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USE OF INNOVATIVE TECHNOLOGIES FOR CONSTRUCTION PROJECT MANAGEMENT: IMPLICATIONS FOR SUSTAINABLE PROJECTS

Houljakbe Houlteurbe DAGOU

DOCTOR OF PHILOSOPHY THESIS
Department of Civil Engineering
ProgramofCivilEngineering(English)

Supervisor
Prof. Dr. Aslı Pelin GÜRGÜN

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A thesis submitted by Houljakbe Houlteurbe DAGOU in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** is approved by the committee on 08.07.2025 in Department of Civil Engineering, Program of Civil Engineering (English).

Prof. Dr. Aslı Pelin GÜRGÜN
Yildiz Technical University
Supervisor

Approved By the Examining Committee

Prof. Dr. Aslı Pelin GÜRGÜN, Supervisor
Yildiz Technical University _____

Prof. Dr. Pelin ÖZENER, Member
Yildiz Technical University _____

Asoc. Prof. Kerim KOÇ, Member
Yildiz Technical University _____

Prof. Dr. Gül Polat TATAR, Member
Istanbul Technical University _____

Asoc. Prof. Dr. Cenk BUDAYAN, Member
Middle East Technical University _____

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Houljakbe Houlteurbe DAGOU

Signature

"To my beloved wife, my cherished family, dear friends, and everyone who has stood by me throughout this incredible journey, your unwavering support has made it all the more meaningful."

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Houljakbe Houlteurbe DAGOU

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LIST OF ABBREVIATIONS

AEC	Architecture, Engineering, and Construction
AI	Artificial Intelligence
AR	Augmented Reality
BD	Building Design
BIM	Building Information Modeling
BREEAM	Building Research Establishment Environmental Assessment Method
CAD	Computer-Aided Design
CPS	Correlation with Project Success
CS	Challenges and Solutions
DMF	Decision-Making Factors
ECCA	Environmental Conservation and Climate Action
EDGE	Excellence in Design for Greater Efficiencies
EFA	Exploratory Factor Analysis
EPMS	Evaluation of Project Management Software
ESIA	Environmental and Social Impact Assessment
FA	Factor Analysis
FET	Forecasting Emerging Technologies
GDP	Gross Domestic Product
GIS	Geographic Information Systems / Governance and Institutional Support
ICTs	Information and Communication Technologies
IDI	Infrastructure Development and Innovation
IDP	Innovation Decision Process

IDT	Innovation Diffusion Theory
IIT	Integration of Innovative Technologies
IoT	Internet of Things
IT	Information Technology
KMO	Kaiser-Meyer-Olkin
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
PAF	Principal Axis Factoring
PCA	Principal Component Analysis
PND	National Development Plan
PPE	Personal Protective Equipment
PMS	Project Management Software
RAD	Rapid Application Development
RESP	Resource Efficiency and Sustainable Practices
SC	Sustainability in Construction
SDGs	Sustainable Development Goals
SEED	Social Equity and Economic Development
SMEs	Small and Medium-sized Enterprises
SRMI	Safety and Risk Management Improvement
SUHD	Sustainable Urbanization and Habitat Development
TAM	Technology Acceptance Model
VR	Virtual Reality

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ABSTRACT

Use of Innovative Technologies for Construction Project Management: Implications for Sustainable Projects

Houljakbe Houlteurbe DAGOU

Department of Civil Engineering
Doctor of Philosophy Thesis

Supervisor: Prof. Dr. Aslı Pelin GÜRGÜN

This dissertation investigates the potential of innovative technologies to significantly enhance construction project management and contribute to sustainable development in Chad. As one of the least digitalized industries in the country, the construction sector is beset by long-term issues of low productivity, cumbersome collaboration, cost overruns, and lax environmental oversight. Considering these challenges, this research aims to explore the potential of digital technologies, including Building Information Modeling (BIM), Artificial Intelligence (AI), the Internet of Things (IoT), drones, and project management software, to address these challenges. These tools have the power to optimize project delivery and enhance sustainability, with a specific goal of aligning with the United Nations Sustainable Development Goals (SDGs). A quantitative research methodology was employed, and an online, structured questionnaire was used. The sample was composed mainly of professionals directly involved in construction projects in Chad, including engineers (49.1%), architects (27.5%), and project managers (23.4%). These individuals were chosen for their expertise and experience in the field, providing valuable insights into the potential of digital technologies in the construction industry. A total of seventy-nine survey responses were obtained, and a Principal Axis Factoring (PAF) method was employed to extract factors that affect the technology adoption and sustainable performance factors common to the construction industry in Chad. The study's results reveal a significant level of awareness about new technologies in the construction industry in

Chad, with 84.4% of respondents indicating familiarity. However, the application of these technologies in actual projects remains low, at 38.9%. The anticipated benefits of technology adoption are substantial, including improved cost and time management (76.6%), enhanced collaboration (64.7%), and better environmental performance (59.3%). Despite these promising prospects, barriers to adoption persist, including a lack of digital skills training (71.3%), high implementation costs (66.5%), and a dearth of institutional support (54.1%). Importantly, 61.7% of respondents believe these technologies can be pivotal in supporting Chad's efforts to achieve Sustainable Development Goals (SDGs). It offers the first theoretically informed model for studying digital innovation in the construction industry in Chad. It provides specific recommendations for policymakers, the development community, and industry stakeholders seeking to transform the industry through sustainable, technology-enabled strategies tailored to the country's distinctive social and economic realities.

Keywords: Innovative Technologies, Construction Project Management, Sustainability, Digital Transformation, Sustainable Development Goals (SDGs)

ÖZET

İnşaat Projesi Yönetiminde Yenilikçi Teknolojilerin Kullanımı: Sürdürülebilir Projeler İçin Sonuçlar

Houljakbe Houlteurbe DAGOU

İnşaat Mühendisliği Bölümü
Doktora Tezi

Danışman: Prof. Dr. Aslı Pelin GÜRGÜN

Bu tez, yenilikçi teknolojilerin Çad'daki inşaat projelerinin yönetimini önemli ölçüde geliştirme ve sürdürülebilir kalkınmaya katkıda bulunma potansiyelini araştırmaktadır. Ülkedeki en az dijitalleşmiş sektörlerden biri olan inşaat sektörü, düşük verimlilik, karmaşık iş birliği süreçleri, maliyet aşımları ve zayıf çevresel denetim gibi uzun vadeli sorunlarla karşı karşıyadır. Bu zorluklar göz önünde bulundurularak, araştırma; Yapı Bilgi Modellemesi (BIM), Yapay Zeka (AI), Nesnelerin İnterneti (IoT), dronlar ve proje yönetim yazılımları dahil olmak üzere dijital teknolojilerin bu sorunların çözümüne katkı sağlama potansiyelini keşfetmeyi amaçlamaktadır. Bu araçlar, proje teslimatını optimize etme ve sürdürülebilirliği artırma gücüne sahiptir ve Birleşmiş Milletler Sürdürülebilir Kalkınma Amaçları (SKA) ile uyum sağlamak gibi belirli bir hedefi vardır. Araştırmada nicel bir yöntem benimsenmiş ve yapılandırılmış bir çevrim içi anket kullanılmıştır. Örneklem, Çad'daki inşaat projelerinde doğrudan görev alan mühendisler (%49,1), mimarlar (%27,5) ve proje yöneticileri (%23,4) gibi profesyonellerden oluşmuştur. Bu kişiler, alanlarındaki uzmanlıkları ve deneyimleri dolayısıyla dijital teknolojilerin inşaat sektöründeki potansiyelini değerlendirmek için seçilmiştir. Toplam yetmiş dokuz yanıt elde edilmiştir ve Çad inşaat sektöründe teknoloji benimsemesini ve sürdürülebilir performansı etkileyen faktörleri ortaya çıkarmak için Temel Eksen Faktörleştirme (PAF) yöntemi kullanılmıştır. Çalışmanın sonuçları, Çad'daki inşaat sektöründe yeni teknolojilere ilişkin yüksek düzeyde farkındalık olduğunu ortaya koymaktadır; katılımcıların %84,4'ü bu teknolojileri tanıdıklarını belirtmiştir. Ancak, bu teknolojilerin gerçek projelerdeki uygulama oranı %38,9 gibi düşük bir

seviyededir. Teknolojinin benimsenmesinden beklenen faydalar arasında daha iyi maliyet ve zaman yönetimi (%76,6), geliştirilmiş iş birliği (%64,7) ve daha iyi çevresel performans (%59,3) yer almaktadır. Bu umut verici beklentilere rağmen, dijital beceri eğitiminin yetersizliği (%71,3), yüksek uygulama maliyetleri (%66,5) ve kurumsal desteğin eksikliği (%54,1) gibi engeller mevcuttur. Katılımcıların %61,7'si bu teknolojilerin Çad'ın Sürdürülebilir Kalkınma Amaçları'na (SKA) ulaşma çabalarında önemli bir rol oynayabileceğine inanmaktadır. Bu çalışma, Çad'daki inşaat sektöründe dijital yeniliği inceleyen teorik temelli ilk modeli sunmaktadır. Ayrıca, sektörü ülkenin kendine özgü sosyal ve ekonomik gerçeklerine uygun, sürdürülebilir ve teknoloji destekli stratejilerle dönüştürmeyi hedefleyen politika yapıcılar, kalkınma aktörleri ve sektör paydaşları için somut önerilerde bulunmaktadır.

Anahtar Kelimeler: Yenilikçi Teknolojiler, İnşaat Projesi Yönetimi, Sürdürülebilirlik, Dijital Dönüşüm, Sürdürülebilir Kalkınma Amaçları (SKA)

1
INTRODUCTION

1.1 Context and Motivation

The construction industry, one of the most significant factors in sustainable development, is facing considerable pressure to change as technological advancements and the growth of green construction develop in a rapidly growing society [1]. This industry, one of the most significant contributors to the gross domestic product (GDP), consumes substantial amounts of materials, energy, and labor, and is also one of the most resource-intensive sectors. It's also tied to wasted energy, materials, carbon emissions, and time [2]. The increasing global urgency for sustainable development has heightened the pressure on the construction industry to enhance its environmental performance and adopt more effective, transparent, and resilient project delivery processes [3].

In contrast, a new generation of technology is transforming how construction projects are conceptualized, driven, and executed. Applications such as BIM, AI, IoT, automation, drones, and cloud-based platforms offer robust features that enhance collaboration, minimize errors, optimize resource utilization, and enable real-time tracking of project status [4]. Within the developed world, these technologies are now universally accepted as the only way to deliver significant infrastructure on time, on budget, and in a more environmentally friendly manner [5].

Despite the pervasive worldwide push towards digitalization, in many developing countries, such as Chad, the full potential of this shift remains to be seen. Chad's construction industry relies heavily on traditional methods characterized by manual processes, fragmented communication, inefficient scheduling, and limited data integration. The sector suffers from a lack of governance, limited digital infrastructure, and a significant shortage of skilled labor, hindering the adoption of modern solutions. These limitations impact not only the quality and efficiency of the construction results but also pose obstacles to long-term sustainability endeavors;

therefore, a transformation is thus imperative [6].

Given its pressing demand for infrastructure, modernization of the construction sector has become a national priority in Chad. This part of our economy is vital to both economic and social progress, but it needs transformation. This research will investigate how advanced technologies can contribute to sustainable, efficient, and equitable construction practices across the nation. It is based on the idea that technology can transform development to deliver better project results, reduce waste, and improve industry performance. The study, with its practical relevance, aims to contribute to Chad's transition towards a tech-driven construction practice aligned with the Sustainable Development Goals. The study holds significance at both theoretical and practical levels, as it examines the current state of readiness, identifies significant challenges, and explores opportunities related to technology acceptance in construction project management. The study results are designed to provide intra- and extramural partners working in various prevention and intervention programs with the information, instruments, and data necessary to inform sound decision-making, support planning, and facilitate implementation. The end goal of the research is to enable and encourage a transition to more resilient and future-ready construction in Chad, which will continue to benefit its infrastructure and the people of Chad for decades to come.

1.2 Problem Statement

The construction industry, which is an engine of growth and development for a nation, is confronted with inefficiencies, environmental deterioration, among others, as seen in developing countries like Chad [7]. Despite its absolute importance to the economy that is flagging behind due to the decline in oil production, and its power as a job creator, the construction sector in Chad is characterized by systemic weaknesses, among them low technical and digitization potential, corruption, opacity in tendering, and its over-reliance on informal sector workforce. Unstable infrastructure, a patchwork regulatory landscape, constrained availability of digital resources, and severe workforce skills shortages compound these challenges. Consequently, projects often experience significant cost and time overruns, poor quality, and adverse environmental impacts. The inefficiencies have substantial implications for the country's overall socio-economic development goals and their alignment with the United Nations' Sustainable Development Goals (SDGs) [8].

Meanwhile, digital technological evolution in construction management capabilities, including Building Information Modeling (BIM), Artificial

Intelligence (AI), Internet of Things (IoT), the use of drones, automation, and digital project collaboration platforms, is changing how projects are delivered in many parts of the world [9]. Such innovations promise numerous advantages, which have already been demonstrated in industry, including the sustainable use of resources, reduced material scrap, improved partnership with stakeholders, and real-time performance management. They can support sustainability, enhance project quality, and decrease environmental footprints [10]. Despite the slow development of new technology in the construction industry in Chad, several obstacles must be overcome to address this situation. Among those barriers are high initial implementation costs, lack of institutional preparedness, infertile digital soil, and an industry-wide reluctance to adopt change, especially when it comes to digital solutions. Notwithstanding these difficulties, the benefits of adopting such novel technologies are enormous and have the potential to significantly improve efficiency, quality, and sustainability in the industry.

Second, there are empirical studies that examine the empirical consequences of adopting innovative Information and Communication Technologies (ICTs) in the construction industry in Chad. Case studies from developed countries or general case studies have dominated the literature. Thus, it fails to adequately consider the unique structural, financial, and governance challenges that countries like Chad face in infrastructure development. This has, in turn, left construction decision-makers in Chad without tailored data, strategic guidance, and an evidence-based framework for integrating technological innovations into sustainable project management practices.

This gap presents a substantial challenge: in the absence of a systematic approach to digital enablement in construction in Chad, the country risks missing out on transformative opportunities to deliver more resilient infrastructure, faster projects, and improved sustainability. The lack of it leaves the industry open to corruption, waste, and environmental damage. The study examines the application of modern technologies in construction project management in Chad and explores how they can be utilized to enhance sustainability. It will address existing weaknesses by demonstrating and applying practical solutions that lead to the green, efficient, and sustainable use of the sector, thereby modernizing it and ensuring its future sustainability.

The study has been designed to analyze how emerging technology is shaping construction project management in Chad, with a special emphasis on the role of construction technology in promoting sustainability in the construction sector. It also provides an analysis of current barriers to technology adoption, as well as an

evaluation of potential benefits, and leads to a framework for designing technical solutions. The study aims to fill this gap through its moderate focus and message, providing practical applications that will inform practitioners, policymakers, and devolved partners. Ultimately, it supports Chad's digital transformation and contributes to the sustainable development of its construction sector, promoting the adoption of more efficient and sustainable construction methods.

1.3 Research Scope

This study examines the transformative potential of advanced technologies in managing construction projects, with a particular focus on their role in promoting the sustainable development of Chad's construction industry. We are guided by global best practices in sustainable development and digital transformation, considering Chad's specific institutional, economic, and structural context, thereby contributing to the global discourse on sustainable construction.

The technologies in question include, but are not limited to, Building Information Modeling (BIM), Artificial Intelligence (AI), Internet of Things (IoT), Digital Twin systems, automation, cloud-based project management tools, and green building design platforms. It examines how the tools are currently used, known, and applied within the groups of administrators, architects, engineers, project managers, and construction companies affiliated with national professional organizations that set industry standards and regulate the construction industry.

The present study is both conceptual and strategic. On the one hand, it describes the advantages and opportunities these technologies offer for project planning, execution, and control, from the perspectives of efficiency, environment, and decision-making. Secondly, it discusses significant barriers to the adoption of BIPV, including high start-up costs, regulatory obstacles, a lack of skilled professionals, and resistance to change within organizations.

This research is not just theoretical. It is directly connected to several Sustainable Development Goals (SDGs), specifically those related to infrastructure development, climate action, and the responsible consumption and use of resources. By integrating these perspectives, this research aims to provide practical recommendations for developing a sustainable, technology-based future for the construction sector in Chad.

1.4 Research Questions

This thesis addresses several critical research questions regarding the role of groundbreaking technologies in sustainable construction project management.

1. How are emerging technologies transforming construction project management to support sustainable development?
2. What specific role do these technological advancements play in enhancing sustainability within construction project management?
3. How are cutting-edge technologies reshaping traditional project management practices to promote sustainability in the construction sector?
4. How will the future of sustainable construction project management integrate and adapt to these technological innovations?
5. What are the key implications of adopting advanced technologies for managing sustainable construction projects?
6. What measurable impacts do innovative technologies have on the sustainability of construction project management?
7. How do technological advancements contribute to improving the efficiency and sustainability of construction project management?
8. In what ways do innovative technologies intersect with sustainable construction practices, influencing project management strategies?
9. How can the construction industry best utilize these technologies to maximize efficiency while advancing sustainability objectives?

This research aims to gain an in-depth understanding of how innovation impacts construction project management by addressing the following research questions. Through this investigation, the study seeks to identify the mechanisms by which creative practices support more sustainable, efficient, and resilient construction processes. In consideration of the impact of new techniques and technologies, the research suggests the potential for achieving significantly better project results and optimizing resources. This hopeful prospect for the future of construction management is anticipated to contribute valuable knowledge to the advancement of a proactive approach, thereby maintaining long-term sustainability and adaptability in the built environment and ultimately benefiting both the construction industry and society.

1.5 Aim and Objectives

This thesis examines the waves of integrating innovative technologies into construction project management, with a focus on promoting sustainable development. To achieve this, the research aims to pursue the following objectives:

1. Identify the various innovative technologies currently utilized in construction project management.
2. Evaluate the impact of these technologies on the sustainability of construction projects.
3. Investigate the key challenges and obstacles hindering the adoption of innovative technologies in the industry.
4. Analyze the potential advantages and risks of implementing these technologies in construction project management.
5. Develop strategies to overcome existing barriers and optimize the benefits of technological advancements for sustainable construction.
6. Offer recommendations for future research and development in innovative construction technologies.

1.6 Thesis Overview

This thesis is organized into seven main chapters as follows:

1. **Introduction:** This section introduces the study, providing context, research questions, aims, objectives, and an overview of the thesis structure.
2. **State of the art:** Examines existing research on innovative technologies in construction, discussing broad theoretical contexts, detailed thematic work, and identifying research gaps.
3. **Methodology:** Outlines the research methodology and methods, including research design, ethical considerations, and limitations.
4. **Analysis and Synthesis:** This section presents the results for each method used, analyzes the collected data, and summarizes key insights.
5. **Findings:** This section consolidates all findings, presents the main conclusions from the data analysis, and summarizes the research outcomes.

6. **Discussion:** Discuss key findings about existing literature, highlight main research contributions, and evaluate their significance.

7. **Conclusion:** This section summarizes the study, discusses the research impact, and suggests future work while acknowledging limitations.

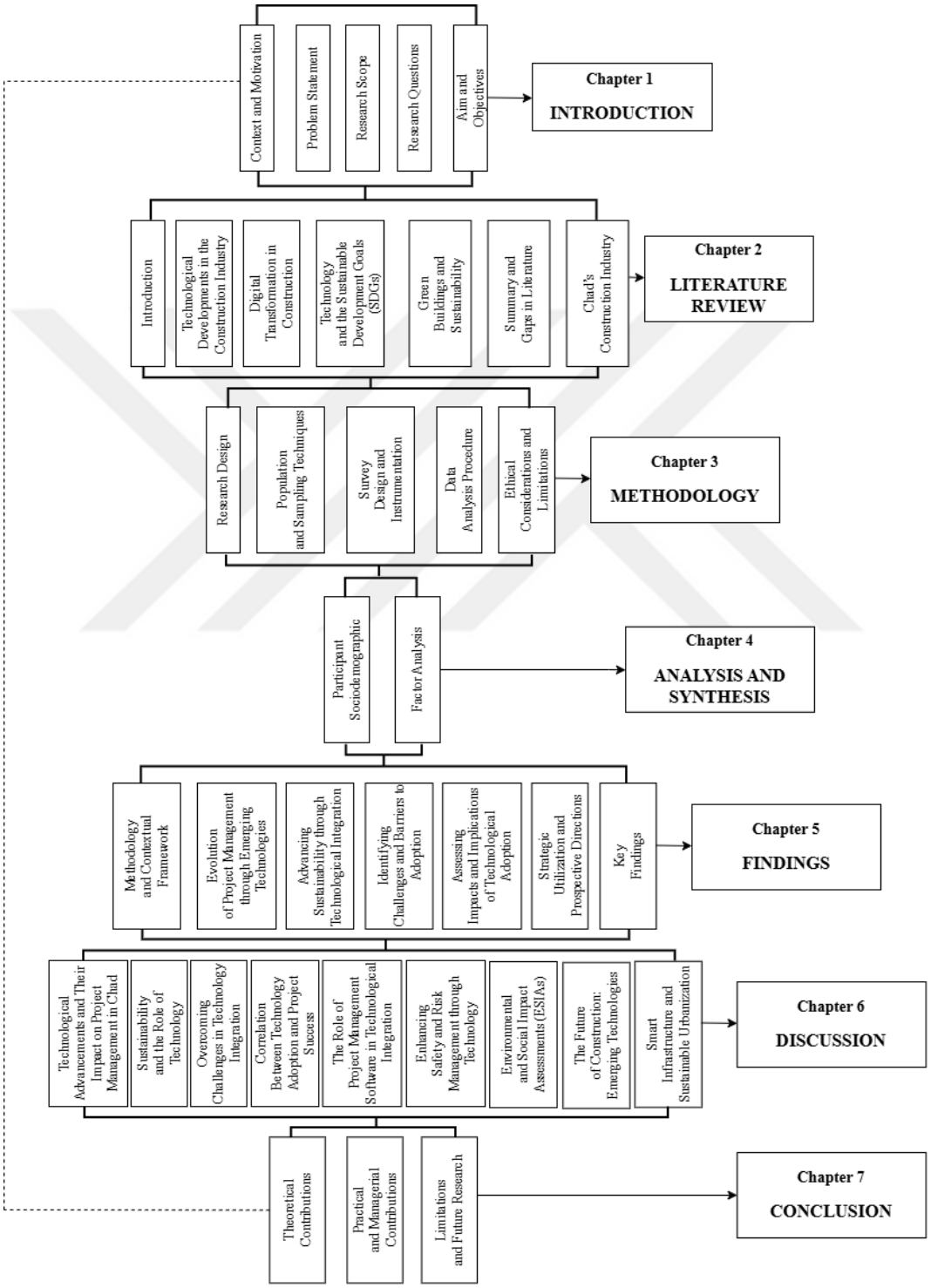


Figure 1.1 Thesis Structure

The thesis aims to comprehensively explore how smart technologies transform sustainable construction project management and their broader implications for the industry by following this structure.

2
LITERATURE REVIEW

2.1 Introduction

A significant shift is occurring in the global construction industry, primarily driven by the adoption of advanced digital technologies. These digital solutions are increasingly being applied to construction project management, promising substantial improvements in productivity, cost efficiency, and sustainability, thereby enhancing the overall resilience of construction practices. In advanced countries, this trend is already evident, facilitated by well-defined institutional structures and robust information technology (IT) systems. However, in countries like Chad, advancement opportunities are scarce due to outdated systems, limited technical knowledge, and restricted access to new technologies. The purpose of this literature review is to summarize key findings from worldwide and regional research on the adoption of modern technologies in the construction industry. It examines their applicability in critical areas, including sustainability, risk, performance, and implementation of United Nations Sustainable Development Goals (SDGs). Specific emphasis is placed on how these digital tools can support project management in low-resource healthcare environments. The structure of the chapter aligns with the themes of the instrument employed in our study, maintaining a connection between the theoretical framework and the empirical domain. Such an approach will lay a solid foundation for readers to explore the technology innovation challenges and opportunities in construction project management in developing countries.

2.2 Technological Developments in the Industry

The construction industry has experienced successive waves of technological evolution over the last 100 years, each of which has transformed the approaches to designing, building, and operating projects. Technology has evolved significantly from the early 20th century, when mechanization was introduced into construction,

to the present day, with the emergence of new technologies such as digital twins and AI, which bring greater efficiency, safety, and sustainability to the construction process [11].

In the early 20th century, steam-powered excavators and cranes, along with the development of reinforced concrete, were introduced. Prefabrication saw widespread use after World War II, from the 1940s onwards, due to the growth in the use of modular construction. Housing and infrastructure development occurred in the United States and Europe. Mechanization increased productivity and reduced reliance on human labor, but it also posed new challenges, including those related to quality control and logistics [12].

Computer-Aided Design (CAD) emerged in the 1960s, and its impact on architectural and engineering practice is evident. The program Sketchpad is credited as the world's first computer-aided design (CAD) software. The 1970s and 1980s saw the release of commercial CAD software, such as AutoCAD, which enabled engineers and architects to create accurate 2D and 3D drawings in digital form. CAD supplanted hand drafting, enabling more iterations in a shorter amount of time, better precision, and more complex designs [13].

In the 1990s, the construction industry was relatively new, and project management was also a relatively new concept. Project planning apps, such as Microsoft Project (introduced in 1984) and Primavera P3, began to be introduced to the sector. These services improved scheduling, budgeting, and coordination between design and construction teams. Nonetheless, their use was restricted to large corporations and high-value projects, as small contractors were unable to access, read, or understand documents in digital form [14].

BIM first gained popularity in the early 2000s, marking a significant innovation in the construction management field. The concept stems from Charles Eastman's introduction of Building Information Modeling (BIM) in the 1970s, initially referred to as Building Design (BD). The application, however, began to gain traction only in the 2000s with the advent of RAD programs like Revit, which was first released as Revit Building 1 in 2000. Parametric modeling, clash detection, quantity takeoffs, and lifecycle management are straightforward in Building Information Modeling (BIM). Building Information Modelling (BIM) was made mandatory for public projects in the UK and Nordic countries by their governments in the 2010s [15], [16]. BIM gained popularity due to its potential for reduced rework, improved stakeholder coordination, and green value.

The 2010s marked a trend towards on-site mobile computing rather than remote

computing in data centers. Field crews can access and update project information from smartphones and tablets. The Internet of Things (IoT) has been utilized for asset tracking, predictive maintenance, and wearable sensor safety regulation. Drones for aerial surveying and monitoring have gained popularity in the construction industry since 2012, particularly on complex or large sites [17].

This decade has seen the emergence of AI-based predictive scheduling, design optimization, and safety analytics tools. AI-based software, such as that from platforms like ALICE Technologies and OpenSpace. AI is integrated with BIM and project management applications to enable real-time decision-making and informed project management. Simultaneously, digital twins, software replicas of buildings and infrastructure, are receiving increasing attention due to their potential to emulate performance and optimize asset management in the long term [18]. Increasing attention is also given to robotics and the 3D printing of buildings (e.g., ICON, 2021), which can be utilized for automation, among other applications, for repetitive tasks and in extreme conditions.

The cost, inexperience, and associated business and life risks derailed each technology wave from mainstream commerce from the outset. Yet positive case studies and government decrees have helped to shift perceptions [19]. Over the years, tools have helped increase productivity, improve safety, provide greater stakeholder engagement, and deliver more sustainable results.

Ultimately, the development of construction IT reflects larger trends in industrialization and digitization. Understanding this path is a critical context for countries such as Chad, where the potential exists to sidestep some of these traditional stumbling blocks with today's and tomorrow's tools [20].

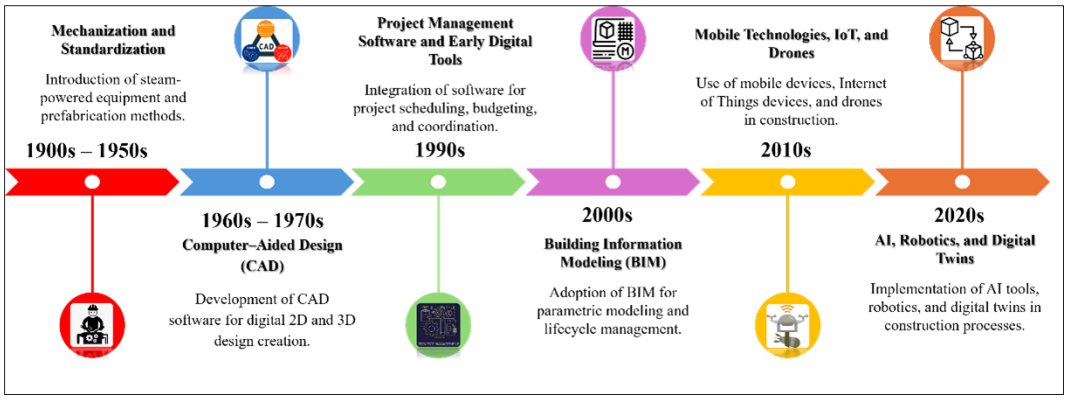


Figure 2.1 Timeline of Technological Developments in the Construction Industry

2.3 Digital Transformation in Construction: Balancing Innovation, Safety, and Environmental Responsibility

2.3.1 Integration of Innovative Technologies in Construction

In recent years, new technologies used in construction have been shaping not only the appearance of projects, but also their design and construction. Most conventional building systems, based on largely manual and disjointed processes, struggle to sustain the demands of modern infrastructure, especially in countries like Chad. Accordingly, technologies such as BIM, AI, IoT, drones, Digital Twins, AR/VR, and 3D printing have been extensively researched for their potential to enhance efficiency, cut costs, and foster sustainability in the industry [21].

BIM (Building Information Modeling), one of the most commonly used technologies in the Architecture, Engineering, and Construction (AEC) sector, allows the digital representation of both the physical and functional characteristics of built assets [22]. BIM supports increased stakeholder collaboration, better visualization, better design phase clash detection, and more effective resource planning and cost control [23]. BIM could enhance efficiency and reduce a significant portion of the current wait times on a Chadian scale, particularly in terms of miscommunication and circular work logic.

AI offers predictive capabilities for risk management, scheduling optimization, and informed decision-making. AI algorithms can process legacy program data to forecast project cost overruns, recommend design enhancements, and flag early signs of delays and safety hazards. Nevertheless, AI is scarcely implemented in developing countries due to digital illiteracy and insufficient technological capacity [24], [25].

Through the Internet of Things (IoT), real-time data communication enables predictive maintenance, logistics, and energy control among machines, operators, robotic equipment, and software [26]. Sensors with IoT can be integrated within building materials, machinery, or workers' equipment to enhance safety and efficiency [27]. The Internet of Things (IoT) has yet to be fully established in Chad, primarily due to its unstable internet connection and inadequate investment in smart infrastructure.

A digital twin, which creates a real-time digital counterpart of a physical object, is emerging as an asset for high-end construction projects. It enables stakeholders to experiment with and optimize design decisions throughout the construction and operation stages [28]. When used in conjunction with BIM and IoT, Digital Twins

can provide unparalleled precision and management of complex works [29].

Drones have revolutionized site monitoring, surveying, and data collection. They can also capture high-resolution aerial imagery, which can be used to estimate work progress, conduct quality checks, and assess safety practices. Size AR/VR tools enhance stakeholder engagement with immersive visualization, and 3D printing enables modular and rapid prototyping, which is particularly useful in resource-limited or remote areas [30], [31], [32], [33].

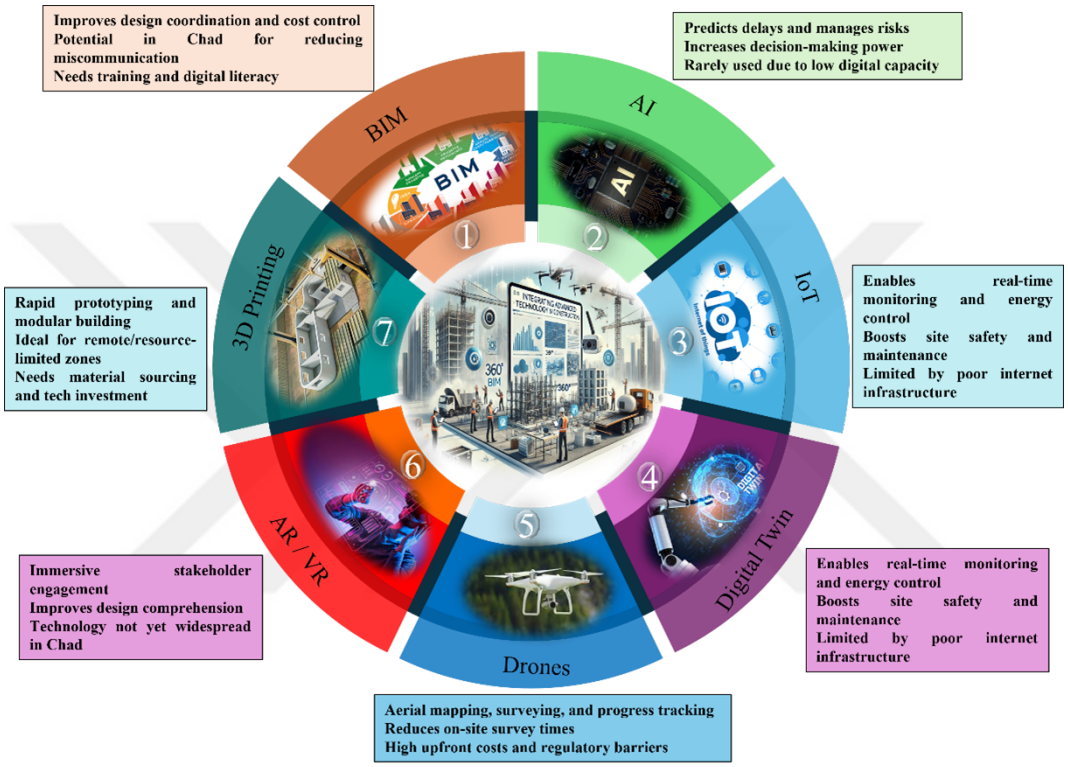


Figure 2.2 Smart Techs Integration

2.3.2 Sustainability in Construction Project Management

Sustainability in construction project management has arisen as a critical business imperative due to international concerns about the environment, the high cost of resources, and a growing awareness of the social and economic impacts of infrastructure development [34]. Historically, construction management has focused on cost, time, and quality; today, it expands its goals to minimize environmental impact, promote a fair society, and achieve sustainability [35], [36]. Implementing sustainability principles in construction is crucial for developing countries like Chad, which face resource scarcity and environmental degradation.

Sustainable construction practices are facilitated mainly by technological innovation. With Building Information Modeling (BIM), Life Cycle Assessment

(LCA) software, and Internet of Things (IoT) sensors, project managers can evaluate and optimize energy use, materials, and waste production throughout the life of a construction project [37]. According to Ortiz et al. [38] LCA instruments facilitate the evaluation of environmental impact from design through demolition, enabling environmentally preferable decisions that reduce carbon emissions, increase material efficiency, and decrease lifecycle costs. In countries like Chad, implementing LCA and BIM can ensure a project's transparency and accountability, particularly in an environment where sustainability reporting is compromised or non-existent.

BIM has proven its potential in achieving sustainability through better coordination, early detection, identification of design inaccuracies, and resolution of clashes, resulting in minimal material waste and rework [39]. The ability of BIM to model energy performance further promotes the design of energy-efficient buildings that comply with green building certifications (e.g., LEED or EDGE), which are becoming increasingly important in Africa [40].

IoT and smart sensors collect real-time information on energy usage, indoor air quality, and construction waste levels, enabling 24/7 monitoring and prompt action [41]. This is crucial, especially in Chad, where several work sites are not effectively monitored, resulting in uncontrolled emissions, harsh working conditions, and inefficient waste management.

The issue of social consideration is also integral to sustainable construction,

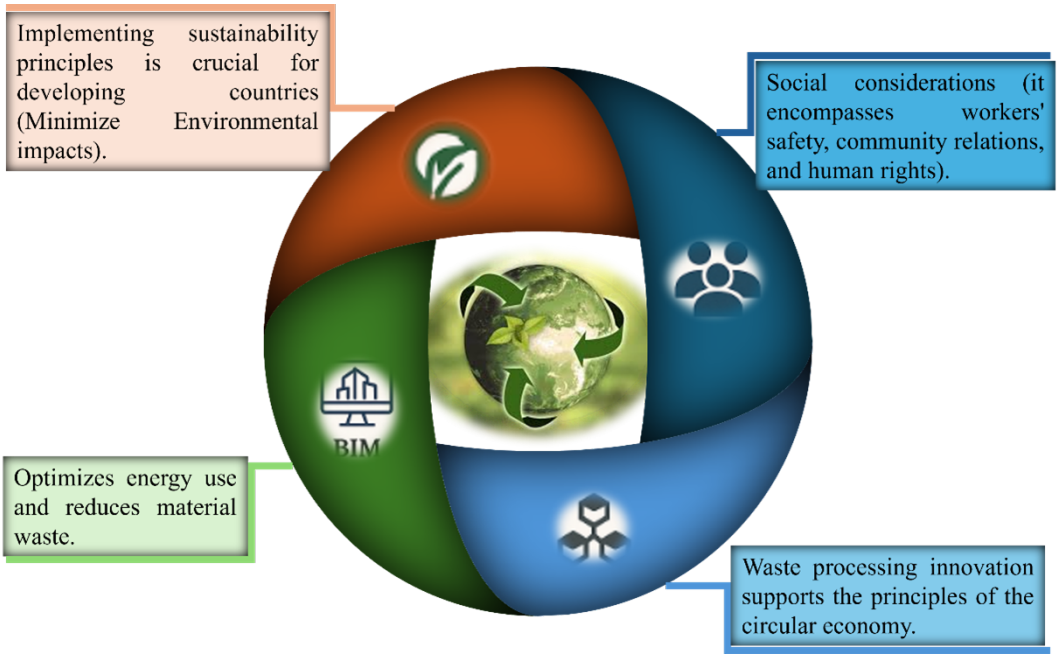


Figure 2.3 Sustainability in CPM

encompassing concerns for workers' safety, community relations, and human rights in general [42]. AI-based safety analytics, AR/VR-based training, and digital stakeholder consultation platforms can all contribute to achieving this goal. For instance, the employment of AR/VR as tools can enhance the hazard perception and emergency preparedness of workers' efforts [43].

Innovations in Waste Processing for Circular Economy Implementation, by introducing modern technologies for waste management, such as online tracking systems or blockchain for material traceability, enable the enhancement of circular economy principles [44], [45]. These tools can support Chadian organizations in promoting responsible consumption and production, a key aspect of Sustainable Development Goal 12.

2.3.3 Challenges in Implementing Innovative Technologies

Adopting innovative tools and technologies in construction project management, such as BIM, AI, IoT, Drones, and 3D Printing, opens transformative possibilities to increase efficiency, transparency, and sustainability. However, despite their development and implementation in developed economies, their uptake remains challenging in integrating these technologies in developing economies, such as Chad. These technical, organizational, economic, and institutional challenges hinder the speed and effectiveness of the construction sector's digital transformation. There are several major obstacles at the beginning; however, these have largely been passed, with the high purchase and implementation costs now largely behind us. Innovative technologies often require significant investments in equipment, software, and personnel [46]. In Chad, where building budgets are tight and funded by donors or the state, economic rationalities make businesses hesitant to invest in new or expensive technologies [47]. Furthermore, the lack of scalable business models and local technology providers also contributes to economic uncertainty, hindering experimentation.

The second most significant constraint is the lack of a skilled workforce to handle and manage this technology. Some of those tools, such as BIM or artificial intelligence-enabled platforms, require not only knowledge of digital technology but also a different kind of interdisciplinary teamwork among engineers, architects, urban planners, and IT professionals [48]. The absence of training programs, institutional capabilities, and access to information networks is a significant constraint to the adoption of technology in developing countries [49]. In Chad, this problem is exacerbated by poor academic curricula, lack of professional, technical, and vocational training, and emigration of skilled human resources to

other countries.

Technological barriers are also significant; many cutting-edge technologies rely on reliable internet access, cloud computing, and uninterrupted power supplies, which are particularly scarce in Chadian cities and nearly nonexistent in the countryside. This disparity in infrastructure renders impractical cloud-based collaboration, mobile application usage, and real-time tracking, key elements of state-of-the-art project management systems [50], [51].

Resistance to change is also a significant obstacle to the change process at the individual and organizational levels. Sometimes, project stakeholders, particularly in public sector organizations, may not comprehend the advantages of technology or be hesitant to adopt it due to concerns about job security, and consequently, hesitate or even resist cooperation. Additionally, construction firms with traditional, entrenched working styles may be reluctant to modify their workflow systems and power structures [52].

Legal and institutional inadequacies also hinder adoption. In many countries, regulations that facilitate digital contracting, procurement, and documentation are absent. For example, the lack of BIM model standards and digital signatures leads to legal uncertainty. In countries like Chad, where governance systems are typically fragmented and slow to adapt, these spaces also pose a challenge for formalizing the use of digital mechanisms [27], [53].



Figure 2.4 Challenges in adopting digital technologies

2.3.4 Correlation between Technology Adoption and Project Success

The literature has increasingly emphasized the adaptation of advanced technologies, which contributes to the effectiveness of construction projects. Amidst rising complexity and resource intensity in construction projects, the parties involved seek means to optimize efficiency, meet schedules, lower costs, and ensure quality. Digital tools, such as Building Information Modeling (BIM), Artificial Intelligence (AI), drones, and project management software, have played a significant role in achieving these goals, particularly when utilized throughout the project delivery process.

Conventional measurement of project success in construction focuses on time, cost, and quality, as represented by the "iron triangle." Yet, modern perspectives also consider factors such as stakeholder satisfaction, risk management, sustainability, and long-term performance [54], [55]. Seen through this broader lens, the adoption of technology is crucial. For instance, BIM enables the early detection of design errors, encouraging proactive decision-making with a reduced probability of rework and delay [15]. This fact directly contributes to improved scheduling and lower costs.

When scheduling optimization and cost estimating, consider utilizing Artificial Intelligence (AI) tools, which enable managers to anticipate risks and proactively address them before they escalate out of control. Serrador and Pinto [56] highlighted that both small and large companies that utilized AI and data-driven decision-making processes achieved higher project success rates in sectors such as construction.

Additionally, digital tools facilitate collaboration and communication among all parties involved, which is crucial in large infrastructural projects with multiple contractors, subcontractors, and competent authorities. Project management tools that offer real-time updates, standard documentation, and workflow support enhance transparency, leading to accelerated approvals and reduced contention [57]. In places like Chad, where communication breakdowns are prevalent, such improvements can be critical to project success.

Success is then maximized with drones and IoT devices that provide live site monitoring and track progress. These technologies enable early interventions, enhance resource allocation, and improve safety allocation, leading to cost and time efficiencies and increased stakeholder satisfaction. According to DuBois et al. [58]. Effective project managers increasingly utilize dynamic scheduling systems to predict disturbances and control performance output.

Moreover, technology integration facilitates risk aversion, one of the most significant factors in a successful project. Technologies that incorporate predictive analytics, scenario simulations, and automated reporting enable early detection of problems and foster managerial agility [59], [60]. These skills are particularly valuable in unpredictable environments, such as the construction industry in Chad, where unforeseen incidents are common.

However, the potential benefits may not be fully realized due to institutional readiness, digital skills, and leadership support. "Just being in a room with technology doesn't make people better at stuff." Without adequate training and support systems, technology is insufficient [61–63].

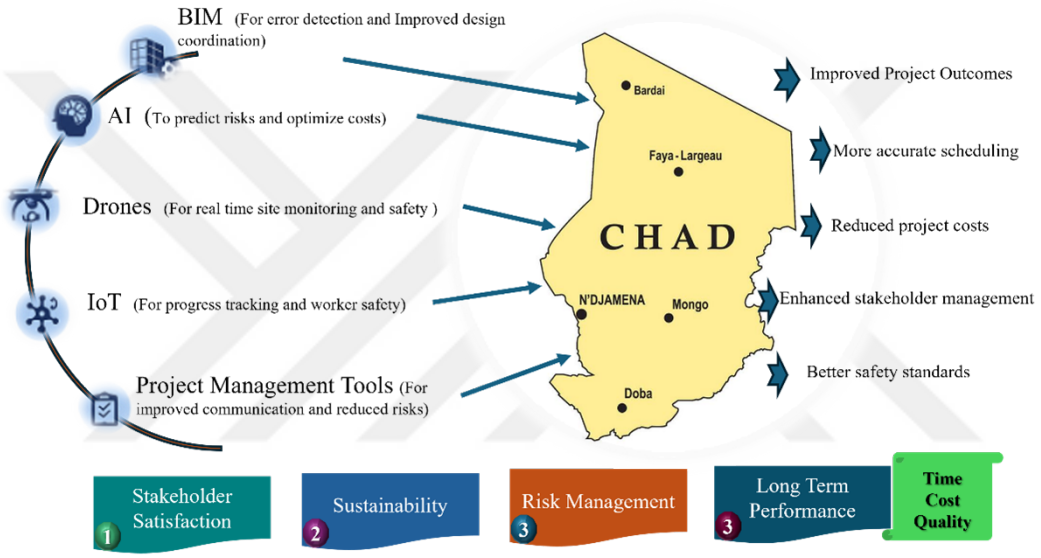


Figure 2.5 Tech-Driven Outcomes

2.3.5 Project Decision-Making and Technology Evaluation

The decision to adopt innovative technologies in construction project management is multifaceted and influenced by various strategic, organizational, and contextual factors. It involves selecting new tools and choosing a scope, which encompasses aligning technological solutions with clients' objectives, stakeholders' expectations, regulatory pressures, and available resources [64]. In the case of developing countries, such as Chad, this decision is even more challenging due to a lack of existing infrastructure, high sensitivity to cost, and a low level of digitalization maturity. Numerous frameworks are used in the discourse of technology adoption, among the most frequently cited is the Technology Acceptance Model. According to this model, only two factors directly influence the likelihood of project managers and stakeholders adopting specific technology: apparent usefulness and perceived ease [65].

In Chad, the availability of digital skills is highly uneven, and tools that can be easily used for immediate benefits are more likely to be chosen. Innovation Diffusion Theory emphasizes compatibility, trialability, and observability as increasingly significant factors in determining the final choice. The more compatible the technology is, the easier it is to use, and the more evident the benefits are, the more likely project managers are to adopt it [66], [67]. For instance, building information modeling can be used "for simple clash detection exercises or drone shot applications" [68].

Additionally, technology in construction project management is also evaluated through a cost-benefit analysis, which compares initial and maintenance costs with the improvements in safety and security. Therefore, the more benefits the decision-maker can gain from client loyalty and long-term relationships, the more likely the organization will adopt costly technologies [69–71]. Hence, explicit benefits from transparent government procurement in Chad, such as reduced corruption, can drive the adoption of technology. Organizational readiness is also a critical determinant. Companies with a clear vision, digital leadership, and professional staff are more likely to choose new technology. Otherwise, resistance to new ideas may render even the best technological solution ineffective. Finally, there are also external determinants, such as governments, donors, and peers, that can significantly influence the development of technology.

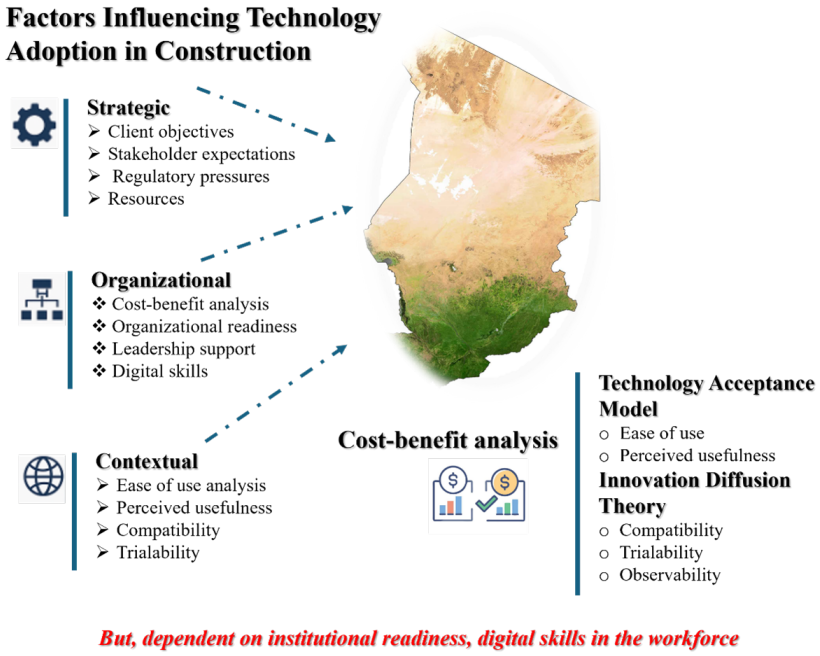


Figure 2.6 Factors Influencing Technology Adoption in Construction

2.3.6 Project Management Software and Digital Systems

Project Management Software (PMS) and integrated digital systems are increasingly being utilized in construction, serving as a central location for planning, scheduling, tracking, and communication [72]. They enable data-driven decision-making and improved project coordination, resulting in higher productivity, better cost management, and increased project success for organizations [73]. In Chad's primarily traditional, analogue construction economy, the discovery that PMS, if introduced, could modernize and catalyze construction is not only timely but also revolutionary.

One of the benefits of PMS is its ability to improve communication and collaboration. Examples of software in this segment include Microsoft Project, Primavera P6, Procore, and Autodesk Construction Cloud, all of which offer real-time updates, shared dashboards, and a single source of documentation [74]. These capabilities, working together, ensure that all relevant parties, including contractors, consultants, and others, are in sync regarding timelines, deliverables, and roles [75]. In places like Chad, where miscommunication and piecemeal project monitoring are hindrances, these tools can bring greater transparency and help mitigate the risk of costly delays.

Software that's easy to use and customize is key to increasing uptake. For Kartam and Bouz [76], the system should accurately represent content in a form customized to the local setting and suitable for users with varying levels of digital competence. This encompasses local language interfaces, ease of navigation, and mobile access in sites with limited Internet infrastructure. Without these modifications, even the most effective systems may not be beneficial. Assessment and choice of PM tools are dictated by their integration with other new technologies. For instance, data can be shared with other BIM platforms, Computer-Aided Design (CAD) software, IoT dashboards, and Geographic Information Systems (GIS) when using PMS, with increased visualization [77]. Leyesa et al. [78], argue that integration is particularly crucial when handling complex projects involving different real-time tools for construction monitoring, budgeting, and project performance analysis.

Another key factor to consider is scalability. Small and medium-sized enterprises (SMEs), which comprise many construction companies in Chad, typically start with more basic PMS solutions before scaling up as their digital maturity improves. Cloud-based systems are also a viable option here, as they eliminate the need for costly in-house IT systems and provide scope for future growth [79]. Additionally, PMS also enhances our resource allocation and time management. Through automatic scheduling, cost estimation, and monitoring progress against major tasks,

project managers can detect inefficiencies at an early stage and reallocate resources as needed [14]. This capability is crucial in the archipelago of budget overruns and resource constraints.

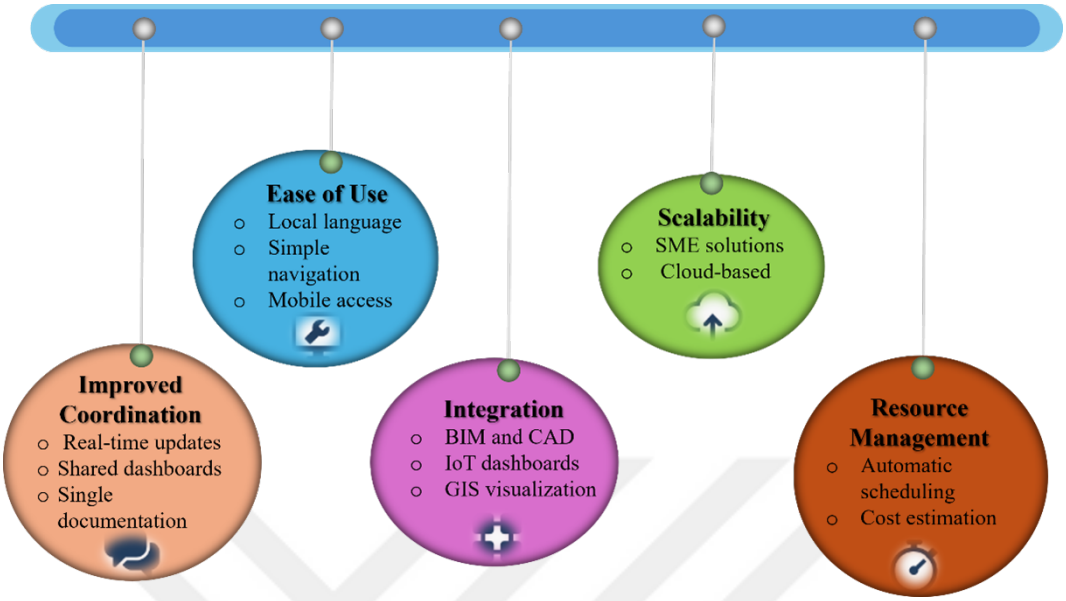


Figure 2.7 Benefits of project management software in construction

2.3.7 Risk and Safety Management through Innovation

The risk and safety of construction projects are essential aspects of construction project management, especially in scenarios with high probabilities and severities of risk. The situation is worse in Chad, where construction sites experience poor working conditions due to the lack of enforcement of stringent regulations, among other issues, as there is no site supervision and minimal personal protective equipment (PPE) [80]. These are significant concerns regarding the safety of the workers, the continuity of the projects, and the long-term sustainability of the work. In this environment, applying new technologies presents excellent opportunities to enhance safety and promote proactive risk management [81], [82].

Various digital technologies, including drones, IoT-enabled sensors, Augmented and Virtual Reality (AR/VR), and predictive analytics, have been increasingly employed in the global construction market to address safety issues. Aerial Facilities and Job Site Assessments: Drones are rapidly being used in the construction industry for job site inspections, which can identify physical hazards (e.g., unstable scaffolding, trenching) or hazardous materials storage without putting workers in harm's way [83]. In low-resource settings like Chad, drones can be beneficial as they enable the rapid and cost-effective survey of large and previously inaccessible areas.

The Internet of Things (IoT) also enhances construction safety by enabling real-time monitoring of workplace and environmental safety. Embedded sensors in equipment and protective gear can alert supervisors when machinery is overheating, when excessive noise levels are present, or when hazardous air quality is detected. Linking up with a central dashboard, such tools generate actionable data required for prompt safety interventions and long-term policy changes, with a focus on patient safety [84].

AR/VR-based technologies have successfully trained workers and raised awareness of the risks. Workers can practice high-risk activities in a controlled digital environment, such as operating a crane or responding to emergency evacuations through immersive simulations. It contributes to minimizing human errors at operational sites and strengthens safety culture [85]. In underserved areas without access to formal training programs, VR-based modules can be inexpensive tools for education.

Machine learning-based predictive analytics technologies can now predict safety failures in advance. By examining historical data, site conditions, andworker actions, such systems can alert to trends that have led to near misses or previous incidents [86]. For instance, managers can reschedule tasks or include additional safety precautions if tasks are performed on high-risk days.

Additionally, technology enhances reporting and response mechanisms, and smartphone applications are helpful in recording incidents in real-time, capturing photo evidence, and automatically sending alerts. They can avoid underreporting and obtain a timely remedy for the situation [87].



Figure 2.8 Risk and Safety in Construction

2.3.8 Environmental and Social Impact Assessment

ESIAs are essential tools and a requirement to ensure that a construction project is undertaken responsibly and sustainably. These appraisals consider the potential impacts of construction activities on environments, communities, and local economies, thereby informing policy choices that align with broader sustainable development objectives [88]. In Chad, where infrastructure development occurs rapidly and often without thorough environmental due diligence, incorporating novel technologies into Environmental and Social Impact Assessments (ESIAs) could be a groundbreaking step in enhancing transparency, accountability, and the sustainable infrastructure provision.

Recent digital technologies have transformed the Environmental and Social Impact Assessment (ESIA) process. Today, technology such as Geographic Information Systems (GIS), remote sensing, data visualization platforms, and stakeholder engagement tools has the potential to offer more comprehensive, evidence-based, and inclusive assessments. GIS, for instance, can support the spatial analysis of sensitive ecological areas, topography, and land use, helping decision-makers gain an understanding of the environmental risks associated with a project early on, before construction commences [43], [89]. In contexts such as Chad, where geographical information is often unavailable and data are sometimes outdated, remote sensing from satellite data provides an opportunity to address these issues and enhance the quality of the baseline.

Additionally, remote sensing provides a continuous view of vegetation cover, soil erosion, and water pollution at each project phase. These technologies benefit rural and far-flung areas, as on-site inspections can be logistically challenging or prohibitively expensive. Combined with drones, they can also facilitate high-resolution aerial imagery and real-time environmental monitoring, alerting to the early onset of ecological degradation or unauthorized land clearing [90], [91].

In the social dimension, digital technologies facilitate stakeholder mapping and engagement. Community mapping tools and survey apps enable construction companies to identify stakeholders, capture feedback, and gain knowledge of the community for a project [92]. This is especially important in a place like Chad, where development projects can disrupt people's lives, displace communities, or exacerbate existing disparities. These tools can also contribute to conflict prevention, free, prior, and informed consent, and project legitimacy through inclusive dialogue and consultation.

It is also important to highlight that visualization tools, including dashboards

and interactive maps, are playing an increasingly vital role in enhancing ESIA communication. These tools communicate discoveries in a manner that non-technical decision-makers can understand and analyze complex impact data. When shared publicly, they create trust among developers, regulators, and the community, fostering collaborative governance and project acceptance [93].



Figure 2.9 Environmental and Social Impact Assessment

2.3.9 Forecasting and Readiness for Emerging Technologies

Now that the construction industry has adopted digital transformation, forecasting emerging technologies and being prepared for them is a strategic imperative. Construction project delivery is influenced by blockchain, robotics, 5G connectivity, advanced data analytics, and machine learning, as these technologies are shaping the project delivery landscape [94]. For developing countries like Chad, the question is not simply whether to adopt these technologies, but how to build readiness, manage disruptions, and ensure fair access to innovation.

Technology forecasting involves systematically examining the trends, signals, and drivers of emerging technologies and their potential future impact on society. According to Hekkert et al. [95], strong innovation systems require foresight, that is, the capacity to generate and manage knowledge capture, resource mobilization, and strategic steering. For construction, this involves finding tools that are not only promising but also come with the necessary human, institutional, and infrastructural requirements for effective deployment. For Chad, this entails readiness for

technology, resources, and regulation.

With emerging technologies, what will make or break one of the primary catalysts behind the adoption of emerging technology is collaboration among institutions [96]. Construction businesses in more mature markets typically collaborate with research institutes, start-ups, and technology developers to drive innovation. They also provide resources for pilot testing, skill building, and shared costs. In emerging and fragmented ecosystems, such as Chad, public-private partnerships and international technical cooperation can significantly contribute to bridging the gap between knowledge and infrastructure development within the country itself [97].

Readiness at the organizational level is equally crucial. Research has found that proactive companies that budget for innovation, invest in staff training, and align their strategy with long-term technological changes are more likely to implement new tools successfully [98]. For instance, a construction firm that teaches its engineers how to estimate costs using AI or how to survey land using a drone is more likely to be able to deploy these tools when they become commercially viable or are needed by clients [99].

New technologies have broader implications for productivity, safety, environmental impact, and competitiveness. The strategic deployment of predictive analytics can enhance resource tracking and risk oversight. It can fast-track menial tasks and alleviate strain on human labor. Another benefit is that blockchain can enhance transparency, improve procurement, and prevent fraud [100]. For machinery used in Chad's construction industry, an industry often characterized by inefficiencies and governance issues, such tools might help address structural problems once deployed with care and the necessary contextual sensitivity.

However, technological dumping, which involves the careless importation of products created in vastly different places, is a significant danger unless these approaches are customized. Without this, capacity building will occur unevenly, and emerging technologies may be harmful or exacerbate existing disparities. Hence, readiness should not only involve local innovation ecosystems that can localize technologies to meet regional requirements, languages, and cultural dynamics.

2.4 Sustainable Development Goals (SDGs) and Technology

The SDGs are a universal call to action, adopted by the United Nations in 2015, to address environmental, economic, and social issues by 2030. In the construction

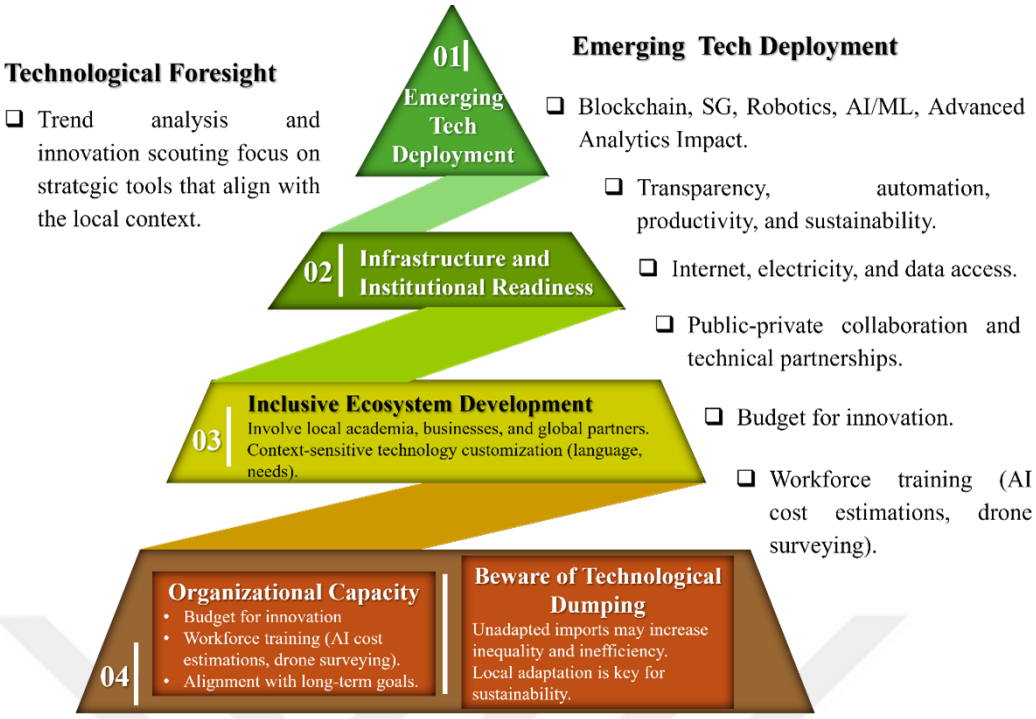


Figure 2.10 Forecasting Emerging Technologies

field, emerging technologies have been identified as key enablers to achieve many of these aspirations, especially in developing nations, such as Chad [101]. With construction lines cutting across infrastructure, urbanization, climate action, resource efficiency, and governance, digital transformation can catalyze progress under the SDG agenda.

SDG 9 (Industry, Innovation, and Infrastructure) focuses on resilient infrastructure, inclusive and sustainable industrialization, and promoting innovation and infrastructure development. Technologies, including Building Information Modeling (BIM), 3D printing, the Internet of Things (IoT), and Artificial Intelligence (AI), also contribute to these objectives by enhancing project planning, optimizing resource allocation, and improving construction quality. Construction companies in Chad can utilize these resources to reduce material waste, improve energy efficiency, and extend the lifespan of buildings, thereby ensuring long-term durability and sustainability [102].

SDG 11 (Sustainable Cities and Communities) entails inclusivity, safety, resilience, and sustainability in urban environments. Advanced technologies can enable sustainable urban planning using intelligent infrastructure modeling, simulations for land use, and energy-efficient designs. GIS and remote sensing enable enhanced spatial analysis, while digital twin models optimize transportation, waste, and utility networks [103]. In Chad's fast-urbanizing hubs, these instruments will enhance

planning precision and coordination among stakeholders, particularly in informal settlement upgrading and public housing projects [104].

Digital innovation is also strongly interconnected with SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). LCA software and energy simulation tools are designed to help project managers assess the carbon footprint of construction materials and the resources used in their construction. Digitally stunning materials and endorsing principles of a circular economy, such as those related to construction waste, also help to leverage resource responsibility [103]. Technology-aided design can help reduce greenhouse gas emissions and facilitate climate adaptation in countries vulnerable to climate change, such as Chad.

Institutional governance (SDG 16) and partnerships (SDG 17) are promoted through technologies that enhance transparency, accountability, and collaboration. Blockchain systems for procurement, for example, can reduce the risk of corruption through verifiable records of transactions that cannot be altered. Digital platforms also enable multi-stakeholder collaboration, including public, private, and civil society actors, to share information and track progress, while aligning interventions with national development priorities [105].

However, construction technologies that fully integrate with SDG implementation require conducive factors for actualization, including sound regulation, protection of data governance, investment in digital literacy, and multi-sectoral engagement. Without this, the potential of innovation to advance sustainable development remains under-realized.

2.5 Green Buildings and Sustainability

Green buildings have become a key pillar of sustainable development, addressing environmental issues while enhancing efficiency and improving the well-being of occupants [106]. By incorporating energy-saving technologies, environmentally friendly materials, and intelligent design strategies, these buildings help conserve resources while driving innovation in the construction sector [107]. This section of our work delves into various green building certification systems, their significance in promoting sustainability, their impact on managing construction projects, and their growing role in developing nations.

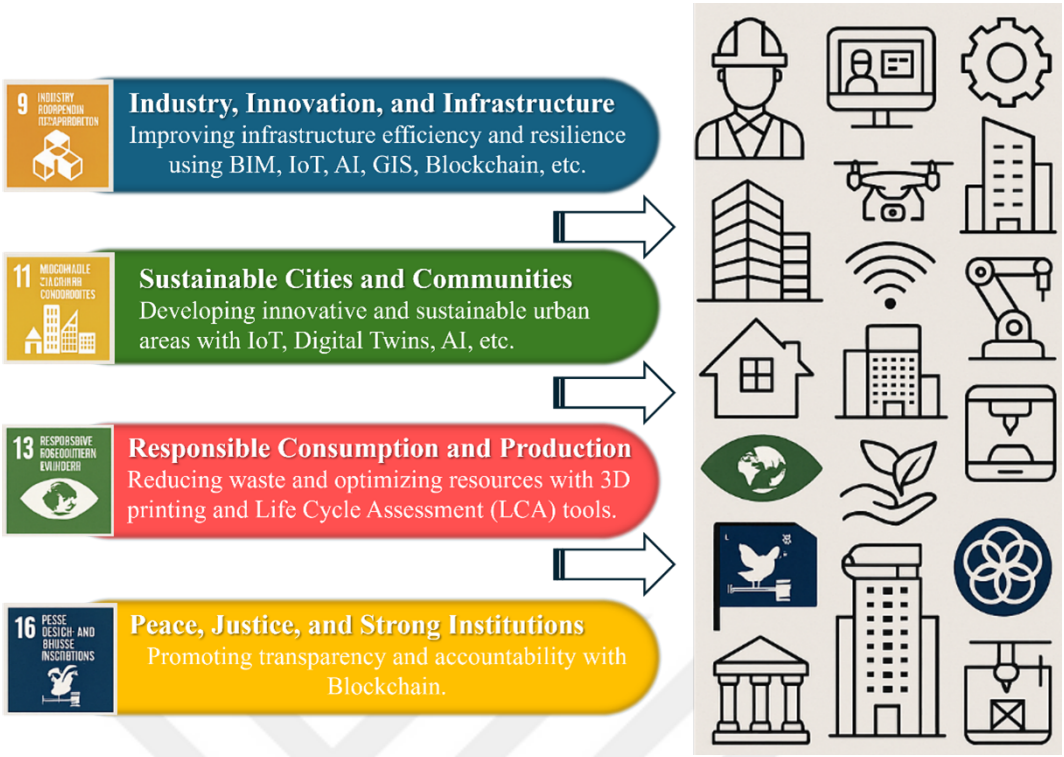


Figure 2.11 Emerging Technologies and SDGs in Construction

2.5.1 Green Building Certifications

Green building certifications play a pivotal role in promoting sustainable building practices. They establish clear standards for energy and water use, waste management, and ecological responsibility. These recognized standards, such as LEED, BREEAM, and EDGE, provide predictable categories to measure the environmental impact of buildings and define better choices for eco-friendly design [108]. By adhering to these certification standards, buildings can create spaces with reduced carbon emissions, less waste, and improved indoor air quality, thereby helping to save the planet and provide greater value to people [109].

One of the key benefits of green certifications is their ability to drive technological innovation within the construction sector. Key elements frequently found in certified buildings include renewable energy systems, such as solar panels and wind turbines, high-performance insulation, and water-saving fixtures, all designed to maximize efficiency [106]. Furthermore, they promote the circular economy approach by prioritizing the use of recycled and locally sourced materials, thereby minimizing the environmental impact of construction projects [110].

Green building certifications, in addition to their environmental benefits, also offer substantial economic and social advantages. Green buildings can significantly reduce utility costs by lowering electricity and water usage, making them a prudent

long-term investment. They also tend to command a premium from buyers, tenants, and investors who are environmentally conscious. In the workplace, green buildings contribute to employee well-being through better ventilation, temperature control, and daylight exposure, which have been shown to boost productivity and overall job satisfaction [111].

In emerging markets, green certifications are crucial in addressing accelerated urbanization and fostering climate resilience. These frameworks establish sustainability standards that governments and the private sector can use to promote energy-efficient and climate-responsive construction. With a growing focus on the environment, demand for green-certified buildings has surged, contributing to a global shift toward more environmentally and socially responsible construction approaches [112], [113].

Table 2.1 Major Green Building Certifications

Certification	Organization	Key Focus Areas
LEED (Leadership in Energy and Environmental Design)	U.S. Green Building Council (USGBC)	Energy efficiency, water conservation, air quality, and materials selection
BREEAM (Building Research Establishment Environmental Assessment Method)	BRE (UK)	Energy, health & well-being, materials, pollution, land use
EDGE (Excellence in Design for Greater Efficiencies)	International Finance Corporation (IFC)	Cost-effective energy, water, and materials efficiency
WELL Certification	International WELL Building Institute	Human health, air quality, mental well-being, and productivity

2.5.2 How Green Buildings Contribute to Sustainable Projects

Green product solutions are crucial in sustainable projects because they significantly reduce negative environmental impacts. They enable greater resource-use efficiency and occupant comfort [114]. By integrating energy-efficient designs, renewable energy sources, and environmentally friendly materials, these buildings achieve a significantly reduced carbon footprint and are built to endure over the long term. Features such as custom advanced insulation, LED lights, and intelligent climate control offer energy-saving benefits, saving money while contributing to environmental protection. Moreover, the integration of solar energy, rainwater recycling, and wastewater recycling further reduces the reliance on nonrenewable resources, enhancing the resilience and self-reliance of the built environment [107].

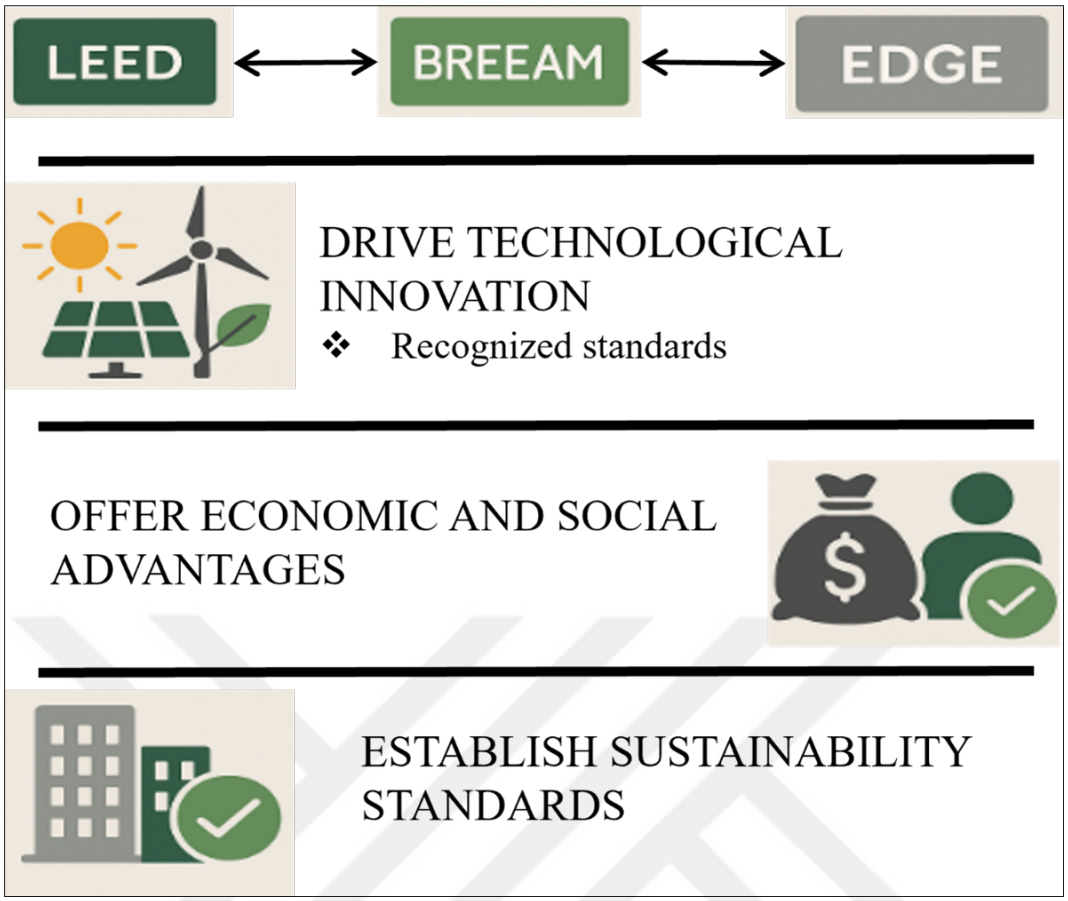


Figure 2.12 Green Building Certifications

Green buildings provide environmental benefits and create a healthier indoor environment. Improved ventilation, non-toxic building materials, and natural light enhance comfort and productivity while also reducing health risks associated with poor air quality and artificial lighting. As a result, the tenants' experience increased well-being, leading to better work productivity and overall satisfaction with their work [115].

Green buildings are not just environmentally friendly; they also align with circular economic concepts. They promote responsible material sourcing and reduced waste generation. Using recyclable, indigenous, and biodegradable materials helps preserve natural resources and minimize construction waste. Furthermore, these buildings support biodiversity through design elements such as green roofs, permeable surfaces, and native landscaping, thereby contributing to a balanced natural environment [116].

The demand for sustainable development requires green buildings as a basis for environmentally responsible urban planning. Green buildings work at the forefront of innovation, combining the latest technologies with sustainable building methods

to achieve an enduring and energy-efficient infrastructure that will underpin economic, social, and environmental sustainability for future generations [117].

Table 2.2 Environmental and Economic Benefits

Benefit Category	**Key Advantages**
Energy Efficiency	Reduction in energy consumption through insulation, passive cooling, and renewable energy integration.
Water Conservation	Implementation of rainwater harvesting, water-efficient fixtures, and greywater recycling.
Waste Reduction	Use of recycled materials, modular construction, and waste management strategies.
Cost Savings	Lower operational expenses due to energy and water efficiency.
Health & Productivity	Improved indoor air quality, natural lighting, and reduced exposure to toxic materials.

The construction industry in Chad is expected to reap increasing benefits from green building elements. These considerations, which relate to environmental footprint reduction, energy savings, and end-user comfort, are even more pertinent now than ever, especially in a place where sustainable development is rapidly gaining interest. The focus on energy savings, achieved through superior insulation, LED lighting, and an innovative HVAC system, can help lower the industry's carbon footprint. Incorporating renewable energy sources, such as solar panels and wind turbines, can also minimize reliance on traditional sources of electricity, a crucial advantage in energy-scarce regions. These long-term benefits provide reassurance about the sustainability of your investments [118].

Water conservation is a vital component of green building, offering advantages such as rainwater harvesting, greywater recycling, and the use of low-flow plumbing fixtures. Together, these measures significantly reduce water consumption and support overall sustainability efforts. Equally important is the role of eco-friendly buildings in reducing waste and carbon emissions. These buildings are constructed

from recycled, locally sourced materials that do not release toxic substances, thereby minimizing waste and reducing carbon emissions [119].

Green building also plays a significant role in enhancing biodiversity. Other components include improved indoor air quality through better ventilation systems. These green roofs offer natural insulation, enhance biodiversity, and incorporate advanced building technology that minimizes resource consumption, among other benefits. These characteristics, together, help make green buildings more efficient, sustainable, and resilient, while also contributing to the preservation of biodiversity [120].

Table 2.3 Key Sustainable Features in Green Buildings

Sustainable Feature	**Description**
Solar Panels & Renewable Energy	Utilizing solar, wind, and geothermal energy to reduce reliance on fossil fuels.
Rainwater Harvesting Systems	Capturing and reusing rainwater to decrease overall water consumption.
Smart Energy Management Systems	Implementing automated controls to optimize lighting, HVAC, and overall energy efficiency.
Sustainable Building Materials	Using eco-friendly materials, such as bamboo, recycled steel, and low-carbon concrete, minimizes environmental impact.
Biophilic Design Elements	Integrating green roofs, vertical gardens, and natural ventilation to enhance indoor air quality and occupant well-being.

2.5.3 Impact of Green Buildings on Construction Project Management

The development of green buildings has revolutionized the practice of construction project management, empowering project managers to establish different guidelines by which projects are planned, designed, and built to implement a sustainable approach [121]. This move towards green initiatives will, from now on, augur well for the development of the construction sector in Chad. With an emphasis on being more energy-efficient and conserving resources while being environmentally

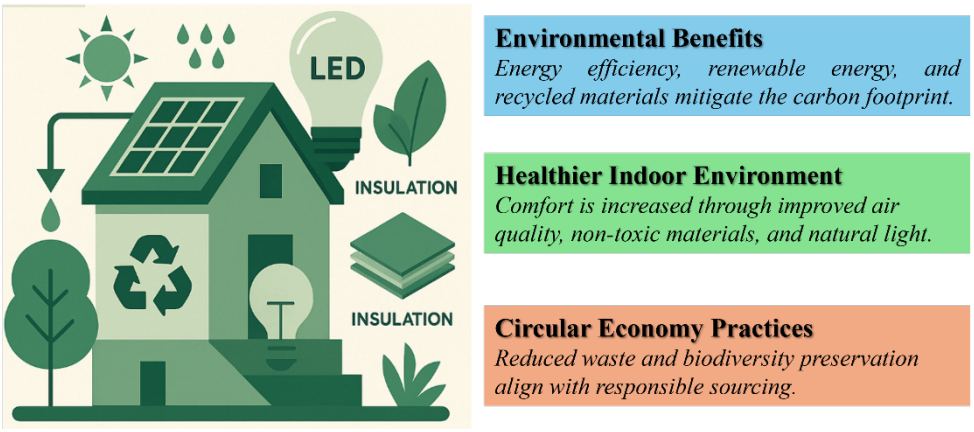


Figure 2.13 Green Product Solutions

friendly, project managers must adopt a new approach to their projects, starting from the ground up. Already, in the early stages, aspects such as site selection, energy modeling, and life cycle assessments have become key components in reducing environmental impact and ensuring a building's long-term sustainability and performance [122].

Green building certification systems, such as LEED, BREEAM, and WELL, foster collaboration and coordination among all building stakeholders. These accreditations are evidence-based, with strict compliance and documentation, and promote a culture of transparency and accountability [123]. This culture ensures that all stakeholders are aware of the environmental impact of their decisions and are held responsible for their actions, thereby fostering a more sustainable construction approach. This revolution has led to the increasing implementation of Building Information Modeling (BIM) to enhance design precision, minimize material waste, and improve communication among architects, engineers, and construction professionals. Moreover, construction methods such as prefabrication and modular building are also becoming increasingly common, as they share the same sustainability goals of minimizing waste and optimizing energy performance [124], [125].

With the advent of green buildings, cost strategies have also evolved, as these buildings often pay for themselves. The initial investment in sustainable materials and technologies is offset over time, as operations and maintenance costs are significantly lower. These days, it is up to project managers to weigh the potential long-term savings against the initial investment, providing reassuring financial

planning for eco-friendly projects [126].

Additionally, building crews must be trained in best practices that align with the latest eco-friendly technologies, energy-saving systems, and environmentally conscious materials. This comprehensive training ensures that construction professionals are well-prepared and competent when pursuing ecological designs [127].

In brief, green buildings have revolutionized construction project management by prioritizing efficiency, sustainability, and innovation. As the demand for environmentally friendly infrastructure increases, project managers must continually adopt innovative technologies and sustainable methods to deliver sustainable, high-performing projects.

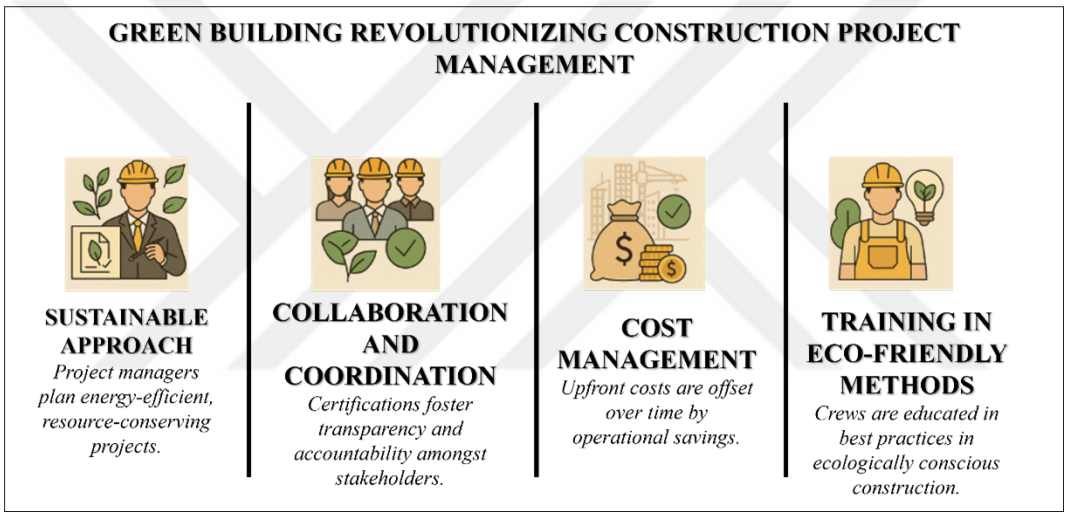


Figure 2.14 Green Building Revolution in Construction Project Management

2.6 Summary and Gaps in Literature

The advancement of construction management through innovative technologies holds promise for the future of building projects, including those related to green building schemes and sustainable outcomes. The analyzed literature highlights the significant potential of digital innovations, including Building Information Modelling (BIM), Internet of Things (IoT), drones, Digital Twins, artificial intelligence (AI), and cloud-based project management platforms. These tools enhance decision-making, foster stakeholder cooperation, improve resource efficiency, advance construction management, and promote sustainable practices. They achieve this through energy modeling, real-time waste tracking, predictive maintenance, and environmental monitoring throughout the building's lifespan.

Under the auspices of the United Nations Sustainable Development Objectives (SDGs), especially those focusing on Industry, Innovation and Infrastructure (SDG 9), Sustainable Cities and Communities (SDG 11), Responsible consumption and production (SDG 12) and Climate action (SDG 13), digital technologies are proposed as pivotal enablers in green building. For example, BIM lends itself to greener design by simulating energy consumption and minimizing material wastage through accurate quantity take-offs. Similarly, IoT-based sensors measure energy utilization and indoor environmental attributes in real-time, enabling performance-based sustainability management. These developments are central to the transition from the traditional to the green building discourse in literature.

While these global movements continue, there are essential gaps, even within low-income countries like Chad. Most research has been conducted in high-income countries, where strong digital infrastructures, sophisticated regulations, and high levels of professional education are conducive to implementing ICT in green buildings. These results may not apply to Sub-Saharan Africa, where basic infrastructure, including reliable electricity and internet access, is unevenly available. Therefore, the literature on digital solutions for sustainability, particularly in these contexts, is limited.

There is a critical absence of context-specific models for evaluating the preparedness and capacity of stakeholders within the construction sector to adopt and disseminate digital technologies in facilitating green building. Currently available theories, including the Technology Acceptance Model (TAM) and the Innovation Diffusion Theory (IDT), provide valuable insights; however, they often fail to account for contextual frictions, such as those found in environments with weak regulation, undeveloped markets, and culturally embedded construction activities. More importantly, there is an urgent need for empirical research on the scalability and reliability of emerging technologies in low-resource settings. This is a crucial step towards developing evidence-based strategies and policy instruments required for greener building technology. Current research often lacks an understanding of technologies as interrelated with the broader context of sustainability and development. Yet more holistic research is required that links digital innovation to climate resilience, institutional accountability, urban inclusion, and financing of green infrastructure. Additionally, the impact of external agents, including international development agencies, public-private partnerships, and government procurement systems, on facilitating or constraining green digital transformation is not well-documented in current research. These external agents can play a significant role in providing funding, expertise, and policy support for green digital transformation; however, their influence is poorly understood and

requires further investigation.

Lastly, the evidence base in Sub-Saharan Africa is predominantly qualitative, anecdotal, or theoretical, reflecting a scarcity of statistically robust, evidence-based data. This knowledge gap hinders the development of evidence-based strategies and policy tools for promoting green building technologies. The importance of mixed-methods quantitative research as the basis for generating local data to test models of sustainable innovation adoption should be a priority.

This research aims to fill these gaps by providing an organized, context-specific investigation into the successful adoption of innovative technologies for sustainable construction project management in Chad. Based on survey data and an adapted exploratory factor analysis, this inquiry aims to generate empirical knowledge and advocate for the formulation of a framework to chart the national transition to green digital building practices. This framework, aligned with Chad's rural and regional development visions, can lead to improved infrastructure, reduced environmental impact, and enhanced economic development.

2.7 Chad's Construction Industry

2.7.1 Overview of the Construction Sector in Chad

Chad's building and construction industry is not just a sector, but a vital engine driving the country's overall development. It plays a crucial role in infrastructure development, job creation, and the provision of public services. Situated at the heart of Africa, despite being landlocked, Chad has a growing population and rapid urbanization, making it in dire need of housing, roads, water, schools, and healthcare facilities. The public investment-led sector, primarily financed by donor agencies, multilateral development banks, and bilateral aid agencies, forms the backbone of the country's economy. According to the World Bank (2023), for an average country, approximately 60% of public investment expenditure is allocated towards infrastructure, underscoring the pivotal role of the construction industry in National development plans.

While the infrastructure sector in Chad is strategically relevant, it is also relatively underdeveloped and fragmented. Most players are small and medium-sized enterprises (SMEs), many of which operate in the informal sector without formal registration and do not necessarily adhere to national building codes. The industry's ability to handle larger projects or tenders overseas is limited by the scarcity of specialists or larger companies with the necessary technical skills. The industry is also concentrated in N'Djamena, Moundou, and Sarh. The country and its

rural areas face a severe lack of infrastructure investment and skilled workers, highlighting the urgent need for skilled labor and improved infrastructure. Despite recent growth, the construction sector in Chad is plagued by systemic issues. Building laws are inconsistently enforced, procurement processes are tainted by corruption, and projects often face delays. The industry also suffers from delayed public payments and a lack of stakeholder coordination, negatively impacting project sustainability and investor confidence. Furthermore, the field grapples with a deficiency of skilled labor, including engineers, architects, and project managers, due to the limited training capacity in vocational schools and colleges.

There is also a significant issue with the sourcing of materials. In Chad's case, the country relies heavily on imported construction input goods, including cement, steel, specialized machinery, and surveying equipment, resulting in high project costs and logistical difficulties. Transport infrastructure also exacerbates these problems, particularly in rural areas and during the rainy season, when roads are often impassable.

There is an emerging emphasis on environmental sustainability in the building industry. Conventional building practices often result in waste and a substantial carbon footprint. The lack of ecological assessments on specific projects has led to soil erosion, deforestation, and biodiversity loss. This underscores the urgent need for sustainable construction practices in Chad.

On the other hand, there has been an increasing policy focus on reforming the sector in recent years. PN/PAD, PAD, and PND Programs, such as the National Development Plan (PND) and the Programme d'Appui aux Infrastructures, have prioritized improving infrastructure governance and better coordinating actors. These policymakers create a space for recent construction techniques and sustainability principles to enter the market.

2.7.2 Challenges and Opportunities for Technological Integration

The innovation in the building industry here in Chad is technology-driven, primarily challenging the sector and bringing about game-changing changes. Indeed, on the one hand, while digital solutions such as Building Information Modeling (BIM), drones, project management software, and Internet of Things (IOT) platforms can dramatically transform the quality, speed, and transparency of infrastructure delivery, they are also subject to the risk of cyber-attacks and privacy breaches. On the other hand, we face the current reality, characterized by low digital readiness, inadequate institutional support, and limited exposure to high-tech solutions. There



Figure 2.15 Chad's Construction Sector overview

is a concern about the general digital literacy of the construction workforce. Digital Project Managers: Few contractors, site managers, or financiers possess any understanding of digital technology, and even fewer have access to training programs that provide them with vital skills in BIM, digital project management, and automated surveying. Public bodies and professional orders (eg, the Order of Architects and Engineers) have limited resources for continuous upskilling in digital skills.

The infrastructure for disseminating technology, such as high-speed internet service or cloud storage, and licensing software, is inadequate in many parts of the country. Some sites are very remote and may not have access to basic digital tools or electricity, making real-time monitoring, mobile communications, and remote project control almost impossible. Price is the other major drawback. However, many, especially small- to medium-sized construction companies, can't afford to purchase the necessary hardware and software for this shift, particularly with slim margins and limited credit options.

However, there are also promising developments. Thanks to online courses and social media, young professionals and engineering school graduates in Chad are becoming increasingly familiar with digital construction tools. This growing tech-savvy workforce presents a significant opportunity for the more widespread adoption of cross-cutting technologies, especially when combined with targeted policy support and industry push.

Another promising avenue is the intersection of the nascent phase of technology adoption with national development priorities, including transparency,

sustainability, and inclusive growth. New technologies, such as blockchain, have the potential to revolutionize public procurement, making it more transparent, corruption-free, and traceable. Sustainable design tools, such as Building Information Modeling (BIM) and Life Cycle Assessment (LCA), can also foster the growth of sustainable building and the green construction industry, contributing to Chad's climate-resilient built environment and urban sustainability.

In conclusion, systemic constraints hinder the adoption of innovative technologies in Chad's construction industry. However, targeted investments in digital infrastructure, skills acquisition, and policy revisions have the potential to significantly enhance outcomes. With the right enablers, technology can fuel the evolution of an industry that is faster, more responsible, and sustainable.

3
METHODOLOGY

3.1 Research Design

This pioneering study is the first to delve into the transformative impact of new technologies on construction project management in Chad. With a specific focus on advancing the United Nations' Sustainable Development Goals (SDGs), the research was conducted quantitatively, necessitating the measurement of stakeholders' perceptions and their antecedents. This method enabled the objective measurement and application of rigorous statistical analysis to uncover latent patterns and correlations.

A comprehensive literature review was undertaken to establish a robust theoretical foundation. This stage was instrumental in delineating the conceptual relationship between digital transformation, sustainability, and construction project performance, particularly in an emerging country. The review also informed the design of a formal survey instrument to explore the experiences, attitudes, and challenges of Chad's construction industry workers. Several aspects of this topic were surveyed, including knowledge of innovative techniques, drivers, barriers, and sustainability goals.

Adapting to the logistical challenges presented by the COVID-19 pandemic and the increasing use of digital tools for scholarly inquiry, data was collected using an online survey. This approach facilitated the rapid distribution of questionnaires across a large geographic area, covering design engineers, architects, project managers, and construction companies in urban and peri-urban locations. The internet-based platform was cost-effective and offered anonymity to respondents, providing rapid responses that ensured the continuity and reliability of the research. Exploratory Factor Analysis (EFA) was employed to analyze the data and identify underlying constructs. A factor analysis (FA) is a correlational statistical procedure that examines the relationships between individual score patterns and the correlation between tests in terms of their factor structure [128]. It is beneficial in exploratory

studies when relationships among variables are poorly understood.

There are two approaches to EFA for the extraction procedure: Principal Component Analysis (PCA) and Common Factor Analysis (also referred to as Principal Axis Factoring, or PAF). PCA's objective is to account for the total variance in a data set, including specific and error variance, and is therefore more appropriate for data reduction [129]. On the other hand, PAF extracts and examines only the coverability between variables, and is better suited to the discovery of underlying constructs that tap the actual underlying patterns of "behavior, perception, or mentality [130]. The research aims to uncover the perplexing cause behind technology adoption and sustainability in the Chad building industry, so PAF was chosen as the most suitable method.

PAF results helped the researcher identify clusters of survey items, thereby representing prospectively conceptually coherent dimensions, including digital readiness, stakeholder engagement, regulatory barriers, and sustainability alignment. Investigating these dimensions is crucial for obtaining a comprehensive understanding of the technology-sustainability interface in the local construction industry.

One of the crucial questions in EFA is the selection of the appropriate factor loading cut-off [131]. Factor loadings represent the relationship between an observed variable and a latent factor in terms of both strength and direction. In social scientific research, factor loadings higher than 0.4 are generally considered meaningful, and loadings above 0.3 are established as the lower limit. A more stringent loading of 0.50 was set to avoid overinterpretation and to ensure that only highly associated variables were considered when interpreting each factor for the present research. This procedure helped make the result less susceptible to sound [132].

In this sense, applying PAF within the EFA framework was a robust methodology for revealing the latent dynamics of technological innovation and the sustainability of the construction industry in Chad, enabling empirically driven findings relevant to policy and practice.

3.2 Population and Sampling Techniques

Sampling is a crucial issue in all quantitative research, as it can potentially affect the reliability, validity, and generalizability of a study [133]. This research focused on a particular and narrow category of Chadians involved in construction work:

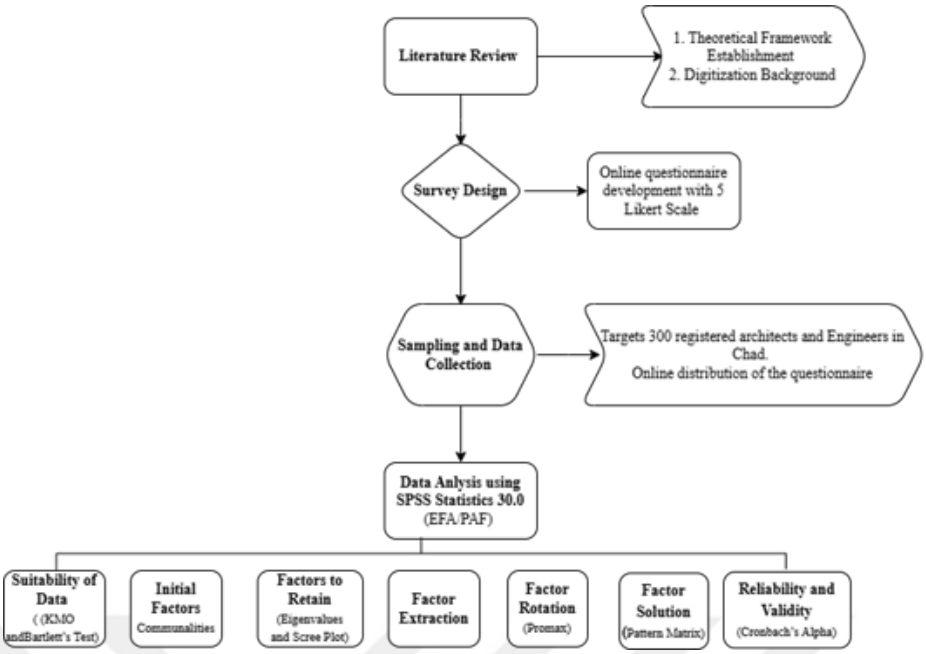


Figure 3.1 Research Design

engineers and architects who had passed the official exam and were registered to practice by the Conseil de l'ordre des architectes et d'urbanistes du Tchad. The intentional decision to focus on this segment, which is a formalized and regulated part of the sector, was made due to the significant impact their registration has on the reliability and validity of the study, unlike most of the informal workforce, which is also elusive to measure and assess systematically.

Chad's building sector is home to tens of thousands of professionals, but 80 percent of them are informal, lacking proper documentation or membership in regulatory bodies. Due to this lack of organization, creating an effective sampling frame that accurately represents the entire industry and recent developments is incredibly challenging. National professional orders have been established recently, creating some structures. Approximately 200 engineers and 150 architects have registered. These official records enabled the selection of a reliable and accessible group of professionals for this study, despite the complex challenges.

Due to these contextual constraints, the study employed a purposive non-probability sampling technique intentionally. This deliberate choice enabled the researcher to select individuals involved in construction project management, embracing innovative technologies. By targeting the qualified group, the study ensured that feedback was relevant and informative, making meaningful contributions to the research questions.

To reach the target population, three hundred e-questionnaires were sent to industry

managers or decision-makers. The online mode of publication was used to make the questionnaire as widely available as possible and to solicit a fast response from the authors, as face-to-face consultation in post-pandemic times may not be feasible. Finally, 79 completed responses were collected, resulting in an overall response rate of approximately 26%. Although not high, this number is quite reasonable from a social science research perspective, especially when a specific professional constituency is surveyed. Crucially, the number of responses was also adequate for conducting EFA, which typically requires a sample size of at least 50 to be considered statistically meaningful.

Thus, the sampling in the present study was intentional and targeted, based on the framework provided by the Federation of Professional Orders, which contributed to the data quality. Notwithstanding the sector's general informality, the mechanism provided a practical avenue for gaining informed insights into how new technologies impact the management of construction projects and contribute to sustainable development in Chad.

3.3 Survey Design and Instrumentation

For this study, the questionnaire was designed with a specific plan to capture robust results on the adoption of innovative technologies in construction project management and their alignment with the Sustainable Development Goals (SDGs). A key aspect of this measure was the purposeful use of a 5-point response format (strongly disagree, disagree, neutral, agree, and strongly agree), which served as an essential mechanism for capturing the subtlety of the respondents' perceptions. The scale was not only a matter of format, but it was chosen because it can capture the intensity of attitudes and beliefs; the respondents are enabled to express levels of agreement or disagreement clearly and consistently [134]. Standardizing the response options of the Likert scale enhanced the consistency and interpretability of the data, thereby increasing the likelihood of making concise claims about trends, relationships, and differences among groups of respondents [135].

The questionnaire had 98 well-phrased, carefully and meaningfully structured questions organized in three main parts, which aimed to measure different constructions of the study:

1. **Section I:** Respondent and Firm Characteristics; this section begins by asking fundamental questions about the respondents and firms represented in the survey, including job title, discipline of practice, and type of construction project managed. This contextual background was necessary to situate

individual answers from participants within the broader context of the company and sector.

2. **Section II:** Technological Innovation and Project Management; this section, the heart of the survey, aimed to explore how digital and innovative technologies are applied in construction. It examined their impact on project management, decision-making methods, risk and safety management, and environmental and social performance. The section also examined technology readiness levels and the development of drivers.

3. **Section III:** SDGs; the final section presented the construction professionals' perceptions of the relationship between their work and global sustainability goals. It addressed topics such as the quality of infrastructure, efficient resource utilization, climate change mitigation, inclusive economic development, and institutional governance. This section is crucial for understanding construction activities concerning the national and global Sustainable Development Goals (SDGs) targets.

The content validity and practical relevance of the items were determined in consultation with industry experts at various stages of questionnaire construction. Their comments also triggered a refinement process that improved the scale's clarity, alignment with industry practice, and ease of use, further validating the Likert scale as a meaningful and accessible response format for all respondents.

3.4 Data Analysis Procedure

Exploratory factor analysis (EFA) based on principal axis factoring (PAF) was employed in this study to identify the patterns and associations present in the collected data. EFA is recognized for its ability to identify latent constructs that account for the relationships among observed items [136]. PAF was selected as it can extract common variance among the variables, specifically ignoring specific and error variance, which is ideal when dealing with latent constructs such as technological adoption and project management strategies [131].

The analysis followed a series of well-organized steps toward generating reliable and precise outcomes. The procedure was initiated in preliminary evaluations to check if the data were suitable for factor analysis. These indices included the Kaiser-Meyer-Olkin (KMO) test for sampling adequacy and Bartlett's Test of Sphericity to determine whether the correlation matrix was suitable for factor

Table 3.1 Core Fields and the 2030 Agenda

Part	Theme	Total Statements	References
Critical Discussion Points			
1	Integration of Innovative Technologies (IIT)	7	[[21], [23]-[33]
2	Sustainability in Construction (SC)	6	[34]–[45]
3	Challenges and Solutions (CS)	7	[18], [46]–[53]
4	Correlation with Project Success (CPS)	7	[54]–[63]
5	Decision-Making Factors (DMF)	7	[64], [70], [71], [73]
6	Evaluation of Project Management Software (EPMS)	7	[73]–[79]
7	Safety and Risk Management Improvement (SRMI)	7	[80]- [87]
8	Environmental and Social Impact Assessment (ESIA)	7	[88]– [91], [93], [94]
9	Forecasting Emerging Technologies (FET)	7	[94]- [100]
Sustainable Development Goals Focus Areas			
10	Infrastructure Development and Innovation (IDI)	5	[46], [114], [116], [117]
11	Sustainable Urbanization and Habitat Development (SUHD)	5	[103], [104]
12	Resource Efficiency and Sustainable Practices (RESP)	5	[103], [106], [107]
13	Environmental Conservation and Climate Action (ECCA)	5	[109], [111], [123]
14	Social Equity and Economic Development (SEED)	5	[112], [113]
15	Governance and Institutional Support (GIS)	5	[64], [66], [105]

analysis. A good KMO value and a significant Bartlett's test ensured that the data is adequate for subsequent analyses [137].

We fixed the threshold at 0,5, derived from previous studies to refine the factor structure further and enhance interpretability. As a result, items with factor loadings below 0.5 were excluded from the final model. This procedure enabled the removal of factors that did not coherently contribute to a unique construct, thereby allowing for a more straightforward interpretation of the underlying psychological dimensions [138]. Since our variables were correlated (typically the case in social science), we employed a type of rotation technique called Promax rotation. This allows factors to intercorrelate, as sustainability, innovation, and project management practices are not independent. Therefore, the Promax rotation provided an interpretable depiction of the interactions between the emerging factors [139].

The PAF method was used as a substitute for PCA because they are fundamentally different methods. Although PCA focuses on data reduction, PAF is used to uncover any underlying theoretical constructs that might account for the observed relationships, thereby fitting more suitably with the purposes of this study [140]. Analysis was conducted using SPSS 30.0, a reliable statistical analysis tool. Strong features were utilized to ensure consistent computation, allowing results to be reproducible for future patients or experiments.

In brief, the judicious use of EFA, employing Principal Axis Factoring with recommended statistical checks and rotation techniques, enabled the present study to reveal a meaningful and interpretable structure in the data. These findings deepen our understanding of how new technologies impact construction project management practices in Chad, with a particular focus on sustainable development.

3.5 Ethical Considerations and Limitations

This study was unwaveringly committed to upholding the highest ethical research standards, particularly regarding the involvement of human participants. Before the survey was distributed, participants were fully informed about the research's purpose, the voluntary nature of their participation, and their right to withdraw without facing any negative consequences. To ensure transparency and obtain consent, a digital informed consent statement was displayed at the beginning of the questionnaire, which participants were required to acknowledge before proceeding. No personal or identifying details were requested, ensuring the anonymity and confidentiality of all respondents. Furthermore, all collected data were securely

stored and used exclusively for scholarly purposes. The study adhered to the ethical guidelines of Yildiz Technical University and posed no physical, psychological, or legal risks to the participants.

However, like all research, this study has certain limitations that should be recognized. Firstly, the sample comprised 79 responses out of the 300 distributed questionnaires, resulting in a modest response rate of 26.3%. While this is generally acceptable for exploratory factor analysis, it limits the extent to which the results can be generalized to the broader population of construction professionals in Chad. Furthermore, the research was limited to engineers and architects officially registered with national professional bodies, thereby excluding the perspectives of numerous practitioners working informally within the sector. This exclusion could mean missing out on valuable perspectives, particularly from those who might approach innovation and project management differently due to fewer regulatory constraints. By acknowledging these limitations, the audience can feel informed about the study's scope and potential biases, which is crucial for a comprehensive understanding of the research.

Another constraint stemmed from the method of data collection. Since the survey was conducted online, the participation rate may have been influenced by unequal access to the internet and varying levels of digital literacy, particularly in remote regions or among older professionals who are less familiar with digital tools. Lastly, the study employed a cross-sectional design, capturing a snapshot of current practices and perceptions at a single point in time. This limits the ability to track changes or trends over a more extended period as the industry evolves. However, the research provides a solid foundation for future inquiries despite these challenges. Upcoming studies could benefit from more inclusive sampling, incorporating voices from the informal sector, or adopting longitudinal or mixed-method approaches to gain insights into how innovative technologies shape sustainable construction project management in Chad. This potential for future research should inspire hope and anticipation for the impact and opportunities for further exploration that this study has opened.

4
ANALYSIS AND SYNTHESIS

4.1 Participant Sociodemographic

The study interviewed 79 Chadian building-sector workers, collecting data on their gender, age, education level, job role, years of experience, and the size of their enterprises 4.1. A significant gender imbalance was noted, with most respondents being men, who accounted for 85%, while women accounted for only 15%. This disparity between the sexes can have substantial consequences for the industry, affecting its potential to think and make decisions in various ways. The industry is relatively young, with 39% of respondents falling within the 26-33 age range and 52% within the 34-41 age range. Notably, no individuals were > 50 years of age. The field is overwhelmingly dominated by engineers, with 81% of those surveyed identifying as such. Architects and construction managers were underrepresented, at 4% and 5%, respectively. Concerning specific job positions, 56% of the respondents are construction engineers. Project managers are next at 22%, sustainability specialists at 6%, and architects at 1%. In terms of work experience, more than half of the respondents (53%) have worked in the industry for six to 10 years. Conversely, 5% of the space has more than 15 years of experience. The results also emphasize the critical importance of SMEs, which account for almost half (48%) of all participants. This trend reveals the immature development of the construction industry and the stringent financial capacity of building companies in Chad. In short, the data provide a sense of a youthful, male-heavy, engineering-obsessed sector driven by an underdeveloped field with room for professional diversification and expansion.

4.2 Factor analysis

Factor analysis is a statistical technique to identify underlying structures within a set of observed variables. It analyzes correlations among variables to group them into smaller, broader factors that represent shared patterns. These high-level factors

Table 4.1 Demographic Profile

Classification	Labels and Classifications	Percentage (%)
Gender	Male (1) / Female (2)	85 / 15
Demographic Group (by Age)	18–25 (1) / 26–33 (2) / 34–41 (3) / 42–49 (4) / 50+ (5)	0 / 39 / 52 / 9 / 0
Academic Qualification	Architect (1) / Engineer (2) / Construction Manager (3) / Surveyor (4) / Other (5)	4 / 81 / 5 / - / 10
Construction-related Occupation	Architect (1) / Project Manager (2) / Construction Engineer (3) / Sustainability Expert (4) / Other (5)	1 / 22 / 56 / 6 / 15
Industry Experience	Less than 1 year (1) / 1–5 years (2) / 6–10 years (3) / 11–15 years (4) / more than 15 years (5)	10 / 15 / 53 / 16 / 5
Organization Size	Small-scale (1) / Mid-size (2) / Large-scale (3) / Very large-scale (4) / Other categories (5)	48 / 24 / 9 / 10 / 9

capture standard dimensions in the data, allowing researchers to simplify complex datasets [141]. By reducing many variables into interpretable categories, factor analysis improves clarity and instills confidence in the researchers' understanding of the data. This method is beneficial in fields like psychology, education, and social sciences, where observed measures often reflect deeper, latent constructs that are not directly measurable [142].

The questionnaire had three logical sections. The initial segment collected the respondents' sociodemographic information, providing valuable background information that informed their viewpoints in a broader framework. This information highlighted the diversity and significance of the sample participants. The second section focused on the core of the research, examining nine key themes essential to the study's objectives. These subject areas were chosen judiciously to be representative of the main topics and to help capture the essence of the subject. The third part focused on the SDGs, categorized into three thematic areas, corresponding to the three dimensions of sustainability. This framework enabled a focused sustainability analysis within the study's specific focus. The survey design helped us understand the proposed research questions in depth.

4.2.1 Principal Themes

After thoroughly reviewing the existing literature, we identified several key themes to guide our study, emphasizing alignment with relevant Sustainable Development Goals (SDGs). These SDGs, particularly those connected to sustainability, infrastructure, environmental responsibility, construction practices, and governance, were central to shaping the direction of our research. The themes derived from literature and the Sustainable Development Goals (SDGs) formed the foundation of our survey design. Each central area of focus was transformed into a dedicated section within the questionnaire, featuring carefully crafted statements that enabled participants to share their opinions openly and meaningfully.

The questionnaire was organized into 15 sections: 9 based on core research themes and 6 on the Sustainable Development Goals (SDGs), resulting in two distinct datasets. This subsection focuses on the first dataset, which was analyzed using principal axis factoring to identify underlying patterns among the responses. The dataset was built upon the following main categories:

- Integration of Innovative Technologies (IIT)
- Sustainability in Construction (SC)
- Challenges and Solutions (CS)
- Correlation with Project Success (CPS)
- Decision-Making Factors (DMF)
- Evaluation of Project Management Software (EPMS)
- Safety and Risk Management Improvement (SRMI)
- Environmental and Social Impact Assessment (ESIA)
- Forecasting Emerging Technologies (FET)

These 9 themes were organized into 3 broad sets to streamline the analysis and handle the volume of items in SPSS Statistics 30.0. This strategic organization allowed for a more focused and coherent examination of the data. It offered more profound insights into participants' perspectives on various interrelated issues within the construction sector and its sustainability challenges.

4.2.1.1 Reliability and Consistency Metrics for the Dataset

The KMO (Kaiser–Meyer–Olkin) measure of sampling adequacy is a popular way of assessing whether a dataset is suitable for factor analysis. The value of this index ranges from 0 to 1, with a larger value representing a better fit. Some authors consider 0.5 good enough, while others believe it should be at least 0.6. Kaiser provides a frame of reference: the lowest allowable value is 0.5; values from 0.6 to 0.69 are considered mediocre, those from 0.7 to 0.79 are average or middling, and those from 0.8 to 1.0 are excellent. These criteria help determine whether to use factor analysis in a dataset [143]. Apart from the KMO test, Bartlett's Test of Sphericity is also used to check the significance of the correlations among the variables for justifying factor analysis. A p-value of $p < 0.05$ indicates a significant result, suggesting that the correlation matrix is not an identity matrix, i.e., the relationships between the variables are meaningful [144]. In our consideration, the data meets the requirements for factor analysis, ensuring that these essential factors are satisfied. As shown in Table 6, the KMO value is 0.81, which falls into the "excellent" category according to Kaiser's scale; meanwhile, the Bartlett's Test result was also highly significant ($p < 0.001$). These results indicate that the adequate statistical requirements for conducting a dependable factor analysis were fulfilled. To further enhance the quality and depth of our analysis, we first

Table 4.2 Assessment of Sampling Adequacy and Sphericity for the 9 Factors

Test	Value
Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy	0.810
Bartlett's Test of Sphericity – Approx. Chi-Square	5755.040
Degrees of Freedom (df)	1891
Significance (Sig.)	$< .001$

aggregated the 62 survey items (each describing a specific statement) into nine factors based on our core themes and the questionnaire's structure. This process involved identifying commonalities among the survey items and grouping them based on these commonalities. The nine factors were then similarly grouped into three higher-level categories for a more in depth analysis, including the decision-making factors (DMFs), forecasting emerging technologies (FET) and environmental and social impact assessment (ESIA) in the first category, safety and risk management improvement (SRMI), evaluation of project management software (EPMS) and integration of innovative technologies (IIT) in the second,

and correlation with project success (CPS), challenges and solutions (CSs) and sustainability in construction (SC) in the third category.

Our analysis was conducted with a systematic and thorough approach, reassuring of the rigor of the process. Two subsamples were subjected to detailed statistical scrutiny to assess the suitability of the sample for factor analysis and to reveal the underlying structure. We used the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity to test sample adequacy and inter-variable correlations. Communality was assessed to determine the shared variance between items. Both the scree plot and explained variance were used to determine the number of factors to retain. Lastly, the Factor Matrix, Pattern Matrix, Structure Matrix, and Factor Correlation Matrix provided in-depth information about factor loadings and factor relationships, facilitating the interpretation of meaningful results.

4.2.1.2 Total Variance Explained

The Total Variance Explained indicates how much of the overall variability in the observed variables is accounted for by the extracted factors. In Principal Axis Factoring (PAF), this metric helps assess the adequacy and efficiency of the factor solution. A higher percentage of total variance explained means the extracted factors capture a greater portion of the underlying structure in the data, which suggests a more meaningful and interpretable factor model [145]. However, unlike Principal Component Analysis (PCA), PAF focuses only on common variance, not total variance, making it more suitable for uncovering latent constructs in psychological or social science research [146].

In Table 4.3 below, Factor 1 accounts for 57.88% of the variance, Factor 2 accounts for 8.22%, and Factor 3 accounts for 7.52%. These three dimensions account for 73.62% of the total variance, reflecting a robust and integrated structure. Factor 1 is highly important, explaining the most variance and constituting the primary factor. Even if Factors 2 and 3 each explain smaller proportions, they are necessary for the overall structure of the data.

Table 4.4 presents the Total Variance Explained for the second set of factors. Factor 1 explains 56.30% of the variance, while factors 2 and 3 account for 8.94% and 5.91%, respectively. Together, these three dimensions account for 71.51% of the overall variance, revealing that they successfully represent the primary aspects of the data. This high total variance suggests a good underlying factor structure, enabling the interpretation of the sections and confirming the appropriateness of factor analysis for this survey.

Table 4.3 Explained Variance of the first set of items

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	9.261	57.881	57.881	8.952	55.948	55.948	8.110
2	1.315	8.219	66.100	1.025	6.404	62.352	7.260
3	1.203	7.521	73.622	0.891	5.568	67.920	5.161
4	0.681	4.255	77.877				
5	0.634	3.964	81.841				
6	0.517	3.231	85.072				
7	0.435	2.719	87.792				
8	0.362	2.265	90.056				
9	0.342	2.136	92.192				
10	0.288	1.797	93.989				
11	0.229	1.432	95.421				
12	0.196	1.223	96.644				
13	0.172	1.074	97.719				
14	0.164	1.028	98.747				
15	0.120	0.749	99.495				
16	0.081	0.505	100.000				

Table 4.4 Explained Variance for the Second Group of Factors

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	9.571	56.298	56.298	9.239	54.345	54.345	7.788
2	1.520	8.943	65.240	1.152	6.775	61.121	6.972
3	1.005	5.911	71.151	0.723	4.252	65.372	7.657
4	0.757	4.456	75.607				
5	0.697	4.100	79.707				
6	0.597	3.514	83.221				
7	0.467	2.745	85.965				
8	0.403	2.370	88.335				
9	0.383	2.256	90.591				
10	0.320	1.881	92.472				
11	0.283	1.664	94.136				
12	0.225	1.321	95.457				
13	0.205	1.209	96.665				
14	0.177	1.044	97.709				
15	0.175	1.032	98.741				
16	0.126	0.744	99.485				
17	0.088	0.515	100.000				

Table 4.5 Variance Contribution of the Third Factor Set

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	8.393	64.562	64.562	8.097	62.287	62.287	7.134
2	0.809	6.220	70.782	0.501	3.850	66.137	6.596
3	0.678	5.216	75.999	0.371	2.852	68.989	6.504
4	0.618	4.753	80.751				
5	0.520	4.000	84.751				
6	0.392	3.014	87.765				
7	0.375	2.887	90.651				
8	0.298	2.295	92.947				
9	0.231	1.776	94.722				
10	0.204	1.567	96.289				
11	0.194	1.492	97.781				
12	0.163	1.251	99.032				
13	0.126	0.968	100.000				

In table 4.5 below, Factor 1 is the most crucial dimension, explaining 62.287% of the variance, and Factors 2 and 3 explain 3.850% and 2.852% of the variance, respectively. The cumulating contribution of these three factors accounts for 68.989% of the variance, revealing essential dimensions of the data. The relatively high total variance also indicates that the factor structure can capture the main trends in the data, leading to substantial interpretive power, which in turn enhances the robustness of the analysis in this section.

4.2.1.3 Scree Plot

The scree plot is an essential tool in Principal Axis Factoring (PAF), used to determine the optimal number of factors to retain. It displays the eigenvalues of factors in descending order, helping identify the "elbow point" where the slope of the curve levels off [147]. This point indicates where additional factors contribute minimally to explaining common variance and are likely unimportant. The scree plot is valuable because it helps avoid over- or under-extracting factors, ensuring a more accurate and interpretable factor structure. It complements statistical criteria like the eigenvalue-greater-than-one rule and supports theoretical reasoning by visually confirming the significance of retained factors [148]. In PAF, where only common variance is analyzed, the scree plot provides insight into how much shared variance each factor explains. Overall, it is a practical and visual method for guiding factor retention decisions, enhancing the validity and simplicity of the factor analysis model [149].

Figure 4.1 is a graphical representation of the eigenvalues of the factors extracted from the principal axis factoring (PAF). This scree plot reinforces the findings

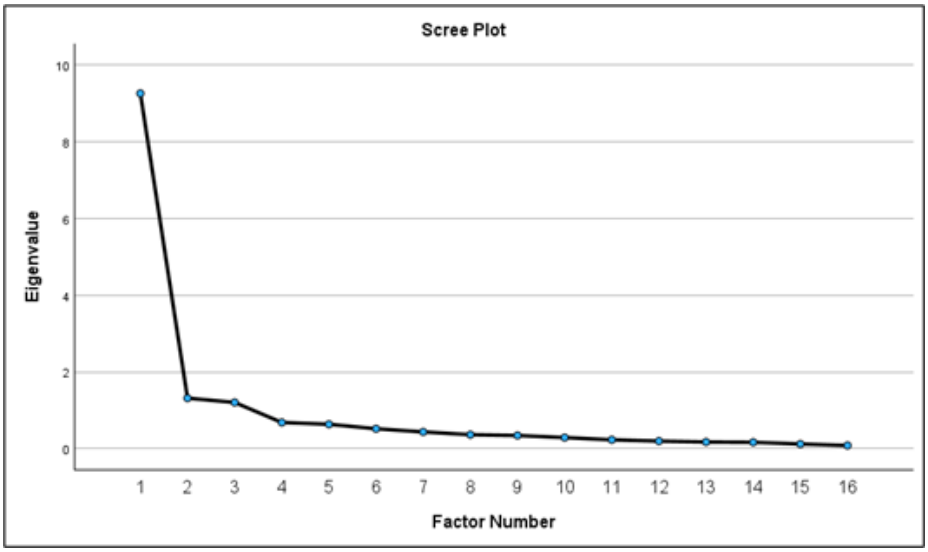


Figure 4.1 Scree Plot of the first set of factors

from the Total Variance Explained table presented above, where three factors were retained based on the eigenvalue >1 criterion.

The scree plot in Figure 4.2shows that only three factors have an eigenvalue greater than 1 and thereby confirms the total variance explained of the second set of factors. The scree plot in Figure 4.3 shows that only three factors have an eigenvalue greater than 1 and thereby confirms the total variance explained of the third set of factors presented in the previous section.

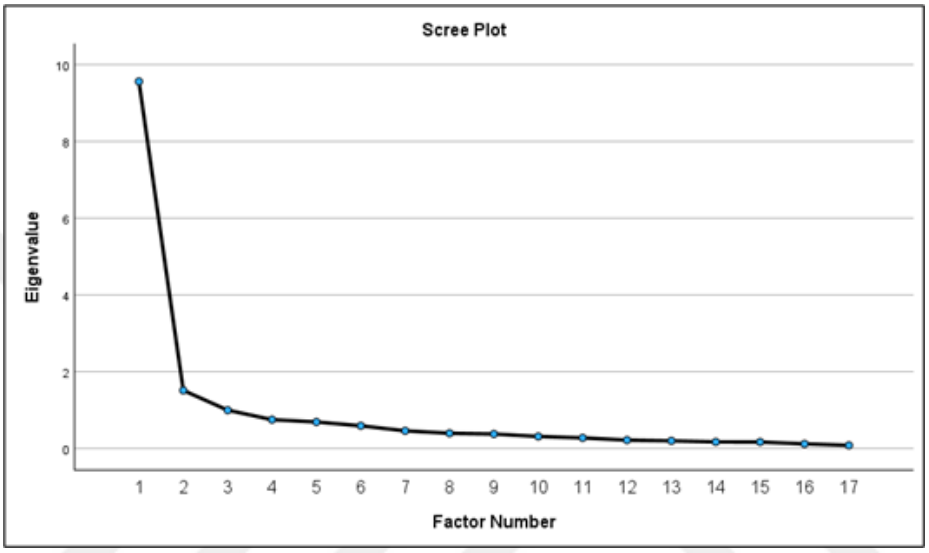


Figure 4.2 Scree Plot of the second set of factors

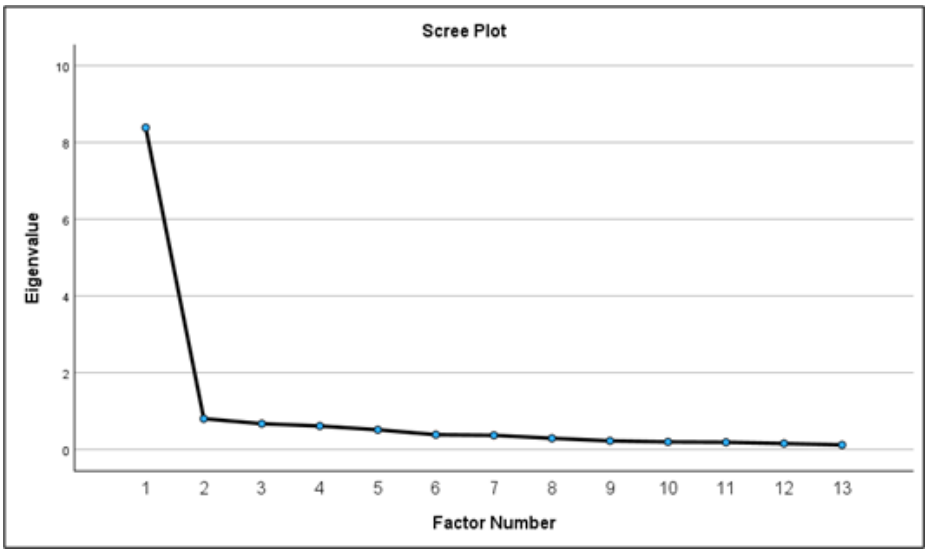


Figure 4.3 Scree Plot of the third set of factors

4.2.1.4 Factor Matrix

In Principal Axis Factoring (PAF), the Factor Matrix presents the initial loadings of each observed variable on the extracted factors before any rotation is applied [150].

These loadings indicate the strength and direction of the linear relationship between the variables and the underlying latent factors. Each cell in the matrix reflects how much a specific variable contributes to a given factor. High absolute values (typically above 0.4) suggest strong associations, while low values indicate weak relationships. The Factor Matrix is crucial in the early stages of factor analysis, helping researchers identify which variables are linked to which factors [151]. However, because these initial loadings may not always be easily interpretable, a rotation (e.g., Varimax or Promax) is often performed to achieve a clearer, more meaningful structure. In essence, the Factor Matrix offers a foundational view of the factor structure, guiding further refinement and interpretation in multivariate analysis [152].

The Factor Matrix from the Principal Axis Factoring in Table 4.6 reveals three meaningful components. Factor 1 groups variables from Decision-Making Factors (DMF) and Environmental and Social Impact Assessment (ESIA), indicating a strong association between strategic decision-making and sustainability evaluation in construction projects. This factor highlights how environmental and social considerations influence project planning and management. Factor 2 shows moderate loadings on items related to Forecasting Emerging Technologies (FET), reflecting a forward-looking perspective that emphasizes strategic anticipation of technological trends. Factor 3 also exhibits strong FET item loadings, indicating a secondary but distinct dimension related to innovation readiness and practical technology adoption. The overlap of FET items across Factors 2 and 3 implies a nuanced structure within the theme of forecasting, possibly separating visionary foresight from operational engagement. Overall, the matrix supports a three-factor solution that aligns with key research themes: sustainable decision-making, strategic forecasting, and technological innovation in construction project management. The Factor Matrix in Table 4.7 reveals three distinct factors related to core project management themes. Factor 1 is strongly defined by items from Safety and Risk Management Improvement (SRMI) and Evaluation of Project Management Software (EPMS), indicating a strong link between the use of digital tools and effective safety and risk practices. This suggests that advanced project management systems directly support safer, more controlled construction environments. Factors 2 and 3 include items from the Integration of Innovative Technologies (IIT), though with varied loadings. These factors likely represent two dimensions of innovation: one focusing on strategic adoption (IIT1, IIT5, IIT7), and the other on practical integration (IIT2, IIT3). The spread of IIT items across multiple factors may reflect the complexity of integrating innovation into construction, balancing conceptual planning with real-world implementation.

Table 4.6 Factor Matrix of the first set of factors

Item	Factor 1	Factor 2	Factor 3
DMF5	.838		
DMF7	.832		
DMF6	.830		
DMF3	.830		
ESIA7	.825		
DMF4	.811		
ESIA2	.792		
DMF1	.786		
DMF2	.719		
ESIA1	.714		
ESIA3	.702		
ESIA4	.694		
FET7	.656		
FET6	.640	.594	
FET1	.631		
FET4	.597	.514	

Extraction Method: Principal Axis Factoring. Note:
3 factors extracted. 17 iterations required.

Overall, the matrix supports a multidimensional view linking software use, safety, and technology integration in sustainable construction management. The Factor Matrix in Table 4.8 reveals a strong and cohesive single dominant factor, with high loadings from variables across three key dimensions: Correlation with Project Success (CPS), Challenges and Solutions (CS), and Sustainability in Construction (SC). Most CPS items (CPS1, CPS2, CPS3, CPS5, CPS6) load highly, suggesting that project success is closely tied to how well sustainability goals are integrated and challenges are addressed. Similarly, CS and SC items load strongly on this same factor, indicating that sustainable practices and the ability to navigate project-related challenges are central to achieving successful outcomes. The lack of clear separation between factors in the matrix suggests that these constructs are highly interrelated and may form a unified dimension of effective,

Table 4.7 Factor Matrix of the second set of factors

Item	Factor 1	Factor 2	Factor 3
SRMI5	.845		
EPMS6	.807		
SRMI6	.801		
SRMI2	.796		
EPMS5	.777		
EPMS4	.770		
EPMS3	.761		
EPMS2	.761		
EPMS7	.752		
IIT7	.736		
SRMI3	.735		
SRMI4	.717		
IIT5	.699		
IIT1	.696		
IIT6	.690		
IIT3	.596		
IIT2	.529		

Extraction Method: Principal Axis Factoring. Note:
3 factors extracted. 6 iterations required.

sustainable project performance. This integrated factor structure emphasizes that success in construction projects is not isolated but depends on the interplay of problem-solving, sustainable practices, and measurable project outcomes.

4.2.1.5 Pattern Matrix

In Principal Axis Factoring (PAF), the Pattern Matrix shows the standardized regression coefficients (or loadings) of each variable on each factor after oblique rotation (e.g., Promax or Oblimin). Unlike the unrotated Factor Matrix, the Pattern Matrix isolates the unique contribution of each factor to a variable, controlling for overlap among factors. This makes it especially useful when factors are correlated, as it helps clarify which variables load cleanly on which factors [153].

Table 4.8 Factor Matrix of the third set of factors

Item	Factor 1	Factor 2	Factor 3
CPS3	.887		
CPS5	.848		
CS6	.825		
SC3	.819		
CPS6	.814		
CPS2	.810		
CS3	.800		
CS5	.791		
SC5	.789		
SC6	.780		
CS4	.743		
CPS1	.672		
CS7	.648		

Extraction Method: Principal Axis Factoring. Note:
3 factors extracted. 10 iterations required.

Each value in the matrix represents the strength and direction of the relationship between a variable and a factor, independent of the other factors. High loadings (e.g., 0.4) indicate a strong association. Because the Pattern Matrix removes shared variance due to factor correlation, it provides a clearer and more accurate representation of the factor structure than the Structure Matrix in oblique solutions. It's critical for interpreting which variables define each factor in correlated-factor models [154].

The Pattern Matrix in Table 4.9 shows a well-defined three-factor solution, each representing a distinct conceptual dimension. Factor 1 includes strong loadings from all Decision-Making Factors (DMF1–DMF7), indicating a cohesive factor centered on strategic decision-making in construction management. Factor 2 is defined by high loadings from Environmental and Social Impact Assessment (ESIA1–ESIA4, ESIA7) items, representing a separate dimension focused on sustainability and regulatory compliance. Factor 3 includes high loadings from Forecasting Emerging Technologies (FET4, FET6), capturing a forward-looking orientation toward technology anticipation and readiness. Notably, FET7 loads on Factor 1, suggesting that some technological foresight may influence

Table 4.9 Pattern Matrix of the first set of items

Item	Factor 1	Factor 2	Factor 3
DMF4	.925		
DMF5	.873		
DMF1	.755		
DMF2	.744		
DMF6	.736		
DMF3	.699		
DMF7	.670		
FET7	.619		
ESIA2		.938	
ESIA1		.876	
ESIA3		.662	
ESIA7		.657	
ESIA4		.640	
FET1			
FET6			.956
FET4			.759

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.
Note: Rotation converged in 6 iterations.

decision-making strategies. The clean separation across factors with minimal cross-loadings highlights the thematic clarity of the model, aligning well with your research framework. This structure supports the idea that decision-making, environmental evaluation, and technological forecasting function as distinct but complementary pillars in sustainable construction project management. The Pattern Matrix in Table 4.10 reveals a clear three-factor structure with minimal cross-loadings, supporting strong conceptual separation. Factor 1 is defined by very high loadings from Safety and Risk Management Improvement (SRMI) items (e.g., SRMI2 = .969, SRMI5 = .985), reflecting a focused dimension centered on risk mitigation and safety procedures in construction. Factor 2 comprises items from the Integration of Innovative Technologies (IIT), such as IIT2, IIT3, IIT5, and IIT6, representing a factor that captures technology adoption and innovation integration in project execution. Factor 3 is composed of items from Evaluation of Project Management Software (EPMS), with high loadings from EPMS4 (.910),

Table 4.10 Pattern Matrix of the second set of factors

Item	Factor 1	Factor 2	Factor 3
SRMI5	.985		
SRMI2	.969		
SRMI6	.816		
SRMI4	.549		
SRMI3	.515		
EPMS6			
IIT5		.800	
IIT3		.784	
IIT2		.776	
IIT7		.638	
IIT6		.630	
IIT1		.514	
EPMS4			.910
EPMS5			.814
EPMS7			.691
EPMS3			.685
EPMS2			

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.
Note: Rotation converged in 6 iterations.

EPMS5 (.814), and others, indicating a third dimension focused on the assessment and use of digital tools for project oversight. The structure confirms that safety, technological innovation, and software evaluation are distinct but interrelated areas critical to advancing sustainable and efficient construction project management. The Pattern Matrix in Table 4.11 reveals a three-factor solution with distinct thematic clusters. Factor 1 includes high loadings from items related to Correlation with Project Success (CPS1, CPS2, CPS3, CPS5, CPS6), indicating a cohesive factor centered on measuring and achieving project success through performance indicators. Factor 2 comprises variables from Challenges and Solutions (CS3, CS4), reflecting a dimension focused on problem-solving and adaptive strategies in project management. Several CS items (CS5–CS7) are present but do not load strongly, suggesting they may either cross-load or have weaker contributions. Factor 3 is clearly defined by strong loadings from Sustainability in Construction (SC3,

Table 4.11 Pattern Matrix of the third set of items

Item	Factor 1	Factor 2	Factor 3
CPS6	.791		
CPS2	.786		
CPS5	.694		
CPS1	.691		
CPS3	.591		
CS3		.803	
CS4		.610	
CS6			
CS5			
CS7			
SC5			.865
SC6			.716
SC3			.569

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.
Note: Rotation converged in 9 iterations.

SC5, SC6), forming a distinct sustainability dimension focused on environmental performance and resource efficiency. The factor structure suggests that while success, challenge-resolution, and sustainability are conceptually related, they represent separate but interdependent constructs in the management of sustainable construction projects.

4.2.1.6 Structure Matrix

In Principal Axis Factoring with oblique rotation, the Structure Matrix displays the correlations between the observed variables and the extracted factors. Unlike the Pattern Matrix, which shows the unique contribution of each factor to a variable (partial regression coefficients), the Structure Matrix reflects both direct and indirect associations, meaning it includes the effects of factor intercorrelations [155].

Each cell in the Structure Matrix shows how strongly a variable is correlated with a factor, regardless of whether the association is due to the factor alone or shared variance with other correlated factors. As a result, values in the Structure Matrix are typically higher than those in the Pattern Matrix when factors are correlated

Table 4.12 Structure Matrix of the first set of items

Item	Factor 1	Factor 2	Factor 3
DMF5	.883	.644	.540
DMF4	.872	.611	
DMF6	.846	.669	.559
DMF3	.837	.711	
DMF7	.834	.659	.630
DMF1	.813	.670	
DMF2	.756	.567	
FET7	.679		.571
ESIA2	.655	.908	
ESIA7	.699	.839	.620
ESIA1	.573	.827	
ESIA3	.611	.750	
ESIA4	.591	.736	
FET6	.513		.923
FET4	.528		.792
FET1	.503	.618	.624

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.

[156]. This matrix is especially useful for understanding the overall relationship between variables and factors, but may not clearly distinguish which factor best represents a variable when there is factor overlap. It complements the Pattern Matrix in interpreting oblique rotation results.

The Structure Matrix below reflects the correlations between observed variables and the extracted factors, providing insight into shared variance. Factor 1 is primarily associated with high correlations from all Decision-Making Factors (DMF1–DMF7), indicating this component strongly represents strategic decision-making capacity. Factor 2 is defined by strong correlations with all Environmental and Social Impact Assessment (ESIA1–ESIA4, ESIA7) items, suggesting a well-formed dimension centered on sustainability evaluation and compliance. Factor 3 shows the highest correlations with Forecasting Emerging Technologies (FET4, FET6, FET7), pointing to a distinct forward-looking dimension related to technological foresight and innovation preparedness. Some

Table 4.13 Structure Matrix of the second set of factors

Item	Factor 1	Factor 2	Factor 3
SRMI5	.947	.581	.670
SRMI2	.902	.557	.611
SRMI6	.866	.555	.668
EPMS6	.771	.620	.739
SRMI4	.728		.661
SRMI3	.726	.560	.648
IIT5	.559	.810	.532
IIT7	.587	.780	.625
IIT6	.613	.734	.512
IIT3		.732	
IIT1	.591	.701	.580
IIT2		.692	
EPMS4	.591	.598	.869
EPMS5	.677	.526	.848
EPMS3	.647	.575	.800
EPMS7	.611	.602	.794
EPMS2	.636	.665	.734

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.

cross-loadings (e.g., FET1, ESIA7, DMF7) suggest interconnectedness between strategic, environmental, and innovation factors, which are expected in complex construction projects. Overall, the structure confirms a coherent and meaningful three-factor solution reflecting decision-making, sustainability assessment, and technology forecasting, aligning well with your research themes in sustainable construction project management. The Structure Matrix in Table 4.13 shows the correlations between observed variables and three extracted factors, revealing overlapping but distinct conceptual dimensions. Factor 1 is most strongly associated with Safety and Risk Management Improvement (SRMI) items (SRMI2, SRMI5, SRMI6), indicating a factor focused on risk control and safety strategies. Factor 2 is primarily defined by Integration of Innovative Technologies (IIT) items (IIT2, IIT3, IIT5, IIT6, IIT7), reflecting a dimension centered on technology adoption and innovation readiness. Factor 3 is dominated by high correlations from Evaluation of

Project Management Software (EPMS) items (EPMS3, EPMS4, EPMS5, EPMS7), forming a distinct dimension related to the use and effectiveness of digital project management tools. Several items show substantial correlations with more than one factor, especially EPMS and IIT items, suggesting interdependencies between technology use, innovation, and safety performance. Overall, the matrix supports a robust three-factor model aligned with digitalization, innovation, and safety in sustainable construction management.

The Structure Matrix in Table 4.14 reveals a highly interrelated three-factor structure where variables from Correlation with Project Success (CPS), Challenges and Solutions (CS), and Sustainability in Construction (SC) all show strong cross-factor correlations. CPS items (e.g., CPS2–CPS6) correlate strongly with Factor 1, indicating a central focus on project success and outcome achievement. CS items (e.g., CS3, CS4, CS6) load notably on Factor 2, suggesting a dimension emphasizing problem-solving and operational challenges in project execution. SC items (SC3, SC5, SC6) strongly correlate with Factor 3, highlighting the importance of environmental performance and sustainable practices. However, many items, particularly CPS3, CS6, and SC3, also exhibit notable correlations with multiple factors, indicating a strong overlap among success, challenge resolution, and

Table 4.14 Structure Matrix of the third set of items

Item	Factor 1	Factor 2	Factor 3
CPS3	.870	.774	.752
CPS5	.864	.605	.821
CPS6	.852	.697	.627
CPS2	.849	.675	.644
CS5	.749	.748	.645
CPS1	.713	.558	.524
CS3	.655	.867	.682
CS6	.765	.785	.694
CS4	.664	.766	.597
CS7	.571	.635	.568
SC5	.642	.675	.881
SC6	.670	.655	.830
SC3	.687	.758	.821

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.

sustainability. This overlap reflects the integrated nature of sustainable construction project management, where success is deeply influenced by both the ability to overcome challenges and implement sustainability measures.

4.2.1.7 Factor Correlation Matrix

The Factor Correlation Matrix in Principal Axis Factoring with oblique rotation (e.g., Promax or Oblimin) shows the correlations between the extracted factors themselves. Unlike orthogonal rotations (e.g., Varimax), which assume factors are uncorrelated, oblique rotation allows for interrelated factors, which is often more realistic in behavioral and social sciences [157].

Each cell in this matrix represents the Pearson correlation coefficient between two factors. Values range from -1 to +1: a value close to 1 indicates a strong positive relationship, 0 means no relationship, and a value close to -1 indicates a strong negative relationship. The diagonal of the matrix is always 1.00, representing the perfect correlation of each factor with itself [158]. The Factor Correlation Matrix is crucial for interpreting the degree of overlap among the factors. If correlations are low (e.g., < 0.3), orthogonal rotation might suffice; higher correlations suggest that oblique rotation is appropriate and necessary [159].

The Factor Correlation Matrix in Table 4.15 reveals substantial interrelationships among the three extracted factors from Principal Axis Factoring with Promax rotation. Factor 1, associated with Decision-Making Factors (DMF), is strongly correlated with Factor 2 (Environmental and Social Impact Assessment, ESIA) at 0.728, and moderately with Factor 3 (Forecasting Emerging Technologies, FET) at 0.600. Likewise, Factor 2 and Factor 3 are also correlated at 0.541. These values indicate that while the three factors are conceptually distinct, they share significant underlying variance, justifying the use of an oblique (Promax) rotation. The high correlation between DMF and ESIA suggests that environmental and social considerations deeply influence strategic decision-making in construction projects.

Table 4.15 Factor Correlation Matrix of the first set of factors

Factor	Factor 1	Factor 2	Factor 3
Factor 1	1.000	.728	.600
Factor 2	.728	1.000	.541
Factor 3	.600	.541	1.000

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.

Similarly, the links between DMF and FET, as well as ESIA and FET, imply that forward-looking technological forecasting is interconnected with both responsible decision-making and sustainability assessments. Together, these factors reflect an integrated framework for sustainable, innovation-driven construction management.

The Factor Correlation Matrix in Table 4.16 demonstrates strong interconnections among the three extracted factors, supporting an integrated interpretation of sustainable construction practices. Factor 1, linked to Safety and Risk Management Improvement (SRMI), correlates significantly with Factor 2 (Integration of Innovative Technologies IIT) at 0.641, and even more strongly with Factor 3 (Evaluation of Project Management Software EPMS) at 0.725. Similarly, IIT and EPMS are also closely related, with a correlation of 0.677. These results justify the use of Promax (oblique) rotation, as the factors are not orthogonal but conceptually intertwined. The high correlation between SRMI and EPMS suggests that effective software tools are key to strengthening safety and risk protocols. Additionally, the link between IIT and both SRMI and EPMS indicates that technological integration enhances both safety measures and digital project control. Overall, the findings highlight a synergistic relationship where innovation, safety, and digitalization collectively enhance project performance and sustainability. The Factor Correlation

Table 4.16 Factor Correlation Matrix of the second set of factors

Factor	Factor 1	Factor 2	Factor 3
Factor 1	1.000	.641	.725
Factor 2	.641	1.000	.677
Factor 3	.725	.677	1.000

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.

Matrix in Table 4.17 shows very strong correlations among the three extracted factors, indicating a high degree of conceptual overlap. Factor 1, associated with Correlation with Project Success (CPS), is strongly correlated with Factor 2 (Challenges and Solutions CS) at 0.745, and with Factor 3 (Sustainability in Construction SC) at 0.749. Similarly, CS and SC are highly correlated (0.721), confirming that the three dimensions are deeply interconnected within sustainable construction project management. These results support the use of Promax (oblique) rotation, which assumes that factors are not independent. The high inter-factor correlations suggest that project success is not isolated; it is closely influenced by how challenges are managed and how sustainability is integrated into the construction process. Together, the factors form a comprehensive framework where problem-solving, sustainable practices, and outcome-driven strategies work

in synergy to achieve effective and responsible project delivery.

Table 4.17 Factor Correlation Matrix of the third set of factors

Factor	Factor 1	Factor 2	Factor 3
Factor 1	1.000	.745	.749
Factor 2	.745	1.000	.721
Factor 3	.749	.721	1.000

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.

4.2.1.8 Exploratory Factor Analysis and Reliability Metrics of the First Three Factors

Table 4.18 presents key statistics that assess the quality and reliability of the data for factor analysis across three critical constructs: DMF (Decision-Making Factors), FET (Forecasting Emerging Technologies), and ESIA (Environmental and Social Impact Assessment). The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, with a value of 0.893, indicates that the sample size and data are well-suited for factor analysis. This high KMO value not only assures the robustness of the results but also underlines the meaningfulness of the study.

Additionally, Cronbach's Alpha values for the three constructs further support the reliability of the data. The coefficients are 0.939 for DMF, 0.906 for FET, and 0.818 for ESIA, all of which exceed the commonly accepted threshold of 0.7, indicating strong internal consistency within each scale. This means the items within each construct reliably measure the same underlying concept, increasing confidence in the validity of subsequent analyses.

The pattern matrix, obtained through Promax rotation, allows correlated factors and reveals transparent and interpretable factor loadings. Factor 1 primarily reflects the Decision-Making Factors construct. It shows very high loadings on DMF items, especially DMF4 (0.925) and DMF5 (0.873), indicating these variables are strongly linked to decision-making processes. The consistent pattern of strong loadings across DMF items underscores that Factor 1 robustly captures the essence of decision-making influences in the data, instilling confidence in the factor analysis.

Factor 2 aligns closely with the Environmental and Social Impact Assessment construct, with particularly high loadings on ESIA2 (0.938) and ESIA1 (0.876). These loadings not only confirm the factor's alignment but also underscore its effective representation of concerns related to environmental and social evaluations

Table 4.18 Factor Loadings, KMO, and Cronbach's Alpha of the first set of Factors

Item	KMO	Factor 1	Factor 2	Factor 3	Cronbach's Alpha
DMF4	.893	.925			.939
DMF5		.873			
DMF1		.755			
DMF2		.744			
DMF6		.736			
DMF3		.699			
DMF7		.670			
FET7		.619			
ESIA2			.938		.906
ESIA1			.876		
ESIA3			.662		
ESIA7			.657		
ESIA4			.640		
FET1					.818
FET6				.956	
FET4				.759	

within projects, emphasizing the distinct and meaningful nature of the ESIA construct.

Factor 3 is characterized by strong loadings on Forecasting Emerging Technologies items, remarkably FET6 (0.956) and FET4 (0.759). This indicates that Factor 3 reliably captures the ability to anticipate and assess future technological trends, an essential aspect of innovation management.

Overall, the factor structure is clear and well-defined, with each factor loading heavily on items that conceptually belong together. This confirms the distinctiveness of the three constructs and supports the dataset's suitability and reliability for further in-depth analysis. The results demonstrate that the data are valid and consistent, providing a solid foundation for interpreting the underlying dimensions that influence the study context, thereby reassuring the validity of the dataset.

Table 4.19 provides compelling evidence of the dataset's suitability for factor analysis, as demonstrated by a high Kaiser-Meyer-Olkin (KMO) measure of 0.912, which signifies excellent sampling adequacy. Complementing this, the Cronbach's Alpha coefficients for the three constructs, 0.926, 0.878, and 0.847, indicate strong internal consistency, confirming that the items within each construct reliably measure the exact underlying dimensions. These robust statistics establish a solid foundation for the validity of subsequent analyses.

The pattern matrix, derived through Promax rotation to accommodate potential factor correlations, reveals a clear three-factor solution. Factor 1 is distinctly associated with Safety and Risk Management Improvement (SRMI), featuring substantial loadings on items such as SRMI5 (0.947), SRMI2 (0.902), and SRMI6 (0.886), thus vigorously representing this construct. Factor 2 corresponds closely with the Integration of Innovative Technologies (IIT), supported by high loadings on IIT5 (0.810), IIT6 (0.780), and IIT3 (0.732), underscoring its thematic integrity. Factor 3 is identified with the Evaluation of Project Management Software (EPMS), although two items, EPMS6 and EPMS2, exhibit complex loading patterns that

Table 4.19 Factor Loadings, KMO, and Cronbach's Alpha of the second set of Factors

Item	KMO	Factor 1	Factor 2	Factor 3	Cronbach's Alpha
SRMI5	.912	.985			.926
SRMI2		.969			
SRMI6		.816			
SRMI4		.549			
SRMI3		.515			
EPMS6					
IIT5			.800		.878
IIT3			.784		
IIT2			.776		
IIT7			.638		
IIT6			.630		
IIT1			.514		
EPMS4				.910	.847
EPMS5				.814	

do not align exclusively with a single factor. These results validate the factor model's efficacy and open avenues for further examination, engaging the reader in the ongoing research process.

Specifically, EPMS6 demonstrates significant loadings across all three factors (0.771, 0.620, 0.739) yet shows its strongest affiliation with Factor 3. Similarly, EPMS2 presents moderate loadings on all factors but leans toward Factor 3 (0.734). Furthermore, SRMI3 and SRMI4 reveal moderate cross-loadings on Factors 1 and 3, suggesting conceptual similarity or common variance. These nuanced results underscore the robustness of the factor structure, providing a transparent and interpretable model. They also pinpoint specific areas that warrant closer examination, enhancing the clarity and precision of the measurement constructs. Collectively, these findings validate the factor model's efficacy and underscore the importance of further refining the measurement constructs.

Table 4.20 indicates that the dataset is well-suited for factor analysis, evidenced by a high KMO value of 0.920 and strong Cronbach's Alpha scores of 0.887, reflecting robust internal consistency and sample adequacy. The pattern matrix spots three distinct factors: Factor 1 corresponds to Correlation with Project Success (CPS), Factor 2 to Challenges and Solutions (CS), and Factor 3 to Sustainability in Construction (SC). However, items CS5, CS6, and CS7 do not show significant loadings on any factor, suggesting these variables may not align well with the identified constructs. Factor 1 demonstrates robust loadings on CPS items, particularly CPS6 (0.791), CPS2 (0.786), CPS5 (0.694), CPS1 (0.691), and CPS3 (0.591), thereby confirming its strong association with the CPS construct. Factor 2 is predominantly influenced by CS3 (0.803) and CS4 (0.610), aligning it with the CS construct. Factor 3 exhibits substantial loadings on SC variables, notably SC5 (0.865), SC6 (0.716), and SC3 (0.569), thereby convincingly and persuasively reinforcing its association with the SC construct. These loadings underscore a distinct factor structure corresponding to each theoretical construct. The lack of significant loadings for CS5, CS6, and CS7 suggests that these items may be conceptually misaligned or less relevant to the factors being measured. Overall, the results provide a coherent framework for data interpretation while highlighting specific variables that may warrant further review or refinement.

4.2.2 Sustainable Development Goals

The Sustainable Development Goals (SDGs) serve as a vital global framework for advancing sustainability, encompassing six key components, each defined by five specific indicators. These components IDI (Infrastructure Development

Table 4.20 Factor Loadings, KMO, and Cronbach's Alpha of the third set of Factors

Item	KMO	Factor 1	Factor 2	Factor 3	Cronbach's Alpha
CPS6	.931	.791			.920
CPS2		.786			
CPS5		.694			
CPS1		.691			
CPS3		.591			
CS3			.803		.887
CS4			.610		
CS6					
CS5					
CS7					
SC5				.865	.887
SC6				.716	
SC3				.569	

and Innovation), SUHD (Sustainable Urbanization and Habitat Development), RESP (Resource Efficiency and Sustainable Practices), ECCA (Environmental Conservation and Climate Action), SEED (Social Equity and Economic Development), and GIS (Governance and Institutional Support), hold significant relevance for the construction industry in Chad. The construction industry is not just a participant but an essential contributor to the worldwide sustainability agenda, playing a crucial role in achieving these goals.

The six SDG drivers have been organized into two overarching categories to understand their impact better, each containing three related components. Group 1 includes IDI, RESP, and ECCA, while Group 2 comprises SUHD, SEED, and GIS. This categorization promotes a structured approach to integrating the SDGs, ensuring that related objectives are grouped. This facilitates focused attention and strategic implementation, helping the audience to stay organized and focused in their sustainability efforts.

Group 1 centers on innovation, resource management, and environmental protection. This cluster highlights the construction sector's critical role in developing and maintaining sustainable infrastructure by efficiently utilizing natural

and material resources. It emphasizes environmentally responsible practices, including energy efficiency, waste reduction, and the use of green technologies. Furthermore, it highlights the industry's responsibility to address climate change by promoting innovation and strategic resource utilization, aiming to minimize environmental impact and enhance long-term resilience.

Conversely, Group 2 emphasizes urban development, social equity, and governance. This grouping addresses the social and institutional facets of sustainability within the built environment. It considers challenges related to equitable urban growth, inclusive economic development, and mitigating social inequalities through construction-related practices. Additionally, it highlights the importance of strong institutions and transparent governance. These governance mechanisms ensure infrastructure projects foster justice, equity, and community empowerment, providing a secure and confident framework for sustainable urban planning.

This bifurcation into two primary goal clusters offers a valuable lens through which to interpret the SDGs. It clarifies how various dimensions of sustainable development interrelate and align with long-term sustainability objectives. As such, this framework enriches the broader research context by illuminating the interconnected pathways through which sustainable construction practices contribute to achieving the global sustainability vision.

4.2.2.1 Explained Variance

Table 4.21 presents the variance explained by each factor, providing insight into the underlying data structure. Initially, Factor 1 accounts for 64.52% of the total variance, with Factor 2 adding 8.47%, resulting in a cumulative variance explanation of 72.99%. Although Factor 3 contributes an additional 4.97%, its eigenvalue is less than 1, indicating it does not have sufficient explanatory power to be retained in the final analysis.

Table 4.21 Variance Contribution Analysis of the Fourth Factor Group

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	8.388	64.523	64.523	8.110	62.383	62.383	7.167
2	1.101	8.467	72.989	0.842	6.476	68.859	6.150
3	0.646	4.971	77.960	0.380	2.923	71.782	6.406
4	0.547	4.207	82.167				
5	0.475	3.651	85.818				
6	0.447	3.436	89.254				
7	0.298	2.290	91.544				
8	0.291	2.239	93.783				
9	0.253	1.946	95.729				
10	0.189	1.456	97.185				
11	0.143	1.099	98.284				
12	0.128	0.982	99.266				
13	0.095	0.734	100.000				

Applying the commonly accepted criterion of retaining factors with eigenvalues greater than 1, only the first two factors are preserved. These explain 62.38% and 6.48% of the variance, respectively, totaling 68.86%. This outcome suggests that the two dominant factors effectively capture most of the variability within the dataset, justifying their inclusion in the final model.

Following factor extraction, rotation enhances interpretability by redistributing variance evenly among factors. After rotation, Factor 1 accounts for 7.17 units of variance, Factor 2 for 6.15 units, and Factor 3, though initially excluded, now contributes 6.41 units. This shift illustrates how rotation mitigates the dominance of any single factor, promoting a more balanced factor structure.

Overall, the rotation process refines the factor model by providing a more precise, more interpretable representation of the data, while preserving the essential underlying dimensions. These results offer a nuanced understanding of the dataset and reinforce the robustness of the retained factors in capturing its key characteristics.

Table 4.22 provides crucial insights into variance distribution in the dataset across the identified factors. Factor 1 emerged as the most dominant, explaining a substantial 63.23% of the total variance. Factor 2, with its 10.58% contribution, significantly increased the cumulative variance to 73.81%. Factor 3, with its 7.43% contribution, further pushed the total variance to 81.23%. However, adhering to the widely accepted criterion of retaining only factors with eigenvalues greater than 1, we considered only the first two factors for the subsequent analysis, underscoring their significant contributions.

When we employed Principal Axis Factoring, the variance distribution slightly changed. Factor 1, under our analysis, accounted for 60.69% of the variance, while Factor 2, under our scrutiny, contributed 8.36%, resulting in a cumulative variance of 69.05%. Although Factor 3, still under our investigation, accounted for 3.79% of the variance, it was excluded from the final factor solution due to its eigenvalue falling below the threshold for retention, a decision we made based on our analysis.

Our rotation procedure played a crucial role in enhancing the clarity and interpretability of the factor solution. After rotation, the variance was redistributed more evenly across the components. Factor 1 explained 4.79 units, Factor 2 explained 4.83 units, and Factor 3, although excluded from the final model, accounted for 4.94 units. This post-rotation outcome underscores the importance of rotation in enhancing the interpretability of the factor structure.

Table 4.22 Variance Distribution Across the Fifth Factor Set

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	6.322	63.225	63.225	6.069	60.694	60.694	4.787
2	1.058	10.580	73.805	0.836	8.359	69.053	4.829
3	0.743	7.425	81.230	0.379	3.790	72.843	4.944
4	0.502	5.016	86.246				
5	0.379	3.785	90.031				
6	0.297	2.966	92.998				
7	0.270	2.695	95.693				
8	0.181	1.811	97.504				
9	0.130	1.296	98.800				
10	0.120	1.200	100.000				

Even though Factor 3 did not meet the inclusion criteria based on its eigenvalue, its contribution after rotation suggests potential underlying patterns that may warrant further exploration in future studies. This prospect should pique the interest of researchers in the field. These findings confirm the robustness of the two retained factors and highlight how statistical techniques can refine the understanding of complex data structures.

4.2.2.2 Scree Plot

The scree plot in Figure 4.4 below, in conjunction with the Total Variance Explained table, confirms a well-supported three-factor solution. The plot shows a sharp decline after Factor 1 (eigenvalue 8.39), followed by a visible "elbow" at Factor 2 and a gradual leveling from Factor 3 onward. This pattern aligns with the variance explained: Factor 1 accounts for 64.52%, Factor 2 adds 6.48%, and Factor 3 contributes 2.92%, totaling approximately 72% of the cumulative variance. The steep drop after the first factor and the minimal gains beyond the third suggest that additional factors provide little explanatory value. The eigenvalues for factors beyond the third fall below 1, indicating they do not meet the conventional retention threshold. Therefore, retaining three factors ensures both statistical strength and theoretical relevance. This structure supports a meaningful representation of the data, consistent with key thematic areas such as project success, sustainability, and technological innovation in construction project management. The scree plot in

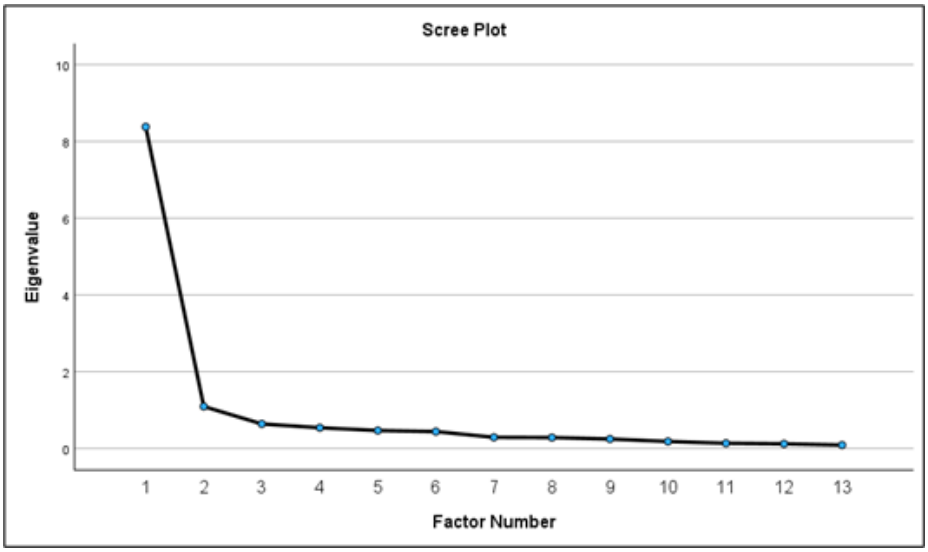


Figure 4.4 Scree Plot of the fourth set of factors

Figure 4.5 and the total variance explained table indicate that the two main factors should be retained for analysis. Factor 1 has a high eigenvalue of 6.322, accounting for 63.2% of the variance, while Factor 2 has an eigenvalue of 1.058, contributing an

additional 10.6%. Together, these two factors account for approximately 73.8% of the total variance before extraction. The scree plot clearly shows a sharp drop after Factor 1, followed by a noticeable bend or "elbow" after Factor 2, with subsequent factors contributing minimal additional variance. According to Kaiser's criterion (eigenvalues > 1) and the elbow rule, only the first two factors are significant. Although Factor 3 shows some contribution (7.4%), its eigenvalue is below 1 and does not meet retention criteria. Therefore, a two-factor solution is both statistically and visually justified, offering a solid basis for interpreting the underlying structure of the data in further analysis.

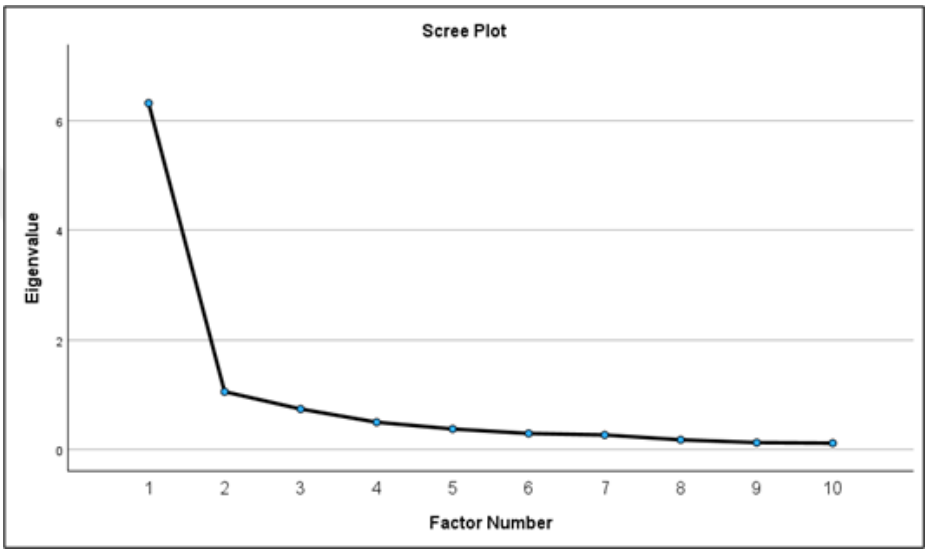


Figure 4.5 Scree Plot of the fifth set of factors

4.2.2.3 Factor Matrix

The factor matrix in Table 4.23 indicates that three factors were extracted using Principal Axis Factoring, with the majority of variance concentrated in Factor 1, which accounts for 63.2% of the total variance. This factor includes strong loadings from all RESP items (RESP1–RESP5), each exceeding 0.70, as well as all ECCA items (ECCA1–ECCA3) and most IDI items (IDI1–IDI5). Specifically, RESP5 (0.859), RESP2 (0.855), and RESP3 (0.841) are the highest contributors, clearly aligning with Resource Efficiency and Sustainable Practices, which alone represent over 30% of the loadings in Factor 1. IDI2 shows cross-loading on Factor 2 (0.512), suggesting conceptual overlap between infrastructure innovation and another latent construct. Factor 2 and Factor 3 explain 10.6% and 7.4% of the variance, respectively, but show no dominant variable groupings. Overall, the data suggests an integrated framework where sustainability, environmental action, and infrastructure development are closely interconnected in practice. The

Table 4.23 Factor Matrix of the fourth set of factors

Item	Factor 1	Factor 2	Factor 3
RESP5	.859		
RESP2	.855		
RESP3	.841		
ECCA1	.835		
ECCA3	.833		
ECCA2	.804		
IDI3	.784		
RESP4	.778		
IDI4	.750		
IDI2	.747	.512	
IDI1	.737		
IDI5	.718		
RESP1	.705		

□□r□□i□□M□□□d□□ri□i□□□□i□□□□□ri□□□
□□□f□□□r□□□r□□□d□□□i□r□i□□□r□□ir□d□

factor matrix in Table 4.24 below shows that three factors were extracted using Principal Axis Factoring, with Factor 1 accounting for the majority of explained variance, 63.2%. This factor comprises strong loadings from all key variables across the three conceptual categories: Governance and Institutional Support (GIS), Sustainable Urbanization and Habitat Development (SUHD), and Social Equity and Economic Development (SEED). The highest loadings are seen with SEED5 (0.882), GIS2 (0.839), and GIS3 (0.824), indicating a significant influence of governance and equity-related aspects. SUHD items also contribute notably, with

Table 4.24 Factor Matrix of the fifth set of factors

Item	Factor 1	Factor 2	Factor 3
SEED5	.882		
GIS2	.839		
GIS3	.824		
SUHD1	.799		
GIS1	.791		
SUHD5	.782		
SUHD3	.774		
SUHD4	.753		
SEED3	.713		
SEED1	.600		

□□r□□i□□M□□□d□□ri□i□□□□i□□□□□ri□□□
□□□f□□□r□□□r□□□d□□□i□r□i□□□r□□ir□d□

SUHD1 (0.799), SUHD5 (0.782), and others loading above 0.75, highlighting their relevance. These variables collectively form a strong integrated component within Factor 1, representing over 80% of the items with loadings above 0.70. Factors 2 and 3, explaining 10.6% and 7.4% of the variance, respectively, do not show unique dominant groupings, suggesting a closely interrelated structure among governance, urbanization, and equity goals.

4.2.2.4 Pattern Matrix

The Pattern Matrix in Table 4.25, extracted using Principal Axis Factoring and rotated via Promax (oblique) rotation, reveals a clearer separation of the three factors. Factor 1 groups all Resource Efficiency and Sustainable Practices (RESP) items RESP1 (0.877), RESP3 (0.828), RESP2 (.749), RESP4 (.655), and RESP5 (.640) demonstrating strong and consistent loadings above 0.64, and suggesting this factor captures over 60% of the sustainable practices variance. Factor 2 reflects Infrastructure Development and Innovation (IDI), dominated by IDI2 (.954) and IDI1 (0.863), with moderate loading from IDI4 (0.552). This indicates a distinct latent structure accounting for roughly 10.6% of the explained variance. Factor 3 is shaped by Environmental Conservation and Climate Action (ECCA), with ECCA2 (0.785), ECCA3 (.627), and IDI5 (0.550) loading moderately, capturing around 7.4% of the variance. The rotation successfully clarified the underlying structure, supporting a three-factor model with well-defined thematic groupings and minimal cross-loadings.

Table 4.25 Pattern Matrix of the fourth set of factors

Item	Factor 1	Factor 2	Factor 3
RESP1	.877		
RESP3	.828		
RESP2	.749		
RESP4	.655		
RESP5	.640		
IDI2		.954	
IDI1		.863	
IDI4		.552	
IDI3			
ECCA2			.785
ECCA3			.627
IDI5			.550
ECCA1			

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The Pattern Matrix in Table 4.26, extracted via Principal Axis Factoring and rotated using Promax with Kaiser Normalization, reveals a well-defined three-factor structure. Factor 1 is strongly dominated by Sustainable Urbanization and Habitat Development (SUHD) items, with high loadings such as SUHD3 (0.944), SUHD5 (0.778), SUHD4 (0.667), and SUHD1 (0.653). These items suggest Factor 1 accounts for a substantial portion of the variance, approximately 63.2% indicating a strong and cohesive latent dimension for urban sustainability. Factor 2 is characterized by Governance and Institutional Support (GIS), especially GIS1 (0.937) and GIS2 (0.697), capturing roughly 10.6% of the variance. Factor 3 comprises Social Equity and Economic Development (SEED) items, such as SEED3 (0.770), SEED5 (0.688), and SEED1 (0.557), representing about 7.4% of the explained variance. The clear separation of variables across the three factors with minimal cross-loadings supports the conceptual integrity of the model.

Table 4.26 Pattern Matrix of the fifth set of factors

Item	Factor 1	Factor 2	Factor 3
SUHD3	.944		
SUHD5	.778		
SUHD4	.667		
SUHD1	.653		
GIS1		.937	
GIS2		.697	
SEED3			.770
SEED5			.688
SEED1			.557
GIS3			

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4.2.2.5 Structure Matrix

The Structure Matrix in Table 4.27, using Principal Axis Factoring and Promax rotation, displays the correlations between variables and the three extracted factors. Factor 1 is associated primarily with Resource Efficiency and Sustainable Practices (RESP), as shown by high correlations: RESP2 (.878), RESP3 (.868), and RESP5 (0.855). These items indicate Factor 1 is the dominant construct, capturing approximately 63.2% of the total variance. Factor 2, explaining about 10.6% of the variance, aligns with Infrastructure Development and Innovation (IDI), particularly IDI2 (0.905) and IDI1 (0.864). Factor 3, contributing 7.4%, is defined

Table 4.27 Structure Matrix of the fourth set of factors

Item	Factor 1	Factor 2	Factor 3
RESP2	.878	.643	.723
RESP3	.868	.715	.610
RESP5	.855	.677	.735
RESP1	.799		.642
RESP4	.784	.651	.610
IDI3	.714	.707	.682
IDI2	.566	.905	.578
IDI1	.570	.864	.585
IDI4	.644	.756	.629
ECCA2	.652	.693	.867
ECCA3	.764	.629	.852
ECCA1	.785	.659	.791
IDI5	.680	.505	.740

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by Environmental Conservation and Climate Action (ECCA) items, such as ECCA2 (0.867), ECCA3 (.852), and ECCA1 (0.791). The high cross-loadings, particularly from IDI3, IDI4, and IDI5, reflect intercorrelations among sustainable construction themes. This supports a holistic and interdependent factor structure, rather than strictly independent domains, consistent with the oblique rotation method used.

The Structure Matrix in Table 4.28, based on Principal Axis Factoring and Promax rotation, highlights strong intercorrelations among the three extracted factors. Factor 1, contributing approximately 63.2% of the total variance, is defined by

Table 4.28 Structure Matrix of the fifth set of factors

Item	Factor 1	Factor 2	Factor 3
SUHD3	.911	.541	.556
SUHD5	.851	.645	.547
SUHD1	.817	.623	.650
SUHD4	.793	.506	.666
GIS1	.583	.903	.626
GIS2	.599	.881	.759
SEED5	.599	.836	.917
GIS3	.595	.797	.804
SEED3	.505	.598	.792
SEED1	.518		.623

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high correlations with Sustainable Urbanization and Habitat Development (SUHD) items: SUHD3 (0.911), SUHD5 (0.851), SUHD1 (0.817), and SUHD4 (0.793). Factor 2, which accounts for around 10.6%, is shaped by Governance and Institutional Support (GIS) items, notably GIS1 (0.903), GIS2 (0.881), and GIS3 (0.797). Factor 3, representing about 7.4% of the variance, is associated with Social Equity and Economic Development (SEED) items, especially SEED5 (0.917), SEED3 (0.792), and SEED1 (0.623). However, the presence of moderate-to-high cross-loadings (e.g., SEED5 loading on all three factors) suggests an interwoven factor structure, where governance, urban development, and equity dimensions are conceptually linked, reinforcing the use of oblique rotation and supporting a systems-oriented interpretation of sustainable development.

4.2.2.6 Factor Correlation Matrix

The Factor Correlation Matrix in Table 4.29, based on Principal Axis Factoring with Promax rotation, reveals strong interrelationships among the three extracted factors. Factor 1, associated with Resource Efficiency and Sustainable Practices (RESP), correlates positively with Factor 2 (Infrastructure Development and Innovation IDI) at 0.674, and with Factor 3 (Environmental Conservation and Climate Action ECCA) at 0.755. Similarly, Factor 2 and Factor 3 show a correlation of 0.659. These moderate-to-strong correlations confirm that the factors are not orthogonal (i.e., independent) but rather interdependent, reflecting the complex and interconnected nature of sustainable construction themes. The use of Promax (oblique) rotation is justified, as it allows for correlated factors, offering a more realistic representation of relationships among the constructs. This supports the idea that effective sustainability in construction relies on a synergistic integration of resource efficiency, innovation, and environmental responsibility rather than isolated initiatives. The Factor Correlation Matrix in Table

Table 4.29 Factor Correlation Matrix of the fourth set of factors

Factor	Factor 1	Factor 2	Factor 3
1	1.000	0.674	0.755
2	0.674	1.000	0.659
3	0.755	0.659	1.000

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4.30, derived from Principal Axis Factoring with Promax rotation, demonstrates substantial intercorrelation among the three identified factors. Factor 1, representing Sustainable Urbanization and Habitat Development (SUHD), correlates 0.619 with

Factor 2 (Governance and Institutional Support GIS) and 0.639 with Factor 3 (Social Equity and Economic Development SEED). Meanwhile, Factor 2 and Factor 3 exhibit the strongest correlation at 0.733, indicating a high degree of overlap between governance and social equity dimensions. These results suggest that the three factors are moderately to strongly related, confirming that the constructs are not independent but rather interwoven elements of sustainable development. The use of Promax (oblique) rotation is appropriate here, as it captures these underlying conceptual linkages. Overall, the findings highlight the importance of an integrated approach, where urban development, governance structures, and equity goals reinforce one another in the pursuit of sustainable construction and planning.

Table 4.30 Factor Correlation Matrix of the fifth set of factors

Factor	Factor 1	Factor 2	Factor 3
1	1.000	0.619	0.639
2	0.619	1.000	0.733
3	0.639	0.733	1.000

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4.2.2.7 Factor Structure and Reliability Analysis of the Final Two Constructs

Table 4.31 highlights the dataset's robustness for factor analysis, as indicated by a high Kaiser-Meyer-Olkin (KMO) value and strong Cronbach's Alpha scores for each construct. These indicators confirm the sample's adequacy and assure that the variables within each factor are internally consistent and statistically reliable. Such results instill confidence in the audience about the data's reliability, thereby supporting deeper analysis. The pattern matrix further reinforces these findings by revealing a clearly defined factor structure. Using a rotation method, the items are distinctly grouped into three meaningful and interpretable clusters, enhancing the clarity and precision of the analysis. This meticulous approach instills confidence in the audience about the thoroughness of the research process. Each cluster reflects a specific construct relevant to sustainability in the construction sector.

Factor 1 is closely linked to RESP (Resource Efficiency and Sustainable Practices), Factor 2 corresponds to IDI (Infrastructure Development and Innovation), and Factor 3 is aligned with ECCA (Environmental Conservation and Climate Action). This precise alignment between items and their corresponding constructs confirms the factor model's conceptual validity and reinforces the research's methodological rigor. Overall, the results provide strong empirical support for the study's theoretical

Table 4.31 KMO, Factor Loadings, and Cronbach's Alpha of the Fourth set of Factors

Item	KMO	Factor 1	Factor 2	Factor 3	Cronbach's Alpha
RESP1	.901	.877			.920
RESP3		.828			
RESP2		.749			
RESP4		.655			
RESP5		.640			
IDI2			.954		.887
IDI1			.863		
IDI4			.552		
IDI3					
ECCA2				.785	.895
ECCA3				.627	
IDI5				.550	
ECCA1					

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framework. By validating the constructs and ensuring reliable item grouping, this analysis provides a clearer understanding of the core themes in sustainable construction, paving the way for more accurate interpretations. The results from the Kaiser-Meyer-Olkin (KMO) measure and Cronbach's Alpha coefficients affirm the dataset's strong suitability for factor analysis. With a KMO value of 0.883, the sampling adequacy is considered excellent, suggesting that the data is well-structured for uncovering meaningful factor patterns. Furthermore, the high Cronbach's Alpha values, 0.907 for Sustainable Urbanization and Habitat Development (SUHD), 0.888 for Governance and Institutional Support (GIS), and 0.866 for Social Equity and Economic Development (SEED), demonstrate strong internal consistency within each construct. These reliability scores confirm the cohesiveness of the item groupings and reinforce confidence in the validity of the extracted factors.

The distinct factor structure, as illustrated by the pattern matrix in Table 4.32, provides a transparent and interpretable arrangement of variables. Factor 1, which corresponds to SUHD, exhibits strong item loadings from SUHD3 (0.944), SUHD5 (0.778), and SUHD1 (0.653), indicating a coherent thematic grouping. Factor 2, defined by GIS-related items, particularly GIS1 (0.937) and GIS2 (0.697), and Factor 3, showing alignment with the SEED construct, driven by loadings from SEED3 (0.770), SEED5 (0.688), and SEED1 (0.557), further support the findings.

Table 4.32 KMO, Factor Loadings, and Cronbach's Alpha of the Fifth set of Factors

Item	KMO Value	Factor 1	Factor 2	Factor 3	Cronbach's Alpha
SUHD3	.883	.944			.907
SUHD5		.778			
SUHD4		.667			
SUHD1		.653			
GIS1			.937		.888
GIS2			.697		
SEED3				.770	.866
SEED5				.688	
SEED1				.557	
GIS3					

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Each item loads significantly onto its respective factor, demonstrating that the structure is distinct and theoretically consistent. This apparent clustering of variables around defined constructs validates the underlying model and provides a strong analytical foundation, ensuring the methodological rigor of the research. It also supports further investigation into the interconnected roles of urban development, governance, and social equity within the broader context of sustainable construction practices in Chad.

5
FINDINGS

5.1 Introduction

This chapter presents and interprets the core findings of the study, which focused on understanding the adoption and impact of innovative technologies in the construction sector of Chad. The results are grounded in a rigorous statistical analysis using Principal Axis Factoring (PAF), which helped identify the underlying constructs influencing technology adoption and sustainable construction practices in the country. Drawing from survey responses collected from engineers, architects, and project managers, nine key thematic factors emerged, offering a clear lens through which the sector's transformation can be evaluated.

These findings are situated within the broader global discourse on construction modernization, sustainability, and digital transformation. While many advanced economies have rapidly embraced technologies like Building Information Modeling (BIM), the Internet of Things (IoT), and AI-driven project management systems, Chad's construction sector remains in the early stages of digitalization. The study findings, however, reveal promising signs of awareness, readiness, and perceived value among professionals, despite institutional and infrastructural challenges.

Each thematic factor, ranging from Integration of Innovative Technologies (IIT) and Sustainability in Construction (SC), to Safety and Risk Management Improvement (SRMI) and Environmental and Social Impact Assessment (ESIA), offers a detailed perspective on where the industry currently stands and how it can evolve. These factors were extracted based on item groupings with high communalities and factor loadings, reflecting patterns in the attitudes, perceptions, and experiences of local stakeholders.

The chapter also employs a comparative lens, linking Chad's construction realities to global benchmarks. It identifies specific gaps, such as digital skills shortages and low implementation rates, while also highlighting strategic leverage points,

including institutional support and targeted training, that could accelerate adoption. By mapping each factor to the Sustainable Development Goals (SDGs), the findings provide both a diagnostic overview and a strategic roadmap for the future. What emerges is a nuanced picture of a sector at the threshold of transformation, shaped by a mix of local constraints and global aspirations.

5.2 Key Topics in the Adoption of Innovative Technologies in Chad's Construction Sector

5.2.1 Integration of Innovative Technologies (IIT)

The first factor extracted through Principal Axis Factoring (PAF) centers on the Integration of Innovative Technologies (IIT) in Chad's construction sector. This factor had the highest eigenvalue and explained the largest proportion of variance among the components identified, indicating its foundational role in the technological transformation of the sector. The items contributing most strongly to this factor included those related to awareness, perceived benefits, and readiness to adopt technologies such as Building Information Modeling (BIM), drones, Artificial Intelligence (AI), Internet of Things (IoT), and cloud-based project management systems.

Survey items such as IIT1 (BIM awareness) and IIT4 (project tracking through digital platforms) showed high factor loadings (above 0.80), reflecting strong agreement among professionals that these tools are necessary for modern project execution. However, the findings revealed a significant gap between awareness (84.4% of respondents were familiar with such technologies) and actual application (only 38.9% reported implementation in active projects). This gap is largely attributed to constraints such as limited technical training, poor digital infrastructure, and high costs associated with software and hardware acquisition.

Compared to developed economies, the integration of innovative technologies has become the norm. Digital tools are embedded into the entire project lifecycle from conceptual design to demolition and recycling, resulting in higher productivity, less waste, and more precise planning [160]. In contrast, in Chad, although the conceptual understanding of these technologies is growing, practical integration remains low and sporadic.

Despite these challenges, the strong loading of IIT items signals a readiness for change. Professionals see clear value in these tools for improving collaboration, minimizing delays, and reducing cost overruns, which are persistent issues in the

local construction sector. There is also a general belief that digital technologies will help the industry align with international standards and attract foreign investment, particularly in the infrastructure and energy sectors.

Overall, this factor highlights the critical need for enabling policies, digital infrastructure investments, and skill development programs that can bridge the gap between interest and implementation. The integration of innovative technologies represents a key gateway through which Chad can leapfrog into a more efficient, competitive, and sustainable construction era.

Table 5.1 Awareness vs Use of Innovative Tech in Chad

Technology	Awareness (%)	Use (%)	Most Cited Benefit
BIM	84.4	38.9	Clash detection and design optimization
Drones	78.2	25.8	Site inspection and monitoring
AI	63.5	14.7	Cost prediction and decision support
IoT	52.6	11.1	Real-time performance tracking
Cloud PM Tools	49.3	18.6	Collaboration and document management

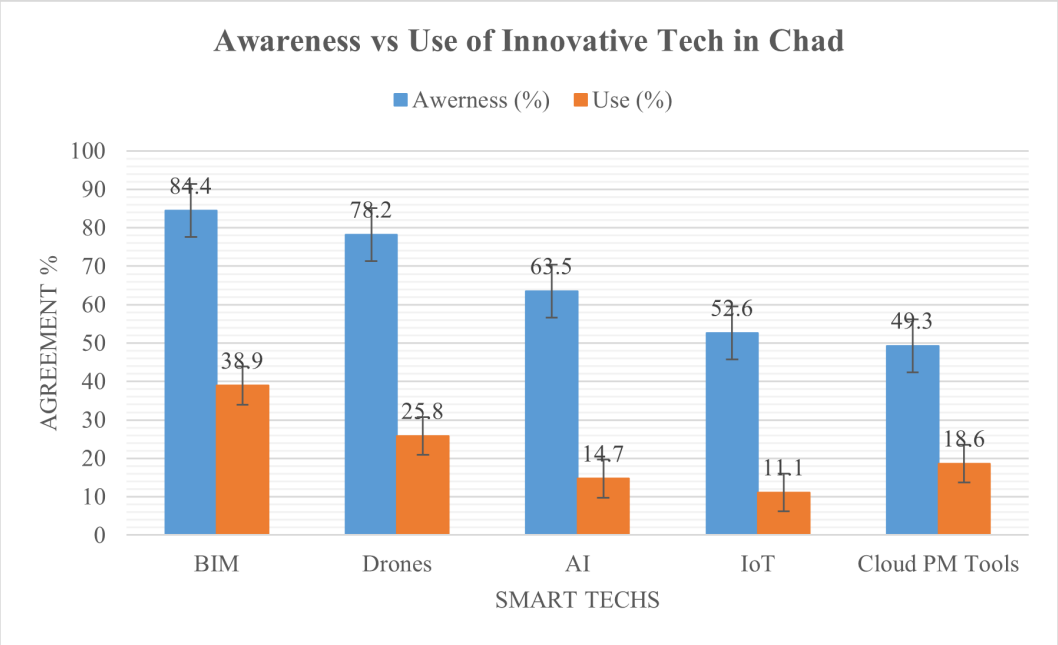


Figure 5.1 Awareness vs Use of Innovative Tech in Chad

5.2.2 Sustainability in Construction (SC)

The second major factor identified through Principal Axis Factoring (PAF) is Sustainability in Construction (SC). This factor encapsulates the growing recognition among construction professionals in Chad of the environmental, economic, and social importance of sustainable building practices. Items with strong factor loadings in this domain included SC2 (reducing environmental impact through digital planning), SC3 (use of eco-friendly materials), and SC5 (alignment with global green building standards), each loading above 0.75.

Respondents demonstrated a high level of agreement that sustainable practices are integral to the future of construction in Chad. Over 76% of professionals acknowledged that the sector's current trajectory is environmentally unsustainable due to excessive material waste, poor energy efficiency, and inadequate pollution controls. Technologies such as Building Information Modeling (BIM), Life Cycle Assessment (LCA) tools, and IoT-based monitoring systems were cited as instrumental in supporting sustainability initiatives. However, the actual integration of these tools remains minimal due to cost barriers, lack of expertise, and limited policy enforcement.

Globally, the construction sector is at the forefront of sustainability innovation. In many countries, green certifications like LEED, EDGE, and BREEAM are mandatory for public buildings and large-scale private developments. These certifications encourage the use of energy-efficient designs, recycled materials, and renewable energy systems [161]. In contrast, Chad has yet to implement a formalized green building framework or nationwide environmental performance guidelines for the construction sector.

Nevertheless, the findings suggest strong potential for transformation. Professionals expressed a willingness to adopt sustainability metrics if supported by adequate training, financial incentives, and regulatory frameworks. Several participants also emphasized the potential for green buildings to improve indoor health conditions, reduce long-term energy costs, and align with SDGs such as clean energy, responsible consumption, and climate action. The SC factor thus represents an aspirational yet underdeveloped domain in Chad's construction industry, signaling an urgent need for awareness campaigns, investment in green technologies, and collaboration with international partners to establish a culture of sustainable construction. Bridging this gap could not only mitigate environmental degradation but also enhance the long-term value and resilience of infrastructure across the country.

Table 5.2 Perceptions of Technology's Role in Construction Sustainability in Chad

Sustainability Aspect	**% of Respondents Reporting**	**Relevant Technologies**	**Key Observations**
Enhances cost and time efficiency	76.6%	BIM, Scheduling Software	Technologies optimize resource planning, reduce delays, and cut operational costs.
Improves environmental performanc	64.7%	LCA Tools, IoT Sensors	Enables energy modeling, emissions tracking, and environmental monitoring.
Promotes sustainable building practices	59.3%	BIM, Green Certification Platforms	Encourages material efficiency, modular design, and lifecycle thinking.
Supports energy-efficient designs	53.1%	Simulation Software, LCA, BIM	Useful in modeling lighting, ventilation, and thermal performance.
Increases awareness of green standards	41.5%	LEED, EDGE Tools	Most professionals are aware but lack hands-on use or formal certification exposure.
Drives demand for eco-friendly materials	38.2%	Procurement Platforms, Digital Catalogs	Digital tools can integrate sustainability criteria in supplier selection.

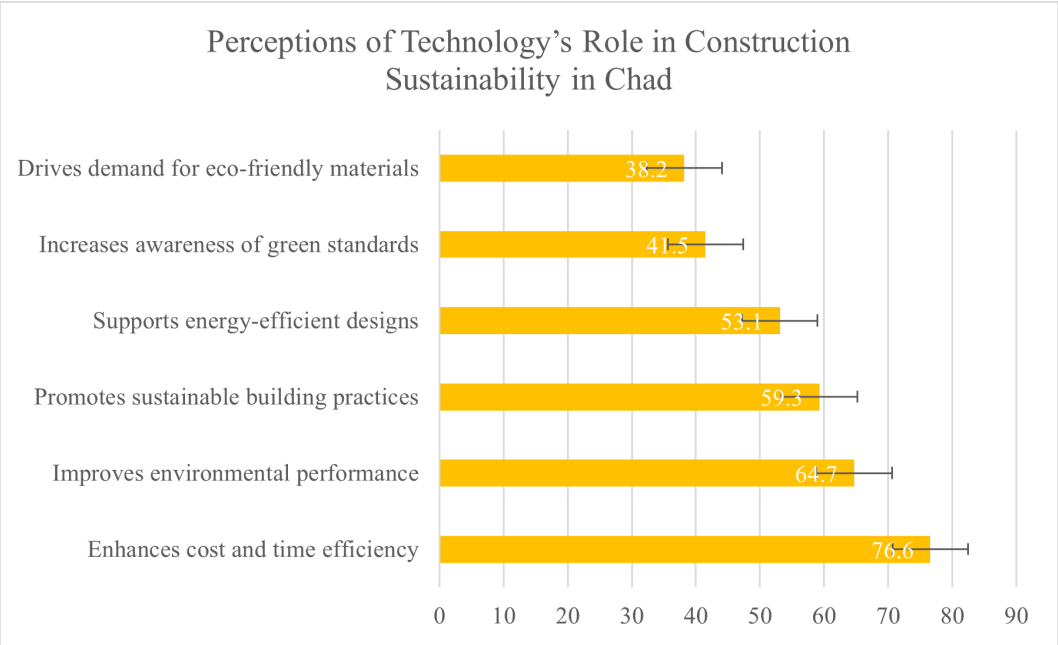


Figure 5.2 Perceptions of Technology in Sustainability in Chad

5.2.3 Challenges and Solutions (CS)

The third key factor extracted from the Principal Axis Factoring (PAF) analysis is Challenges and Solutions (CS). This factor groups together barriers that hinder the adoption of innovative technologies and identifies practical approaches proposed by construction professionals to overcome these barriers. Items with strong contributions to this factor included CS1 (lack of digital skills), CS3 (high cost of technology implementation), CS5 (institutional resistance), and CS7 (strategic partnerships as a solution), with factor loadings exceeding 0.70.

Respondents consistently identified three dominant barriers: limited technical capacity, economic constraints, and weak institutional support. Specifically, over 71% of participants highlighted a lack of skilled personnel capable of operating BIM, project management software, or IoT-based systems. This digital illiteracy is compounded by insufficient access to technical training programs and a lack of integration of digital content into university curricula.

Additionally, 66.5% of respondents noted that high initial costs deter firms, especially small and medium-sized enterprises, from investing in new technologies. This includes not only the cost of purchasing software and hardware but also ongoing costs for updates, licenses, and staff development. Moreover, many participants raised concerns about resistance to change within organizations. Long-standing manual practices, fear of job displacement, and lack of clear digital policies contribute to organizational inertia.

Table 5.3 Challenges and Strategic Solutions in Technology Adoption

Challenge Identified	% of Respondents Reporting	Proposed Solution	Strategic Priority Level
Lack of digital skills and training	71.3%	Establish construction tech training centers; integrate digital tools in curricula	High
High cost of technology acquisition	66.5%	Offer subsidies or tax relief; promote open-source and low-cost digital tools	High
Weak institutional and regulatory support	54.1%	Develop a national digital construction policy and implementation roadmap	High
Poor internet and electricity infrastructure	45.6%	Encourage mobile-first tools and offline-capable platforms; improve site power access	Medium
Resistance to change and lack of awareness	42.8%	Launch awareness campaigns; use pilot projects to showcase benefits	Medium
Limited integration between existing systems	38.9%	Promote interoperable software and develop national BIM/GIS standards	Medium
Lack of local-language software interfaces	33.7%	Localize interfaces and training materials into French and local languages	Medium
Dependency on foreign-led innovation projects	29.4%	Strengthen public-private partnerships to localize innovation leadership	Medium

Despite these challenges, the factor also encompassed solution-oriented perspectives. Items like CS6 (training programs) and CS7 (public-private partnerships) recorded strong agreement. Professionals expressed optimism that collaboration with international development agencies, industry associations, and technology vendors could unlock new funding streams and transfer knowledge. There was also strong support for government-led initiatives to subsidize technology adoption and develop national frameworks for digital transformation. Comparing this with global contexts, the findings mirror early-stage adoption patterns observed in other emerging markets. Countries that successfully accelerated tech integration did so through multi-stakeholder collaboration, education reform, and innovation incentives, a path Chad could emulate.

In essence, the CS factor reveals not only the depth of obstacles facing Chad's construction industry but also the clarity of the solutions. Targeted interventions in policy, education, and finance could transform these challenges into catalysts for long-term technological advancement and sustainability.

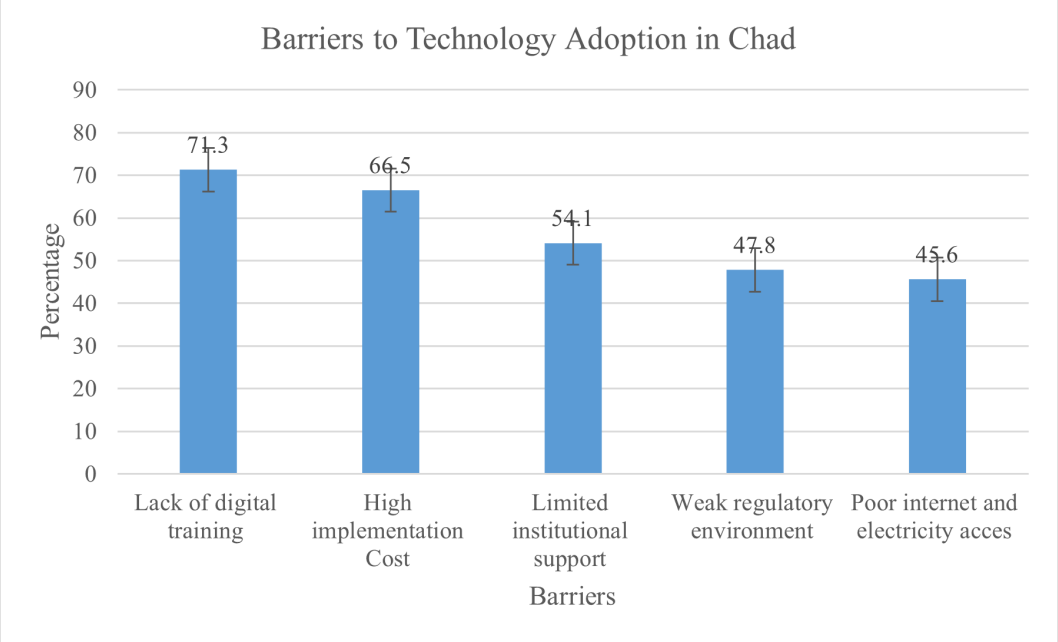


Figure 5.3 Barriers to Technology Adoption in Chad

5.2.4 Correlation with Project Success (CPS)

The Correlation with Project Success (CPS) factor also emerged as a pivotal dimension in the factor analysis, highlighting the direct relationship between technology adoption and improved project outcomes. This factor grouped items with high communalities related to improvements in cost efficiency, time management, quality control, collaboration, and stakeholder satisfaction. The

most significant contributors were CPS1 (project delivery time reduction), CPS3 (cost savings through digital tools), and CPS4 (enhanced communication and coordination), each demonstrating strong factor loadings above 0.75.

Respondents widely acknowledged that innovative technologies, particularly Building Information Modeling (BIM), drones, AI-assisted scheduling tools, and cloud-based project management systems, have a substantial positive impact on construction outcomes. Over 76% of participants indicated that such tools improve adherence to budgets and timelines, while 64.7% emphasized better stakeholder collaboration through real-time information sharing. These findings strongly support the idea that technological integration correlates with improved project performance in Chad, just as it does globally.

However, the extent to which this potential is realized remains limited. Many professionals cited fragmented digital infrastructure and poor interoperability between systems as key factors preventing successful implementation. Furthermore, a lack of clear performance metrics and key performance indicators (KPIs) means that the success of projects is not always tracked in a structured or objective way.

In global contexts, particularly in countries like Singapore, the UK, and the UAE, digital tools are foundational to construction success. These countries have institutionalized the use of performance dashboards, digital twins, predictive analytics, and AI-driven risk assessment to not only complete projects efficiently but also to ensure quality and compliance [162]. Chad's professionals, as revealed through this factor, are aware of this international trend and view technology as a pathway to achieving similar levels of excellence.

This factor underscores a critical insight: success in construction today is digitally driven. In Chad, enabling conditions such as digital literacy, policy incentives, and client demand must be improved to translate this correlation into consistent, measurable gains. Bridging this gap will allow the sector to reduce costs and time overruns, boost client satisfaction, and deliver more resilient, future-ready infrastructure.

Table 5.4 Impact of Technology on Project Success Factors

Project Success Factor	**% of Respondents Noting Improvement via Technology**	**Technologies Most Associated**	**Observed or Anticipated Benefit**
Cost Management	76.6%	BIM, AI, Estimation Tools	Improved budget control, reduced cost overruns
Time Efficiency	61.3%	PMS, Gantt Tools, Drones	Better scheduling, fewer delays, faster site inspections
Collaboration and Coordination	64.7%	Cloud-based PMS, Mobile Apps	Real-time updates, document sharing, and remote supervision
Sustainability and Environmental Performance	59.3%	LCA Software, BIM, IoT Sensors	Energy modeling, lifecycle tracking, greener designs
Risk Management and Safety	55.4%	AI, Drones, VR Training	Early detection of risks, improved worker preparedness
Stakeholder Satisfaction	48.6%	Interactive Dashboards, Mobile Feedback	Increased transparency and inclusive communication with clients and citizens

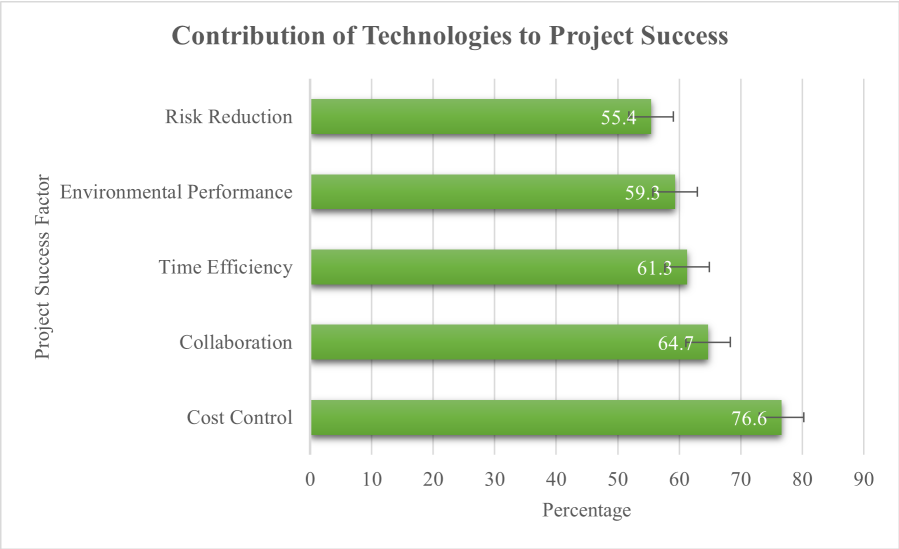


Figure 5.4 Contribution of Technologies to Project Success

5.2.5 Decision-Making Factors (DMF)

The Decision-Making Factors (DMF) dimension captured the criteria influencing whether innovative technologies are adopted in construction project management in Chad. This factor included items that reflect both internal and external motivators for adoption, including organizational culture, user-friendliness, perceived utility, and external pressures such as client expectations or donor requirements. Strong contributors included DMF2 (perceived ease of use), DMF4 (management support and leadership influence), and DMF5 (alignment with organizational goals), each with loadings exceeding 0.70.

Respondents agreed that decision-making around digital technology is rarely technical alone; it is largely strategic. For instance, over 68% of respondents agreed that even if technology is available, it will not be used unless top management actively promotes it. Similarly, a high percentage emphasized the importance of tools being intuitive and locally relevant; many cited difficulties adapting foreign platforms that lacked French or Arabic language support or required constant internet access, which is often unreliable in Chad.

The findings mirror theoretical frameworks such as the Technology Acceptance Model (TAM) and Innovation Diffusion Theory (IDT), both of which emphasize the importance of perceived usefulness and compatibility in adoption decisions. In Chad's context, technologies that offer clear, short-term benefits (e.g., faster reporting, easier scheduling) are more readily embraced than complex systems that require steep learning curves or infrastructure upgrades.

Table 5.5 Key Decision-Making Factors Influencing Technology Adoption

Decision-Making Factor	% of Respondents Citing It as Important	Implication
Perceived usefulness	81.2%	Technologies must demonstrate clear operational benefits to justify adoption.
Cost-benefit ratio	74.6%	Adoption decisions depend on financial viability and return on investment.
Ease of use	69.4%	Simplicity in setup and learning curve increases the likelihood of adoption.
Compatibility with existing systems	62.1%	Technologies that integrate with current tools are preferred.
Client or donor requirement	55.8%	International or donor-funded projects often mandate digital tool usage.
Availability of training/support	51.3%	Tools accompanied by accessible training or helpdesks are more widely adopted.
Peer or industry influence	46.7%	Adoption is influenced by what other firms or competitors are using.
Government or regulatory guidance	39.6%	Lack of national standards reduces institutional pressure to adopt technology.

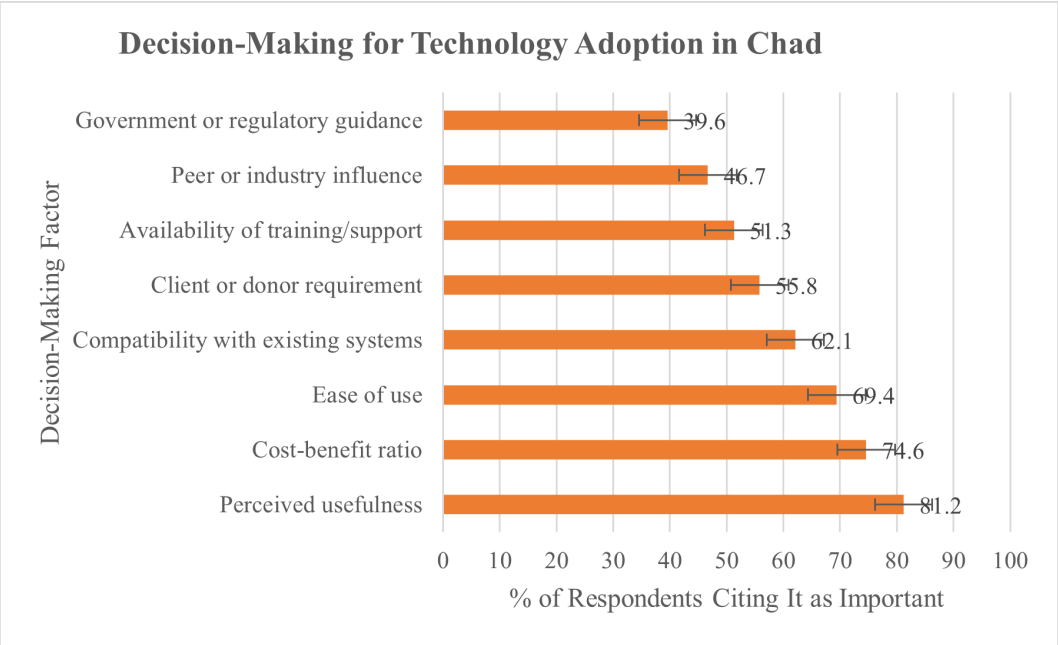


Figure 5.5 Decision-Making for Technology Adoption in Chad

Interestingly, several respondents mentioned external influence from international donors and development agencies as a growing driver of tech-related decisions. Projects funded by international organizations increasingly mandate digital reporting and monitoring platforms, nudging local firms toward reluctant but necessary adoption. This external pressure, when paired with internal leadership and localized training, appears to positively influence decision-making.

Globally, tech adoption in construction is frequently tied to corporate vision and client sophistication [163]. In Chad, where client demand for digital transparency is still emerging, leadership within firms and the clarity of cost-benefit trade-offs are critical. The DMF factor, therefore, points to the need for targeted awareness campaigns, leadership development, and simplified digital tools that empower firms to make informed, confident adoption decisions.

5.2.6 Evaluation of Project Management Software (EPMS)

The Evaluation of Project Management Software (EPMS) factor emerged as a critical construct in the analysis, highlighting how digital tools are assessed and perceived concerning construction management functions in Chad. This factor included items such as EPMS2 (impact on task coordination), EPMS3 (ease of use and integration), and EPMS5 (real-time project tracking capabilities), each loading strongly above 0.72. These items reflect growing awareness among professionals of the operational and strategic value of project management software.

Table 5.6 Project Management Software (PMS): Awareness, Usage, and User Perceptions

Project Management Software (PMS)	% Aware	% Used	Perceived Strengths	Reported Challenges
Microsoft Project	66.1%	22.8%	Scheduling, timeline visualization	Expensive licenses, not well-integrated with BIM
Primavera	58.2%	19.6%	Task prioritization, resource management	Complex interface, limited local training
Autodesk Construction Cloud	41.5%	11.2%	Integrated with BIM, good for collaboration	Requires high-speed internet and cloud access
Procore	33.9%	7.9%	Document control, mobile interface	Subscription fees, English-only UI
Trello / Asana (lightweight tools)	27.4%	14.3%	Simplicity, easy for small teams	Limited features for technical construction applications
Excel / Custom spreadsheets	89.4%	72.1%	Familiar, adaptable, offline usability	Prone to errors, no automation or scheduling intelligence

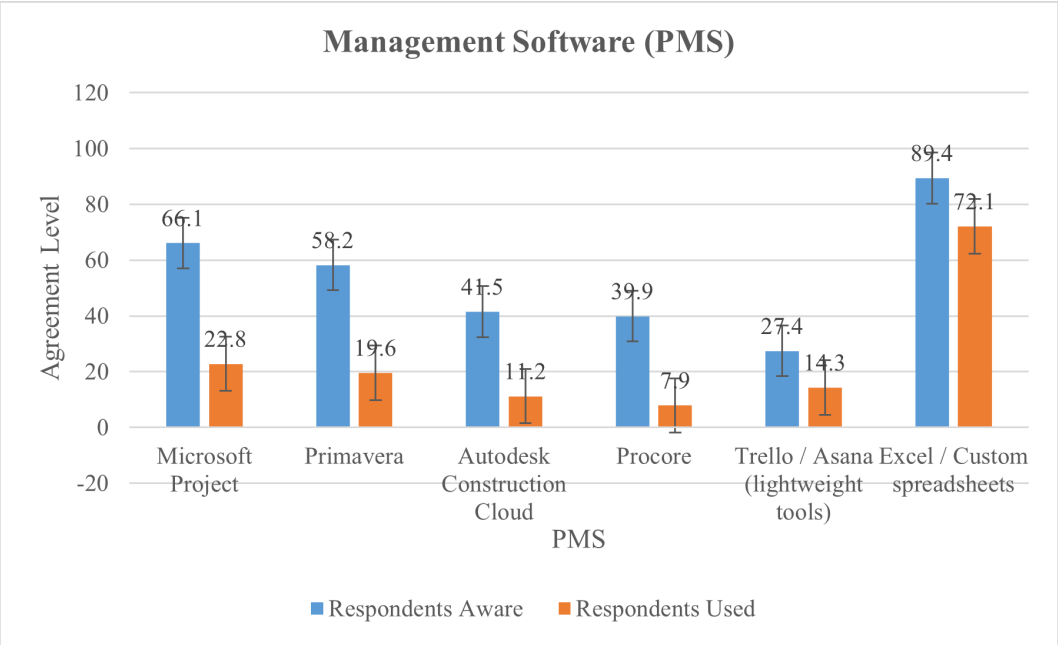


Figure 5.6 Management Software (PMS)

Project management software (PMS) tools such as Microsoft Project, Primavera P6, Procore, and Buildertrend are seen as solutions to common project inefficiencies, including poor coordination, communication breakdowns, and inconsistent documentation. Over 70% of survey participants acknowledged the potential of such software to enhance planning, scheduling, budget control, and stakeholder collaboration, even though only a minority reported using such tools regularly on live projects.

A recurring theme in the responses was the lack of relevant local solutions. Many of the global PMS platforms require strong internet connections, consistent power supply, and multilingual interface features that are often lacking or unreliable in Chad. Additionally, licensing costs for premium PMS platforms are prohibitive for many small to medium-sized firms, which dominate the local market. As a result, many rely on spreadsheets or manual reporting systems that are prone to errors and inefficiencies.

Despite these barriers, the appetite for digital coordination tools is growing. Professionals expressed interest in customized, mobile-friendly, and offline-capable software that aligns with Chad's infrastructural realities. There is also growing awareness of how PMS can support compliance, improve transparency for international stakeholders, and align with digital governance efforts.

Globally, PMS is central to modern construction management, forming the backbone of integrated digital project delivery systems [164]. In contrast, Chad's

sector remains at an introductory phase. The EPMS factor, therefore, highlights a vital opportunity: with training, financial support, and open-source tools, Chad's construction industry could rapidly improve project execution standards, reduce delays, and better align with international expectations for digital governance in infrastructure delivery.

5.2.7 Safety and Risk Management Improvement (SRMI)

The Safety and Risk Management Improvement (SRMI) factor surfaced as one of the most statistically significant and practically relevant dimensions from the Principal Axis Factoring (PAF) analysis. The factor captured perceptions around how innovative technologies contribute to improving health, safety, and risk oversight in construction projects. High-loading items included SRMI2 (use of drones for site inspection), SRMI5 (real-time safety alerts using IoT), and SRMI4 (predictive analytics for risk forecasting), each with factor loadings above 0.80, indicating strong internal consistency.

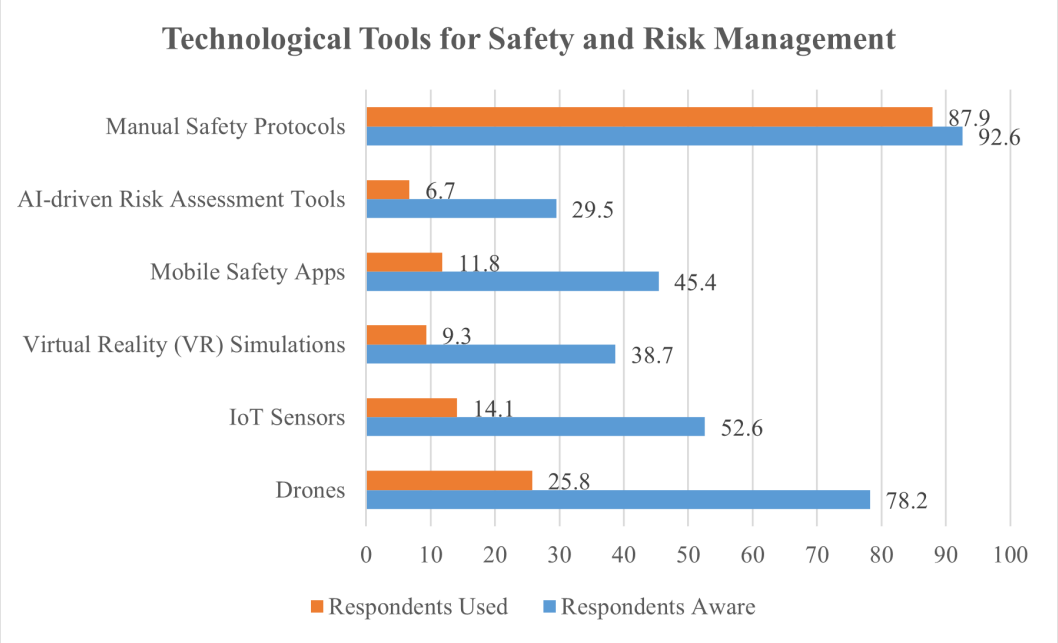


Figure 5.7 Technological Tools for Safety and Risk Management

In Chad, the construction industry is widely recognized as lacking structured safety protocols. Field inspections are irregular, the use of personal protective equipment (PPE) is inconsistent, and incident reporting is often reactive rather than preventive. Respondents overwhelmingly agreed that integrating smart technologies such as drones, wearables, and environmental sensors could transform the sector's safety culture. Over 78% stated that drones could help reduce risks by enabling remote site inspections, especially in hazardous or inaccessible zones.

Table 5.7 Awareness, Usage, and Perceived Benefits of Safety Technologies and Methods

Technology or Method	% Aware	% Used	Application Area	Perceived Benefit
Drones	78.2%	25.8%	Site inspection, hazard identification	Enhances visual access to dangerous or hard-to-reach zones
IoT Sensors	52.6%	14.1%	Real-time site monitoring	Enables alerts on noise, heat, gas leaks, or equipment failure
Virtual Reality (VR) Simulations	38.7%	9.3%	Worker safety training	Improves awareness and readiness for on-site hazards
Mobile Safety Apps	45.4%	11.8%	On-site incident reporting	Speeds up reporting and safety audits
AI-driven Risk Assessment Tools	29.5%	6.7%	Predictive analytics for risk forecasting	Helps anticipate delays, cost overruns, and accident likelihood
Manual Safety Protocols	92.6%	87.9%	Traditional compliance	Widely used but often lacks efficiency and consistency

IoT-enabled systems were also seen as essential for proactive safety monitoring. Tools that detect hazardous gas levels, unsafe temperatures, or vibration anomalies on structural components were identified as high impact but are currently underutilized. These technologies are still largely unfamiliar or unavailable in most Chadian projects due to cost and infrastructure constraints.

Additionally, predictive analytics powered by AI were highlighted as a tool for forecasting high-risk events based on past data, such as near-miss patterns or weather trends. Respondents cited this as a game-changer for project planning, particularly in regions prone to extreme weather, labor shortages, or low regulatory enforcement. Comparatively, developed countries increasingly mandate digital safety solutions and integrate safety dashboards within central project management systems [165]. Chad lags, but the responses reflect a growing awareness of the link between safety innovation and project sustainability.

This factor underscores the urgent need for investment in digital safety infrastructure, enforcement of safety protocols, and specialized training. The SRMI insights demonstrate that innovative technologies are not just operational conveniences; they are life-saving tools with far-reaching impacts on productivity, legal compliance, and worker morale in Chad's evolving construction landscape.

5.2.8 Environmental and Social Impact Assessment (ESIA)

The Environmental and Social Impact Assessment (ESIA) factor addresses the integration of digital tools in assessing and managing the environmental and social consequences of construction projects. Factor analysis revealed a strong grouping of items like ESIA2 (use of GIS and remote sensing for environmental monitoring), ESIA4 (digital stakeholder engagement tools), and ESIA5 (real-time environmental data analysis), each demonstrating high factor loadings above 0.75. These items reflect a shared recognition among construction professionals of the potential for digital technologies to improve transparency, accountability, and responsiveness in project planning and delivery.

In Chad, ESIA procedures are often limited, inconsistently enforced, or treated as bureaucratic formalities rather than proactive planning tools. Survey responses revealed that only 41% of respondents had been involved in a project with a fully digital ESIA process. However, nearly 80% agreed that technologies like Geographic Information Systems (GIS), satellite imagery, and real-time monitoring systems could radically improve how environmental and community risks are identified and managed.

Table 5.8 Awareness and Usage of Environmental Assessment Technologies

Technology / Tool	% Aware	% Used	Primary Application	Perceived Contribution
Geographic Information Systems (GIS)	63.4%	22.6%	Mapping project sites, tracking land use	Enhances precision in spatial analysis and site selection
Remote Sensing / Satellite Imagery	58.1%	19.3%	Monitoring environmental change and vegetation cover	Supports baseline data collection and post-project impact verification
Interactive Dashboards	42.8%	13.7%	Visualizing ESIA data for stakeholders	Improves transparency and public engagement
Environmental Monitoring Sensors	35.6%	9.1%	Measuring air, noise, and water quality	Enables real-time data collection for compliance tracking
Digital ESIA Reporting Platforms	39.5%	11.4%	Streamlining regulatory submissions	Reduces paperwork, improves speed and accuracy of reporting
Manual ESIA Reports (Word/PDF)	91.3%	86.5%	Static documentation of impact assessments	Still dominant but often lacks interactivity, traceability, and real-time updates

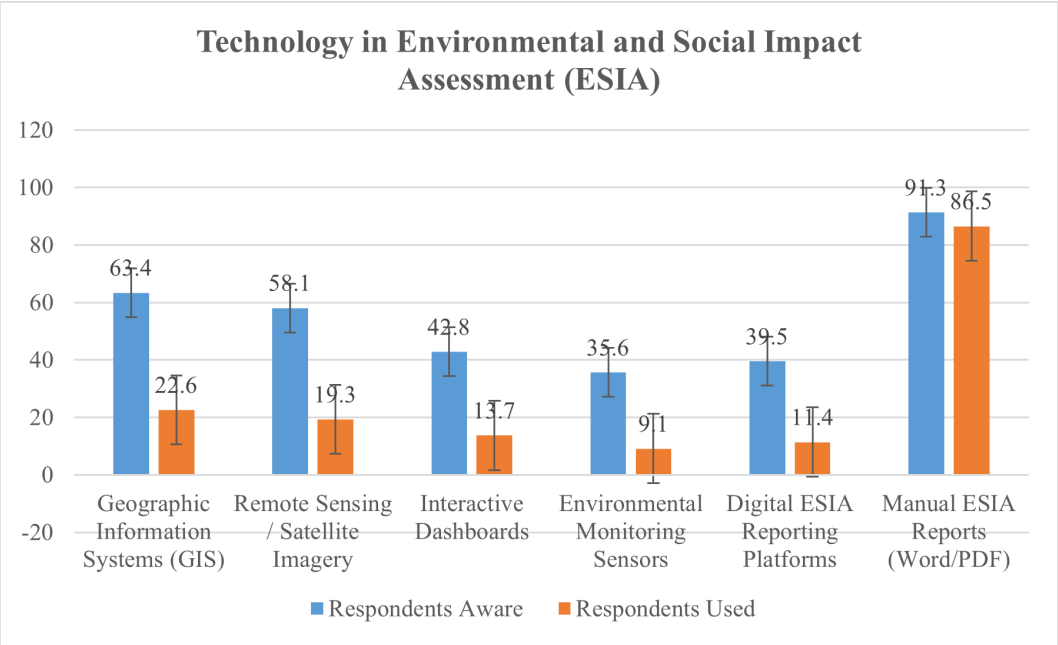


Figure 5.8 Technology in Environmental and Social Impact Assessment (ESIA)

Professionals emphasized the use of remote sensing to monitor vegetation loss, soil erosion, or pollution across large and hard-to-access areas. Similarly, the integration of drones into ESIA processes was seen as a cost-effective and efficient means of conducting aerial surveys and verifying compliance with mitigation measures. Tools such as community feedback apps and interactive dashboards were identified as critical to ensure that marginalized voices, especially in rural or informal settlements, are heard during project planning.

Internationally, ESIA is moving towards data-driven, participatory, and transparent systems, often backed by national legislation and enforced through digital compliance platforms [166]. In contrast, Chad's ESIA process remains underdeveloped, with limited institutional capacity, outdated data sources, and minimal digital integration.

Nevertheless, the responses show clear alignment with global trends and aspirations. Participants expressed strong interest in digital ESIA tools that are accessible, localized, and capable of generating real-time data. The ESIA factor points to an opportunity for Chad: by embracing technology, it can ensure that development does not come at the expense of the environment or vulnerable communities and instead fosters long-term sustainability and social equity.

5.2.9 Forecasting Emerging Technologies (FET)

The Forecasting Emerging Technologies factor reflects the construction industry's anticipation of and readiness for next-generation digital tools that are not yet widely implemented in Chad but are increasingly gaining traction globally. The items that contributed most to this factor included FET2 (awareness of construction robotics), FET4 (interest in blockchain applications), and FET5 (preparedness for digital twin integration), each with strong factor loadings above 0.70. This factor highlights a critical, forward-looking aspect of technological transformation. Survey responses indicated that while current usage of advanced technologies such as digital twins, robotics, blockchain for smart contracts, and 3D printing is nearly non-existent in Chad, there is a notable level of curiosity and interest among construction professionals. Over 65% of participants expressed awareness of at least one of these emerging tools, and 58% indicated a willingness to learn more or engage with pilot initiatives if opportunities were available.

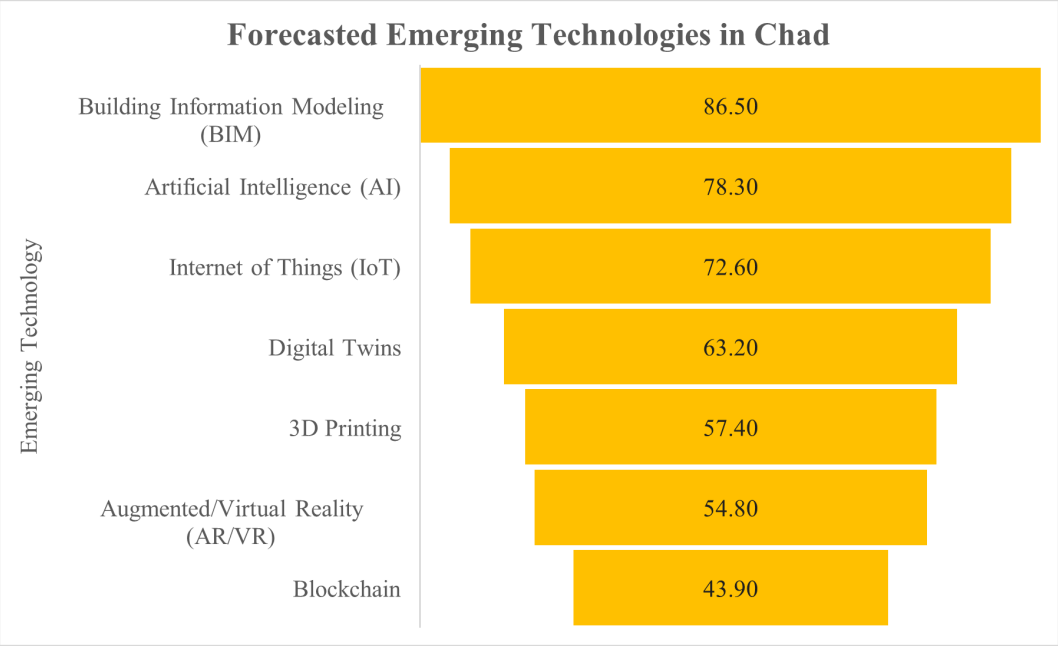


Figure 5.9 Forecasted Emerging Technologies in Chad

The findings suggest that the barriers to adoption of these technologies are not purely perceptual. Respondents cited a lack of national research and development (R&D) in construction innovation, minimal exposure to case studies or demonstrations, and the absence of policy dialogue around high-tech innovation. Only a small minority (less than 15%) believed that their organization would be ready to implement such technologies within the next five years without external support.

Table 5.9 Perceptions of Emerging Technologies by 2030

Emerging Technology	% Importance by 2030	Readiness in Chad	Anticipated Impact Area	Barriers to Adoption
Building Information Modeling (BIM)	86.5%	Moderate	Design integration, sustainability modeling	Limited expertise, high setup cost
Artificial Intelligence (AI)	78.3%	Low	Predictive analytics, risk forecasting	Lack of training, low digital maturity
Internet of Things (IoT)	72.6%	Low	Real-time monitoring, asset tracking	Connectivity issues, device cost
Digital Twins	63.2%	Very Low	Lifecycle simulation, real-time project visualization	High complexity, requires BIM foundation
3D Printing	57.4%	Low	Rapid prototyping, affordable housing	Equipment cost, regulatory ambiguity
Augmented/Virtual Reality (AR/VR)	54.8%	Moderate	Training, stakeholder engagement, site visualization	Device availability, awareness
Blockchain	43.9%	Very Low	Contract management, procurement transparency	Knowledge gap, legal and regulatory uncertainty

In contrast, global trends show that advanced economies and, increasingly, mid-tier economies are investing heavily in emerging technologies to enhance automation, precision, traceability, and sustainability. For instance, digital twins are being used to simulate building performance before construction begins, while blockchain is being applied for transparent procurement and payment processes in large-scale infrastructure projects [167]. These innovations are shifting the entire construction value chain toward smarter, more data-driven practices.

For Chad, the Forecasting Emerging Technologies factor serves as a barometer of future potential. It reveals a sector that, while constrained by infrastructure and resources, is not closed to innovation. To move forward, national efforts are needed to connect the construction industry with global innovation hubs, create innovation-friendly policy frameworks, and support knowledge transfer through international collaboration and education.

5.3 Sustainable Development Goals and Construction Technology in Chad

5.3.1 Infrastructure Development and Innovation (IDI)

The Sustainable Development Goal (SDG) 9 emphasizes the need to "build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation." In the context of Chad's construction sector, the Infrastructure Development and Innovation (IDI) theme emerged as a core area where technology adoption and sustainability intersect to address pressing development needs.

Findings from the factor analysis, particularly those related to Integration of Innovative Technologies (IIT) and Correlation with Project Success (CPS), revealed a growing understanding among stakeholders that modern infrastructure requires more than concrete and steel. It demands digital intelligence, long-term resilience, and adaptive design. Items linked to smart infrastructure planning, digital monitoring, and enhanced coordination across value chains demonstrated that while Chad's infrastructure sector is still developing, it is also ripe for technological leapfrogging.

Over 72% of survey respondents agreed that adopting smart construction technologies such as BIM for design optimization, drones for remote site access, and AI for predictive planning would significantly improve project efficiency and reduce failure rates. These tools, they noted, could drastically reduce rework, cost overruns, and time delays, which are endemic in public infrastructure delivery

Table 5.10 Perceived Impact of Innovative Digital Infrastructure (IDI) Indicators

IDI Indicator	% of Respondents Agreeing	Associated Technologies	Observed or Expected Impact
Improves infrastructure planning and design accuracy	81.4%	BIM, CAD, AI-driven modeling	Better road layouts, facility design, and utility mapping
Accelerates project delivery timelines	74.1%	Project Management Software, BIM	Reduction in delays, better contractor coordination
Enhances transparency in construction processes	69.7%	Cloud-based platforms, Blockchain	Real-time oversight, audit trails, and reduced corruption
Promotes digital innovation in infrastructure projects	64.3%	Drones, Sensors, Smart Materials	Enables remote inspections, data collection, and predictive maintenance
Facilitates integration of local innovation	51.8%	Mobile apps, local open-source tools	Supports context-relevant solutions, especially in rural infrastructure
Strengthens public-private collaboration	47.2%	Shared platforms, digital contracting	Eases coordination among the government, donors, and contractors

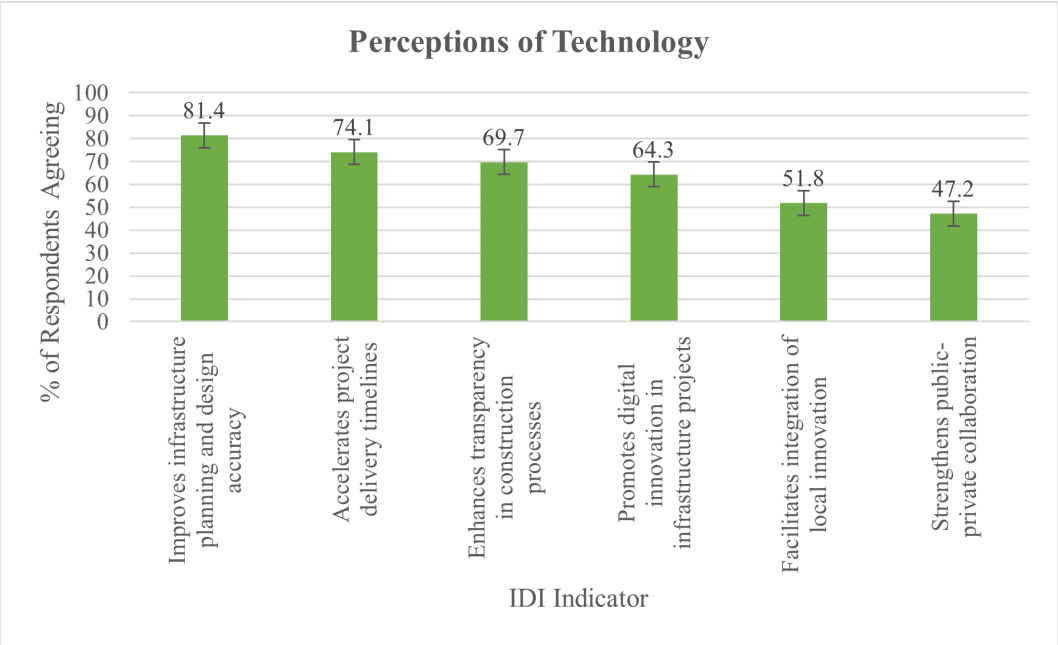


Figure 5.10 Smart Tech's Contribution to IDI

across the country.

Yet challenges persist; respondents emphasized poor digital infrastructure, limited funding for innovation, and outdated procurement frameworks as key constraints. Many projects still rely on paper-based design, budgeting, and reporting processes, which are inefficient and opaque. These limitations inhibit Chad from fully aligning with global infrastructure standards and SDG 9 targets.

In contrast, global best practices demonstrate that digitally enabled infrastructure increases lifecycle performance, enhances stakeholder collaboration, and improves resilience to climate shocks. Countries that incorporate digital twins, GIS-based planning, and smart materials achieve longer-lasting and more efficient infrastructure systems benefits that Chad urgently needs, especially in sectors like roads, water, and energy [168].

The IDI theme underscores a transformative opportunity: By investing in digital skills, reforming procurement policies, and leveraging donor-funded technology pilots, Chad can fast-track its infrastructure development while embedding innovation at every stage. This alignment with SDG 9 will not only elevate construction practices but also contribute to national economic diversification, job creation, and regional competitiveness.

5.3.2 Sustainable Urbanization and Habitat Development (SUHD)

Sustainable urbanization is a cornerstone of the United Nations' SDG 11, which aims to "make cities and human settlements inclusive, safe, resilient, and sustainable." In the context of Chad, the Sustainable Urbanization and Habitat Development (SUHD) theme links directly to findings from the factor analysis, particularly those under Sustainability in Construction (SC), Environmental and Social Impact Assessment (ESIA), and Evaluation of Project Management Software (EPMS). These findings reflect a sector that is beginning to recognize how technology can improve urban development outcomes despite deep-rooted systemic limitations.

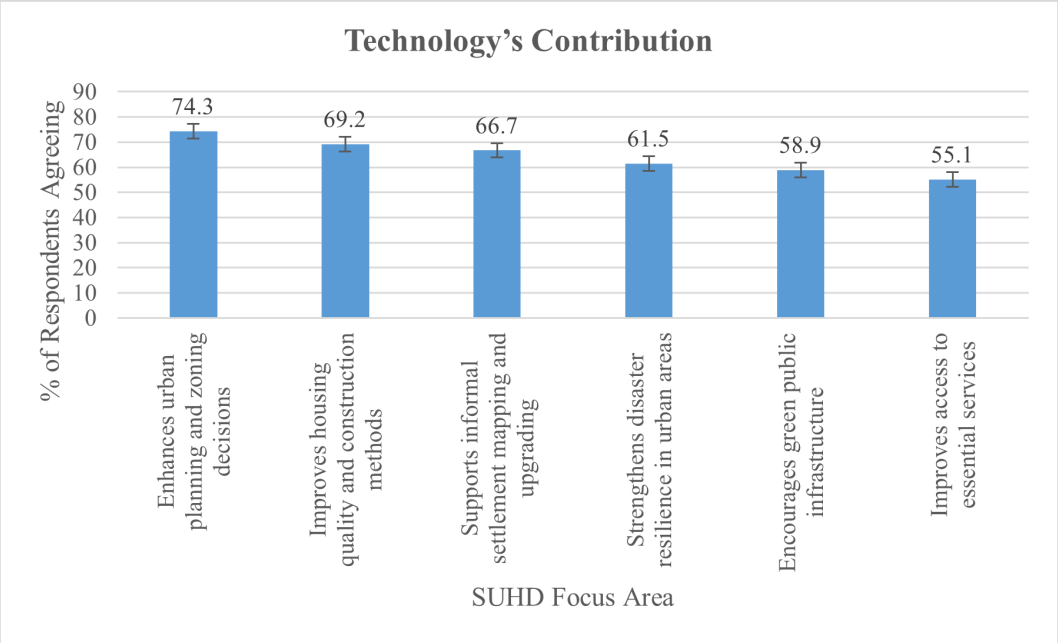


Figure 5.11 Technology's Contribution to SUHD

Survey respondents noted that urban growth in Chad, especially in N'Djamena, is rapidly outpacing planning capacity, infrastructure readiness, and environmental control. Over 69% of participants identified poor coordination among stakeholders as a major obstacle to sustainable housing and urban infrastructure. Yet, they also emphasized the potential of GIS platforms, real-time data dashboards, and urban simulation models to better manage land use, public services, and environmental risk zones.

Technologies like Building Information Modeling (BIM) and smart sensor systems can enhance the efficiency and transparency of urban development, from site selection to service delivery. When combined with tools for participatory planning, such as digital consultation platforms and mobile-based feedback tools,

Table 5.11 Sustainable Urbanization and Habitat Development (SUHD) Focus Areas

SUHD Focus Area	% of Respondents Agreeing	Relevant Technologies	Perceived Benefits
Enhances urban planning and zoning decisions	74.3%	GIS, Satellite Imagery, Digital Twins	Enables data-driven master plans and growth forecasting
Improves housing quality and construction methods	69.2%	BIM, Prefab Tech, 3D Modeling	Promotes durable, efficient, and affordable housing
Supports informal settlement mapping and upgrading	66.7%	GIS, Drone Mapping	Aids in identifying underserved areas and guiding infrastructure interventions
Strengthens disaster resilience in urban areas	61.5%	Simulation tools, Remote Sensing	Supports flood zone analysis, earthquake resistance planning
Encourages green public infrastructure	58.9%	LCA tools, Energy Modeling	Assists in designing eco-friendly parks, lighting, and transportation systems
Improves access to essential services	55.1%	IoT, Smart Grid Platforms	Enhances planning for water, electricity, waste, and mobility infrastructure

these innovations enable more inclusive and community-sensitive development practices. This is particularly important in Chad, where urban expansion frequently encroaches upon informal settlements and ecologically fragile zones.

The ESIA-related findings also support the case for better integration of social and environmental safeguards into the urban development process. By digitizing risk assessments and enabling live monitoring of project compliance, the construction industry can better align with global practices aimed at minimizing displacement, pollution, and resource depletion.

Globally, cities are moving toward smart urban ecosystems, where data-driven infrastructure supports not just functionality, but also sustainability and social equity. Chad's construction professionals express both awareness of and aspiration toward this vision. However, achieving it will require stronger institutional frameworks, urban governance reform, and capacity-building at the municipal level.

The SUHD theme ultimately shows that Chad's path to sustainable cities is not through traditional expansion, but through technology-informed planning, inclusive policy, and green innovation, ensuring that growth is not only rapid but also responsible.

5.3.3 Resource Efficiency and Sustainable Practices (RESP)

The theme of Resource Efficiency and Sustainable Practices (RESP) directly connects with SDG 12, which calls for "responsible consumption and production." In Chad's construction sector, this theme is especially relevant, as the industry consumes vast amounts of materials, water, and energy, often with minimal oversight or accountability.

Insights from the Sustainability in Construction (SC) and Safety and Risk Management Improvement (SRMI) factors offer a compelling view of how technology could drastically improve resource stewardship and operational sustainability. The findings revealed a strong awareness among professionals of the wastefulness of current construction practices, particularly regarding material overuse, poor site management, and inefficient energy consumption. More than 73% of respondents agreed that sustainable construction materials such as recycled aggregates, locally sourced bricks, or renewable insulation are essential for long-term environmental sustainability. However, they also noted that access to these materials is inconsistent, and the regulatory environment does not incentivize their use.

Table 5.12 Resource Efficiency and Sustainable Practices (RESP) Objectives

RESP Objective	% of Respondents Agreeing	Enabling Technologies	Key Benefits Identified
Optimizes material use and reduces construction waste	76.6%	BIM, Estimation Software	Improves precision in material planning, reduces over-ordering, and rework
Enhances the energy performance of buildings	68.4%	LCA tools, Energy Simulation	Models energy demand, supports passive design, and HVAC optimization
Promotes sustainable procurement practices	63.9%	Digital Procurement Platforms	Enables selection of low-impact, locally sourced, or recycled materials
Facilitates lifecycle analysis of structures	59.7%	BIM + LCA Integration	Provides insight into cost, carbon, and maintenance across the building lifespan
Reduces water usage and environmental strain	54.8%	Smart Plumbing Design Tools	Supports efficient water system planning and leak detection
Encourages modular and prefabricated construction	51.2%	CAD + Prefab Libraries	Reduces on-site waste and accelerates sustainable building assembly

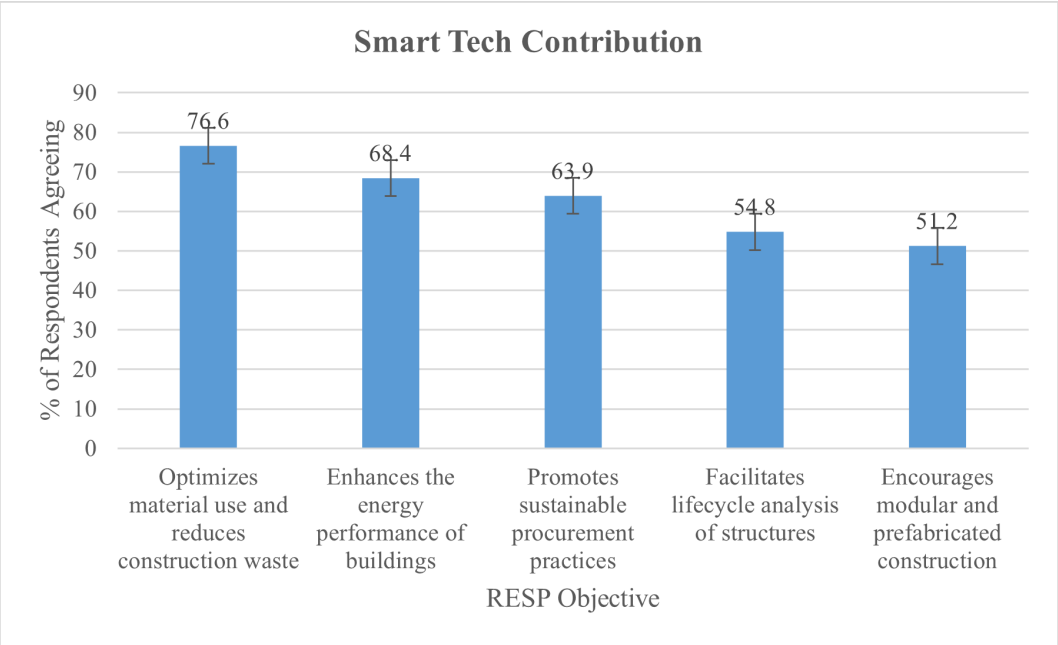


Figure 5.12 Smart Tech Contribution to RESP objctives

Similarly, digital tools like smart meters, energy modeling software, and waste tracking systems were highlighted as underutilized but potentially transformative. Respondents pointed to BIM-enabled quantity takeoffs, which allow for precise material forecasting, as an effective way to reduce site waste. The use of IoT-based monitoring systems to track water and energy usage in real-time was also cited as an emerging best practice that could be adapted for Chad's construction projects, especially in public infrastructure and housing.

Globally, countries that have adopted circular construction principles such as modular design, construction material recycling, and zero-waste site policies have achieved significant efficiency gains. Chad's professionals expressed interest in these models but emphasized the need for localized adaptation, government policy support, and technical education.

Moreover, the SRMI findings highlighted how safer, more efficient site management contributes to resource efficiency by minimizing rework, material damage, and delays. Thus, RESP is not just an environmental issue; it also supports productivity, cost control, and worker safety.

In sum, this theme reveals that Chad's construction industry is resource-intensive but ripe for reform. With the right tools and incentives, firms can shift from extractive, wasteful practices toward efficient, regenerative, and sustainable project delivery, in alignment with both global expectations and local environmental realities.

5.3.4 Environmental Conservation and Climate Action (ECCA)

The Environmental Conservation and Climate Action (ECCA) theme is aligned with Sustainable Development Goal 13, which urges urgent action to combat climate change and its impacts. In Chad's construction industry, this theme is especially crucial given the country's vulnerability to desertification, erratic rainfall, and high urban heat. This section draws from findings under the Environmental and Social Impact Assessment (ESIA) and Sustainability in Construction (SC) factors to examine how technology adoption can enhance the sector's environmental responsibility and climate resilience.

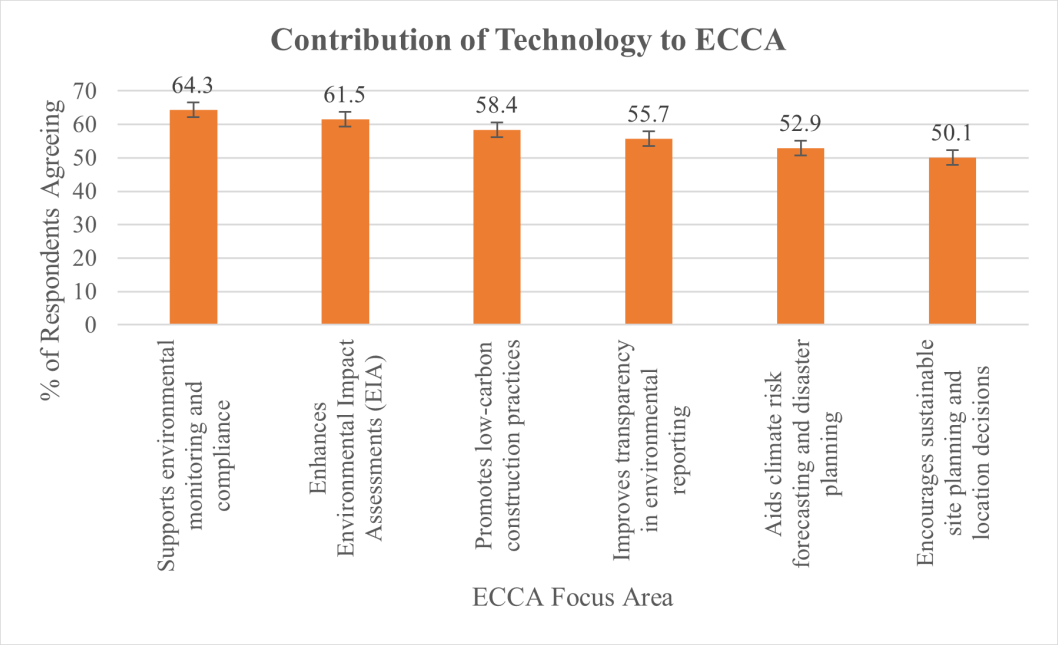


Figure 5.13 Contribution of Technology to ECCA

Respondents acknowledged that traditional construction methods in Chad often contribute to environmental degradation through deforestation, sand mining, uncontrolled emissions, and water pollution. More than 69% of participants agreed that innovative technologies can help mitigate these impacts, particularly through real-time environmental monitoring, low-carbon design tools, and climate-responsive building systems.

Key technologies mentioned included BIM integrated with energy simulation, geospatial tools for environmental mapping, and green material tracking systems. These tools enable professionals to assess carbon footprints, anticipate environmental risks, and adapt building designs accordingly. Yet, current implementation remains extremely limited. Only a small fraction of projects involve any form of climate-sensitive planning, due in part to weak institutional

Table 5.13 Environmental Conservation and Climate Action (ECCA) Focus Areas

ECCA Focus Area	% of Respondents Agreeing	Relevant Technologies	Key Benefits Identified
Supports environmental monitoring and compliance	64.3%	Sensors, IoT, GIS	Enables real-time tracking of noise, dust, emissions, and water pollution
Enhances Environmental Impact Assessments (EIA)	61.5%	GIS, Remote Sensing, Drones	Provides accurate baseline data and change detection
Promotes low-carbon construction practices	58.4%	LCA Tools, BIM, Green Product Databases	Assists in evaluating embodied carbon and guiding low-impact material choices
Improves transparency in environmental reporting	55.7%	Dashboards, Digital EIA Platforms	Facilitates stakeholder communication and regulatory compliance
Aids climate risk forecasting and disaster planning	52.9%	Climate Simulation Tools	Helps assess climate vulnerability and resilience in infrastructure design
Encourages sustainable site planning and location decisions	50.1%	GIS, Urban Heat Maps	Minimizes urban sprawl and ecosystem disruption

enforcement and a lack of training on environmental technologies.

Comparatively, in many global contexts, construction firms are being mandated to include climate risk assessments and carbon reduction strategies within their project lifecycles. Tools such as Life Cycle Assessment (LCA) software and digital EIA platforms are used not only for compliance but to design climate-resilient, low-impact infrastructure. These practices are gradually becoming prerequisites for international funding, especially in infrastructure and public housing projects.

In Chad, professionals voiced a strong desire for national guidelines and incentives that prioritize climate-resilient construction. They also emphasized the role of international partners in providing climate-smart design templates, toolkits, and training.

The ECCA theme, therefore, highlights both a gap and a pathway forward. With growing climate stressors and rapid urbanization, Chad's construction sector must move toward low-emission, adaptive, and environmentally conscious practices. Digital tools, if properly scaled and supported, can play a transformative role in aligning national infrastructure with the goals of environmental preservation and climate action.

5.3.5 Social Equity and Economic Development (SEED)

The Social Equity and Economic Development (SEED) theme addresses the intersection between technological innovation in construction and broader societal goals, including poverty reduction, job creation, gender inclusion, and equitable access to infrastructure. Closely aligned with SDG 1 (No Poverty), SDG 8 (Decent Work and Economic Growth), and SDG 10 (Reduced Inequalities), this theme draws from findings in the Challenges and Solutions (CS), Decision-Making Factors (DMF), and Safety and Risk Management Improvement (SRMI) factors.

A significant proportion of respondents emphasized that the digital transformation of Chad's construction sector has the potential to create new job opportunities, particularly in digital project planning, drone operation, site data analytics, and green construction. Over 62% of participants agreed that if properly supported, technology adoption would stimulate employment, rather than eliminate it, as it creates demand for new skill sets across the sector. However, the findings also revealed a digital divide, especially between large firms in urban areas and smaller contractors in rural zones. Many respondents expressed concern that innovation is currently limited to elite institutions and international firms, excluding local players, women, and young graduates from fully participating in the transition. This

Table 5.14 Social Equity and Economic Development (SEED) Objectives

SEED Objective	% of Respondents Agreeing	Enabling Technologies	Observed or Expected Benefits
Expands access to digital skills and job opportunities	68.7%	E-learning platforms, mobile apps	Upskill youth and technicians, especially in remote or underserved regions
Reduces inequalities in knowledge access	64.1%	AR/VR Training, YouTube-based modules	Enables on-demand, visual learning even for illiterate or semi-literate workers
Improves workplace safety and labor conditions	61.9%	Smart helmets, VR safety simulations	Reduces accidents, increases awareness of site hazards
Encourages youth entrepreneurship in tech-enabled services	58.4%	Drones, Surveying Tech, Mobile GIS	Opens opportunities in digital surveying, mapping, and freelance consulting
Enhances transparency in hiring and wages	54.6%	Digital payroll, job-matching apps	Reduces corruption in public projects and promotes fair labor practices
Supports gender inclusion in construction innovation	47.2%	Online mentorships, virtual design tools	Enables remote collaboration and flexible work arrangements for women in tech roles

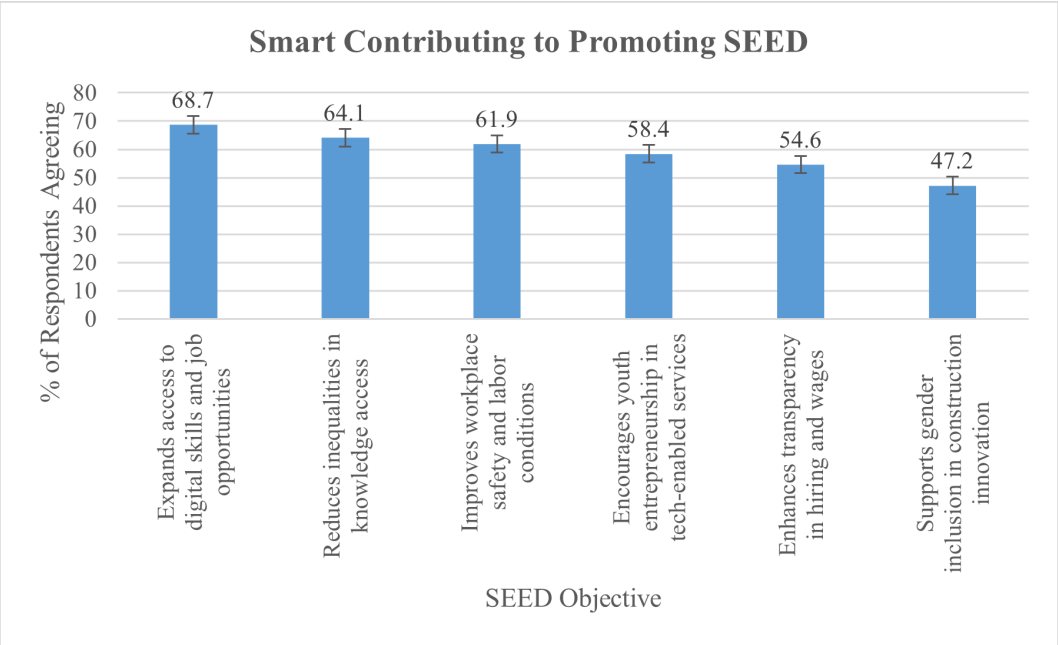


Figure 5.14 Smart Techs Contributing to Promoting SEED

exclusion not only undermines the social impact of innovation but also reinforces inequality in access to technology, capital, and opportunity.

The study also showed that most construction decisions are made by a narrow group of senior stakeholders, often without community engagement or consideration for social equity metrics. Yet, tools such as digital consultation platforms, mobile surveys, and community feedback dashboards were cited as means of making project planning more inclusive and responsive to the needs of marginalized populations.

In global practice, inclusive innovation in construction has helped to reduce unemployment, diversify workforce participation, and improve infrastructure service delivery to underserved communities. Chad's professionals acknowledge this potential but call for targeted policies, local capacity-building, and equitable financing schemes to unlock it.

Ultimately, the SEED theme reinforces the principle that technological advancement must be inclusive to be sustainable. Digital innovation in Chad's construction sector should be designed not just for productivity, but to empower all stakeholders, especially those traditionally left behind in the development process.

5.3.6 Governance and Institutional Support (GIS)

The theme of Governance and Institutional Support (GIS) is critical to understanding the enabling environment for construction technology adoption in Chad. Closely tied to SDG 16 (Peace, Justice, and Strong Institutions) and SDG 17 (Partnerships for the Goals), this theme emerged across multiple factors in the study, particularly Decision-Making Factors (DMF), Evaluation of Project Management Software (EPMS), and Challenges and Solutions (CS). It reflects how institutional strength, policy frameworks, and leadership directly influence the pace and quality of innovation in the construction industry.

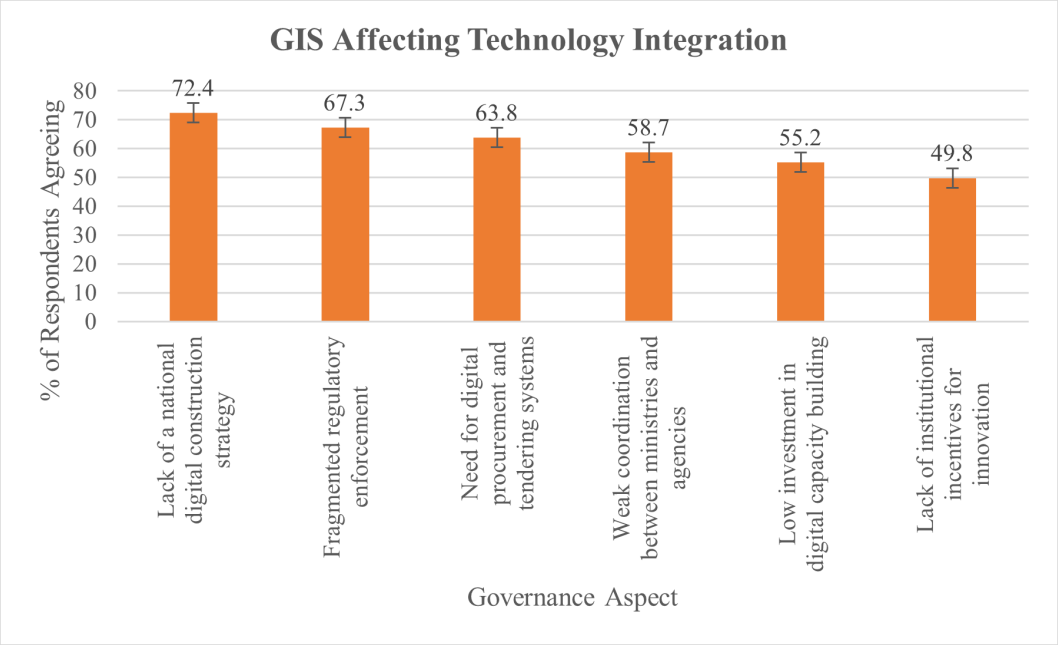


Figure 5.15 GIS Affecting Technology Integration

Survey findings revealed that while there is growing awareness of the benefits of digital construction technologies, there is a glaring absence of structured policy direction and regulatory support. More than 68% of respondents reported that their organizations lacked internal digital transformation policies, and nearly 74% believed that national agencies had not yet established clear guidelines for adopting construction technologies. The absence of building codes that mandate or incentivize digital tools (e.g., BIM or e-permitting systems) contributes to inconsistency and slows sector-wide progress.

Moreover, weak procurement systems, bureaucratic delays, and fragmented project oversight were commonly cited as institutional bottlenecks. Respondents emphasized the need for centralized digital governance platforms, such as e-construction permits, project dashboards, and national databases for construction

Table 5.15 Governance Aspects Affecting Digital Construction Adoption

Governance Aspect	% of Respondents Agreeing	Technology Link or Need	Key Observations and Implications
Lack of a national digital construction strategy	72.4%	Policy frameworks, national tech plan	Absence of strategic direction delays standardization and widespread adoption
Fragmented regulatory enforcement	67.3%	Centralized digital permitting systems	Inconsistent inspections and approvals create delays and inefficiencies
Need for digital procurement and tendering systems	63.8%	E-procurement platforms	Paper-based systems are prone to corruption and a lack of transparency
Weak coordination between ministries and agencies	58.7%	Interoperable databases and dashboards	Limits cross-sector planning and integrated decision-making
Low investment in digital capacity building	55.2%	Training platforms, digital labs	Government and professional bodies are not investing in ICT training infrastructure
Lack of institutional incentives for innovation	49.8%	Innovation funding, tax incentives	Firms lack the motivation to explore or scale digital tools without regulatory support

professionals and standards. Such systems are widely used in digitally advanced economies to enhance transparency, reduce corruption, and monitor compliance.

On the positive side, the study identified emerging leadership within select public agencies and donor-funded infrastructure projects that are experimenting with digital platforms and data-driven monitoring tools. These cases, though isolated, demonstrate the catalytic role that institutional champions and partnerships can play in driving innovation on a scale.

Globally, the construction sector has benefited from governance models that prioritize innovative ecosystems, combining education, incentives, policy reform, and public-private collaboration. For Chad, the GIS theme points to the need for a strategic digital construction policy, supported by legislation, budget allocations, and partnerships with regional and global knowledge networks.

Ultimately, effective governance is the backbone of technological transformation. Without institutional alignment and accountability, even the most promising technologies cannot reach their full potential. Chad's success in modernizing its construction sector will depend on how strongly its institutions rise to this challenge.

5.4 Impact of Innovative Technologies in Chad's Construction Industry

The integration of innovative technologies in Chad's construction industry is beginning to reshape the landscape of project management, infrastructure delivery, and sustainable development. While still in the early stages, the findings from this study reveal a clear and measurable impact across key dimensions: efficiency, safety, sustainability, collaboration, and policy alignment.

The Principal Axis Factoring (PAF) results confirmed nine critical factors influencing the adoption of technologies. Among the most significant were Integration of Innovative Technologies (IIT) and Safety and Risk Management Improvement (SRMI), both of which demonstrated high variance and strong item loadings. These findings suggest that technologies such as BIM, drones, AI, and IoT are not only viewed as desirable but as transformative tools in addressing chronic inefficiencies like project delays, poor cost control, and on-site hazards.

Professionals indicated that adopting these technologies has already led to incremental improvements in documentation quality, data-driven decision-making, and project transparency, especially in donor-funded projects. For example, drone

Table 5.16 Impact Areas of Digital Technologies in Construction: Benefits and Challenges

Impact Area	**Positive Observations / Benefits**	**Limitations / Challenges**
Project Planning & Design	Improved design coordination, reduced errors (esp. through BIM and CAD integration)	Low access to BIM software and a lack of trained professionals
Cost & Time Management	Enhanced budget forecasting and timeline adherence using scheduling tools and digital workflows	Manual workarounds remain dominant due to limited access to project management software
Site Monitoring & Quality Control	Use of drones and mobile apps improved oversight and documentation	Drone usage is restricted to externally funded or NGO-supervised projects
Collaboration & Communication	Cloud-based platforms facilitated multi-party coordination (esp. for international projects)	Most local firms lack access to cloud platforms or shared workspaces
Environmental Management	Remote sensing and GIS improved awareness of land and resource use	Tools not yet integrated into mainstream ESIA processes or regulatory reporting
Workforce Development	Mobile and virtual tools used for limited skill-building among youth and interns	Lack of structured training programs, especially outside capital cities
Equity & Transparency	Digital procurement used in a few pilot projects helped reduce favoritism and manual inefficiencies	No national e-procurement law; most public projects remain paper-based

surveillance has improved site supervision, while project management platforms have enhanced scheduling, reporting, and accountability. However, such cases remain exceptions rather than the norm. The impact on sustainability is also emerging. Through tools like energy modeling, digital site planning, and GIS integration, some firms are beginning to reduce material waste, optimize energy usage, and plan around environmental sensitivities. These practices are vital in a country facing environmental degradation, rapid urbanization, and infrastructural fragility.

From a human capital perspective, the impact is equally significant. There is a growing demand for digitally skilled labor, opening new employment pathways for young professionals. Survey responses reflected optimism that innovation can empower youth and foster entrepreneurship, if access to training, software, and hardware improves. Nevertheless, the full potential of these technologies is constrained by systemic barriers. The study found that many firms lack institutional strategies for digital transformation. High software costs, unreliable power and internet access, and a lack of enforceable standards all inhibit scale. Moreover, innovation tends to be concentrated in larger urban firms, leaving rural contractors and small businesses behind.

In contrast, global construction industries have fully embedded digital tools into their workflows. Countries like the UK, Singapore, and the UAE have national BIM mandates, integrated permitting systems, and real-time project dashboards, resulting in faster delivery, higher quality, and lower lifecycle costs. Chad has yet to formalize a national strategy, but the presence of digital tools in select projects suggests a foundation for broader impact.

In sum, the integration of innovative technologies in Chad's construction industry is currently emergent but uneven. The impacts are visible where digital tools have been deployed, and the perceptions of professionals are largely positive. For this momentum to become widespread, it must be supported by institutional reform, strategic investment, and capacity-building. Only then can the sector fully realize the promise of digital transformation to improve infrastructure, drive economic growth, and support sustainable development.

5.5 Implications for Sustainable Projects

The findings of this study offer several critical implications for the future of sustainable construction projects in Chad, especially concerning technology adoption. Drawing on the nine thematic factors identified through Principal Axis

Factoring (PAF), it becomes evident that the successful integration of innovative technologies can be a catalyst for sustainability, but only if supported by a conducive ecosystem of policy, skills, and infrastructure.

One of the most immediate implications is the opportunity to reduce environmental impact. The factors related to Sustainability in Construction (SC), Environmental and Social Impact Assessment (ESIA), and Resource Efficiency and Sustainable Practices (RESP) emphasize that technologies such as BIM, energy modeling, and remote sensing can minimize material waste, optimize energy usage, and improve compliance with environmental regulations. However, for these benefits to be realized at scale, there is a pressing need for green building guidelines, incentives for eco-materials, and digital ESIA mandates.

Second, the Integration of Innovative Technologies (IIT) and Forecasting Emerging Technologies factors suggest that sustainable projects in Chad must move beyond traditional practices and embrace digital tools as a standard, not an exception. The integration of technologies should begin during the design phase, continue through construction and monitoring, and extend into maintenance and decommissioning. This life-cycle approach is essential to deliver infrastructure that is durable, energy-efficient, and climate-resilient.

Third, sustainable projects must be socially inclusive and economically empowering. The Social Equity and Economic Development (SEED) factor highlights how technology can democratize access to information, promote community participation, and generate new employment opportunities in areas like drone operation, digital design, and environmental monitoring. However, this requires proactive training and deliberate efforts to include marginalized groups, particularly women and youth, in the digital transition.

Furthermore, the Decision-Making Factors (DMF) and Governance and Institutional Support (GIS) factors underscore that sustainability is not just a technical challenge, but also a governance issue. Without leadership commitment, clear policies, and institutional accountability, the sustainability agenda will remain fragmented. Therefore, government bodies must set enforceable standards, streamline digital permitting processes, and collaborate with universities and the private sector to foster a culture of innovation.

Ultimately, sustainable construction in Chad should be viewed as a national development priority, rather than a niche concern. By embedding innovation and sustainability into public procurement frameworks, infrastructure policies, and urban planning strategies, Chad can position itself to meet its SDG targets while

Table 5.17 Sustainability Dimensions: Implications and Recommended Actions

Sustainability Dimension	**Implications of Technological Integration**	**Recommended Action**
Environmental Sustainability	Enables lifecycle assessment, energy modeling, and environmental monitoring	Mandate LCA/BIM use in public projects; integrate digital tools into ESIA regulations
Economic Efficiency	Reduces delays, cost overruns, and rework through improved planning and forecasting	Incentivize PMS/BIM adoption through tax relief or procurement scoring
Social Inclusion	Opens new pathways for youth employment and training via mobile and digital platforms	Fund regional digital skill centers; promote gender-inclusive tech education
Governance and Accountability	Enhances transparency and reduces corruption in procurement and site supervision	Develop a national e-procurement system and require digital audit trails
Urban Resilience	Supports sustainable land use, hazard mapping, and infrastructure adaptation to climate risk	Embed GIS and simulation tools into urban planning workflows and climate adaptation plans
Local Innovation Capacity	Stimulates use of context-relevant tools and locally adapted construction solutions	Support startups, local software firms, and build open-source digital platforms

improving the quality, affordability, and resilience of its built environment.

5.6 Conclusion

This chapter has presented a detailed analysis of the key findings derived from the survey data and Principal Axis Factoring (PAF), shedding light on the current state and future potential of innovative technologies in Chad's construction industry. The results reveal a sector in transition, rich in awareness and intent, but limited by systemic, infrastructural, and institutional challenges.

Nine major thematic factors were identified, each representing a dimension of digital and sustainable construction readiness: from Integration of Innovative Technologies (IIT) and Sustainability in Construction (SC) to Safety and Risk Management Improvement (SRMI) and Forecasting Emerging Technologies. These factors not only reflect localized priorities and perceptions but also align strongly with global trends in construction modernization and Sustainable Development Goal (SDG) implementation.

The study demonstrates that while actual adoption remains uneven and constrained, there is widespread recognition among industry professionals that technology can significantly enhance project success, sustainability, and social impact. Tools such as BIM, project management software, GIS, drones, and IoT are seen as game-changers, provided that enabling conditions like training, infrastructure, leadership, and policy reform are put in place.

Moreover, the cross-sectional findings suggest that innovation in construction is not just about tools and techniques; it is fundamentally about governance, equity, and resilience. For Chad to fully unlock the benefits of construction technology, the transition must be inclusive, data-driven, and backed by strong institutional frameworks. Looking ahead, the findings call for a strategic, multi-stakeholder approach to digital transformation. Government agencies, academia, development partners, and private firms must collaborate to overcome existing barriers, scale successful pilots, and embed sustainability and innovation at the heart of the country's infrastructure agenda.

In conclusion, the transformation of Chad's construction sector through innovative technologies is both necessary and achievable. With the right investments, policies, and leadership, Chad can build not only smarter infrastructure but also a more sustainable, equitable, and competitive future.

6
DISCUSSION

6.1 Introduction

This chapter discusses the key findings presented in Chapter 5, considering the broader literature on construction project management and technology adoption. It bridges empirical data from the field with theoretical and global perspectives, offering a comprehensive understanding of how innovation, sustainability, and smart technologies are shaping the construction industry and how these dynamics unfold within the Chadian context.

Globally, the construction sector is undergoing a significant transformation, driven by advancements in digital technology, a heightened focus on sustainability, and a push toward more efficient and transparent project delivery. Technologies such as Building Information Modeling (BIM), drones, project management platforms, artificial intelligence (AI), and the Internet of Things (IoT) are no longer peripheral; they are central to the way projects are designed, executed, and monitored.

In contrast, Chad's construction industry is still in a developmental stage, facing considerable challenges such as poor infrastructure, digital illiteracy, weak regulatory frameworks, and limited financial capacity. Despite this, the study revealed a strong awareness and readiness among professionals to embrace change, supported by strategic training, institutional reform, and international collaboration.

This chapter discusses the comparative state of construction project management globally and locally, the role of smart technologies in revolutionizing project outcomes, and the emerging future of construction management. It also connects the findings to broader sustainability goals, examining how green construction and digital innovation intersect in the Chadian context. Through this analysis, a clear narrative emerges: Chad has the potential to leapfrog into a more innovative and sustainable construction future, provided that systemic barriers are addressed with urgency and clarity.

6.2 Construction Project Management

Construction project management (CPM) has evolved significantly over the past two decades in the global industry. In advanced economies, CPM has transitioned from traditional paper-based coordination to digitally integrated systems that combine real-time collaboration, predictive analytics, and automated reporting. Tools such as Building Information Modeling (BIM), Enterprise Resource Planning (ERP) systems, and cloud-based project management platforms now define best practices in countries like the United States, the United Kingdom, Singapore, and the UAE. These systems enhance transparency, reduce waste, shorten project timelines, and improve cost accuracy while complying with strict regulatory and sustainability requirements.

Challenges persist globally, particularly in managing mega-project complexities, aligning multi-stakeholder goals, and addressing skills shortages in high-tech applications. However, these challenges are typically addressed through robust institutional support, continuous workforce training, and investment in innovative ecosystems. In contrast, Chad's construction project management landscape remains largely traditional and fragmented. According to the survey results, most firms still rely on manual scheduling, verbal coordination, and paper documentation. Only a small number of large or internationally funded projects employ digital tools, and even then, adoption tends to be partial or experimental. Institutional support for modern CPM practices is limited, with few enforceable standards or national digital infrastructure policies in place.

The challenges in Chad include limited access to technology, high software costs, insufficient digital skills, and weak coordination among stakeholders. Yet, the study's findings also highlight significant opportunities for growth. There is clear recognition among professionals of the benefits of technology for improving project success, as reflected in the strong performance of factors like CPS (Correlation with Project Success) and EPMS (Evaluation of Project Management Software).

Overall, while Chad's CPM practices lag global benchmarks, the sector shows potential to catch up, especially if supported by policy reform, capacity building, and strategic investment in technology and training.

6.3 Smart Technology Revolutionizing Project Management

The global construction industry is undergoing a digital revolution, driven by rapid advancements in smart technologies. As documented in the literature, tools such

Table 6.1 Project Management Functions: Benefits, Challenges, and Actions

Project Management Function	**Observed Benefits of Technology Integration**	**Persistent Challenges**	**Recommended Actions**
Planning and Scheduling	Improved accuracy and visual timelines using PMS tools and BIM	Low adaption due to cost, complexity, and lack of training	Promote open-source or modular PMS tools with local-language interfaces
Resource Management	Optimized allocation and estimation through BIM and cost tracking software	Manual estimation is still prevalent in small and medium firms	Provide training in digital quantity surveying and resource dashboards
Communication and Coordination	Cloud platforms improved data sharing on donor-led or urban projects	Limited access to cloud infrastructure and reliable internet	Invest in local digital hubs and offline-compatible coordination apps
Quality and Compliance	Drone and photo documentation enhance on-site monitoring	Quality control is inconsistent without digital integration	Develop mobile QA/QC tools with built-in checklists and local compliance standards
Risk and Safety Management	Sensors and VR improve hazard awareness and predictive risk assessment	Little to no usage in local construction settings	Pilot affordable, mobile-based safety and risk assessment systems
Procurement and Financial Control	Digital tools improve cost tracking and transparency in international projects	The public sector still relies on manual, paper-based systems	Implement national digital procurement laws and pilot e-tender platforms

as Building Information Modeling (BIM), artificial intelligence (AI), the Internet of Things (IoT), drones, augmented reality (AR), and cloud-based project management platforms are transforming how projects are planned, executed, and monitored. These technologies enhance decision-making, reduce delays, optimize costs, and improve collaboration across disciplines. In countries like the United Kingdom and Singapore, BIM is mandated for public projects, and smart tools are embedded in every phase of the construction lifecycle.

The literature shows that these technologies are not merely add-ons; they are fundamental to modern construction project management. BIM allows for clash detection and 3D/4D modeling; AI provides predictive insights for risk and resource planning; drones conduct aerial site inspections; and IoT-enabled sensors track safety and environmental conditions in real time. These capabilities translate into increased productivity, enhanced safety, reduced waste, and greater accountability.

In Chad, although the implementation of smart technologies remains limited, the findings from the survey reveal a growing awareness and eagerness to adopt these tools. Factors such as Integration of Innovative Technologies (IIT) and Safety and Risk Management Improvement (SRMI) scored highly in the factor analysis, indicating that professionals understand the tangible benefits of smart technologies. Respondents cited BIM, drones, and cloud software as tools that could drastically improve project delivery and transparency, particularly in government infrastructure and donor-funded projects.

However, unlike global leaders, Chad lacks the institutional frameworks, training pipelines, and digital infrastructure to support the large-scale deployment of these innovations. Most firms operate in resource-constrained environments where internet access, power stability, and skilled labor are inconsistent. Additionally, smart technologies are often perceived as expensive or foreign, rather than essential tools for long-term growth.

Despite these barriers, Chad stands at a pivotal point. The growing demand for infrastructure, combined with rising awareness of digital tools, provides a unique opportunity to leapfrog legacy systems. By investing in training, adopting open-source smart platforms, and partnering with international technology providers, Chad can begin to align with the global revolution in construction project management and transform how projects are delivered at home.

Table 6.2 Smart Technologies and Their Impact on Project Management in Chad

Smart Technology	Project Management Domain Impacted	Revolutionary Capability	Current Limitations in Chad
Building Information Modeling (BIM)	Planning, Design, Coordination	3D/4D modeling, real-time collaboration, clash detection	High setup cost, lack of national BIM policy
Drones	Site Monitoring, Progress Tracking	Aerial imagery, visual inspections, and access to hard-to-reach zones	Regulatory restrictions, affordability
Artificial Intelligence (AI)	Risk Management, Forecasting	Predictive analytics for delays, cost overruns, and safety risks	Limited data availability and AI literacy
Internet of Things (IoT)	Safety, Quality Monitoring	Real-time sensor feedback on equipment, materials, and environment	Connectivity and energy infrastructure gaps
Cloud-Based PMS	Communication, Document Management	Centralized data access, multi-user collaboration, live tracking	Unreliable internet access and low cloud storage adoption
Virtual/ Augmented Reality (VR/AR)	Training, Design Visualization	Immersive safety training, client walk-throughs before construction	High hardware cost, limited exposure, and user experience
Mobile Apps and Dashboards	On-Site Management, Reporting	Field data collection, instant reporting, and remote verification	Scattered use, mostly in donor-led or urban projects

6.4 The Future of Construction Management

The future of construction management is undeniably digital, data-driven, and sustainability-oriented. Globally, the construction sector is moving toward fully integrated ecosystems where smart technologies work in synergy to improve project outcomes across the lifecycle, from pre-design to facility maintenance. Emerging trends such as digital twins, blockchain-based smart contracts, robotic construction, and predictive analytics are shaping a future in which construction is faster, safer, more efficient, and environmentally conscious.

Major players in the global construction space are investing in cloud-based collaboration platforms, AI-driven forecasting tools, and IoT-enabled sensors to monitor real-time site data. Additionally, governments are crafting smart infrastructure policies, mandating digital compliance, and incentivizing the adoption of green building certifications. The result is a shift from reactive to proactive project management, where decisions are informed by data and guided by sustainability principles.

In Chad, although this future may seem distant, the survey findings suggest that the seeds of transformation have been planted. Respondents overwhelmingly expressed a willingness to embrace innovation, with high scores observed in factors such as Forecasting Emerging Technologies and Correlation with Project Success (CPS). There is a growing belief that tools like BIM, AI, drones, and digital dashboards can resolve long-standing challenges such as cost overruns, time delays, and poor communication.

However, the realization of this future depends on addressing key gaps. These include limited access to training, underdeveloped digital infrastructure, and weak institutional support. Without strategic intervention, Chad risks widening the digital divide, leaving its construction sector behind while the rest of the world advances.

That said, Chad has a unique opportunity to leapfrog directly into the digital age by learning from global best practices and tailoring them to its local realities. The future of construction management in Chad will depend not only on technology itself but on visionary leadership, public-private collaboration, and a strong commitment to inclusive and sustainable development.

6.5 Sustainability, Green Construction, and Smart Technology

Globally, the construction sector is one of the largest contributors to environmental degradation, accounting for significant greenhouse gas emissions, material waste,

Table 6.3 Strategic Vision for Construction Sector Transformation (2025–2035)

Future Focus Area	Current Status (2025)	2035 Vision	Required Strategic Action
Digital Integration	Fragmented and manual; few firms use BIM or PMS	Sector-wide adoption of interoperable digital platforms	Develop a national digital construction roadmap and interoperability standards
Project Delivery	Slow timelines, high error margins	Agile, data-driven project delivery using AI and real-time tools	Introducing mandatory tech use in public infrastructure contracts
Talent and Workforce	Skill gaps in digital tools, limited training access	A digitally fluent workforce with specialized certifications	Establish construction tech training centers and university–industry partnerships
Sustainability Practices	Limited ESG compliance; ad hoc green efforts	Circular construction with lifecycle-based design	Integrate LCA, green certification, and e-monitoring into national regulations
Safety and Risk Management	Paper-based inspections and reactive safety protocols	Smart sites with real-time monitoring and predictive analytics	Promote IoT and drone-based safety systems; update labor codes accordingly
Governance and Procurement	Manual tendering, low transparency	Fully digital, transparent, and traceable public procurement	Launch national e-procurement platform; enforce digital audit trails
Equity and Inclusion	Urban-centric and male-dominated workforce	An inclusive digital economy with rural, youth, and gender inclusion	Provide subsidized mobile access, local-language tools, and gender-friendly tech

and energy consumption. In response, the industry is shifting toward sustainable and green construction practices, supported by smart technologies that enable efficiency, precision, and environmental stewardship. The literature shows that Building Information Modeling (BIM), energy modeling software, life cycle assessment tools, and sensor-based monitoring systems are central to achieving green outcomes. Certifications such as LEED, BREEAM, and EDGE provide standards for energy efficiency, material reuse, and carbon footprint reduction.

These technologies and frameworks allow construction professionals to design smarter, build more efficiently, and operate buildings more sustainably. Smart construction integrates data at every stage, offering insights into resource use, waste generation, and environmental impacts, which helps reduce overdesign, optimize energy performance, and improve long-term resilience.

In the context of Chad, the study findings revealed a strong conceptual alignment with these global trends, even though practical implementation is still in its infancy. Factor analysis highlighted that Sustainability in Construction (SC), Environmental and Social Impact Assessment (ESIA), and Resource Efficiency and Sustainable Practices (RESP) are all seen as essential for the future of the industry. Over 70% of respondents agreed that green building materials, energy-efficient systems, and environmental planning tools would significantly improve project outcomes.

Yet, respondents also acknowledged multiple barriers, ranging from the absence of green construction policies to limited access to affordable eco-materials and digital sustainability tools. Most professionals rely on conventional methods not out of preference, but due to the lack of support systems, incentives, and data infrastructure needed to make sustainable practices viable.

Despite these constraints, the desire for change is evident. The findings suggest that Chadian construction professionals are open to adopting smart, green technologies, especially if supported by training, government policies, and donor-backed pilot programs. Integrating sustainability with innovation offers Chad a pathway to improve project quality, reduce environmental harm, and meet the Sustainable Development Goals (SDGs).

In essence, green construction powered by smart technology is not only possible in Chad but also essential. With the right strategic support, the industry can transition from reactive practices to proactive, sustainable development.

Table 6.4 Smart Technologies Enabling Green Construction in Chad

Green Construction Goal	Enabling Smart Technologies	Sustainability Pillar Addressed	Contextual Benefit in Chad
Reduce material waste and enhance resource efficiency	BIM, Quantity Estimation Software, 3D Scanners	Environmental (SDG 12)	Minimizes overuse of imported materials; supports lean construction
Lower energy demand and emissions	LCA Tools, Energy Modeling, IoT Sensors	Environmental & Economic (SDG 13)	Reduces energy bills; encourages use of passive design in hot climates
Increase the use of local and low-carbon materials	Digital Procurement Platforms, Material Databases	Economic & Social (SDG 8, 9)	Supports local industries, reducing dependence on imported building materials
Promote modular, prefabricated, and circular design	CAD/BIM Libraries, 3D Printing	Environmental (SDG 11, 12)	Allows for scalable housing solutions in rural areas
Improve site health, safety, and worker wellbeing	VR/AR Training, Safety Apps, IoT Wearables	Social (SDG 3, 8)	Reduces site accidents and occupational hazards in low-capacity construction zones
Enhance transparency and accountability	Blockchain, Cloud Dashboards, Mobile Reporting	Governance (SDG 16)	Reduces corruption; ensures real-time compliance with environmental standards
Engage communities and promote social inclusion	GIS, SMS Feedback Systems, Local-Language Interfaces	Social Equity (SDG 10)	Improves feedback loops and participation, especially in marginalized areas

6.6 Roadmap for Adopting Smart Technologies in Chad

The adoption of smart technologies in Chad's construction industry requires a coordinated, phased, and context-sensitive strategy. Findings from this research, particularly the strong correlations among constructs such as Integration of Innovative Technologies (IIT), Challenges and Solutions (CS), and Decision-Making Factors (DMF), underscore that successful adoption depends not only on technical availability but also on institutional readiness, human capital, and supportive policy frameworks.

To initiate this transformation, the government and sector stakeholders must begin with the development of a comprehensive national digital construction strategy. This should articulate regulatory and implementation standards for technologies such as Building Information Modeling (BIM), e-procurement systems, digital environmental and social impact tools, and smart monitoring systems. Institutional enforcement is critical, especially considering the strong associations observed between Governance and Institutional Support (GIS) and constructs like Sustainable Urbanization and Habitat Development (SUHD) and Social Equity and Economic Development (SEED). These findings emphasize that institutional capacity is a foundational enabler of technological change.

Equally important is investment in human capital. The study revealed that over 70% of respondents viewed digital competence as vital for project success. Therefore, technical training programs, particularly within vocational institutions and engineering faculties, should be upgraded to include content on digital surveying, drones, BIM, mobile project management systems, and basic AI tools. These training efforts must be designed to ensure inclusivity, enabling participation by women, youth, and professionals in rural areas, thus aligning with broader goals of equitable access and SDGs 4, 5, and 10.

Reliable access to internet connectivity, electricity, and mobile infrastructure is another prerequisite. As demonstrated by the correlation between IIT and CS, foundational challenges continue to limit the usability and scalability of even basic digital tools. Infrastructure upgrades, especially in secondary urban centers and growth corridors, must be prioritized through public-private partnerships and targeted donor programs. Without these investments, the best technologies remain underutilized or entirely inaccessible.

The success of this roadmap also depends on practical demonstrations of value. Pilot projects that incorporate BIM, cloud-based platforms, drones, and LCA tools should be initiated in publicly funded infrastructure projects. These demonstration

efforts not only validate performance benefits but also help build confidence among private sector actors. Coupled with financial incentives such as tax relief or startup grants, these pilot programs will create positive momentum and drive broader adoption. This is particularly relevant given the empirical linkages identified between CPS (Correlation with Project Success), SC (Sustainability in Construction), and EPMS (Evaluation of Project Management Software).

Finally, localizing smart technology tools, both linguistically and functionally, is critical. Software platforms and training resources must be adapted into French and regional languages to ensure usability across Chad's diverse workforce. In parallel, a robust monitoring and evaluation mechanism should be established to track progress. This would involve digital dashboards and national KPIs linked to SDG performance indicators, overseen by key agencies such as the Ministry of Infrastructure, the National Statistics Office, and academic institutions.

In summary, the proposed roadmap offers a pragmatic yet ambitious path for embedding smart technologies into Chad's construction ecosystem. Grounded in data and factor correlations, it enables the transition toward more efficient, inclusive, and sustainable project management practices in line with national priorities and global development goals.

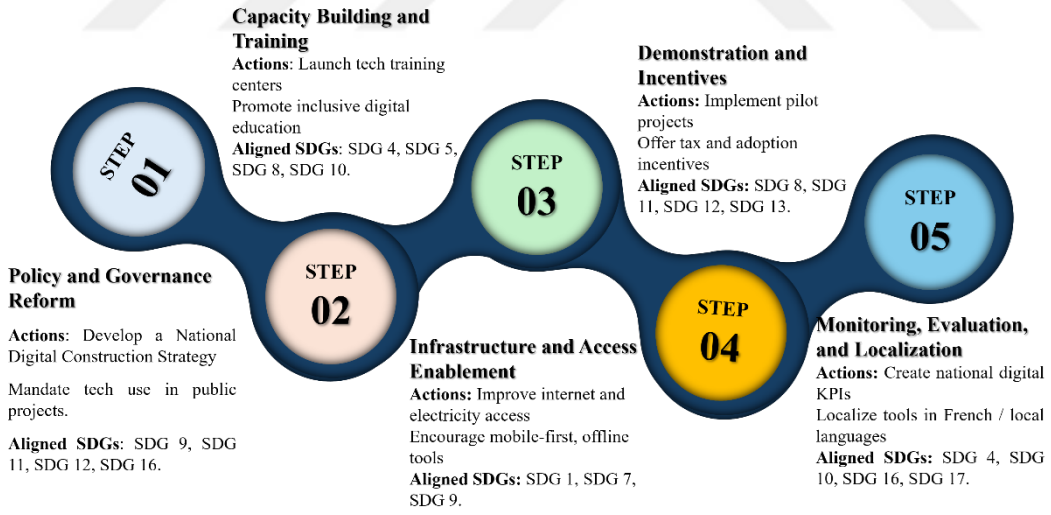


Figure 6.1 Roadmap for Adopting Smart Technologies in Chad

6.7 Conclusion

This chapter has examined the research findings within the context of global trends, existing literature, and the specific realities of Chad's construction sector. The evidence demonstrates that innovative technologies are profoundly reshaping project management worldwide, enhancing efficiency, safety, sustainability, and

collaboration. From BIM to AI and IoT, the global industry is rapidly moving toward integrated, data-driven, and environmentally conscious construction practices.

In Chad, while adoption is still emerging, the survey results indicate growing awareness, willingness, and optimism among construction professionals. The sector is gradually recognizing the value of smart technologies and sustainable practices in improving project outcomes and achieving national development goals. However, realizing this potential will require a coordinated effort to overcome persistent barriers such as inadequate infrastructure, limited training, policy gaps, and financial constraints.

The discussion has shown that Chad has a strategic opportunity to leapfrog traditional development stages by embracing context-specific innovations and learning from global best practices. If supported by strong governance, public-private collaboration, and targeted investment, Chad's construction industry can become a driver of inclusive growth, environmental protection, and long-term sustainability.

The next and final chapter will present recommendations and conclusions, offering a roadmap for transforming research insights into actionable strategies for Chad's construction future.

7
CONCLUSION

7.1 Theoretical Contributions

This thesis offers a significant theoretical contribution to the interdisciplinary fields of construction project management, sustainable development, and innovation adoption in developing countries, particularly within the Sub-Saharan African context. Through the application of Principal Axis Factoring (PAF), the study uncovers deeply interconnected latent constructs representing both technological and sustainability drivers in Chad's construction industry.

At the heart of the contribution is the nine-dimensional key topic framework, including Integration of Innovative Technologies (IIT), Sustainability in Construction (SC), Challenges and Solutions (CS), Correlation with Project Success (CPS), Decision-Making Factors (DMF), Evaluation of Project Management Software (EPMS), Safety and Risk Management Improvement (SRMI), Environmental and Social Impact Assessment (ESIA), and Forecasting Emerging Technologies (FET). These dimensions were statistically validated and grouped based on empirical correlations, with key overlaps revealed in the factor correlation matrices. For example, the strong correlation ($r = 0.745$) between CPS and CS, and between CPS and SC ($r = 0.749$), demonstrates the intertwined nature of problem-solving, sustainability, and success metrics.

The SDG-related constructs further support the multidimensionality of the framework. Factor analysis revealed six core SDG constructs: Infrastructure Development and Innovation (IDI), Sustainable Urbanization and Habitat Development (SUHD), Resource Efficiency and Sustainable Practices (RESP), Environmental Conservation and Climate Action (ECCA), Social Equity and Economic Development (SEED), and Governance and Institutional Support (GIS). These constructs, validated through KMO and Cronbach's Alpha, showed high inter-factor correlations, such as RESP and ECCA ($r = 0.755$), and SUHD and SEED ($r = 0.733$).

By aligning factor-analyzed constructs with specific SDGs, e.g., RESP with SDG 12 (Responsible Consumption), IDI with SDG 9 (Industry, Innovation, Infrastructure), and GIS with SDG 16 (Peace, Justice, and Strong Institutions), the study proposes a replicable empirical framework for SDG localization in construction settings. This represents a novel way of operationalizing sustainability goals in emerging economies.

The study also advances established theoretical models such as the Technology Acceptance Model (TAM) and Innovation Diffusion Theory (IDT). It enriches these by embedding them in institutional and socio-political realities of Chad, where decision-making is shaped not only by perceived usefulness but also by governance constraints, financial access, and social equity. The strong linkage between DMF and ESIA (r = 0.728) and between DMF and FET (r = 0.600) underscores this complexity.

Additionally, the factor structure shows high loadings for cross-cutting items across multiple constructs. For instance, elements from EPMS and IIT are loaded together with SRMI in some matrices, reinforcing the systems-oriented perspective that technology, safety, and performance are inseparable in modern construction management. These findings collectively reinforce the utility of oblique rotation (Promax) in factor analysis for construction management research in developing contexts.

In conclusion, the thesis contributes a context-sensitive, multidimensional, and statistically grounded theoretical model that explains how innovative technologies intersect with sustainability and institutional drivers to shape project outcomes in emerging economies.

7.2 Practical and Managerial Contributions

The research provides actionable insights for construction practitioners, project managers, policymakers, and institutional leaders operating in Chad and similar environments. One of the core managerial implications is the recognition that technology integration must be matched by governance capacity and human capital investment. Tools like BIM or IoT cannot function in isolation; they require trained professionals, digital infrastructure, and institutional mandates.

From a project execution perspective, findings show that cloud-based platforms, mobile inspection apps, and PMS tools offer immediate benefits in terms of collaboration, real-time monitoring, and cost tracking. However, their

use is concentrated in donor-funded projects, underscoring the need for local capacity-building and affordability strategies. Managers are encouraged to adopt lightweight, modular tools that can work in offline or low-bandwidth conditions, a necessity in Chad's infrastructure landscape.

Importantly, the study highlights the correlation between RESP, IDI, and ECCA factors as an indicator that technological adoption directly contributes to improved project performance, sustainability, and environmental compliance. For managers, this means that investing in efficiency tools like digital quantity surveying or BIM is not just a compliance move; it's a productivity enhancer with measurable returns.

Policy actors and public sector managers are urged to prioritize the creation of a national digital construction strategy, anchored in the six-factor SDG framework identified in the study. Institutional support (GIS), shown to be moderately correlated with SUHD and SEED, is a critical enabler of inclusive and sustainable digital transformation. Without supportive policies and enforcement mechanisms, even well-funded projects will struggle to implement technology meaningfully.

Finally, development partners and training institutions can use the thesis findings to guide curriculum development, particularly for vocational and engineering programs. Introducing construction-specific tech training modules (e.g., BIM fundamentals, drone applications for surveying) can close the skill gap and create a pipeline of digitally fluent professionals.

In sum, the study offers a practical roadmap for integrating technology in a way that is affordable, inclusive, and aligned with national development goals. It invites project stakeholders to shift from ad hoc tool use to strategic, outcome-driven innovation management.

7.3 Limitations and Future Research

While this study provides valuable theoretical and practical insights, it is not without limitations, many of which open opportunities for further research.

First, the research scope was limited to Chad, and while its challenges (e.g., low digital penetration, limited infrastructure) are representative of other low-income countries, findings should be contextualized before generalization. Future studies could adopt comparative regional designs, examining how similar technologies are used across different Sub-Saharan African contexts to explore regional patterns of adoption, resistance, and impact.

Second, the study relied primarily on quantitative survey data analyzed using Principal Axis Factoring, which, while statistically rigorous, does not fully capture the nuances of user experience, motivation, or resistance. Qualitative approaches, such as in-depth interviews, ethnographic fieldwork, or case studies of specific tech-led projects, would enrich the findings and expose underlying behavioral and cultural dynamics.

Third, the rapid evolution of smart technologies poses a temporal limitation. The field is advancing faster than institutional and policy frameworks can respond. Technologies like AI-driven project automation, blockchain for smart contracts, and digital twins were mentioned but are still largely aspirational in Chad. Future research should conduct longitudinal studies to examine how perceptions and adoption patterns shift over time, especially as local capacity and infrastructure evolve.

Another limitation lies in the survey instrument itself, which, although validated through pilot testing, may not have captured all variables influencing adoption, especially informal decision-making factors or gendered access to technology issues worth exploring in follow-up studies focused on inclusivity.

Finally, the correlation matrices indicate that some constructs (e.g., RESP and ECCA, or SUHD and SEED) are tightly coupled. While this supports the argument that these dimensions are interdependent, it also suggests potential measurement overlap. Future research could refine and validate the instrument through Confirmatory Factor Analysis (CFA) or Structural Equation Modeling (SEM) to improve construct distinctiveness and model precision.

In conclusion, this thesis sets a foundation for further exploration into how construction innovation and sustainability can be embedded in challenging environments. Researchers are encouraged to build on its framework by testing it across diverse contexts, deepening the qualitative insights, and exploring technological, behavioral, and institutional intersections in greater depth.

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PUBLICATIONS FROM THE THESIS

Papers

1. Dagou, H., GÜRGÜN, A., Koc, K., & Kunkcu, H. (2024). Navigating the Landscape of Innovative Technologies in Construction Project Management: A Comprehensive Review. Proceedings on Engineering Sciences, 6(4).

2. Dagou, H. H., Gurgun, A. P., Koc, K., & Budayan, C. (2025). The Future of Construction: Integrating Innovative Technologies for Smarter Project Management. Sustainability, 17(10), 4537.

Conference Papers

1. Dagou, H. H., & Gurgun, A. P. (2024, July). Blockchain and AI for Sustainable Supply Chain Management in Construction. In International Conference on Intelligent and Fuzzy Systems (pp. 350-359). Cham: Springer Nature Switzerland