a demographic component and a piece asking questions about the difficulties practitioners were having implementing digital twins. Ten questions made up the questionnaire; 40 of the 110 that were sent to experts in the construction sector were completed and returned.

4.2.2.1 Demographics of Respondents:

Out of the 40 replies, 24 came from public or government agencies, 14 from businesses in the private sector, and 2 from other sources. The respondents were employed by various government agencies in Balochistan, including the Works & Services Department, PHE (Public Health Engineering), Irrigation Department, WAPDA (Water & Power Development Authority), NLC (National Logistic Cell), NHA (National Highway Authority), Municipal Corporation, Balochistan Local Government, P & DD (Planning & Development Department), and private consultancies and firms.

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Figure 9: Questionnaire distribution

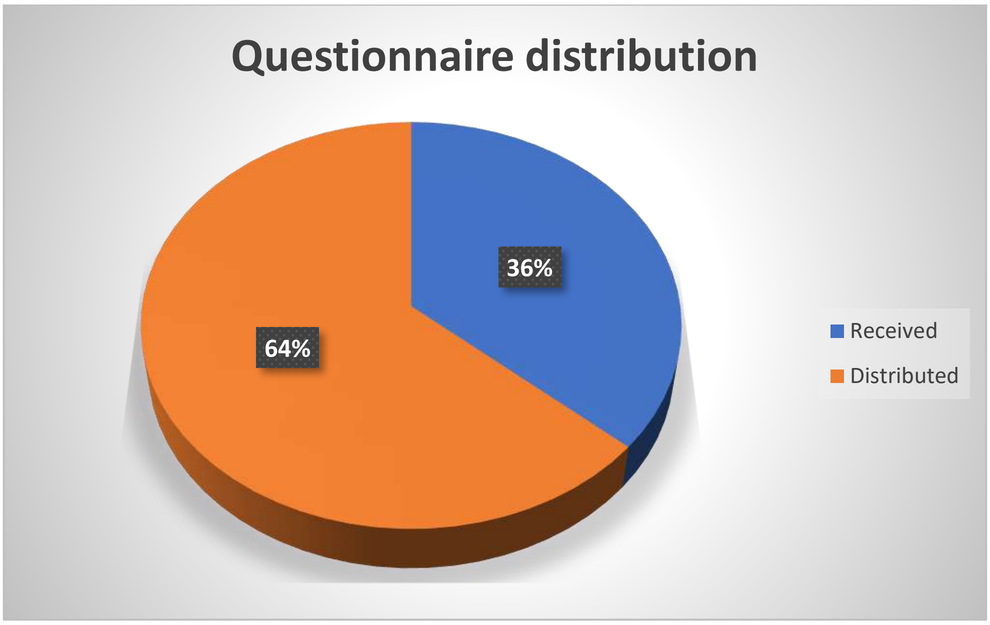


Figure 10: Designation of respondents

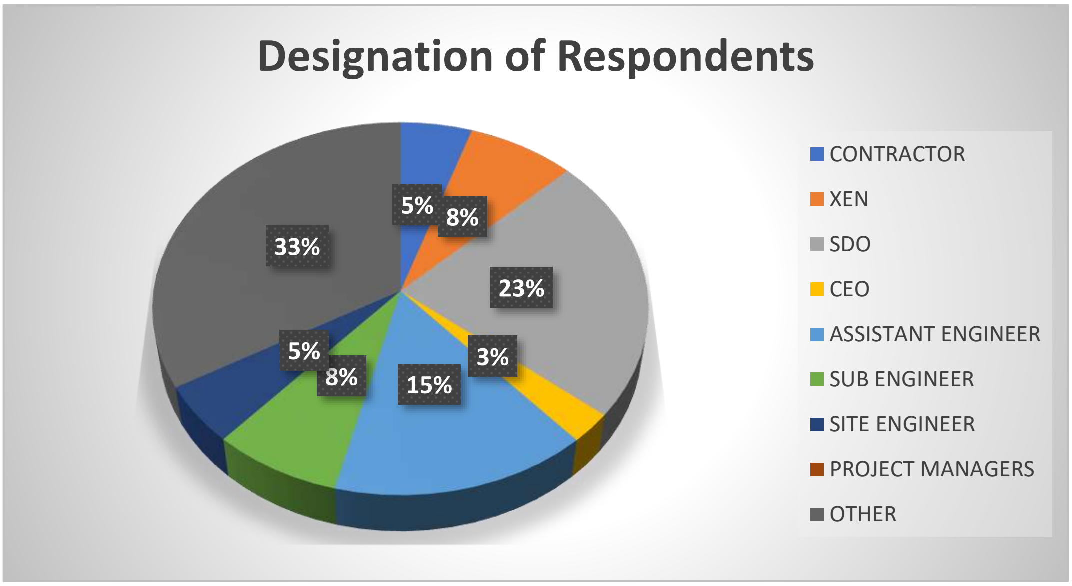


Figure 11: Qualification of respondents

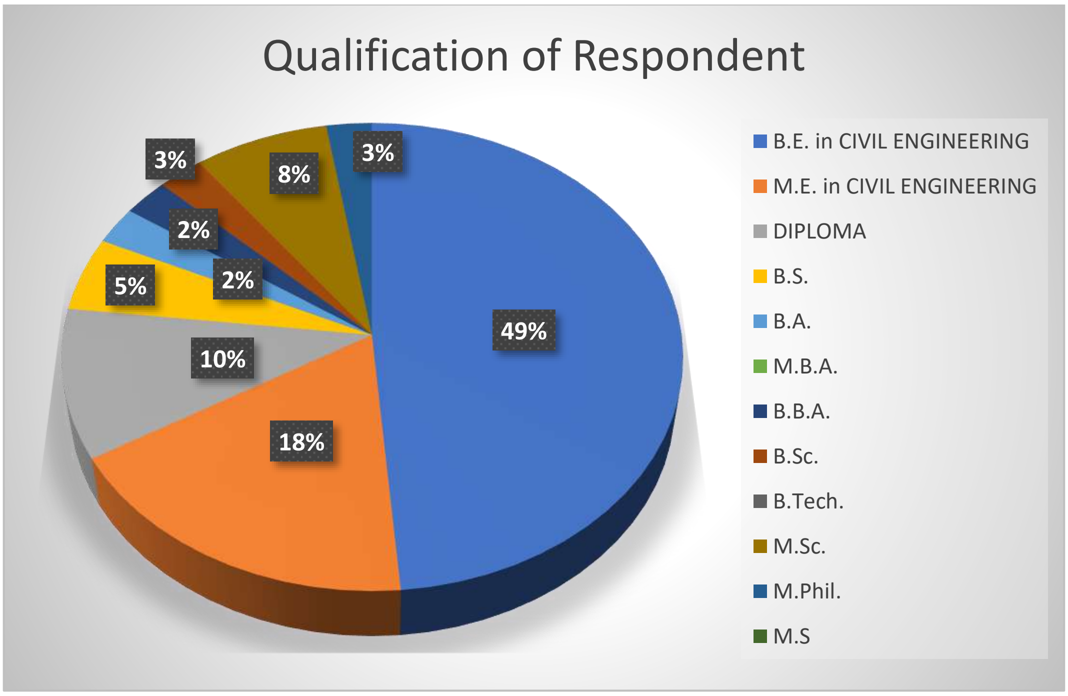


Figure 12: Experience of respondents

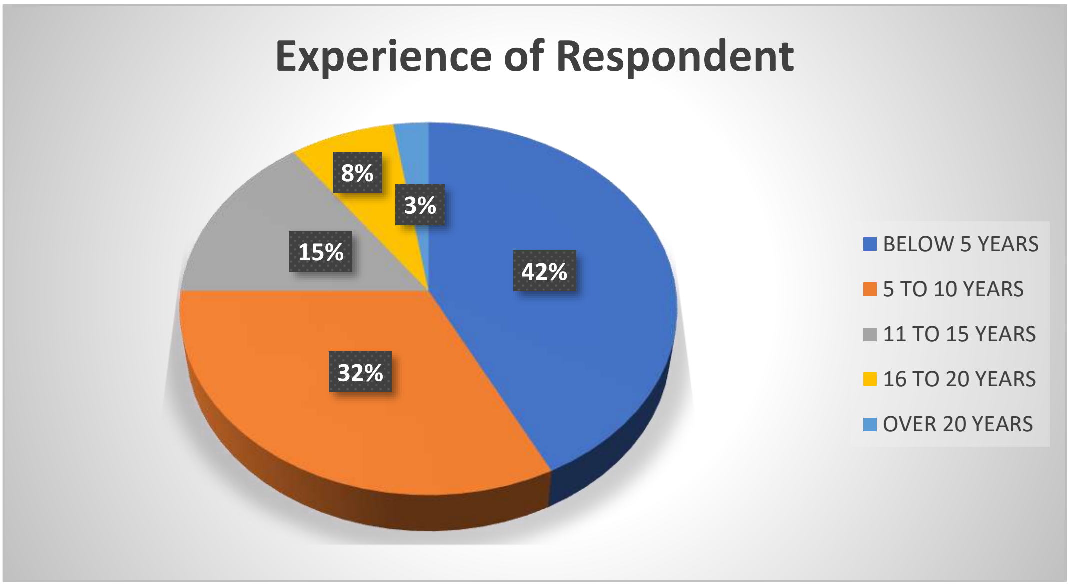
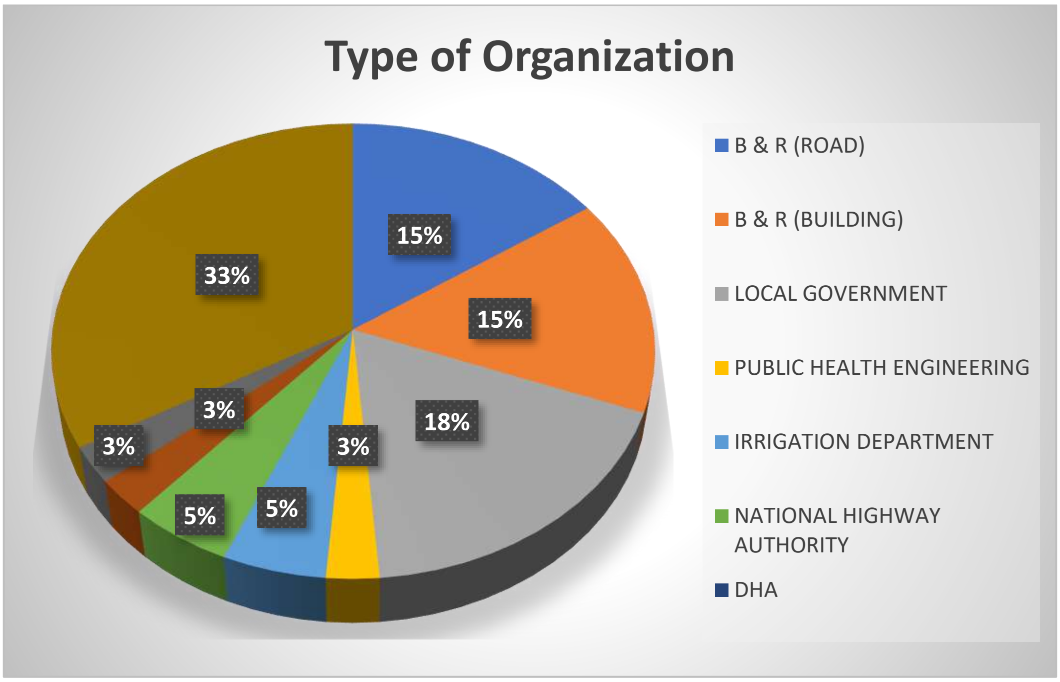


Figure 13: Type of organizations



4.2.2.2 Results and Discussions:

Ten questions on the Challenges in using DT in the construction sector were created and sent as part of a questionnaire to find out what those difficulties were. MS Excel was used to do further analysis on the mean scale questions after SPSS software was used for the original analysis. The entire SPSS program findings, displayed in tabular, pie chart, and bar chart formats using MS Excel

table 3:Questions regarding challenges of DT in construction industry

Sr. No.	Questions regarding Challenges of DT in Construction Industry of Pakistan	Mean	Ranking
1	DT implementation is expected to present challenges	2.99	1
2	Particular difficulties when implementing DT	2.891	2
3	DT adoption is impacted by privacy and data security concerns	2.8	3
4	Current technological infrastructure is not fully capable of supporting DT	2.74	4
5	Impacted by legislative or regulatory obstacles.	2.66	5
6	Successful implementation requires knowledge and abilities.	2.62	6
7	Financial limitations have an impact on DT adopted.	2.59	7
8	Organizational or cultural barriers slow DT adoption in construction	2.43	8
9	Adoption of DT is influenced by the availability and quality of data.	2.39	9
10	Interoperability effect DT integration in the building sector.	2.2	10

Figure 14: Percent of responses regarding Challenges in implementation of DT

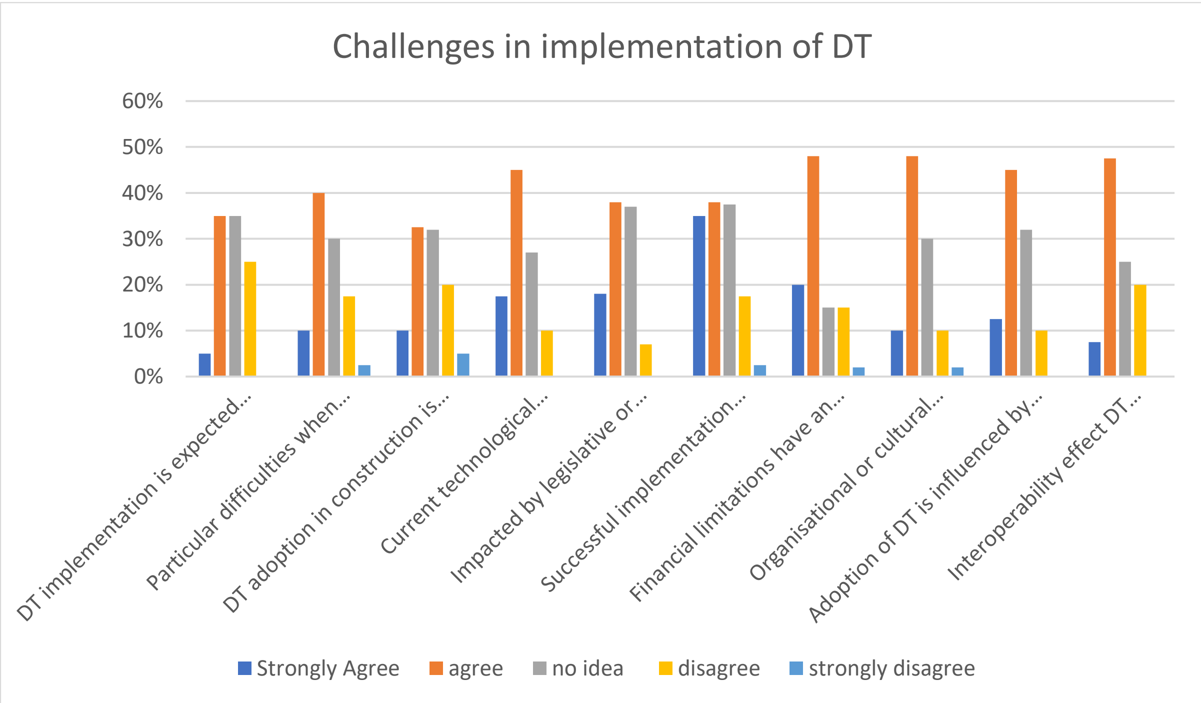
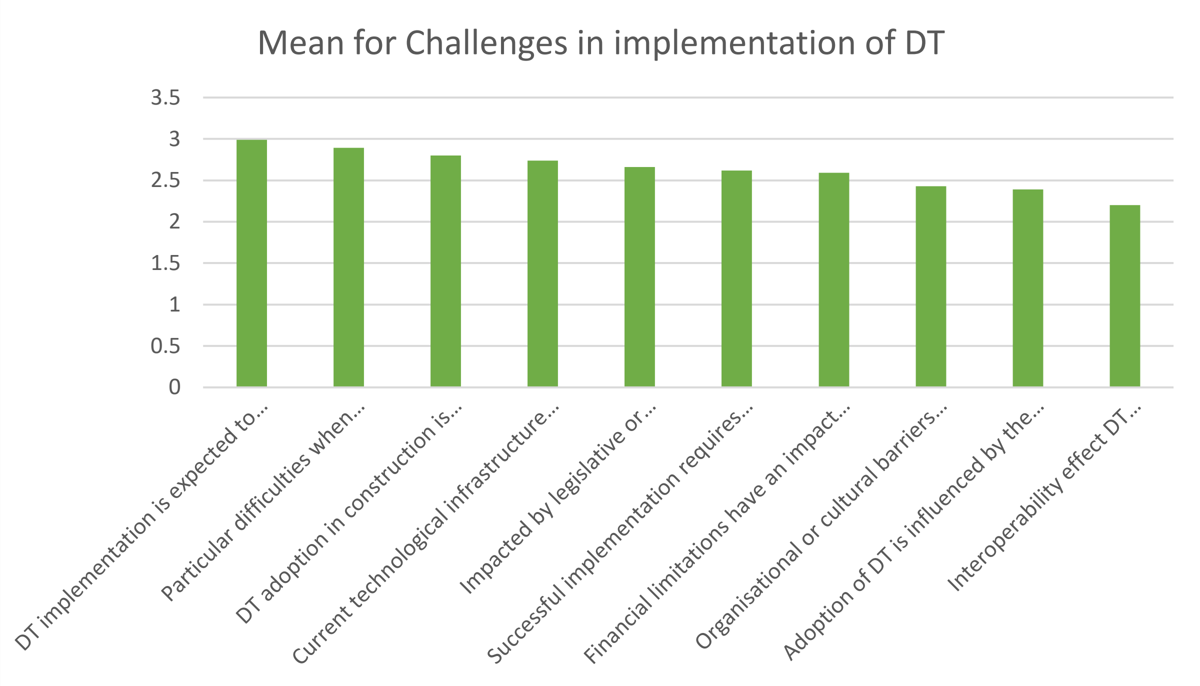


Figure 15: Ranking of questions regarding Challenges in implementation of DT



4.2.3 Objective 3:

In order to accomplish the third study goal, a questionnaire survey was administered. The survey was divided into two sections: one asking questions about demographics and the other asking about the future of digital twins in the construction sector. Ten questions made up the questionnaire; 40 of the 110 that were sent to experts in the construction sector were completed and returned.

4.2.3.1 Demographics of Respondents:

Out of the 40 replies, 24 came from public or government agencies, 14 from businesses in the private sector, and 2 from other sources. The respondents were employed by various government agencies in Balochistan, including the works & services department, PHE (public health engineering), irrigation department, WAPDA (water & power development authority), NLC (national logistic cell), NHA (national highway authority), municipal corporation, Balochistan local government, P&DD (planning & development department), and private consultancies and firms.

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Figure 16: Questionnaire distribution

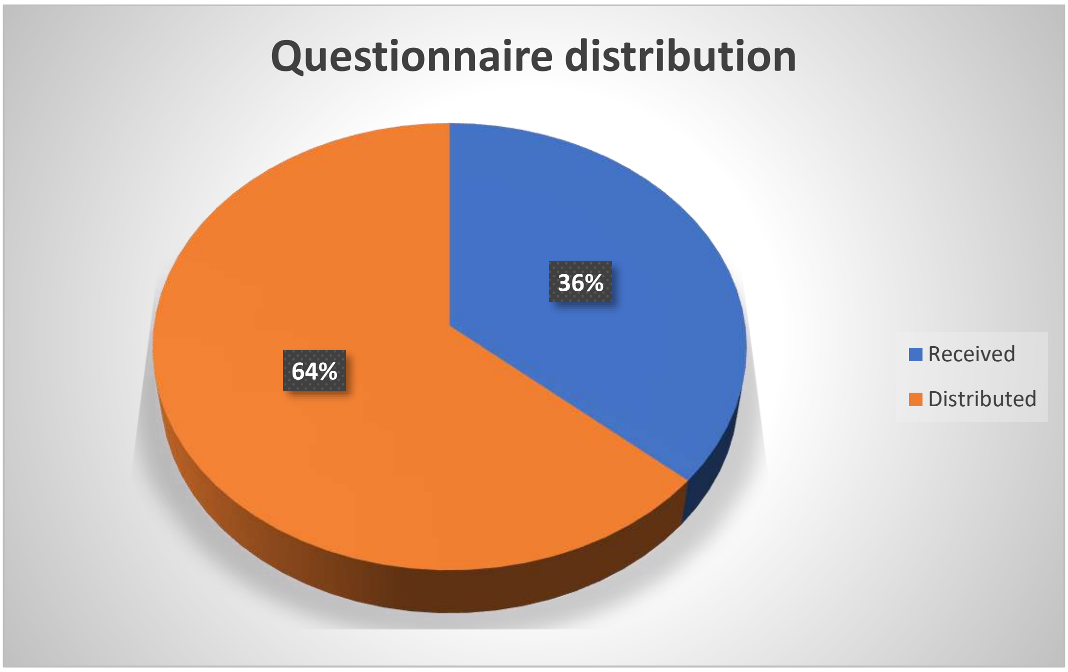


Figure 17: Designation of respondents

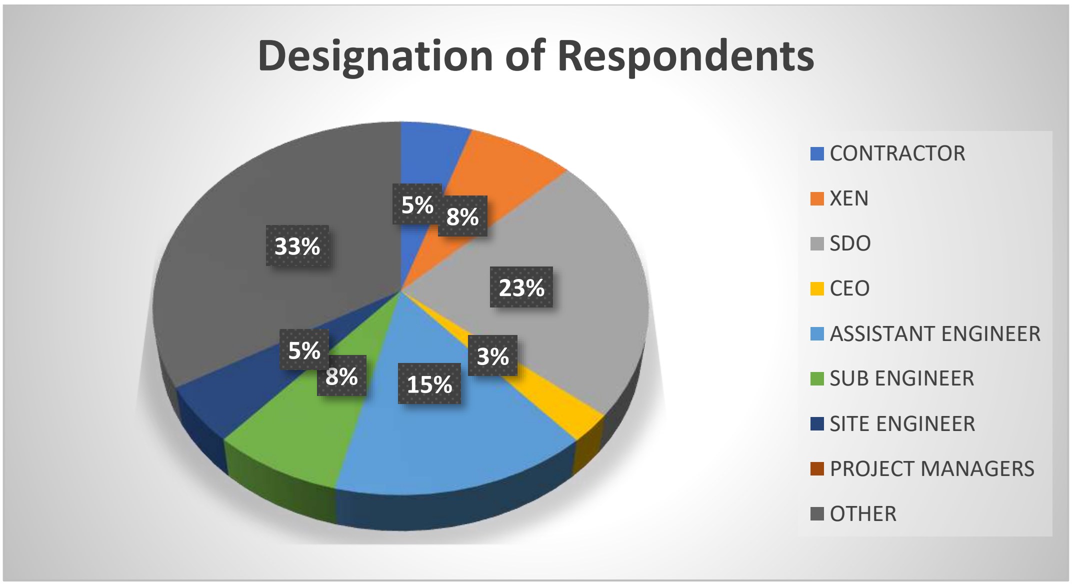


Figure 18: Qualification of respondents

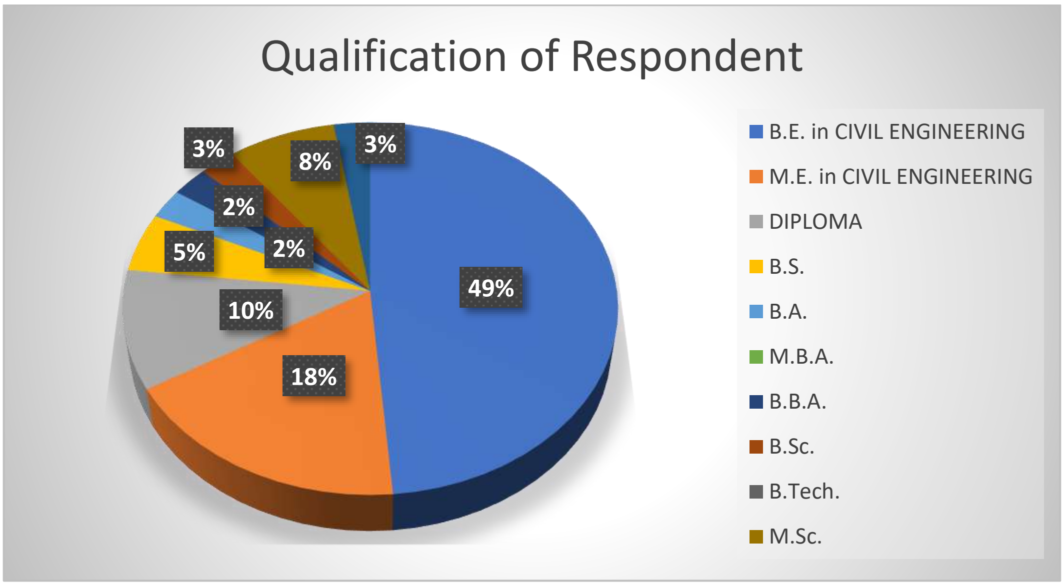


Figure 19: Experience of respondents

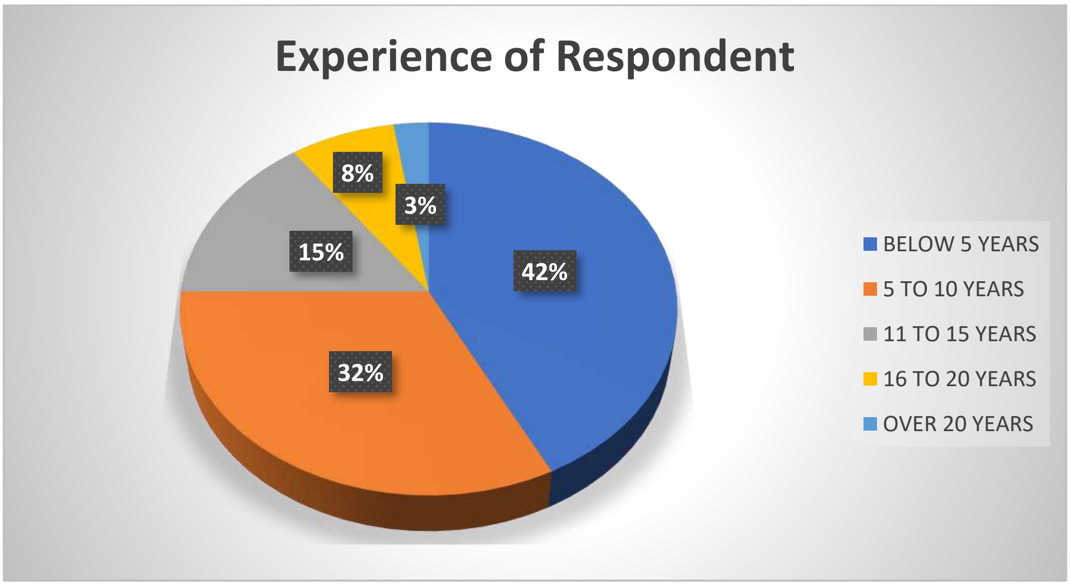
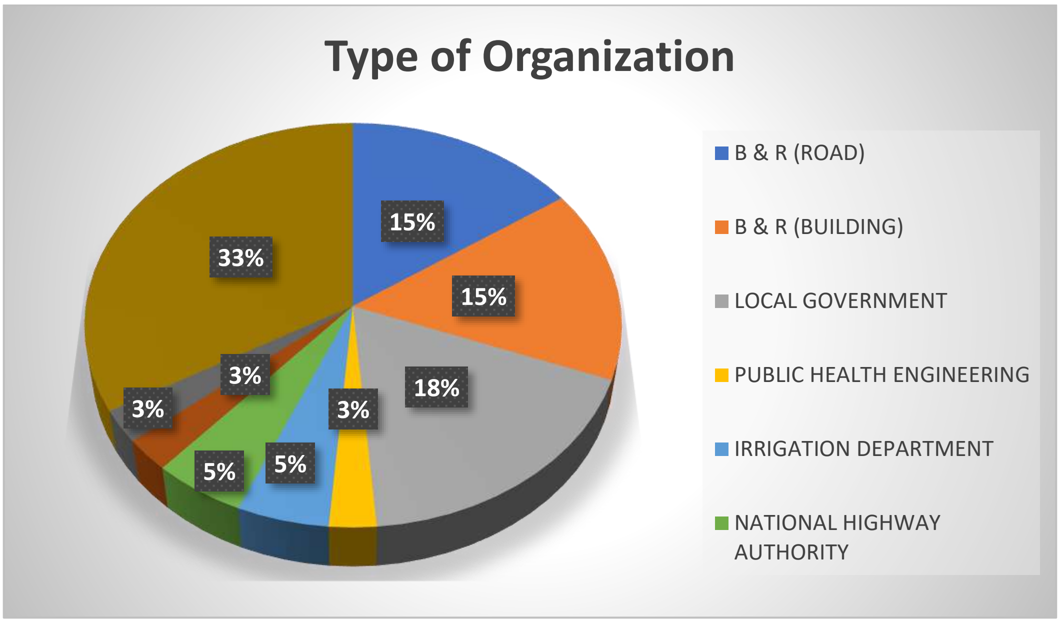


Figure 20: Type of organizations



4.2.3.2 Results and Discussions:

In order to determine the Way Forward for Digital Twin in the construction business, a questionnaire with ten questions about the topic was created and disseminated. MS Excel was used to do further analysis on the mean scale questions after SPSS software was used for the original analysis. The entire SPSS program findings, displayed in tabular, pie chart, and bar chart formats using MS Excel.

Table 4: Questions regarding Way Forward for Digital Twins in Pakistan

Sr. No.	Questions regarding Way Forward for Digital Twins in Pakistan	Mean	Ranking
1	DTs are anticipated to play crucial role in construction.	2.89	1
2	Construction will be substantially changed by DTs.	2.78	2
3	DTs are expected to be adopted in construction sector soon.	2.69	3
4	Some areas of the construction business will be impacted by DTs.	2.64	4
5	DT adoption can be promoted by government policies or incentives.	2.56	5
6	Opportunities available for research and development DT in construction.	2.42	6
7	Increase use of DTs by implementing international best practices.	2.39	7
8	DTs will impact environmental and sustainability.	2.23	8
9	Working together and exchanging knowledge will aid DT development.	2.19	9
10	Significant amount of funding is required for implementation of DTs.	1.9	10

Figure 21: Percent of responses regarding Way Forward for digital twins

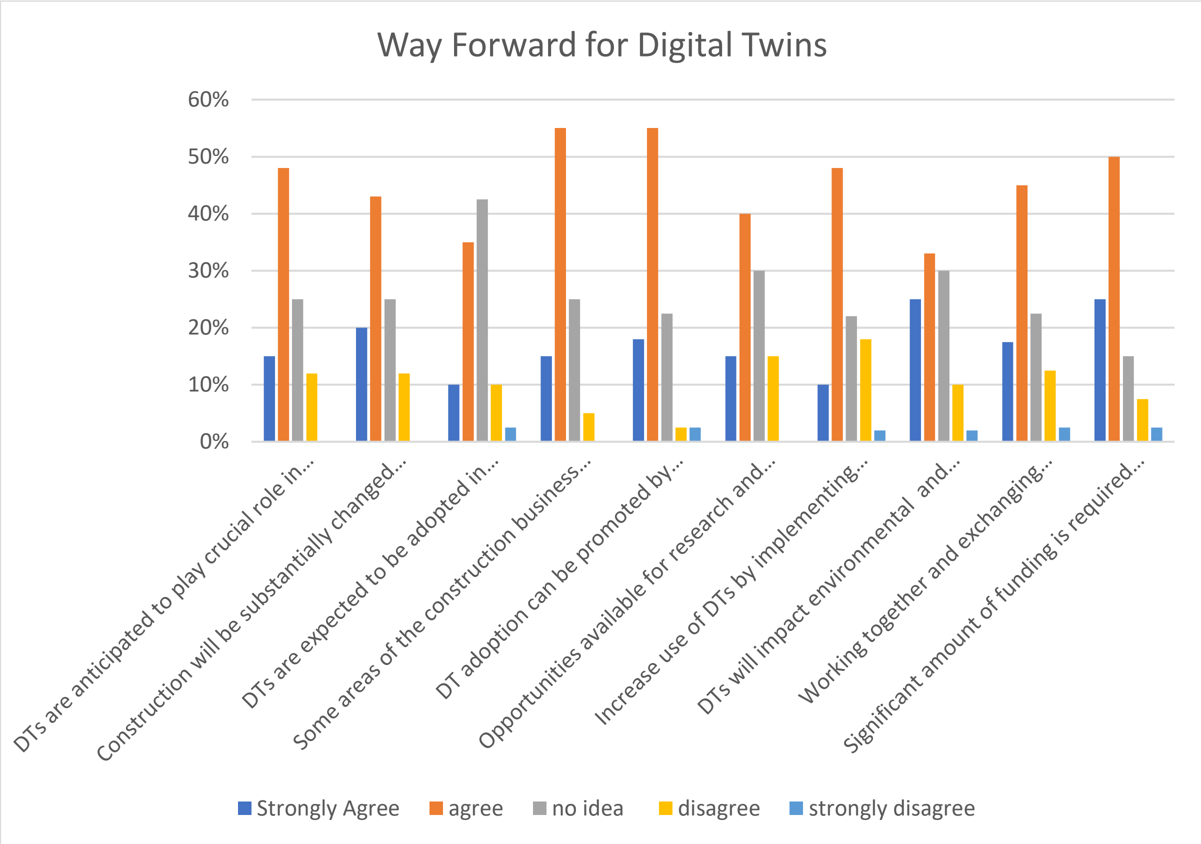
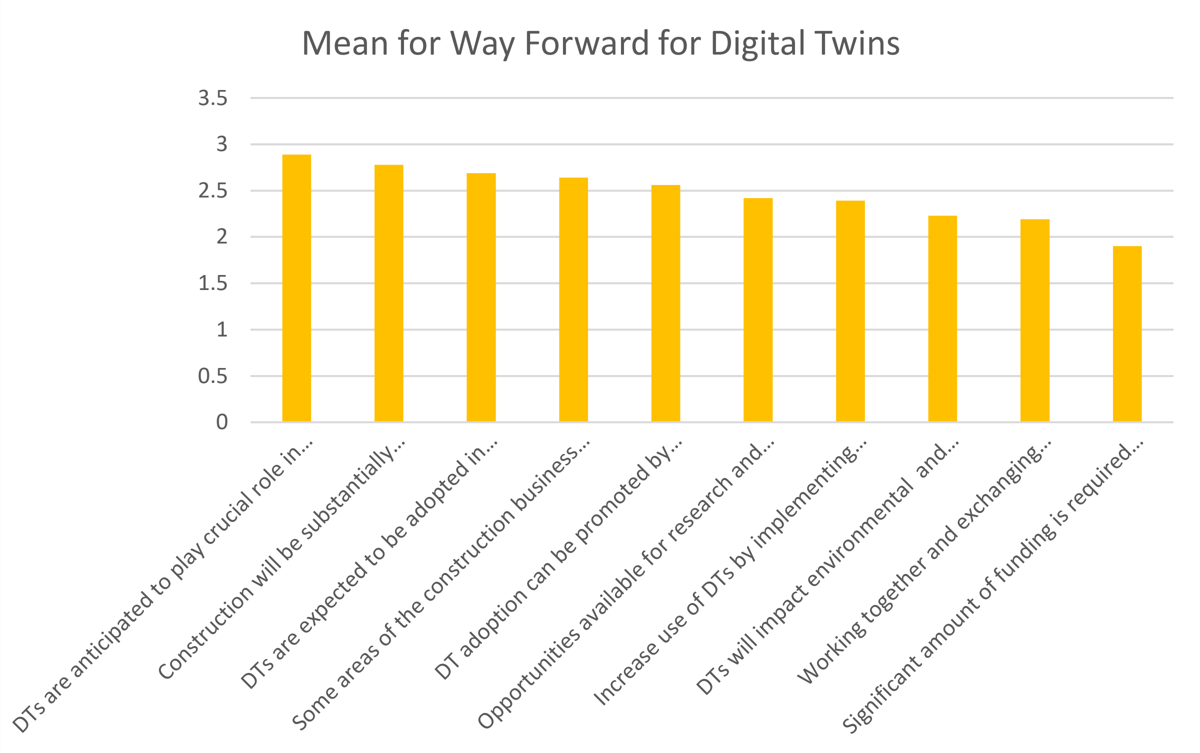


Figure 22: ranking of questions regarding Way Forward



4.3 Network and Density Visualization through VOSviewer

4.3.1 Bibliometric Analysis

1. Publication Retrieval: Using Publish or Perish software, look for papers pertaining to the project subject "**Current Status, Challenges, and Future of Digital Twin in the Construction Industry.**"

2. Data Compilation: RIS files were created from the chosen papers.

3. Text Data Analysis using VOS viewer:

Opened VOS viewer and imported the RIS file containing the text data.

4. Visualization and Analysis - Text Data: To analyze the relationships between authors and co-authors taken from the selected research articles, network and density visualizations were created using VOS VIEWER.

Figure 23: Network Visualization

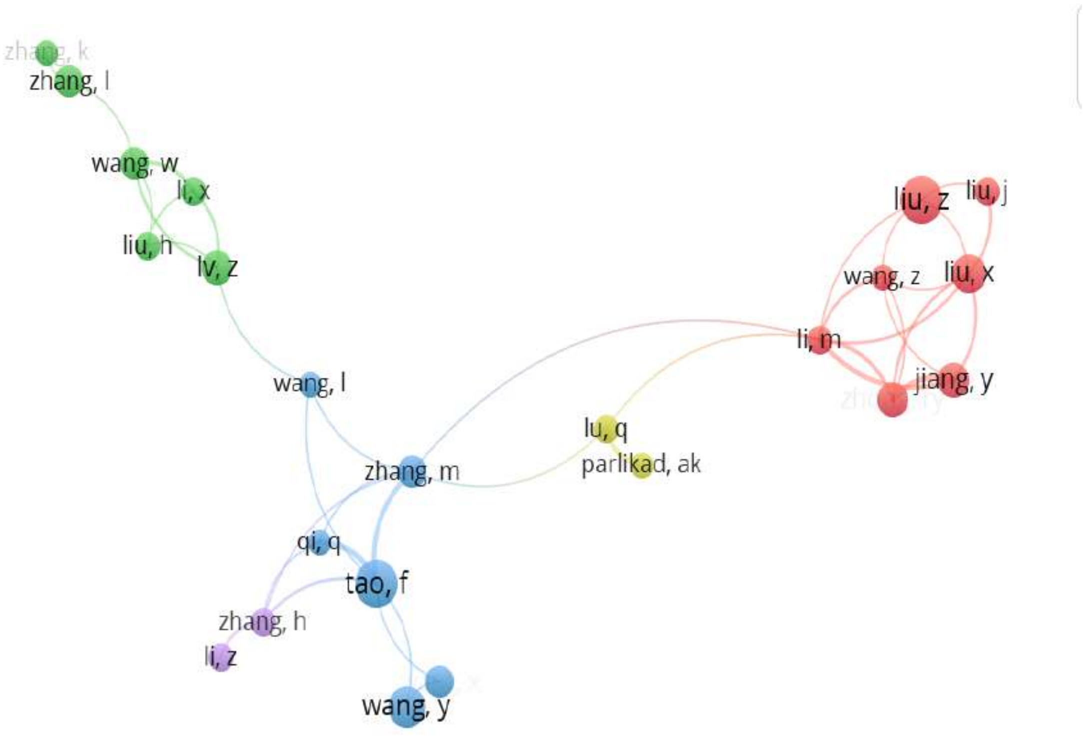
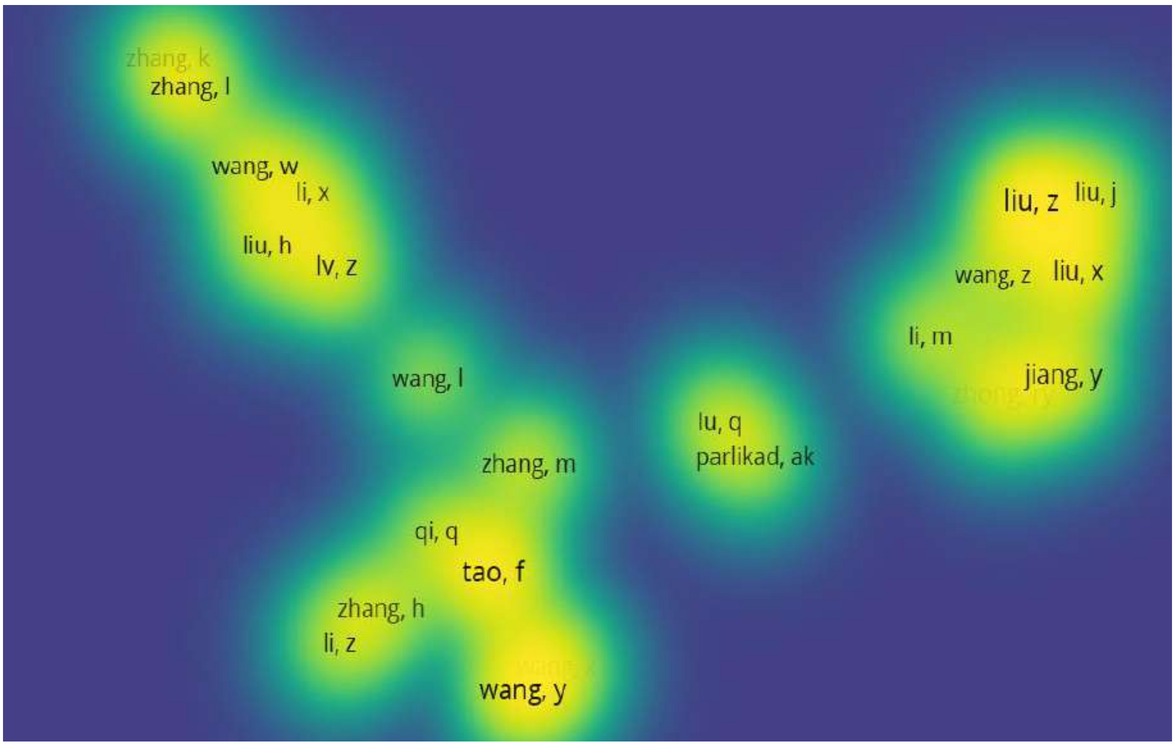


Figure 24: Density Visualization



4.3.2 Through Text Data

Data Compilation: Mendeley was used to store a selection of relevant research papers for the project.

File Conversion: Using Mendeley, converted the chosen papers into RIS file format.

VOS viewer Analysis: Opened VOS viewer and imported the text data-containing RIS file.

Visualization and Analysis: Using VOS viewer, network and density visualizations were carried out to examine the relationships between the keywords taken from the chosen research publications.

Figure 25: Network Visualization

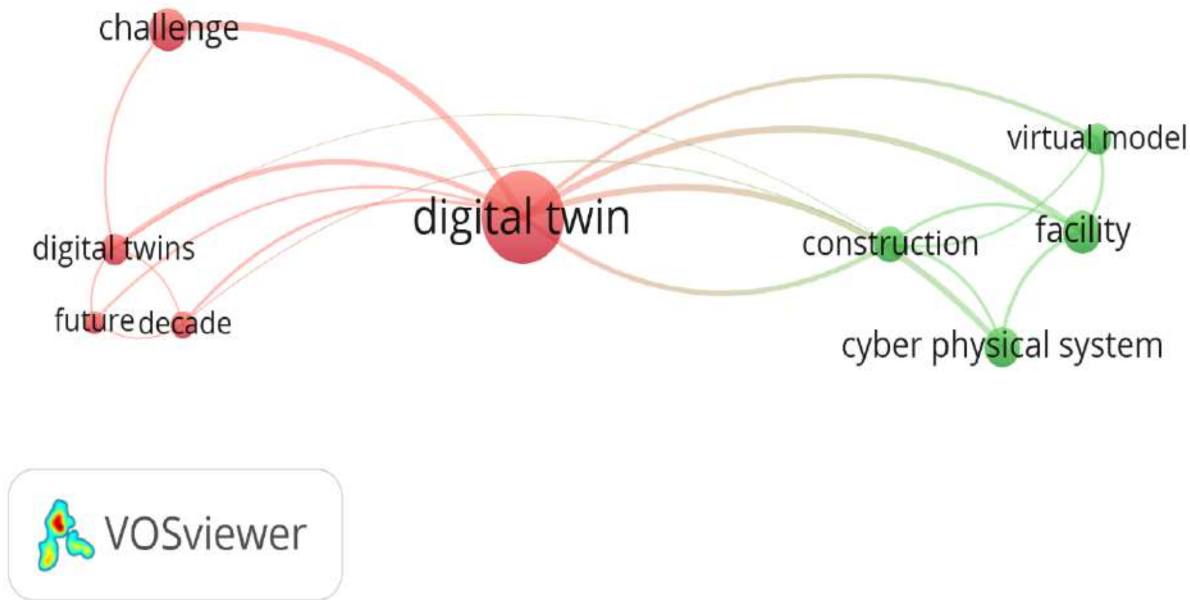
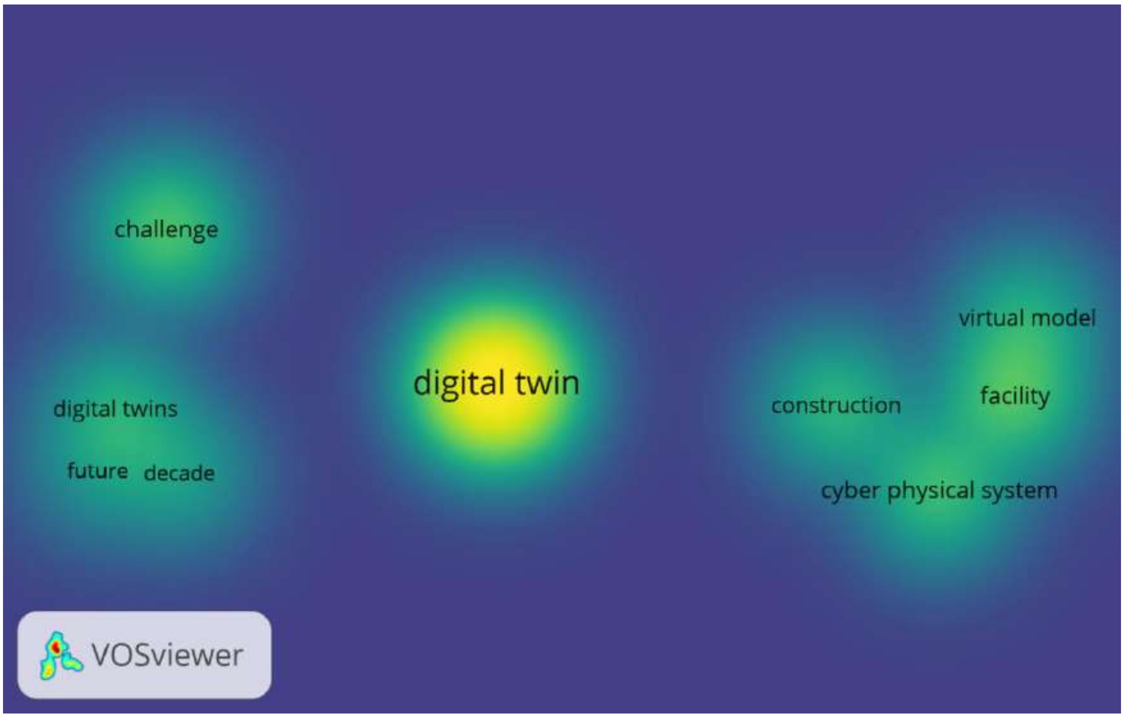


Figure 26: Density Visualization



CHAPTER 5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion:

The research study's findings lead to the following conclusion.

The study concludes that the current state of digital twin usage and understanding in Pakistan is relatively low. Professionals also lack a thorough understanding of the concept, and there are very few government policies in place to encourage the use of digital twins in Pakistan. Additionally, the number of projects incorporating digital twins is very low.

The adoption of digital twins in the construction industry is hampered by a number of issues, including privacy and data security concerns, the inadequacy of the current technological infrastructure to support DT, legislative and regulatory barriers, a lack of knowledge and skill, financial constraints, organizational and cultural barriers, data availability and quality issues, and interoperability issues. To successfully adopt, digital twins, these obstacles must be overcome by; Clearly defining data ownership and access restrictions, Making technological upgrading investments, Working together with oversight organizations, Providing training programs and Partnering with educational institutions, Creating tactics that are economical, Collaborating with technology suppliers and partners, Working together to ensure data accuracy with stakeholders, and Encouragement of a creative culture.

If the government creates policies and provides funding for research into the creation and application of digital twins, the future of digital twins in Pakistan appears to be quite promising given how quickly these technologies are transforming the construction sector. In other words, digital twins will soon be regarded as a crucial component of Pakistan's construction industry. Sustainability and the environment will benefit more from the use of digital twins

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Appendix-A

DIGITAL TWIN IN CONSTRUCTION INDUSTRY: CURRENT STATUS, CHALLENGES AND WAY FORWARD.

QUESTIONNAIRE SURVEY

AIM

The aim of this questionnaire survey is:

- To identify the Current Status of Digital Twins in Construction

CONFIDENTIALITY

All information collected in this questionnaire survey will be kept strictly confidential, no organizations or individuals will be identified in any research report, and all the information provided will be solely for the academic research

FEEDBACK OF RESULT

All the surveys are gathered and analyzed, feedback on the research results will be given upon demand to interested respondents in this study

CONTACT DETAILS

If you have any queries regarding this survey, please do not hesitate to contact:
Engr. Syed Abdullah shah on +92 3331377447 or email: engrabdullah329@gmail.com

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Name (Optional)	
Age	
Qualification	
Department	
Designation in the Department	
Years of Experience in Construction Industry	
Types of Projects (e.g., residential commercial, infrastructure etc.)	

INSTRUCTIONS

The questionnaire is in three parts
Part 1: Introduction
Part 2: Usage and Perception
Part 3: Government Initiatives and Stakeholder Impact

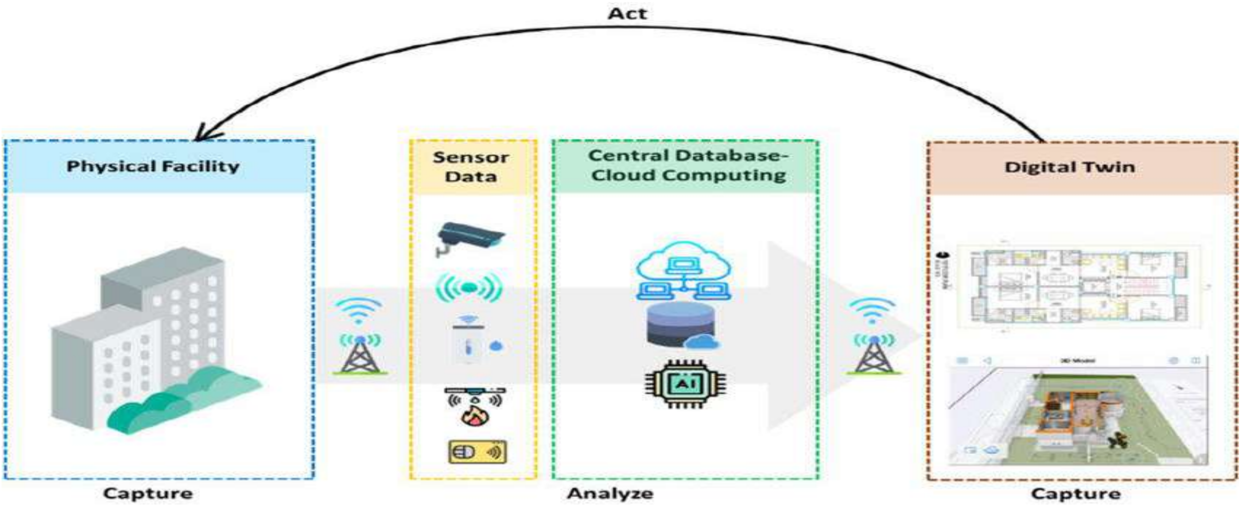
Part 1: Introduction

Q 1. Do you have a basic understanding of digital twins in the construction industry? **(Yes/No)**

If no, please read the following definition and explanation:

Digital twins in the construction industry are virtual models that mirror physical buildings, infrastructure, or projects. These models incorporate real-time data from sensors and various sources, enabling stakeholders to monitor, analyze, and simulate various aspects of the project. They help in making informed decisions, enhancing efficiency, and improving overall project outcomes. (Modeling in CAD is a part of development of Digital twins)

The Following figure depicts the working of Digital Twins in Construction Industry.



Part 2: Usage and Perception

Note: Please in a scale of 5-1 points (decreasing order); respond to the following questions by ticking [√] the appropriate cell

5. Strongly Disagree 4. Disagree 3. No Idea 2. Agree 1. Strongly Agree

S#		Ratings				
1.	The construction sector regularly uses digital twins in day-to-day operations.	**5**	**4**	**3**	**2**	**1**
2.	Digital twins are utilized in our building projects.	**5**	**4**	**3**	**2**	**1**
3.	In Pakistan, building sector uses digital twins as normal procedure.	**5**	**4**	**3**	**2**	**1**
4.	The application of digital twins in the construction industry has shown to have several advantages.	**5**	**4**	**3**	**2**	**1**
5.	The cost and time efficiency of project management are positively impacted by digital twins.	**5**	**4**	**3**	**2**	**1**

Part 3: Government Initiatives and Stakeholder Impact

Note: Please in a scale of 5-1 points (decreasing order); respond to the following questions by ticking [√] the appropriate cell

5. Strongly Disagree 4. Disagree 3. No Idea 2. Agree 1. Strongly Agree

S#		Ratings				
1.	In Pakistan, policies and initiatives from the government encourage the use of digital twins in building.	**5**	**4**	**3**	**2**	**1**
2.	Digital twins have been successfully implemented in notable projects in Pakistan.	**5**	**4**	**3**	**2**	**1**
3.	The application of digital twins is being advanced in large part by education and training.	**5**	**4**	**3**	**2**	**1**
4.	Digital twins are not widely used in Pakistan's construction industry due to various challenges and barriers.	**5**	**4**	**3**	**2**	**1**
5.	Digital twins facilitate improved stakeholder collaboration on projects.	**5**	**4**	**3**	**2**	**1**

Appendix-B

DIGITAL TWIN IN CONSTRUCTION INDUSTRY: CURRENT STATUS, CHALLENGES AND WAY FORWARD.

QUESTIONNAIRE SURVEY

AIM

The aim of this questionnaire survey is:

- To identify the Challenges in Implementing Digital Twins in the Construction Industry.

CONFIDENTIALITY

All information collected in this questionnaire survey will be kept strictly confidential, no organizations or individuals will be identified in any research report, and all the information provided will be solely for the academic research

FEEDBACK OF RESULT

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Name (Optional)	
Age	
Qualification	
Department	
Designation in the Department	
Years of Experience in Construction Industry	
Types of Projects (e.g., residential commercial, infrastructure etc.)	

INSTRUCTIONS

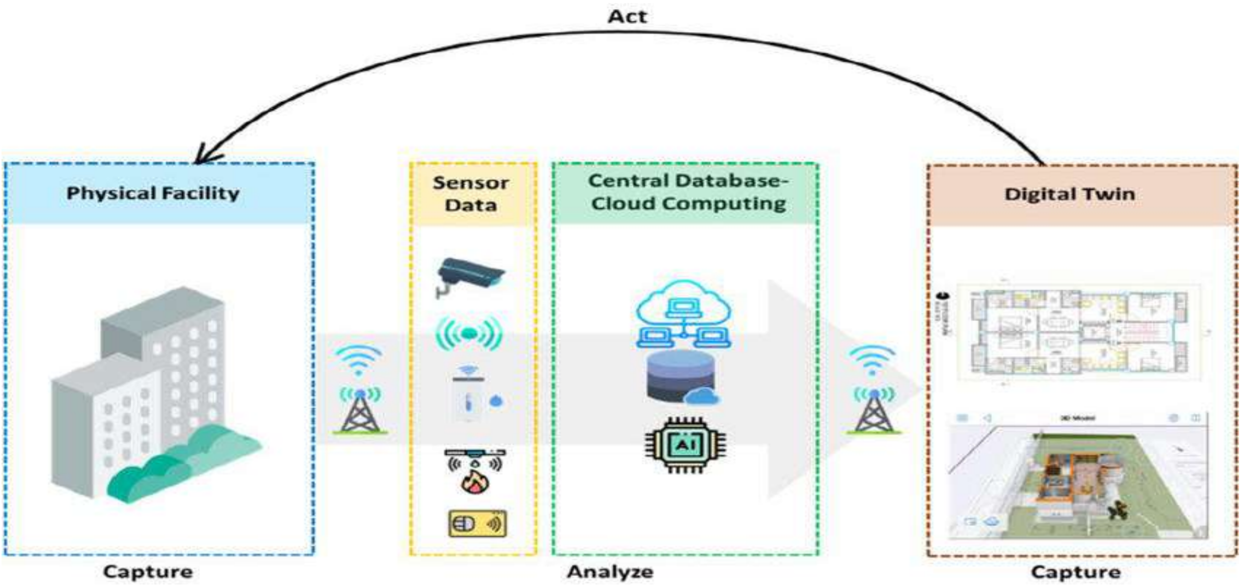
The questionnaire is in three parts
Part 1: Introduction
Part 2: Anticipated Challenges and Expertise
Part 3: Financial, Organizational, and Data-Related Challenges

Part 1: Introduction

Q 1. Do you have a basic understanding of digital twins in the construction industry? **(Yes/No)**

If no, please read the following definition and explanation:

Digital twins in the construction industry are virtual models that mirror physical buildings, infrastructure, or projects. These models incorporate real-time data from sensors and various sources, enabling stakeholders to monitor, analyze, and simulate various aspects of the project. They help in making informed decisions, enhancing efficiency, and improving overall project outcomes. (Modeling in CAD is a part of development of Digital twins). The Following figure depicts the working of Digital Twins in Construction Industry.



Part 2: Anticipated Challenges and Expertise

Note: Please in a scale of 5-1 points (decreasing order); respond to the following questions by ticking [√] the appropriate cell

5. Strongly Disagree 4. Disagree 3. No Idea 2. Agree 1. Strongly Agree

S#		Ratings				
1.	Digital twin implementation is expected to present some challenges in the construction sector.	**5**	**4**	**3**	**2**	**1**
2.	There have been particular difficulties when implementing digital twins in projects.	**5**	**4**	**3**	**2**	**1**
3.	Digital twin adoption in construction is impacted by privacy and data security concerns.	**5**	**4**	**3**	**2**	**1**
4.	Pakistan's current technological infrastructure is not fully capable of supporting digital twins.	**5**	**4**	**3**	**2**	**1**
5.	The application of digital twins in building projects is impacted by legislative or regulatory obstacles.	**5**	**4**	**3**	**2**	**1**

Part 3: Financial, Organizational, and Data-Related Challenges

Note: Please in a scale of 5-1 points (decreasing order); respond to the following questions by ticking [√] the appropriate cell

5. Strongly Disagree 4. Disagree 3. No Idea 2. Agree 1. Strongly Agree

S#		Ratings				
1.	Implementing a digital twin successfully requires knowledge and abilities.	**5**	**4**	**3**	**2**	**1**
2.	Financial limitations have an impact on how widely digital twins are adopted.	**5**	**4**	**3**	**2**	**1**
3.	Organizational or cultural barriers slow digital twin adoption in construction companies.	**5**	**4**	**3**	**2**	**1**
4.	Successful adoption of digital twins is significantly influenced by the availability and quality of data.	**5**	**4**	**3**	**2**	**1**
5.	Interoperability concerns have an effect on how digital twins are integrated in the building sector.	**5**	**4**	**3**	**2**	**1**

Appendix-C

DIGITAL TWIN IN CONSTRUCTION INDUSTRY: CURRENT STATUS, CHALLENGES AND WAY FORWARD.

QUESTIONNAIRE SURVEY

AIM

The aim of this questionnaire survey is:

- ➢ To identify the Way Forward for Digital Twins in Pakistan's Construction Industry.

CONFIDENTIALITY

All information collected in this questionnaire survey will be kept strictly confidential, no organizations or individuals will be identified in any research report, and all the information provided will be solely for the academic research

FEEDBACK OF RESULT

All the surveys are gathered and analyzed, feedback on the research results will be given upon demand to interested respondents in this study

CONTACT DETAILS

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Personal Information	
Name (Optional)	
Age	
Qualification	
Department	
Designation in the Department	
Years of Experience in Construction Industry	
Types of Projects (e.g., residential commercial, infrastructure etc.)	

INSTRUCTIONS

The questionnaire is in three parts
Part 1: Introduction
Part 2: Future Expectations and Transformation
Part 3: Government Role, Opportunities, and Investment

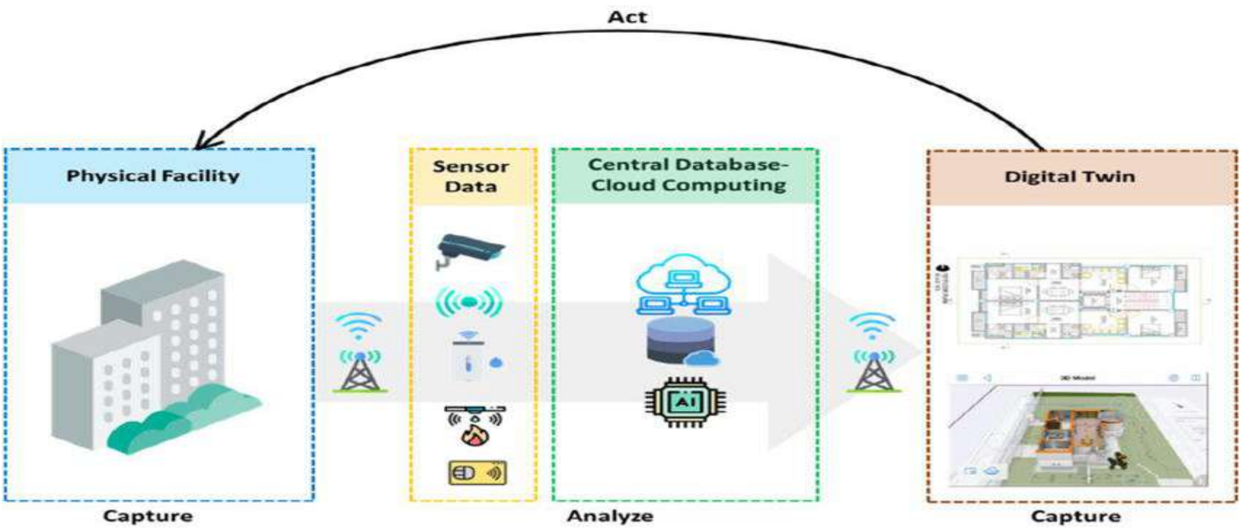
Part 1: Introduction

Q 1. Do you have a basic understanding of digital twins in the construction industry? **(Yes/No)**

If no, please read the following definition and explanation:

Digital twins in the construction industry are virtual models that mirror physical buildings, infrastructure, or projects. These models incorporate real-time data from sensors and various sources, enabling stakeholders to monitor, analyze, and simulate various aspects of the project. They help in making informed decisions, enhancing efficiency, and improving overall project outcomes. (Modeling in CAD is a part of development of Digital twins)

The Following figure depicts the working of Digital Twins in Construction Industry.



Part 2: Future Expectations and Transformation

Note: Please in a scale of 5-1 points (decreasing order); respond to the following questions by ticking [√] the appropriate cell

5. Strongly Disagree 4. Disagree 3. No Idea 2. Agree 1. Strongly Agree

S#		**Ratings**				
1.	In the near future, digital twins are anticipated to play a crucial role in Pakistan's construction sector.	**5**	**4**	**3**	**2**	**1**
2.	Pakistani construction will be substantially changed by digital twins.	**5**	**4**	**3**	**2**	**1**
3.	Digital twins are expected to be widely adopted in Pakistan's construction sector soon.	**5**	**4**	**3**	**2**	**1**

Part 3: Government Role, Opportunities, and Investment

Note: Please in a scale of 5-1 points (decreasing order); respond to the following questions by ticking [√] the appropriate cell

5. Strongly Disagree 4. Disagree 3. No Idea 2. Agree 1. Strongly Agree

S#		**Ratings**				
1.	There will be more of an impact from digital twins in some areas of the construction business.	**5**	**4**	**3**	**2**	**1**
2.	Digital twin adoption in construction projects can be successfully promoted by government policies or incentives.	**5**	**4**	**3**	**2**	**1**
3.	In Pakistan, there are many opportunities for research and development in the area of digital twins for construction.	**5**	**4**	**3**	**2**	**1**
4.	Pakistan can increase the use of digital twins by implementing international best practices.	**5**	**4**	**3**	**2**	**1**
5.	In Pakistan's construction sector, digital twins will have a big impact on environmental impact and sustainability.	**5**	**4**	**3**	**2**	**1**
6.	Industry professionals working together and exchanging knowledge will aid digital twin development in Pakistan.	**5**	**4**	**3**	**2**	**1**
7.	For the construction industry in Pakistan to widely adopt digital twins, a significant amount of funding is required.	**5**	**4**	**3**	**2**	**1**

DIGITAL TWINS IN THE CONSTRUCTION INDUSTRY: CURRENT STATUS, CHALLENGES AND WAY FORWARD

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