

Assessment of the Applications of Digital Tools and Technologies in  
Material Management System: The Case of Mega Building Construction  
Projects in Addis Ababa



Mesfin Girma Ayalew

A Thesis Submitted to The Department of Civil Engineering  
College of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirements of Masters of Science in Civil  
Engineering (Specialization in Construction Engineering and Management)

Office of Graduate Studies  
Adama Science and Technology University

May, 2025

Adama, Ethiopia

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## DECLARATION

This thesis, "Assessment of the Applications of Digital tools and technologies in Material Management system: A case of Mega Building Construction Projects in Addis Ababa" is entirely original with no submissions to other universities for a similar purpose, I, Mesfin Girma, certify. Appropriate citations acknowledge the references used in this thesis.

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## APPROVAL BOARD OF REVIEWERS

We, the undersigned, members of the Board of Examiners of the thesis by Mesfin Girma have read and evaluated his thesis entitled " Assessment of the Applications of Digital tools and technologies in Material Management System: A case of Mega Building Construction Projects in Addis Ababa" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Construction Engineering Management.

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Department Head	Signature	Date
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Mesfin Girma

Adama, Ethiopia. December 2024

## ABSTRACT

*Material management in Addis Ababa's Mega building projects suffers from inefficiencies impacting project outcomes. Despite the potential of digital technologies, adoption is limited. This study investigates the application of digital tools to enhance material management systems in this context. The research aimed to (1) assess current material management practices, (2) identify barriers to digital adoption, (3) prioritize key digital technologies, and (4) develop a strategic implementation framework. A mixed-methods approach used questionnaire surveys (n=42 professionals) and semi-structured interviews (n=8 key informants) alongside document analysis. Data were analyzed using descriptive statistics, Relative Importance Index (RII), and thematic analysis. Current practices show low implementation (RII range: 0.3000-0.5524), with significant weaknesses in technology use (RII=0.3190), inventory tracking (RII=0.3000), and ICT sharing (RII=0.3000). Significant barriers (RII range: 0.6143-0.8762) include BIM ecosystem challenges (lack of capable subcontractors, legal framework ambiguity, risk/cost allocation difficulties; RII=0.8762), lack of standards (RII=0.8619), technology non-availability (RII=0.8762), and deficits in skills/awareness (RIIs  $\leq$  0.8571), correlating with low reported digital familiarity (64.3% unfamiliar). Stakeholders prioritize foundational technologies like Bar-coding (RII=0.8190), Digital PM Systems (RII=0.8095), Excel (RII=0.8000), and BIM (RII=0.7905) over advanced tools like IoT (RII=0.4667). Based on these findings, a six-phase strategic framework was developed, emphasizing assessment, phased planning, pilot testing, capacity building, scaled integration, monitoring, and enabling policy/collaboration. Material management in Addis Ababa's Mega projects relies on inefficient traditional methods, hindered by interconnected barriers related to BIM maturity, standards, skills, cost, and infrastructure. A context-specific, phased strategic approach focusing on foundational technologies and capacity building is essential. The proposed framework offers a roadmap for stakeholders to improve efficiency and project outcomes through guided digital adoption.*

**Keywords:** *Digital technologies; Material management; Mega Construction Projects; Optimized framework; Addis Ababa.*

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## LIST OF ACRONYMS

AI	Artificial Intelligence
ERP	Enterprise Resource Planning
RFID	Radio Frequency Identification
3D	3 Dimension
PDA <sub>s</sub>	Personal Digital Assistants
PDT <sub>s</sub>	Portal Data Terminals
GPS	Global Positioning System
IoT	Internet of Things
BIM	Building Information Modeling
RTLS	Real time location sensing
DT <sub>s</sub>	Digital Twins
AR	Augmented Reality
CE	Circular Economy
OSC	Off-site construction
IS	Information System
IT	Information Technology
ICT	Information Communication Technology
BeCW	Blockchain enhanced Construction Waste
RII	Relative Importance Index
SD	Standard Deviation
PM	Project Management

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background of the Study

Material management constitutes a critical determinant of success in construction endeavors, particularly for Mega-building projects which are inherently defined by their large scale, intricate complexity, and significant resource requirements (Fikre, 2022). The effective orchestration of planning, procurement, storage, transportation, and utilization of materials throughout the project lifecycle is paramount (Bayou, 2020). In Ethiopia, the construction industry serves as a vital engine for socioeconomic development (Belete, 2020; Mulugeta and Kitaw, 2016). However, this sector frequently grapples with persistent challenges, including project overruns, suboptimal productivity, and compromised building quality (Belete, 2020; Birhanu, 2019), many of which are attributable to inefficiencies embedded in traditional material management paradigms (Belete, 2020).

Traditional material management methodologies, which are heavily reliant on manual processes and paper-based documentation, often prove inadequate in addressing the multifaceted demands of large-scale construction undertakings (Ibrahim et al., 2020). These limitations can precipitate a cascade of deleterious consequences, such as delays in material delivery, escalated project costs, diminished quality control, and heightened environmental concerns. Inefficient procurement mechanisms, improper material storage, and excessive material waste can significantly strain project budgets (Belete, 2020; Fikre, 2022; Worku, 2024). Furthermore, the deployment of substandard materials or their improper handling during transit and storage can jeopardize building quality, potentially leading to safety hazards and augmented long-term maintenance costs (Birhanu, 2019; Samuel, 2024). The construction industry, as a notable contributor to environmental impact, stands to benefit considerably from the adoption of sustainable material management practices, encompassing waste minimization and recycling initiatives (Worku, 2024; Berhe, 2021; Jemal et al., 2023).

In response to these enduring challenges, the global construction industry is progressively embracing digital transformation, integrating an array of digital technologies to enhance operational efficiency, productivity, and sustainability (Bui et al., 2016; Ghosh et al., 2021;

Mogalli, 2017). A suite of digital technologies offers diverse solutions for optimizing material management. For instance, Building Information Modeling (BIM) provides a collaborative platform for digital design and construction management, enabling centralized, detailed material estimation, procurement, scheduling, and lifecycle tracking (Turk and Klinc, 2017; Abanda et al., 2018; Belay et al., 2021; Chukwu et al., 2024). Concurrently, technologies such as Radio Frequency Identification (RFID) can streamline material receiving and inventory management with real-time visibility (Ibrahim et al., 2020; Sardroud, 2012), while cloud computing facilitates data accessibility and stakeholder collaboration (Bui et al., 2016; Oke et al., 2023). Mobile applications empower field personnel with crucial project information (Abanda et al., 2018; Oke et al., 2022), and drones equipped with photogrammetry offer advanced capabilities in site surveying and progress monitoring (Duarte-Vidal et al., 2021).

Despite the evident potential of these digital tools, their adoption within the Ethiopian construction industry, particularly in the context of Mega-building projects, remains limited (Bui et al., 2016; Belay et al., 2021). This slow uptake is influenced by several intertwined factors. These include, but are not limited to, constrained IT infrastructure, a deficiency in awareness and specialized training among professionals, substantial initial investment costs, inherent resistance to change from traditional practices, and a lack of comprehensive government support and clear regulatory frameworks (Belay et al., 2021; Bui et al., 2016; Belete, 2020; Tiruneh, 2024).

The adoption of digital technologies in construction is recognized as being highly context-dependent (Belay et al., 2021), shaped by variables such as the prevailing level of technological advancement, prevailing economic conditions, the existing regulatory environment, cultural factors, and the specific needs and challenges of the local industry (Bui et al., 2016; Berhe, 2021; Legesse et al., 2024). Therefore, this study seeks to address the identified gaps by undertaking a comprehensive assessment of the current state of digital technology adoption in material management for Mega-building construction projects within Addis Ababa. The research aims to develop a tailored framework designed to optimize the implementation of these digital solutions. It is anticipated that this study will yield valuable insights for policymakers, construction professionals, and other stakeholders, thereby contributing to the advancement of a more efficient, sustainable, and technologically proficient construction industry in Addis Ababa and, by extension, Ethiopia.

## 1.2 Statement of the Problem

The Ethiopian construction industry, while pivotal to national economic growth and development (Belete, 2020), consistently confronts significant operational impediments. These include recurrent project overruns, diminished productivity levels, and compromised building quality (Bayou, 2020; Birhanu, 2019). Such challenges are frequently traced back to inherent inefficiencies within prevailing material management practices, which consequently exert adverse impacts on project timelines, budgetary adherence, and overall performance metrics (Bayou, 2020; Fikre, 2022). Ideally, the integration of advanced digital technologies would offer robust solutions to mitigate these issues and substantially enhance material management efficiency. However, the adoption of these digital tools within the Ethiopian construction sector, particularly concerning Mega-building construction projects, remains notably limited (Belete, 2020; Bayou, 2020; Belay et al., 2021). This disparity between the potential of digital solutions and their current implementation level constitutes the central problem this research seeks to address.

The existing body of literature reveals several critical research lacunae that perpetuate this problem and hinder the effective digitalization of material management in Addis Ababa's Mega-projects. Firstly, there is a conspicuous dearth of research specifically focused on the digital transformation of material management within the unique context of these large-scale public endeavors. While studies have explored broader BIM adoption in Ethiopia (Bayou, 2020; Belay et al., 2021; Belete, 2020; Desbalo and Bargstadt, 2020), they often lack a granular focus on material management aspects, resulting in an insufficient understanding of the specific challenges and opportunities pertinent to this domain (Desbalo et al., 2024). Secondly, an in-depth comprehension of existing material management workflows, their inherent bottlenecks, and areas amenable to digital intervention is currently inadequate (Belete, 2020; Fikre, 2022). Thirdly, there is limited knowledge regarding the suitability and practical applicability of specific digital technologies when considering local contextual factors such as IT infrastructure, workforce competencies, and the availability of localized software solutions (Abanda et al., 2018; Bui et al., 2016). Furthermore, a systematic comparative analysis and knowledge transfer from successful digital transformation initiatives in other developing nations is largely absent (Bui et al., 2016; Mulugeta and Kitaw, 2016).

Perhaps most critically, this situation is compounded by the absence of a context-specific conceptual framework designed to guide the successful implementation of digital technologies. The development of such a framework, tailored to Addis Ababa's distinct technological maturity, regulatory environment, cultural nuances, and potential risks, is essential for effective and sustainable adoption (Belay et al., 2021; Desbalo et al., 2024). The continued reliance on inefficient, often manual, material management practices in the absence of targeted digital solutions perpetuates project delays, cost escalations, and suboptimal quality, thereby undermining the intended socioeconomic benefits of these significant public investments.

Addressing these identified research gaps presents a significant opportunity to contribute to the body of knowledge and furnish practical, evidence-based solutions. This study, therefore, aims to provide a comprehensive assessment of the current state of digital technology adoption in material management for Addis Ababa's Mega-building projects, identify specific challenges and opportunities, and culminate in the development of a tailored strategic framework to optimize their implementation.

### **1.3 Research Questions**

The following research questions will be answered in the study:

- What are the current practices of material management in Mega building construction projects?
- What are the potential barriers hindering the adopting digital technologies managing building construction materials?
- Which digital technologies can be applied to improve building construction material management efficiency and effectiveness?
- What strategic framework can facilitate the successful adoption of digital technologies in building construction material management?

### **1.4 Objectives of the Study**

The general objective of the study is to investigate the potential applications of digital technologies in material management within Mega building construction projects in Addis Ababa and develop a strategic framework to facilitate its successful implementation.

The specific objectives of the study are stated as follows:

- To assess the current practices of material management in Mega building construction projects.
- To identify and analyze the potential barriers hindering implementation of digital technologies for managing materials.
- To identify and prioritize key digital technologies that can drive digital transformation material management, improving efficiency and effectiveness.
- To develop a strategic framework to guide the successful implementation of digital technologies in material management for Mega building projects in Addis Ababa.

## **1.5 Significance of the Study**

This research holds significant value for both practical application and academic contribution within the field of construction engineering and management, particularly in the context of developing economies like Ethiopia. Practically, the study addresses the pressing challenges of inefficiency, cost overruns, delays, and material waste often associated with traditional material management practices in Ethiopia's vital Mega building construction projects. By assessing the current state, identifying specific barriers, and prioritizing relevant digital technologies, this research provides crucial insights for industry stakeholders – including contractors, government agencies, consultants, and policymakers – operating in Addis Ababa.

The primary practical contribution is the development of a context-specific strategic framework designed to guide the successful adoption and implementation of digital tools for material management. This framework offers actionable recommendations aimed at enhancing operational efficiency, improving project predictability, reducing waste, promoting sustainability, and ultimately contributing to the modernization and improved performance of the Ethiopian construction sector. Academically, this study fills a distinct gap in the literature by providing empirical data and focused analysis on the application of digital technologies specifically for material management within the unique context of Mega projects in Addis Ababa, an area currently under-researched. It contributes to the broader understanding of digital transformation challenges and opportunities in developing countries and offers a methodological approach for investigating similar issues in comparable settings.

## **1.6 Scope of the Study**

The scope of this research is specifically delineated to ensure a focused and in-depth investigation. Thematically, the study concentrates on the application of digital tools and technologies within material management systems in the construction industry. The investigation encompasses the assessment of current material management practices, the identification and analysis of barriers hindering digital technology adoption, the identification and prioritization of potentially beneficial digital tools, and the subsequent development of a strategic framework to facilitate their implementation. The contextual scope is confined to Mega building construction projects located within the geographical boundary of Addis Ababa, Ethiopia. This focus on large-scale public projects is chosen due to their complexity, significant resource demands, and critical role in national development, making them pertinent cases for studying material management challenges and digital solutions.

The study primarily captures the perspectives and experiences of construction professionals (such as Site Engineers, Project Managers, Procurement Officers, Quantity Surveyors, and Consultants) actively involved in these target projects, representing key stakeholder organizations including construction companies, government agencies, and consulting firms. The research does not extend to private sector projects, small-scale constructions, or infrastructure projects other than buildings, nor does it cover aspects of digital transformation beyond the domain of material management. The timeframe is cross-sectional, providing a snapshot of the situation during the data collection period.

## **1.7 Limitations of the Study**

While this study aims for rigor and relevance, certain limitations inherent in its design and execution must be acknowledged. Firstly, the research employed non-probability sampling techniques (purposive and snowball sampling) due to the difficulty in establishing a complete sampling frame for the target population of professionals working on specific mega-projects. Consequently, while the findings provide valuable insights from a diverse and relevant group of participants (n=42 for the survey, n=8 for interviews), statistical generalization of the quantitative results to the entire population of construction professionals in Addis Ababa should be approached with caution. Secondly, the study's geographical scope is limited to Addis Ababa. Although Addis

Ababa serves as a significant hub for construction activity in Ethiopia, the direct transferability of findings to other regions within the country or to different national contexts may be limited without considering local variations in infrastructure, regulations, and market dynamics.

Thirdly, the research relies heavily on self-reported data obtained through questionnaires and interviews. Such data can be susceptible to respondent biases, including social desirability or recall inaccuracies, although triangulation with document analysis was used where possible to mitigate this. Fourthly, the cross-sectional nature of the study provides a snapshot at a specific point in time and does not capture the dynamic evolution of digital technology adoption or its impacts over an extended period. Finally, while the study culminates in a proposed strategic framework grounded in empirical data, this framework itself has not been implemented or tested as part of this research; its practical efficacy requires future validation studies. Despite these limitations, the research provides significant, contextually grounded insights into a critical and understudied area.

## 1.8 Thesis Structure

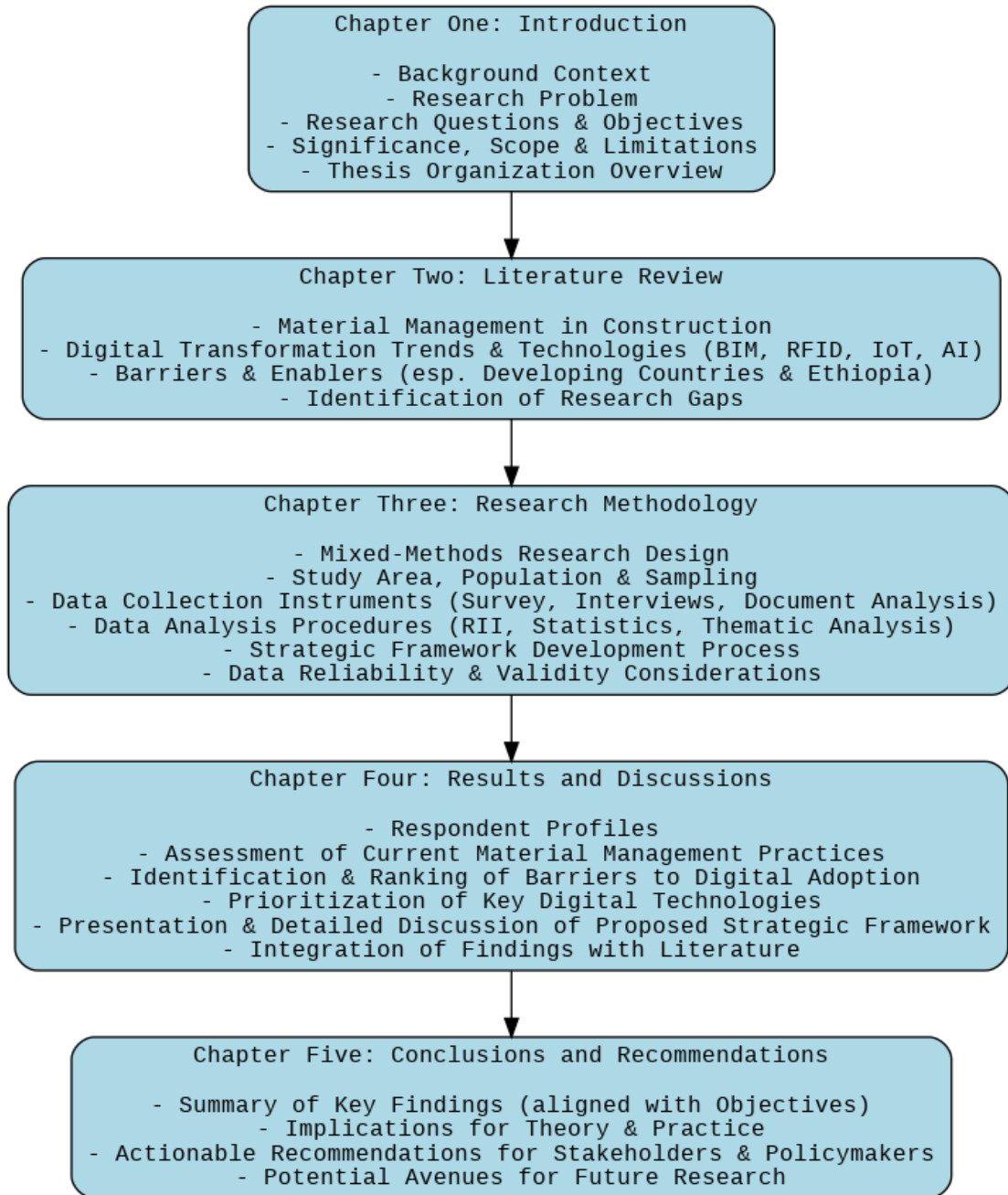


Figure 1.1 Thesis structure

## CHAPTER TWO

### LITERATURE REVIEW

#### **2.1 Introduction**

This chapter comprehensively examines existing research on digital tools and technologies in material management systems for Mega building construction projects in Addis Ababa. Effective material management is crucial for project cost, schedule, and quality, yet traditional methods face challenges, especially in large projects. The global construction industry is embracing digital transformation to improve efficiency and sustainability.

This chapter explores the theory and evidence of digital technology application in optimizing construction material management. Key areas covered include material management practices and their challenges, digital transformation and Industry 4.0 in construction, digital technology adoption in Ethiopian construction (specifically Addis Ababa), the potential of technologies like BIM and RFID for material management efficiency, the benefits and risks of this digital transformation, existing digital material management frameworks, barriers to adoption, and the research gaps this thesis will address. This chapter establishes the context for the study, highlights the need for research on digital material management in Addis Ababa's Mega projects, and provides a basis for the research methodology and a tailored optimization framework by analyzing the current knowledge.

#### **2.2 Material Management Practices in the Building Sector**

Material management is a critical function within the building construction sector, directly impacting project cost, schedule, and quality (Fikre, 2022). It encompasses the processes of planning, procurement, storage, handling, and control of materials from initial acquisition to final incorporation into the project (Fikre, 2022; Mogalli, 2017). Effective material management ensures that the right materials are available at the right time, in the right quantities, and at the right cost, thereby minimizing delays, waste, and cost overruns (Fikre, 2022). Given that material costs can constitute a significant portion of the total project expenditure (Zhiliang et al., 2013), optimizing material management practices is paramount for the successful delivery of building construction projects (Fikre, 2022).

Planning involves determining the required materials, quantities, and timelines based on the project scope and specifications. It includes creating material schedules, forecasting demand, and optimizing material flow to ensure timely delivery and minimize storage costs. (Fikre, 2022). Procurement focuses on acquiring the necessary materials from suppliers at the right time, quality, and price. This process involves selecting vendors, negotiating contracts, and managing purchase orders (Fikre, 2022). Handling encompasses the activities related to receiving, storing, transporting, and distributing materials on the construction site. Efficient handling procedures are essential to prevent damage, minimize waste, and ensure worker safety (Fikre, 2022; Mogalli, 2017).

Stock and waste control involves maintaining optimal inventory levels, tracking material usage, and minimizing waste generation throughout the project. Effective stock control prevents shortages and delays, while waste control reduces environmental impact and saves costs (Fikre, 2022). Logistics refers to the overall coordination and management of the material flow from suppliers to the construction site and, ultimately, to the final installation. It includes transportation planning, route optimization, and ensuring timely delivery of materials to the point of use (Fikre, 2022). Effective material management is crucial for achieving project objectives such as cost control, timely completion, and quality assurance (Fikre, 2022). Construction projects that lack proper material management often face challenges such as cost overruns due to poor planning, delays in procurement, and excessive waste generation; project delays arising from material shortages, late deliveries, and inefficient handling processes; and quality issues resulting from the use of substandard materials or damage during handling and storage.

Traditional material management practices often rely on manual processes, paper-based documentation, and limited communication among project stakeholders (Desbalo et al., 2024). These practices pose significant challenges, particularly for Mega building construction projects in Addis Ababa, which are characterized by their scale, complexity, and the involvement of multiple stakeholders (Fikre, 2022). Specific challenges include inadequate planning and forecasting, Inefficient procurement procedures; poor handling and storage practices, and insufficient waste management strategies.

Inadequate planning and forecasting lead to material shortages, delays, and increased costs. This is exacerbated by unpredictable market conditions and supply chain disruptions, which are

prevalent in developing economies like Ethiopia. Inefficient procurement procedures result in delays, price fluctuations, and difficulty in ensuring material quality. This is often attributed to limited access to reliable suppliers, complex bureaucratic procedures, and a lack of transparency in bidding processes (Fikre, 2022). Poor handling and storage practices cause material damage, waste, and safety hazards. This is compounded by limited site space, inadequate storage facilities, and a lack of skilled labor in material handling. Insufficient waste management strategies lead to environmental pollution and increased disposal costs. This is particularly concerning in urban areas like Addis Ababa, where waste management infrastructure is often strained (Fikre, 2022). These challenges highlight the need for a shift towards more efficient and technologically advanced material management practices in the Ethiopian construction industry.

The significance of effective material management is underscored by its direct impact on project success (Fikre, 2022). Proper management of resources and funds is vital for project practitioners to achieve successful completion of tasks within defined scope, time, and cost. Furthermore, the quality of construction projects heavily depends on the materials used and the efficiency of their management (Fikre, 2022). Recognizing this importance, there is a growing acknowledgment of the need to advance knowledge in digital construction and introduce automation to overcome inefficiencies prevalent in current practices (Belete, 2020).

In light of the complexities and challenges associated with traditional material management practices, particularly in large and complex projects like Mega buildings (Fikre, 2022), there is an increasing interest in exploring the potential of digital technologies to enhance efficiency and effectiveness (Belete, 2020; Bui et al., 2016; Ogundipe et al., 2024). The application of information and communication technology (ICT) solutions, such as Building Information Modelling (BIM) and other digital tools, is being considered to expedite data transfer and facilitate better control over materials on-site (Kasim et al., 2019). These technologies offer the potential to address some of the currently experienced challenges in material management within the construction industry (Bui et al., 2016).

Therefore, understanding the current state of material management practices in Mega building construction projects, such as those in Addis Ababa, is the first critical step in identifying areas where digital technologies can be strategically applied to drive significant improvements in efficiency, reduce waste, and ultimately contribute to enhanced project performance. This

assessment forms the foundation for exploring and developing a strategic framework for the successful implementation of digital technologies in material management for such large-scale public sector projects.

The following Table 2.1 is designed to gather data for the first specific objective of this study, which aims to assess the current practices of material management in Mega building construction projects in Addis Ababa. Understanding the existing methodologies and processes is crucial for identifying areas of improvement and potential for digital technology integration in subsequent phases of the research. The criteria listed under each category of material management practice are formulated based on common themes identified in construction management literature and are intended to provide a structured approach for evaluating current practices through a survey instrument.

Table 2. 1 Assessment criteria for material management practices

Category	Criteria to Assess Current Practices	Source(s)
Planning	A documented material management plan exists for the project	Mogalli, 2017; Fikre, 2022
	Material requirements are planned and integrated with the overall project schedule	Mogalli, 2017; Fikre, 2022; Ibrahim et al., 2020
	Material demand is forecasted based on project progress	Ogundipe et al., 2024
	Budgets are established and monitored specifically for material procurement and usage	Abanda et al., 2018; Fikre, 2022
Procurement	Defined procedures exist for material ordering and purchasing	Mogalli, 2017; Fikre, 2022
	A formal process is in place for selecting and evaluating material suppliers	Ogundipe et al., 2024
	Contracts are used for securing material supply, outlining quality, quantity, and delivery terms	Abanda et al., 2018
	Lead time for material delivery is adequately considered during procurement planning	Mogalli, 2017

	There is a process for ensuring the purchase of products conforms to specified requirements	Beyene, 2024
	There is sufficient availability of a wide range of suppliers	Fikre, 2022
Handling	Established procedures exist for on-site material handling and movement	Mogalli, 2017; Prasad et al., 2015
	Specific types of material handling equipment are used on-site	Prasad et al., 2015
	Safety measures are in place during material handling activities to prevent accidents and damage	Prasad et al., 2015
	The site layout is planned to ensure efficient flow and movement of materials	Mogalli, 2017
Storage	Designated and adequate storage areas exist for different types of construction materials	Fikre, 2022; Zhiliang et al., 2013
	Established stock control and inventory management practices are followed	Mogalli, 2017; Fikre, 2022
	Measures are taken to protect stored materials from damage, deterioration, and loss due to environmental factors or theft	Fikre, 2022; Samuel, 2024
	Storage areas are organized for easy identification and retrieval of materials	Mogalli, 2017
	There are proper ways of storing cement on site	Samuel, 2024
Tracking and Control	Methods are used to track the movement of materials on the construction site	Kasim et al., 2019; Kasim, 2015
	Records are maintained for material receipt, issuance, and current inventory levels	Mogalli, 2017
	Processes are in place for managing and minimizing construction material waste	Fikre, 2022; Samuel, 2024
	The amount of concrete ordered considers actual requirements to minimize wastage	Samuel, 2024

	Mixing quantities of materials are controlled to avoid excessive amounts	Samuel, 2024
	The performance of material management processes is regularly monitored and evaluated	Abanda et al., 2018
	Quality data related to materials is measured on a regular basis	Beyene, 2024
Technology Use	Specific software is used for material management activities (e.g., inventory, procurement)	Mogalli, 2017
	Information and ICT are utilized for sharing material-related data among stakeholders	Kasim et al., 2019
	Digital tools or technologies are currently employed in any aspect of material management	Desbalo & Bargstadt, 2020
Waste Management	There are established procedures for on-site construction waste management	Samuel, 2024
Documentation & Information	Sufficient information is available in the drawings for effective material management	Samuel, 2024
	Contract documents are free from errors that could affect material management	Samuel, 2024
Coordination	Material management practices are well-coordinated among different project stakeholders	Berhe, 2021

## 2.3 Digital Transformation in the Construction Industry

Digital transformation, the integration of digital technologies into all aspects of an organization (Hussein, 2019), is revolutionizing the construction industry. By adopting technologies like Building Information Modeling (BIM), the Internet of Things (IoT), cloud computing, and artificial intelligence (AI), construction firms can optimize processes, enhance collaboration, and improve decision-making throughout the project lifecycle (Oke et al., 2022).

Digital transformation leads to increased productivity and efficiency through task automation, streamlined workflows, and improved communication (Hussein, 2019). Additionally, it enhances safety and quality by enabling real-time monitoring, data analysis, and digital simulations to identify and mitigate hazards and ensure quality compliance (Oke et al., 2022). Digital platforms facilitate seamless communication and information sharing among project stakeholders, leading to better coordination and reduced conflicts (Ghosh et al., 2021). Moreover, access to real-time data and analytics empowers project managers to make informed decisions, optimize resource allocation, and proactively address potential issues (Duarte-Vidal et al., 2021; Oke et al., 2022).

Industry 4.0 concepts and technologies play a crucial role in driving digital transformation within construction (Ghosh et al., 2021; Wang et al., 2020). Industry 4.0, often referred to as the fourth industrial revolution, is characterized by the integration of physical and digital systems, enabled by technologies such as IoT, AI, Big Data, and cloud computing (Ghosh et al., 2021; Pan and Zhang, 2021). These technologies, when applied to the construction sector, create a connected and intelligent ecosystem that facilitates real-time data collection, analysis, and decision-making (Pan and Zhang, 2021; Wang et al., 2020).

Industry 4.0 technologies are significantly impacting the construction industry. Building Information Modeling (BIM) enables the creation of digital building representations, facilitating collaboration, clash detection, and data-driven decision-making throughout the project lifecycle (Jemal et al., 2023; Wang et al., 2020). The Internet of Things (IoT) connects devices and sensors on construction sites, enabling real-time data collection on material location, environmental conditions, and worker safety, leading to improved monitoring and control (Ghosh et al., 2021; Rane et al., 2023; Wang et al., 2020). Big data analytics facilitates the analysis of vast amounts of project data to identify trends, patterns, and insights, optimizing decision-making, improving risk management, and enhancing project performance (Pan and Zhang, 2021; Wang et al., 2020). Cloud

computing provides a centralized platform for data storage, access, and collaboration, enabling real-time information sharing and facilitating remote working (Li et al., 2024; Mallawaarachchi and Jayakodi, 2023; Wang et al., 2020).

The adoption of Industry 4.0 technologies is transforming the construction industry by automating processes, improving safety, and enhancing sustainability. Robots and automated systems are being used for tasks like bricklaying, concrete pouring, and material handling, increasing efficiency and reducing labor costs (Jemal et al., 2023; Oke et al., 2023; Pan and Zhang, 2021). Sensors and AI-powered systems monitor worker behavior, detect potential hazards, and trigger alerts, creating safer working environments (Ghosh et al., 2021; Pan and Zhang, 2021). Digital technologies optimize material usage, reduce waste generation, and improve energy efficiency, contributing to a more sustainable construction industry (Jemal et al., 2023; Wu et al., 2022).

However, the construction industry, particularly in developing countries like Ethiopia, faces challenges in fully embracing digital transformation (Jemal et al., 2023; Oke et al., 2023). These challenges include a lack of awareness and skills among construction professionals to effectively utilize digital technologies (Ghosh et al., 2021; Belay et al., 2021), high initial investment costs for implementing digital technologies, which can be a barrier for smaller companies (Wang et al., 2020), and resistance to change due to traditional practices and mindsets (Wang et al., 2020). Addressing these challenges is crucial to unlock the full potential of digital transformation in the construction industry, particularly in the context of Mega building construction projects in Addis Ababa.

It is worth noting that the successful implementation of these technologies requires careful planning, integration with existing systems, and training for construction professionals. Additionally, industry standards and regulations need to evolve to accommodate the use of these emerging technologies.

## **2.4 Adoption of Digital Technologies in the Ethiopian Construction Industry**

Empirical studies on the adoption of digital technologies in the Ethiopian construction sector, particularly in Addis Ababa, reveal a nascent stage of adoption with a predominant focus on Building Information Modeling (BIM). While the potential benefits of BIM are widely recognized,

several barriers hinder its widespread implementation (Belay et al., 2021; Belete, 2020; Desbalo and Bargstadt, 2020).

The adoption of digital technologies in the Ethiopian construction industry, especially in Addis Ababa, is in its early stages. Research suggests a primary concentration on BIM ((Belay et al., 2021; Belete, 2020; Desbalo and Bargstadt, 2020). Although BIM is acknowledged for its potential advantages, there are obstacles impeding its extensive adoption. A study by Belay et al. (2021) identifies insufficient IT infrastructure, limited government support, and a scarcity of BIM-related research and training programs as major impediments. Belete (2020), through a phenomenological study, reinforces these findings, highlighting the limited awareness and understanding of BIM among construction professionals in Addis Ababa. Despite the Ethiopian government's efforts to promote BIM adoption through initiatives like the 5-year roadmap published by the Ethiopian Project Management Institute (ECPMI) in 2018, practical implementation remains limited.

The types of digital technologies being implemented beyond BIM are sparsely documented in the available sources. Birhanu (2019) explores technology use among grade one building contractors in Addis Ababa but doesn't provide detailed insights into specific digital technologies or their impact on material management. This lack of empirical evidence regarding the adoption of digital technologies beyond BIM in Addis Ababa suggests an area requiring further investigation.

While the impact of digital technologies on material management in Addis Ababa lacks comprehensive empirical documentation, studies from other developing countries provide insights into potential benefits and challenges. Wang et al. (2020) examine the application of digital technologies in off-site construction (OSC), highlighting the potential for improved accuracy, efficiency, and resource optimization. They emphasize that the adoption of technologies like BIM, RFID, and IoT can significantly enhance material management processes within OSC. Transferring these insights to the context of Addis Ababa suggests that similar benefits could be realized through the strategic implementation of these technologies. However, it is crucial to consider the contextual factors identified by Belay et al. (2021) and Belete (2020) to ensure successful adoption.

Success factors for digital technology adoption in the Ethiopian construction industry, as highlighted by Desbalo and Bargstadt (2020), include the need for collaborative initiatives within the industry, comprehensive framework and implementation plans, and strong support from senior

management. These findings underscore the importance of a coordinated and strategic approach to technology adoption, involving all stakeholders and addressing potential barriers proactively. The authors also emphasize the need for adequate training and education to equip construction professionals with the necessary skills to utilize digital tools effectively. (Desbalo and Bargstadt, 2020).

Lessons learned from BIM adoption initiatives in developing countries, as synthesized by Belay et al. (2021), emphasize the importance of context-specific approaches that consider local challenges and opportunities. This involves adapting international best practices to suit local conditions, promoting local content development, and fostering collaboration between industry and academia to bridge knowledge gaps. The findings of this study are important in highlighting the need for a tailored approach to digital technology adoption in Addis Ababa, considering its unique characteristics and challenges.

## **2.5 Digital Technologies for Improved Construction Material Management Efficiency**

The empirical literature extensively discusses a range of digital technologies with the potential to significantly improve the efficiency and effectiveness of construction material management. A prominent technology in this domain is Building Information Modelling (BIM), which serves as a central digital repository for project information, including material specifications, quantities, and schedules (Wang et al., 2020; Jemal et al., 2023). BIM facilitates improved visualization and data sharing among project stakeholders, enabling better coordination of material procurement and delivery (Jemal et al., 2023; Bui et al., 2016). Furthermore, BIM can be integrated with other digital tools to enhance material management processes, such as generating accurate quantity take-offs and linking material information to the project schedule for optimized logistics (Oke et al., 2023; Wang et al., 2020). Studies suggest that BIM adoption can lead to benefits like easier quantity and cost estimates, timely data sharing, and improved project documentation, all of which contribute to more efficient material management practices (Desbalo and Bargstadt, 2020).

Mobile and cloud-based BIM technologies represent another significant advancement, offering the capability to access and exchange project information, including material data, remotely using mobile devices on construction sites (Abanda et al., 2018). This real-time access to information

can improve communication and collaboration among site personnel, enabling quicker decision-making related to material handling, storage, and application (Abanda et al., 2018). The use of mobile devices for tasks such as viewing material specifications, tracking deliveries, and updating inventory records can reduce reliance on paper-based processes and enhance the accuracy of on-site material management (Abanda et al., 2018). Research indicates that mobile/cloud BIM is used for collaborative purposes, which is crucial for effective communication and material coordination on construction projects (Abanda et al., 2018).

Radio Frequency Identification (RFID) technology is frequently cited for its potential to automate the tracking of construction materials on-site (Wang et al., 2020; Kasim et al., 2019; Sardroud, 2012). RFID tags attached to materials can be scanned using handheld or fixed readers, providing real-time information on the location and status of materials throughout the supply chain and on the construction site (Kasim et al., 2019; Ibrahim et al., 2020). This automated tracking can significantly improve inventory management, reduce material losses, and enhance the efficiency of material flow, addressing issues related to the lack of smart systems for controlling and tracking materials (Sardroud, 2012; Ibrahim et al., 2020). Empirical studies suggest that the application of RFID systems can simplify efficient material control, reduce overall costs, and minimize project delays associated with material mismanagement (Ibrahim et al., 2020; Kasim et al., 2019).

Beyond BIM and RFID, other digital technologies are also gaining prominence in improving material management. The Internet of Things (IoT), with its network of interconnected devices and sensors, enables the real-time collection and exchange of data related to material conditions, usage, and location (Wang et al., 2020; Jemal et al., 2023; Oke et al., 2022). This data can be used for predictive maintenance of material storage facilities, monitoring environmental conditions that might affect material quality, and optimizing material logistics (Jemal et al., 2023; Oke et al., 2023). Artificial Intelligence (AI) and machine learning algorithms can analyze large datasets related to material procurement, delivery, and usage to forecast demand, optimize inventory levels, and predict potential supply chain disruptions, leading to more efficient material procurement and logistics (Wang et al., 2020; Ogundipe et al., 2024; Oke et al., 2023). Furthermore, blockchain technology is being explored for its potential to enhance transparency and traceability in the construction material supply chain, providing a secure and auditable record of material origins, transactions, and transfers, which can help in combating issues like counterfeit materials and improving accountability (Wang et al., 2020; Wu et al., 2022).

In conclusion, the empirical literature provides substantial evidence for the potential of various digital technologies, including BIM, mobile/cloud BIM, RFID, IoT, AI, and blockchain, to significantly enhance the efficiency and effectiveness of construction material management. These technologies offer capabilities for improved information management, automated tracking, real-time monitoring, data-driven decision-making, and enhanced supply chain transparency. The adoption of these digital solutions can address many of the challenges associated with traditional material management practices, ultimately contributing to more successful and efficient Mega building construction projects (Bui et al., 2016; Tiruneh, 2024).

The potential benefits of these digital technologies for material management are significant, and their adoption is likely to play a crucial role in transforming the construction industry. Table 2.1 depicts the specific digital technologies that are relevant to construction material management.

Table 2. 2 Digital tools and technologies for construction material management

Digital Technologies	Description	Key Benefit for materials management	Source(s)
Artificial Intelligence (AI)	Analyzes large datasets to identify patterns, forecast demand, and optimize processes.	Predictive analysis for optimized material procurement, inventory management, and waste reduction.	Ogundipe et al., 2024
Enterprise Resource Planning (ERP) software	Integrated software that manages a company's core business operations.	Streamlines business processes, improves data visibility, and enhances resource allocation for efficient material management.	Hilina, 2017
Drones	Unmanned aerial vehicles that capture aerial images and data of construction sites.	Enhanced site monitoring and data collection for improved material quantity surveying, progress monitoring, and site inspection.	Takva et al., 2023; Duarte-Vidal et al., 2021; Obiuto et al., 2024
Photogrammetry	Technique using photographs to create 3D models and measurements of construction sites.	Aids in material quantity surveying, progress monitoring, and site inspection for better material management.	Duarte-Vidal et al., 2021; Takva et al., 2023
RFID (Radio Frequency Identification)	Technology that uses electromagnetic fields to automatically identify and track materials.	Automated tracking to significantly improve inventory management and reduce material losses.	Takva et al., 2023; Duarte-Vidal et al., 2021; Kasim, 2015; Ibrahim et al., 2020
3D Printing	Additive manufacturing process that builds three-dimensional objects from a digital file.	Enables on-demand production of customized building components, reducing waste and optimizing material use.	Anmar et al., 2021; Jemal et al., 2023; Oke et al., 2023; Takva et al., 2023

Bar-coding	Optical scanning technology for identifying and tracking materials using barcodes.	Improves accuracy and efficiency in material tracking and inventory management.	Kasim et al., 2013; Lee et al., 2013
Mobile devices (PDAs, PDTs, tablets, smartphones)	Portable electronic devices that provide real-time access to project information and material data.	Improved communication and collaboration among site personnel, enabling quicker decision-making related to material handling, storage, and application.	Kasim and Ern, 2011; Kineber et al., 2023
GPS (Global Positioning System)	Satellite-based navigation system that provides location and time information.	Enables accurate tracking of material deliveries and on-site material location.	Sardroud, 2012; Takva et al., 2023; Wang et al., 2020
Sensors	Devices that detect and measure physical quantities and convert them into signals.	Real-time data collection on material conditions, usage, and environmental factors for improved monitoring and control.	Kineber et al., 2023; Khan et al., 2024
IoT (Internet of Things)	Network of interconnected devices and sensors that enable data collection and exchange.	Real-time collection and exchange of data for optimized material logistics and monitoring of material quality.	Duarte-Vidal et al., 2021; Jemal et al., 2023; Wang et al., 2020
BIM (Building Information Modeling)	Digital representation of a building that includes information about materials, quantities, and specifications.	Improved visualization and data sharing to enable better coordination of material procurement and delivery.	Khan et al., 2024; Kineber et al., 2023; Maqbool et al., 2023
Automated tracking systems	Systems that automatically monitor and record the movement of materials.	Enhances efficiency and accuracy in material tracking and inventory control.	Dave et al., 2015; Hultgren and Pajala, 2018

Web portals	Online platforms that provide access to project information and facilitate communication among stakeholders.	Centralized access to information and improved communication for better material coordination.	Kasim and Ern, 2011
Wireless systems	Technologies that enable communication and data transfer without physical cables.	Facilitates real-time data sharing and communication on construction sites for efficient material management.	Kasim et al., 2013
Digital project management systems	Software applications that aid in planning, organizing, and managing construction projects.	Streamlines project workflows, improves task management, and enhances collaboration for effective material management.	Ni et al., 2021
Real-time location sensing (RTLS)	Technology that provides real-time tracking of the location of objects or people.	Enables precise tracking of materials on construction sites, reducing losses and improving logistics.	Kineber et al., 2023
Cloud computing	Technology that enables the storage and access of data and applications over the internet.	Enhanced collaboration and real-time information sharing among project stakeholders for efficient material management.	Bui et al., 2016; Maqbool et al., 2023; Kineber et al., 2023
Blockchain technology	Decentralized digital ledger that records transactions securely and transparently.	Enhances transparency and traceability in the material supply chain, reducing fraud and improving accountability.	Legesse et al., 2024; Li et al., 2024; Qian and Papadonikolaki, 2021
Supply chain management software	Applications that optimize the flow of goods and services from suppliers to customers.	Improves efficiency in material procurement, logistics, and supplier collaboration.	San et al., 2019

Digital Twins (DTs)	Virtual replicas of physical assets, processes, or systems.	Enables real-time monitoring, simulation, and optimization of material-related processes.	Maqbool et al., 2023
Handheld devices	Portable electronic devices used for data capture and information access on-site.	Facilitates efficient material tracking, inspection, and data recording.	Khan et al., 2024
AR (Augmented Reality) headsets	Wearable devices that overlay digital information onto the real-world view.	Enhances visualization and information access for material handling, installation, and inspection.	Khan et al., 2024; Kim et al., 2020
Digital documentation	Electronic management of project documents, including material specifications, and records.	Improves accuracy, accessibility, and organization of material-related information.	Kolawole, 2023; Hultgren and Pajala, 2018
Smart contracts	Self-executing contracts with the terms directly written into code.	Automates and secures material transactions, improving efficiency and reducing disputes.	Kim et al., 2020; Ni et al., 2021; Shojaei et al., 2021
Asset tagging solutions	Technologies used to identify and track assets, including materials.	Enhances asset visibility, reduces losses, and improves inventory management.	Lee et al., 2013
Microsoft Excel Spreadsheet	A software program used for organizing, analyzing, and storing data in tabular form.	It helps in storing and analyzing material related data.	Kasim et al., 2012; Kasim and Ern, 2011

The adoption of digital technology in construction material management yields a multitude of direct and significant benefits. Primarily, it enhances operational efficiency through expedited data transfer and effective on-site material control, consequently boosting productivity across the entire construction supply chain (Kasim et al., 2019; Hussein, 2019). Furthermore, digital tools, such as Building Information Modeling (BIM), Artificial Intelligence (AI), and Radio-Frequency Identification (RFID) systems, contribute to substantial cost reductions by optimizing procurement workflows, predicting material demands, and improving material planning, scheduling, and tracking (Jemal et al., 2023; Oke et al., 2023; Ibrahim et al., 2020). These technologies also facilitate significant time savings in material-related processes, streamlining workflows and minimizing delays through real-time tracking and efficient data management (Ibrahim et al., 2020). Moreover, digitalization fosters improved communication and collaboration among project stakeholders. BIM and mobile/cloud platforms enable real-time data sharing and enhance teamwork, regardless of geographical constraints (Oke et al., 2023; Abanda et al., 2018). Digital technologies ensure greater data accuracy for material quantities, specifications, and locations, which is critical for effective management. Integrating laser distance meters with mobile apps and employing RFID systems significantly enhances data collection and tracking precision (Hussein, 2019; Ibrahim et al., 2020). Modern systems also facilitate improved inventory management, allowing for better monitoring of material input and output, and enabling the identification of surpluses and shortages (Ibrahim et al., 2020; Kumar and Shoghli, 2018). The application of BIM contributes to a reduction in material waste through accurate quantity checks and the support of design for longevity and reuse (Nadeem et al., 2018).

Additionally, digital tools enhance cost estimation and control through auto-quantification and precise tracking of material usage (Desbalo and Bargstadt, 2020; Jemal et al., 2023). Comprehensive digital documentation, real-time monitoring of material status and progress, and improved decision-making related to procurement and use are further benefits of digitalization (Desbalo and Bargstadt, 2020; Abanda et al., 2018; Hussein, 2019). Automation of material-related tasks, such as data collection and analysis, reduces manual effort and minimizes errors (Ibrahim et al., 2020; Sardroud, 2012; Pan and Zhang, 2021). Finally, digitalization significantly improves supply chain management, enhancing efficiency and transparency through technologies like blockchain and the Internet of Things (IoT) (Chukwu et al., 2024; Takva et al., 2023; Lanko et al., 2018). Enhanced traceability of materials, particularly through RFID and blockchain, and the

reduction of delays and conflicts related to material availability are also notable outcomes of adopting digital technologies in construction material management (Ibrahim et al., 2020; Shojaei et al., 2021; Abanda et al., 2018; Hussein, 2019).

### **2.5.1 Case Studies of Successful Digital Material Management**

Though there is lack of studies that offer specific case studies of successful digital transformation initiatives in material management within developing contexts, they provide insights into successful implementations of digital tools in construction and emphasize the potential of these technologies to improve material management processes (Jemal et al., 2023; Wang et al., 2020). Analyzing these insights and drawing upon the broader discussion of digital transformation in the construction industry can offer valuable lessons for Ethiopia (Addis Ababa).

Jemal et al. (2023) explored the impact of digital tools on circular economy (CE) implementation in the construction sector, highlighting successful instances of digital technology integration in countries like Denmark. While the study focuses on CE rather than material management specifically, the underlying principles of resource optimization and waste reduction are directly relevant to material management practices. The success of Denmark in implementing CE principles, facilitated by digital tools, underscores the potential of these technologies to transform material management practices. The authors emphasize the need for a supportive policy environment, stakeholder collaboration, and access to digital infrastructure to enable successful implementation. These insights can be transferred to the context of Addis Ababa, suggesting that promoting similar enabling factors could facilitate the adoption of digital technologies for enhanced material management in the city.

Similarly, Wang et al. (2020) evaluate the application of digital technologies in off-site construction (OSC), providing insights into how these technologies can optimize material management processes.<sup>2</sup> While the study does not present specific case studies, it offers a comprehensive overview of digital technology applications in OSC, highlighting their potential to improve accuracy, efficiency, and resource utilization. The authors emphasize that technologies like BIM, RFID, and IoT can significantly enhance material management processes within OSC. They further suggest that these technologies can facilitate real-time tracking of materials, accurate forecasting of demand, and improved coordination of deliveries, leading to reduced material waste, optimized inventory management, and improved efficiency in construction operations. This

analysis, though not specific to developing contexts, provides valuable insights into the potential benefits of digital transformation in material management, offering transferable lessons for Addis Ababa.

Further insights into successful digital tool implementation can be gleaned from Abanda et al. (2018), who explore the potential of cloud/mobile BIM for managing construction projects.<sup>3</sup> While the study focuses on the broader management benefits of BIM, it highlights the importance of accessibility, collaboration, and real-time information sharing facilitated by cloud/mobile platforms. These features can directly enhance material management processes by enabling stakeholders to access and update material information in real-time, improving communication and coordination, and ultimately leading to more efficient material utilization.

Synthesizing these insights suggests that successful digital transformation initiatives in material management share common key elements:

- ~ A supportive policy environment that encourages the adoption of these technologies.
- ~ A collaborative approach that involves all stakeholders in the construction process.
- ~ Access to reliable digital infrastructure that supports the implementation of these technologies.
- ~ Adequate training and education to equip construction professionals with the necessary skills to utilize digital tools effectively.

Transferring these lessons to the context of Addis Ababa requires a tailored approach that considers the city's unique characteristics and challenges. As highlighted in our previous conversation, insufficient IT infrastructure, limited government support, and a lack of awareness and understanding of digital technologies among construction professionals are key barriers to adoption in Addis Ababa (Belay et al., 2021; Belete, 2020). Addressing these barriers through targeted investments, capacity building initiatives, and policy interventions is crucial to facilitating successful digital transformation in Ethiopia construction industry at large and the city's construction sector in particular.

## **2.5.2 Frameworks and Models for Digital Material Management**

The integration of digital technologies is revolutionizing material management processes in the construction industry, offering opportunities for enhanced efficiency, transparency, and

sustainability. Several frameworks and models aim to guide this integration, notably the IoT-enabled Information System (IS) model for construction material sharing conceptualized by Mallawaarachchi and Jayakodi (2023) and the blockchain-enhanced construction waste information management conceptual framework (BeCW) proposed by Wu et al. (2022). The IoT-enabled IS model focuses on fostering a circular economy within the construction industry by facilitating material sharing among geographically proximate projects. This model leverages the power of the Internet of Things (IoT) to create a smart platform that connects projects and enables the timely exchange of materials, reducing waste and promoting resource efficiency (Mallawaarachchi and Jayakodi, 2023). On the other hand, the BeCW framework aims to address the lack of accurate data and information reporting related to secondary materials in construction waste management. This framework utilizes blockchain technology to create a transparent and tamper-proof record of waste management processes, enabling better tracking, classification, and recycling of construction waste (Wu et al., 2022).

While both frameworks offer promising approaches to enhance different aspects of material management, their applicability to Mega building construction projects requires careful consideration. The IoT-enabled IS model's strength lies in its potential to optimize material usage and reduce waste by facilitating material sharing. However, its limitations include the need for robust IT infrastructure and the potential challenges in coordinating material exchanges among multiple stakeholders in large-scale projects. The BeCW framework's strength lies in its ability to enhance transparency and accountability in waste management, a crucial aspect for public projects. However, its limitations include the need for widespread blockchain adoption and the potential complexity in integrating blockchain technology with existing waste management practices (Mallawaarachchi and Jayakodi, 2023; Wu et al., 2022).

Adapting these frameworks to the specific context of Addis Ababa, Ethiopia, requires addressing several challenges and opportunities unique to the region. Studies on BIM adoption in developing countries, like those by Belay et al. (2021) and Belete (2020), highlight the importance of considering local factors such as IT infrastructure limitations, lack of government support, and the need for capacity building. These insights offer transferable lessons for adapting digital material management frameworks. For instance, addressing IT infrastructure limitations may require exploring alternative technologies or phased implementation approaches. The absence of government support can be mitigated by promoting industry collaboration and developing

incentives for digital technology adoption. Lastly, capacity building through training programs and knowledge sharing initiatives is essential to equip construction professionals with the necessary skills to effectively utilize digital tools. By carefully considering these factors, the proposed frameworks can be adapted and implemented effectively to enhance material management practices in Mega building construction projects in Addis Ababa.

## **2.6 Barriers Hindering the Digital Technology Adoption in Construction Material Management**

The integration of digital technologies within the construction industry to enhance material management practices faces a multitude of challenges, as evidenced by existing literature (Afatsawu, 2020; Bui et al., 2016; Omari et al., 2023). These impediments can be broadly categorized into technological and non-technological domains, both of which significantly influence the rate and extent of digital adoption (Afatsawu, 2020; Thirumal et al., 2024). Understanding these barriers is crucial for developing effective strategies to foster the digital transformation of the construction sector, particularly in the realm of materials management (Omari et al., 2023; Thirumal et al., 2024).

### **2.6.1 Technological Barriers**

Among the technological barriers, the inherent complexity of many digital tools and the difficulties associated with their seamless integration into existing organizational infrastructure stand out (Afatsawu, 2020; Oke et al., 2022). The construction industry often grapples with legacy systems, and the transition to newer technologies, such as Building Information Modeling (BIM) evolving towards Digital Twins, presents significant interoperability challenges (Oke et al., 2022). The lack of compatibility between novel software solutions and established tools can create operational bottlenecks and necessitate substantial investment in system overhauls. Furthermore, the diverse range of source systems utilized within the industry exacerbates these integration issues, hindering the effective flow of information across different project phases and stakeholders (Afatsawu, 2020).

Another critical technological concern revolves around data security and privacy (Abhimien et al., 2022; Oke et al., 2022). The utilization of digital platforms for value management and materials management necessitates the sharing and storage of sensitive project data, making robust security

measures paramount (Abhimien et al., 2022). Apprehensions regarding data breaches, unauthorized access, and a general lack of trust in the security protocols of digital technologies have proven to be significant deterrents to their widespread adoption (Afatsawu, 2020). These ethical and privacy considerations related to data collection and management processes require careful attention to build confidence and encourage the embrace of digital solutions (Abhimien et al., 2022).

The issue of interoperability extends beyond system integration to encompass the seamless exchange of data across various digital technologies employed in construction, including BIM, robotics, smart sensors, and web-based platforms (Duarte-Vidal et al., 2021; Ghosh et al., 2021). The inability of these disparate technologies to communicate and share information effectively represents a major obstacle to realizing the full potential of a digitally integrated construction ecosystem (Duarte-Vidal et al., 2021). This lack of interoperability hinders advancements in areas such as automated progress monitoring and real-time material tracking (Oke et al., 2022; Duarte-Vidal et al., 2021).

Furthermore, the rapid evolution of Information and Communication Technologies (ICT) and the consequent risk of obsolescence present a unique set of challenges (Afatsawu, 2020). The swift pace of technological advancements and the continuous cycle of software updates can lead to a situation where newly acquired digital tools become outdated relatively quickly, potentially diminishing the return on investment and discouraging further adoption (Afatsawu, 2020). Concerns about software reliability and the potential for system instability and sudden failures also contribute to hesitations in embracing cutting-edge digital solutions (Abhimien et al., 2022).

Beyond these integration and longevity concerns, the adequacy of the underlying ICT infrastructure within construction organizations plays a pivotal role (Afatsawu, 2020). A lack of sufficient infrastructure, including reliable internet connectivity, can directly impede the deployment and effective utilization of digital technologies like BIM and Digital Twins, particularly on remote construction sites (Afatsawu, 2020; Oke et al., 2022). Moreover, the significant volumes of data generated by digital tools necessitate robust capabilities for data storage, processing, and advanced analytics, which may not be readily available within many construction firms (Oke et al., 2022).

## 2.6.2 Non-technological Barriers

In parallel to these technological hurdles, a range of non-technological barriers significantly impede the adoption of digital material management practices (Omari et al., 2023; Thirumal et al., 2024). Foremost among these are financial constraints, including the substantial upfront costs associated with acquiring and implementing digital technologies (Thirumal et al., 2024). These costs encompass not only the purchase of software and hardware but also investments in staff training and ongoing maintenance (Omari et al., 2023). The perceived uncertainty surrounding the return on investment in digital technologies further exacerbates these financial anxieties, making companies hesitant to commit significant capital (Afatsawu, 2020). The absence of robust financial incentives from governmental or industry bodies can also slow down the adoption process, particularly for sustainable practices like material reuse facilitated by digital tools (Afatsawu, 2020).

Human factors and organizational issues constitute another significant category of non-technological barriers (Thirumal et al., 2024). A lack of awareness and comprehensive understanding of the benefits and applications of digital technologies in material management among industry stakeholders remains a key challenge (Omari et al., 2023). This is often compounded by a shortage of adequately trained personnel possessing the necessary technical expertise to effectively operate and manage these digital tools (Afatsawu, 2020). The inherent resistance to change within an industry traditionally reliant on established practices also contributes to the slow uptake of digital innovations (Omari et al., 2023). Furthermore, the lack of strong commitment and proactive support from top management is a critical impediment to fostering a digital culture and driving the adoption of new technologies across the organization (Afatsawu, 2020). The often-fragmented nature of the construction industry and instances of professional disconnection can further hinder collaborative digital initiatives (Abhimien et al., 2022).

Finally, legal and regulatory ambiguities, coupled with a lack of standardization, pose considerable non-technological barriers (Afatsawu, 2020; Omari et al., 2023). The absence of clear legal frameworks and evolving issues related to the use of digital technologies, especially in areas like data sharing and intellectual property within collaborative platforms, create uncertainty and discourage adoption (Abhimien et al., 2022; Belete, 2020). Similarly, the lack of standardized

tools, methodologies, specifications, and clear guidelines for implementing digital technologies like BIM and Digital Twins hinders their widespread and consistent application across the industry (Omari et al., 2023). The absence of data standardization further complicates the effective utilization of digital tools for advanced material management and circular economy initiatives (Abhimien et al., 2022). A lack of harmonized protocols and processes for data management within construction organizations also impedes the adoption of digital technologies for a circular economy (Thirumal et al., 2024). Moreover, a lack of client interest in digitally enabled construction firms can make companies hesitant to invest in these technologies (Chen et al., 2024; Fasasi et al., 2024). The persistence of status quo industry standards can also slow down the adoption of new digital technologies (Chen et al., 2024). Low market diffusion of certain technologies can limit their availability and increase costs (Tiruneh, 2024).

Addressing these multifaceted technological and non-technological barriers through collaborative efforts involving technological advancements, financial support mechanisms, comprehensive training programs, the establishment of clear regulations and standards, and a fundamental shift in organizational culture and stakeholder mindsets is essential to unlock the transformative potential of digital technologies in construction material management (Afatsawu, 2020; Thirumal et al., 2024). Table 2.3 details the broad categories of technological and non-technological barriers hindering the adoption of digital technologies for managing construction materials in the building sector.

Table 2. 3 Barriers hindering the adoption of digital technologies managing materials

Category	Specific Barrier	Source (s)
Technological barriers	High cost of acquiring needed digital technologies	Abhimien et al., 2022; Schnell et al., 2022
	High cost of maintaining digital technologies needed	Abhimien et al., 2022; Arabshahi et al., 2021
	Incompatibility and interoperability problems	Afatsawu, 2020; Chen et al., 2024; Desbalo and Bargstadt, 2020; Opoku et al., 2023; Thirumal et al., 2024
	Lack of data interoperability	Chen et al., 2024; Thirumal et al., 2024; Opoku et al., 2023
	Data security barriers/concerns/Lack of trust in data security and privacy	Abanda et al., 2018; Abhimien et al., 2022; Chen et al., 2024; Desbalo and Bargstadt, 2020; Opoku et al., 2023
	Lack of proper information management systems	Thirumal et al., 2024
	Difficulties in systems integration	Chen et al., 2024; Opoku et al., 2023
	Uncertainties with data quality and reliability	Opoku et al., 2023
	Lack of standard tools and methodologies	Opoku et al., 2023
	Absence of data standardization	Chen et al., 2024; Thirumal et al., 2024
	Software programs are complex and are not easy to use	Desbalo and Bargstadt, 2020
	Rapid change in ICT technologies	Afatsawu, 2020
	Software and reliability problems	Afatsawu, 2020
	High rate of obsolescence of ICT products	Afatsawu, 2020
Disposal of devices (technology disposal)	Thirumal et al., 2024	

Non-technological barriers	Lack of proper digital training/Lack of skills and competencies/Inadequate technical know-how	Abanda et al., 2018; Abhimien et al., 2022; Arabshahi et al., 2021; Chen et al., 2024; Desbalo and Bargstadt, 2020
	Resistance to change	Abhimien et al., 2022; Bayou, 2020; Arabshahi et al., 2021; Chen et al., 2024; Desbalo and Bargstadt, 2020
	High initial cost/investment difficulties	Abhimien et al., 2022; Bayou, 2020; Chen et al., 2024; Opoku et al., 2023; Schnell et al., 2022; Thirumal et al., 2024
	Lack of awareness of the needed digital technologies among experts/Lack of awareness of benefits	Abhimien et al., 2022; Kasim and Ern, 2011; Ikuabe et al., 2020; Arabshahi et al., 2021; Thirumal et al., 2024
	Clients' unwillingness to incur extra cost/Lack of client interest/demand	Abhimien et al., 2022; Chen et al., 2024; Desbalo and Bargstadt, 2020; Afatsawu, 2020
	Lack of commitment from stakeholders/top management	Afatsawu, 2020; Chen et al., 2024; Omari et al., 2023; Thirumal et al., 2024
	Legal issues associated with the use of digital technologies	Abhimien et al., 2022; Bayou, 2020; Chen et al., 2024; Desbalo and Bargstadt, 2020; Opoku et al., 2023
	Ethical and privacy concerns	Chen et al., 2024; Arabshahi et al., 2021
	Lack of vision and strategy	Abanda et al., 2018; Afatsawu, 2020
	Cultural differences	Abanda et al., 2018; Thirumal et al., 2024
	Lack of transparency	Abanda et al., 2018
	Nature of the VM exercise/complexity of VM and technologies	Abhimien et al., 2022; Opoku et al., 2023; Thirumal et al., 2024
Poor digital culture of the construction industry	Abhimien et al., 2022	

Lack of audit trail	Abanda et al., 2018
Data ownership and confidentiality	Abanda et al., 2018
Lack of legal framework for BIM application	Desbalo and Bargstadt, 2020
Slow uptake of new technologies in the construction industry	Thirumal et al., 2024
Involvement of fragmented parties	Thirumal et al., 2024
Lack of CE regulations	Thirumal et al., 2024
Lack of standardization for DTs	Thirumal et al., 2024
Lack of recognition for DTs	Thirumal et al., 2024
Lack of circularity in product design	Thirumal et al., 2024
Fragmented nature of the construction industry	Desbalo and Bargstadt, 2020; Thirumal et al., 2024
Difficulty in allocating & sharing BIM-related risks & costs	Desbalo and Bargstadt, 2020
Lack of detailed processes or workflow to apply BIM	Desbalo and Bargstadt, 2020
Lack of subcontractors who can use BIM technology	Desbalo and Bargstadt, 2020
Reluctance to introduce new technology	Desbalo and Bargstadt, 2020; Thirumal et al., 2024
Insufficient support from top management	Omari et al., 2023
Failure to envisage the benefits of digital technologies to the VM exercise	Abhimien et al., 2022
Non-availability of needed digital technologies	Abhimien et al., 2022

## 2.7 Summary of Literature Review

The literature review confirms that effective material management is a cornerstone of successful construction project delivery, profoundly impacting cost, schedule, and quality, particularly in the context of large-scale public building projects such as those prevalent in Addis Ababa. Traditional material management practices, often reliant on manual processes and fragmented communication, struggle to meet the complexities of modern mega-projects, frequently resulting in inefficiencies, delays, and material waste. In response, digital transformation is emerging globally as a critical enabler for the construction industry, offering a suite of technologies with the potential to revolutionize material management.

Key digital tools identified include Building Information Modeling (BIM) for integrated planning and visualization, Radio Frequency Identification (RFID) and the Internet of Things (IoT) for real-time tracking and monitoring, cloud computing for enhanced data accessibility and collaboration, and Artificial Intelligence (AI) for predictive analytics and optimization. These technologies collectively promise significant benefits, such as improved operational efficiency, enhanced data accuracy and transparency, optimized inventory control, substantial cost savings, reduced material waste, and better communication among project stakeholders.

However, the review highlights a significant disparity between the potential of these technologies and their current adoption level within the Ethiopian construction sector, particularly in Addis Ababa's public projects. While awareness of BIM is growing, its implementation, along with other advanced digital tools, remains limited. The adoption process is hindered by a complex interplay of technological and non-technological barriers. Technological challenges include the high cost of acquisition and maintenance, issues of software interoperability and integration with existing systems, data security concerns, and the inadequacy of IT infrastructure. Non-technological barriers encompass a lack of awareness and skilled personnel, resistance to change within the industry, insufficient management commitment, financial constraints, fragmented industry structure, and the absence of clear regulatory frameworks and standardization.

Furthermore, while conceptual frameworks and models for digital material management exist, and lessons can be drawn from international case studies, their direct applicability to the Ethiopian context is questionable without significant adaptation. The literature underscores the necessity of considering local factors, including infrastructure readiness, workforce capacity, economic

conditions, and regulatory environments. Consequently, this review reveals a distinct research gap concerning the specific application, challenges, and tailored strategies for implementing digital material management systems within Mega building projects in Addis Ababa, setting the stage for the current study's investigation and framework development.

## **2.8 Research Gaps and Opportunities**

Despite the growing body of research on digital transformation in the construction industry, a significant gap exists regarding the specific application of these technologies for material management in Mega building construction projects in Addis Ababa. Existing research tends to focus on the broader aspects of BIM adoption or explore digital transformation in construction within developed contexts (Bui et al., 2016; Wang et al., 2020), leaving a critical need for context-specific research in developing countries like Ethiopia. The limited research conducted on BIM adoption in Ethiopia (Belay et al., 2021; Belete, 2020; Bui et al., 2016) predominantly concentrates on identifying general barriers and benefits without deeply investigating its impact on material management practices.

This research gap presents an opportunity to conduct a comprehensive assessment of the current state of digital technology adoption in material management for Mega building construction projects in Addis Ababa, identifying specific needs and challenges and developing a framework to guide successful implementation. The study will examine the current material management practices and challenges in this specific context (Fikre, 2022), identify applicable digital technologies that can enhance these processes (Bui et al., 2016; Abanda et al., 2018; Desbalo et al., 2024; Duarte-Vidal et al., 2021; Nadeem et al., 2018; Sardroud, 2012), assess the potential benefits and risks of adopting these technologies (Belay et al., 2021; Belete, 2020; Bui et al., 2016; Ibrahim et al., 2020; Mogalli, 2017; Turk and Klinc, 2017), and ultimately, develop a conceptual framework that addresses the unique needs and challenges of Addis Ababa's Mega building construction projects.

Further research is needed to explore the following areas:

- ~ A comprehensive analysis of the current material management practices in Mega building construction projects in Addis Ababa. This includes an in-depth understanding of the existing workflows, challenges, and opportunities for improvement (Berhe, 2021). It will

also investigate the specific information management practices prevalent in public buildings in Addis Ababa, focusing on the type, level of detail, and categorization of information needed to effectively integrate BIM into decision-making processes (Desbalo et al., 2024).

- ~ Identification of specific digital technologies suitable for enhancing material management in the context of Addis Ababa's Mega building construction projects. This involves analyzing the technological capabilities, costs, and potential benefits of various technologies, considering factors such as the availability of IT infrastructure and the skills of the local workforce (Birhanu, 2019; Bui et al., 2016; Ghosh et al., 2021; Hussein, 2019; Mulugeta and Kitaw, 2016). Additionally, exploring how to integrate BIM with material management to identify the challenges and potential benefits is crucial (Mogalli, 2017).
- ~ A comparative analysis of successful digital transformation initiatives in material management from other developing countries, extracting transferable lessons for Addis Ababa. This includes identifying best practices, key success factors, and potential pitfalls to avoid (Bui et al., 2016). Exploring how professional communities and industry clusters promoting BIM practice can be cultivated in developing countries is recommended (Bui et al., 2016). This can involve investigating how requirements in public procurement can promote the implementation of technologies and identifying major barriers and opportunities for successful implementation in Ethiopia (Tiruneh, 2024).
- ~ Development of a context-specific conceptual framework for the successful implementation of digital technologies in material management for Mega building construction projects in Addis Ababa. This framework should consider the city's unique characteristics, including the level of technological advancement, regulatory environment, and cultural factors (Berhe, 2021; Birhanu, 2019; Belete, 2020; Desbalo et al., 2024; Worku, 2024). Addressing specific aspects like legal aspects of BIM and mandating its application at the industry level may require further studies (Belete, 2020). The framework should also address potential risks and challenges associated with digital transformation, offering mitigation strategies and practical implementation guidelines (Tiruneh, 2024).

This study aims to contribute to the existing body of knowledge by bridging the research gap and providing valuable insights into the digital transformation of material management in a developing context. The study will offer practical recommendations for stakeholders involved in Mega

building construction projects in Addis Ababa, guiding them towards the successful adoption of digital technologies for enhanced efficiency, effectiveness, and sustainability.

Table 2. 4 Research gaps and opportunities: a table view

Research Gap	Research Opportunity	Relevant Sources & Insights
Limited research on digital transformation of material management specifically in Mega building construction projects in Addis Ababa (Belay et al., 2021; Belete, 2020; Bui et al., 2016).	Conduct a comprehensive assessment of the current state of digital technology adoption in material management for these projects (Belay et al., 2021).	Belay et al. (2021) discusses the research design based on extensive systematic literature review and Delphi studies, highlighting the need for context-specific research. Bui et al. (2016) emphasizes the importance of considering local legislation and building traditions. Belete (2020) compares findings with other developing countries, revealing similarities in barriers.
Lack of in-depth understanding of existing material management workflows, challenges, and opportunities for improvement in Addis Ababa's Mega building construction projects (Belete, 2020; Berhe, 2021; Desbalo et al., 2024).	Examine current material management practices, identify challenges, and explore opportunities for improvement through digital technologies (Belete, 2020; Berhe, 2021).	Belete (2020) emphasizes the need for identifying potential problems in BIM adoption in the Ethiopian construction industry. Berhe (2021) and Desbalo et al. (2024) highlight the importance of identifying gaps and challenges in existing practices for effective implementation of new technologies.
Limited knowledge about specific digital technologies suitable for enhancing material management in Addis Ababa's Mega building construction context (Wang et al., 2020).	Identify and analyze the suitability of various digital technologies (BIM, IoT, AR/VR, etc.) for material management, considering local factors such as IT infrastructure and workforce skills (Wang et al., 2020).	Wang et al. (2020) provides examples of digital technologies used in construction and explore their applications in various contexts. The research opportunity lies in tailoring these technologies to the specific needs and challenges of Addis Ababa's Mega building construction projects.
Lack of comparative analysis of successful digital transformation initiatives in material management from other developing countries and transferable	Conduct a comparative analysis of successful initiatives in similar contexts, identifying best practices, success factors, and potential pitfalls (Bui et al., 2016).	Belete (2020) and Bui et al. (2016) emphasize the importance of learning from other countries and adapting solutions to local realities. Mulugeta and Kitaw (2016) discusses the importance of knowledge

<p>lessons for Addis Ababa (Belete, 2020; Bui et al., 2016; Mulugeta and Kitaw, 2016);</p>		<p>transfer and technological capability development in developing economies, particularly through megaprojects.</p>
<p>Absence of a context-specific conceptual framework for successful implementation of digital technologies in material management for Mega building construction projects in Addis Ababa (Berhe, 2021; Jemal et al., 2023; Turk and Klinc, 2017).</p>	<p>Develop a framework that addresses Addis Ababa's unique characteristics, including technological advancement, regulations, cultural factors, and potential risks and challenges, with mitigation strategies and practical implementation guidelines (Jemal et al., 2023; Turk and Klinc, 2017).</p>	<p>Berhe (2021) and Jemal et al. (2023) highlight the need for comprehensive frameworks that guide implementation. Turk and Klinc (2017) emphasizes the need for further research on smart contracts and their integration with BIM for specific tasks. The framework should be tailored to the Addis Ababa context.</p>
<p>Lack of clarity on legal and regulatory aspects of BIM adoption and its industry-level mandates in Ethiopia (Bui et al., 2016; Mulugeta and Kitaw, 2016).</p>	<p>Investigate the legal and regulatory landscape for BIM adoption in Ethiopia. Explore the feasibility and implications of mandating BIM application for Mega building construction projects in Addis Ababa (Bui et al., 2016; Mulugeta and Kitaw, 2016).</p>	<p>Bui et al. (2016) mentions the importance of considering local legislations in BIM adoption. Mulugeta and Kitaw (2016) emphasizes the role of government commitment for learning and technology adoption. This research gap calls for a thorough examination of existing regulations and potential adjustments.</p>
<p>Lack of research on information management practices specifically for public buildings in Addis Ababa and their integration with BIM (Desbalo et al., 2024)</p>	<p>Investigate the existing information management practices in public buildings, identifying the type, level of detail, and categorization of information required for effective BIM integration (Desbalo et al., 2024).</p>	<p>Desbalo et al. (2024) emphasize the need for identifying pertinent information requirements for BIM-enabled asset management. The study provides insights into information categories and data types required for operational teams. This gap highlights the need for understanding information flows.</p>

## **CHAPTER THREE**

### **RESEARCH METHODOLOGY**

#### **3.1 Introduction**

This chapter details the research methodology employed to investigate the digital transformation of material management in Mega building construction projects in Addis Ababa. It outlines the research design, the study area, population and sample, data collection methods, data analysis techniques, and the framework development process. A mixed-methods approach will be utilized, combining quantitative and qualitative data collection and analysis to provide a comprehensive understanding of the research topic. The chapter also addresses considerations regarding data reliability, validity, and ethical implications of the study.

#### **3.2 Area of the Study**

This research will be conducted in Addis Ababa, the capital city of Ethiopia. Addis Ababa is experiencing rapid urbanization and a significant increase in construction activities, including numerous Mega building projects such as government offices, hospitals, and universities. These projects are characterized by their large scale, complex designs, substantial resource requirements, and involvement of multiple stakeholders, making them ideal subjects for investigating the challenges and opportunities related to digital transformation in material management. Focusing on Addis Ababa provides a representative context for examining the current practices, challenges, and potential benefits of adopting digital technologies in material management within a rapidly developing urban environment. The findings from this study will be particularly relevant to Addis Ababa's construction industry and can potentially be generalized to other urban centers in Ethiopia facing similar growth and development challenges (See Figure 3.1).

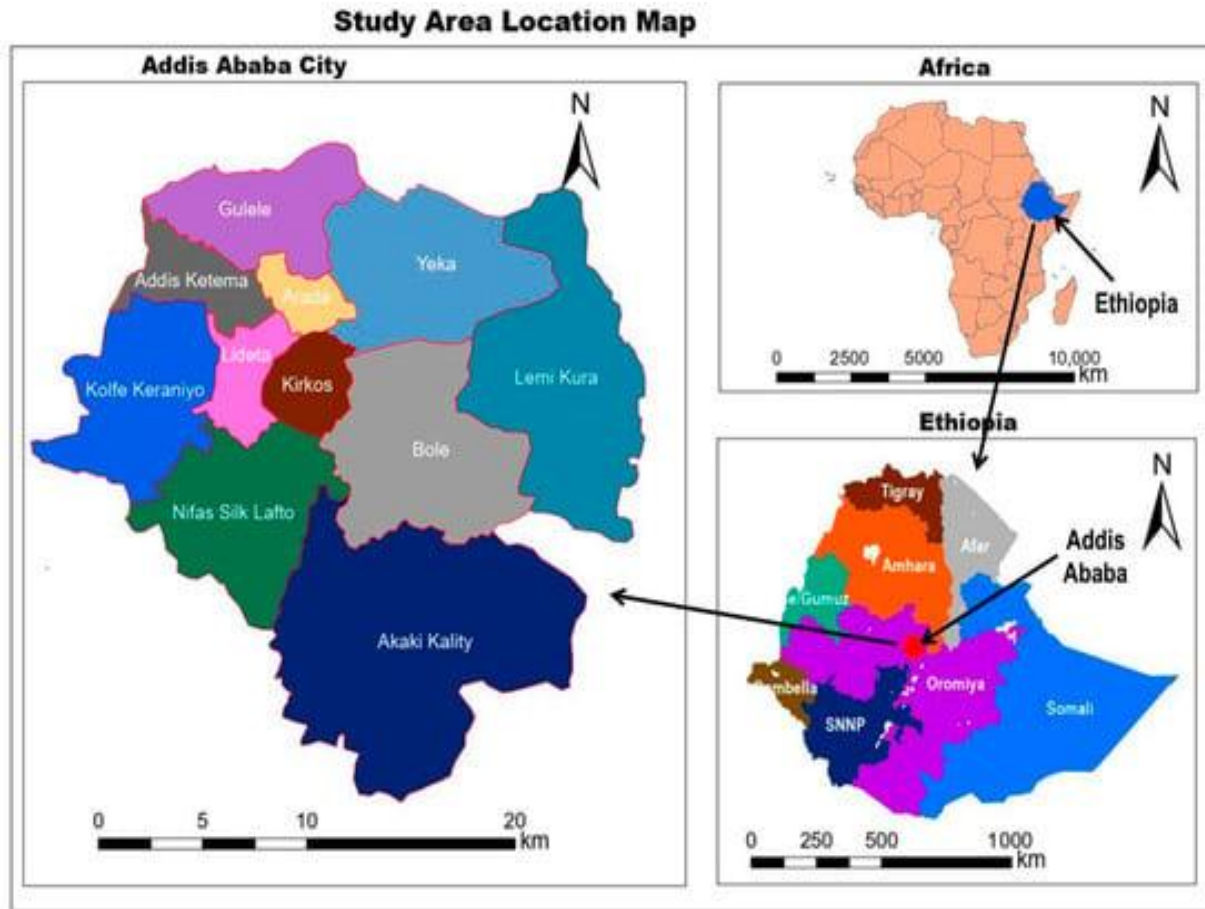


Figure 3. 1 Map of area of the study (Source: Addis et al., 2023)

### 3.3 Research Design and Approach

This study employs a mixed-methods research design to comprehensively investigate the applications of digital tools and technologies in material management systems within the specific context of Mega building construction projects in Addis Ababa. The selection of this approach is underpinned by a pragmatic research philosophy, recognizing that combining both quantitative and qualitative methodologies offers a more holistic and nuanced understanding of the complex interplay between existing practices, perceived barriers, technological potential, and contextual factors influencing digital adoption in this sector. This integrated approach is deemed most suitable for achieving the research objectives, which range from assessing current states and identifying priorities (requiring quantitative measurement) to understanding underlying reasons and developing a contextually relevant strategic framework (requiring qualitative exploration and synthesis).

Specifically, a convergent parallel mixed-methods design is utilized. This involves the concurrent, yet separate, collection and analysis of quantitative and qualitative data. Quantitative data, gathered primarily through the structured questionnaire survey administered to 42 construction professionals (detailed in Sections 3.4, 3.5, and 3.7.1), provides breadth by identifying patterns, frequencies, and the relative importance of current material management practices (Objective 1), hindering barriers (Objective 2), and potential digital technologies (Objective 3) using descriptive statistics and the Relative Importance Index (RII) (Section 3.8.1 and Chapter 4). Concurrently, qualitative data is collected through semi-structured interviews with 8 purposefully selected key informants and document analysis (Sections 3.7.2 and 3.7.3). This qualitative strand provides depth, enabling exploration of the complexities, contextual nuances, and underlying reasons behind the quantitative findings through thematic analysis (Section 3.8.2 and Chapter 4).

The rationale for this convergent design lies in its strength for triangulation – comparing and contrasting findings from both quantitative and qualitative data sources during the interpretation phase (Section 3.8). This integration allows for a more robust validation of results and a richer understanding of the research problem. For example, qualitative insights help explain the significance of specific barriers ranked highly in the survey or the practical reasoning behind the prioritization of certain foundational technologies. The synthesis of these converged findings directly informs the development and validation of the context-specific strategic framework (Objective 4), ensuring it is grounded in both empirical trends and practical realities identified within Addis Ababa's Mega building projects (Section 3.9 and Section 4.6).

The study adopts a cross-sectional time horizon, collecting data over a specific period to capture a snapshot of the current state of digital technology application, associated challenges, and stakeholder perspectives within the defined scope. This approach is appropriate for the exploratory and descriptive nature of the research objectives focused on understanding the present situation to inform future strategy.

### **3.4 Population and Sample Size of the Study**

The target population for this research comprises construction professionals actively involved in the material management processes of Mega building construction projects located within Addis Ababa. This population encompasses individuals working across various stakeholder organizations crucial to these large-scale endeavors, including main contractors, government

agencies (acting as clients or oversight bodies), and consulting firms (involved in design, supervision, or project management). Relevant professional roles within this population include, but are not limited to, Project Managers, Site Engineers, Procurement Officers, Quantity Surveyors, and dedicated Material Managers, as reflected in the respondent profiles targeted by the survey instrument (Section 1 of Questionnaire).

Defining the exact size of this target population is inherently challenging due to the dynamic nature of construction projects, the lack of a centralized, publicly accessible registry of all professionals working on specific Mega projects at any given time, and varying definitions of "mega" projects (as suggested by the diverse projects listed in the supplementary information). However, considering the significant number of ongoing and planned large-scale government-funded initiatives (e.g., federal buildings, housing programs at Addis Ababa and federal level), the population is substantial, dispersed across numerous projects and organizations.

Given these constraints and the exploratory nature of assessing digital tool applications in this specific context, a non-probability sampling approach was deemed appropriate. For the quantitative phase of the study, a sample size of 42 construction professionals, from 28 projects, was achieved and deemed sufficient for the analysis presented in Chapter 4. This sample size, while not statistically determined based on a known population frame, provided a diverse cross-section of the key roles (Site Engineers: 42.9%, Project Managers: 21.4%, Procurement Officers: 16.7%, Quantity Surveyors: 11.9%) and organizational types (Construction Companies: 45.2%, Government Agencies: 38.1%, Consulting Firms: 14.3%) directly involved in the target projects (See Section 4.2). This diversity allows for the identification of key trends, common challenges, and prioritized technologies using Relative Importance Index (RII) and descriptive statistics, fulfilling the research objectives within practical time and resource limitations typical for academic research.

For the qualitative phase, aimed at gaining deeper insights and contextual understanding, a sample size of 8 key informants was purposefully selected. This number was considered adequate to achieve thematic saturation, where further interviews were unlikely to yield significantly new insights related to the core research questions regarding practices, barriers, and the nuances of digital technology adoption in this specific environment.

### **3.5 Sampling Techniques**

Consistent with the challenges in defining a complete sampling frame for the target population, non-probability sampling techniques were employed for both the quantitative and qualitative data collection phases. For the questionnaire survey (quantitative data), a combination of purposive sampling and snowball sampling was utilized.

**Purposive Sampling:** The initial selection targeted professionals based on specific criteria derived from the study's scope: individuals holding relevant roles (Project Manager, Site Engineer, Procurement Officer, Quantity Surveyor, etc.) directly involved in Mega building construction projects currently or recently active in Addis Ababa, with experience pertinent to material management aspects. This ensured that respondents possessed the necessary knowledge and context to provide meaningful data. Potential respondents were initially identified through professional networks, contacts within relevant government agencies overseeing mega projects (like the Addis Ababa City Mega Projects Construction Office or FGBCPO), and major construction/consulting firms known to be involved in such projects.

**Snowball Sampling:** Following the initial contact and data collection from purposively selected individuals, respondents were politely requested to recommend other colleagues or contacts who met the study criteria and might be willing to participate. This technique was particularly useful for extending reach within the relatively closed network of professionals working on these specific, large-scale public projects, helping to achieve the target sample size of 42 respondents.

### **3.6 Sources of Data**

The data for this research were meticulously gathered using a mixed-methods approach, drawing from both primary and secondary sources to ensure a comprehensive understanding of digital technology applications in material management within Addis Ababa's Mega building projects. Primary data formed the core of the empirical investigation. Quantitative primary data were collected via a structured questionnaire survey administered to a sample of 42 construction professionals, including site engineers, project managers, procurement officers, quantity surveyors, and resident engineer (consultants), directly involved in the target projects, as detailed in Section 4.2. This survey elicited data on current material management practices, perceived barriers to digital adoption, and the perceived importance of various digital technologies.

Qualitative primary data were obtained through semi-structured interviews conducted with 8 purposefully selected key informants holding significant experience and relevant roles (such as project managers, site engineers, procurement officers) within these projects, providing in-depth insights, contextual understanding, and nuanced perspectives crucial for interpreting survey results and informing framework development (Objective 4). Secondary data were sought through document analysis, involving the review of available project-related documents such as material management plans, procurement guidelines, progress reports, and relevant organizational policies pertaining to technology adoption or standard operating procedures within the public construction sector. This secondary data served primarily to corroborate information from primary sources, understand the formally established operational environment, and provide contextual background for the study findings. The integration of these diverse data sources facilitated triangulation, enhancing the overall reliability and validity of the research.

### **3.7 Data Collection Methods**

This study employed a mixed-methods approach to data collection, integrating quantitative and qualitative techniques to ensure a comprehensive understanding of the research problem concerning the application of digital tools in material management for Mega building projects in Addis Ababa. The primary methods utilized were a questionnaire survey, semi-structured interviews, and document analysis, each chosen to contribute unique perspectives and data types relevant to the research objectives.

The principal instrument for gathering quantitative data was a structured survey questionnaire. This survey was designed to systematically assess the current state of material management practices (Objective 1), identify and rank the perceived barriers hindering the adoption of digital technologies (Objective 2), and evaluate the perceived importance of various digital tools and technologies for material management (Objective 3). The questionnaire primarily utilized Likert scales to quantify respondent perceptions regarding the extent of practice implementation, agreement with barrier statements, and the importance level of technologies. It was administered to the sample population drawn from professionals involved in Mega building construction projects in Addis Ababa, as detailed in Section 3.5.

To supplement and validate the quantitative findings from the survey, and to gain deeper qualitative insights into the complexities, nuances, and underlying reasons behind the observed trends, semi-

structured interviews were conducted. A total of eight interviews were carried out with purposefully selected key informants, such as experienced project managers, site engineers, procurement officers, and consultants directly involved in the target projects. These interviews were guided by a set of core questions derived from the research objectives but allowed for flexibility to probe specific responses and explore emergent themes. This qualitative data provided rich context, detailed experiences, and explanations that aided in the interpretation of the survey results and the development of the strategic framework (Objective 4).

Further contextualization and corroboration of findings were achieved through document analysis. Relevant project-related documents were reviewed where accessible. This included examining available material management plans, procurement guidelines, progress reports, and potentially internal organizational documents pertaining to technology adoption or standard operating procedures within the public construction sector context. This analysis aimed to verify information gathered through the survey and interviews, understand formally established procedures (whether consistently implemented or not), and gain insights into the official operational environment influencing material management and digital technology use in the selected projects. The integration of these three data collection methods facilitated triangulation, enhancing the overall reliability and validity of the research findings by converging data from multiple sources.

### **3.8 Data Analysis Techniques**

Consistent with the mixed-methods research design, distinct data analysis techniques were employed for the quantitative and qualitative data collected, followed by an integrative synthesis to address the research objectives.

Quantitative data obtained from the 42 survey questionnaires were primarily processed and analyzed using Microsoft Excel, with potential support from Python for specific analytical tasks or visualization related to framework development. Initial analysis involved descriptive statistics (frequencies, percentages) to characterize the respondent profiles (Section 4.2). To address Objectives 1, 2, and 3, the Relative Importance Index (RII) was calculated for Likert scale responses concerning the implementation level of current material management practices, the significance of barriers to digital adoption, and the perceived importance of key digital technologies. RII was employed to systematically quantify and rank these items based on respondent perceptions. Alongside RII, Standard Deviation (SD) was calculated for each item to

assess the degree of consensus or variability in responses among the participants. Furthermore, correlation analyses, specifically employing Spearman's Rank Correlation Coefficient (as conceptualized in Section 4.6.1), were planned and utilized to explore the statistical relationships between identified weaknesses in current practices, perceived barriers, and the prioritization of specific digital technologies. These correlations provided an empirical basis for understanding the interplay between these factors and directly informed the structure and strategic components of the proposed framework (Objective 4).

Qualitative data gathered from the 8 semi-structured interviews were analyzed using thematic analysis. This involved transcribing interview recordings (where applicable and permitted), systematically coding the data to identify recurring patterns, concepts, and themes related to current practices, challenges, opportunities, technology perceptions, and potential implementation strategies. Thematic analysis allowed for the extraction of rich, contextual insights that elucidated the underlying reasons behind quantitative trends and provided critical nuances for framework development. Qualitative data from document analysis were used to verify procedural information, compare formal guidelines with perceived practices, and enrich the overall contextual understanding.

Finally, the quantitative and qualitative findings were synthesized. Qualitative themes and insights were used to interpret and explain the patterns observed in the RII rankings, standard deviations, and correlation results. For instance, interview data helped explain why certain foundational technologies were prioritized or why specific barriers like 'lack of skills' ranked highly, connecting these to the observed low digital familiarity. This integrated analysis ensured that the developed strategic framework (Objective 4, Section 4.6) was not only grounded in the statistically analyzed quantitative data but also enriched and validated by the contextual depth derived from qualitative sources, ultimately leading to a more robust and practically relevant proposal. Both Excel and Python served as instrumental tools in managing the datasets, performing the necessary calculations (RII, SD, correlations), and supporting the synthesis required for the framework's construction.

### **3.9 Strategic Framework Development**

The culmination of this research is the development of a strategic framework aimed at guiding the successful implementation of digital technologies in material management systems for Mega

building construction projects in Addis Ababa (Objective 4). This framework development process is intrinsically linked to and informed by the findings generated from the preceding research objectives. It represents a synthesis of the empirical data gathered, ensuring relevance and practicality within the specific context of the study.

The framework's structure and components will be directly derived from the integrated analysis of quantitative and qualitative data. Specifically, the assessment of current material management practices (Objective 1, Section 4.3) identifies the key weaknesses and operational gaps that the framework must address. The analysis of barriers hindering digital technology adoption (Objective 2, Section 4.4) pinpoints the critical challenges (e.g., skills gaps, cost concerns, lack of standards, BIM-specific issues, infrastructure limitations) that require targeted mitigation strategies within the framework. Furthermore, the prioritization of key digital technologies (Objective 3, Section 4.5) informs the framework's recommendations regarding technology selection, emphasizing foundational tools (like Bar-coding, PM Systems, BIM, ERP) while acknowledging a pathway for adopting more advanced technologies as readiness improves.

Critically, the conceptualized correlation analyses (linking practices, barriers, and technology priorities, as discussed in Section 3.8 and elaborated upon in Section 4.6.1) provide an empirical, data-driven justification for the framework's strategic elements. By statistically connecting identified operational deficiencies (e.g., poor tracking) with perceived barriers (e.g., lack of skills, inadequate systems) and relevant technological solutions (e.g., Bar-coding, Mobile Devices), the framework moves beyond general recommendations to offer targeted interventions grounded in the study's specific findings. The development process involves structuring these insights into actionable phases or pillars, incorporating best practices identified from the literature review (Chapter 2), and ensuring the framework addresses the unique stakeholder dynamics (Section 4.2) and context of Addis Ababa's Mega projects. The final proposed framework, detailed in Chapter 4 (Section 4.6.2), therefore represents a contextually validated strategic guide based on the comprehensive analysis undertaken in this research.

### **3.10 Reliability of Data**

The internal consistency of the survey instrument was assessed using Cronbach's alpha. This test was conducted based on a pilot study to ensure the reliability of the different sections of the

questionnaire. The results indicate good internal consistency for all major constructs, with Cronbach's alpha values exceeding the commonly accepted threshold of 0.7.

Table 3. 1 Reliability Analysis (Cronbach's Alpha)

Survey Section	Number of Items	Cronbach's Alpha ( $\alpha$ )
Section 2: Assessment of Current Practices of Material Management	34	0.88
Section 3: Potential Barriers hindering Digital Technology Adoption	45	0.92
Section 4: Evaluation of Digital Tools and Technologies	27	0.85

### 3.11 Validity of the Study

Validity pertains to the extent to which the research accurately measures what it intends to measure and the degree to which the findings are credible and applicable. This study addresses validity through several means, considering different facets such as internal, external, and construct validity within its defined scope.

Internal validity, or the credibility of the findings within the study's context, is primarily strengthened through triangulation. By synthesizing data from surveys, interviews, and documents, the study seeks converging evidence to support its conclusions regarding current practices, barriers, technology priorities, and the resulting framework. The detailed analysis methods, including the use of RII to rank factors based on respondent perceptions and thematic analysis to explore underlying reasons, ensure findings are rigorously derived from the collected data. Furthermore, grounding the strategic framework (Objective 4) directly in the empirical results from Objectives 1, 2, and 3 ensures its relevance and alignment with the identified needs and challenges of the target population, enhancing its internal validity for this specific context.

External validity, or the generalizability/transferability of findings, is considered within the specific scope defined for this research: Mega building construction projects in Addis Ababa. The findings are most directly applicable to this context. The sampling strategy, which included

professionals with diverse roles, experience levels, and from key organizational types (Contractors, Government Agencies, Consultants) involved in these projects (Section 4.2), supports the representativeness of the findings within this specific population. While direct generalization to all construction projects in Ethiopia or other developing countries should be made with caution, the detailed description of the context, methodology, and findings may provide valuable, transferable insights for researchers or practitioners facing similar challenges in comparable settings.

Construct validity, ensuring the study measures the intended theoretical concepts, is addressed through the careful operationalization of key variables (current practices, barriers, technology importance). The questionnaire items assessing these constructs were developed based on the literature review (Chapter 2, e.g., Tables 2.1, 2.3, 2.2) and tailored to the research objectives. Exploring these concepts through both quantitative surveys (measuring extent or agreement) and qualitative interviews (exploring nuances and meanings) further strengthens the understanding and measurement of these constructs within the study.

## CHAPTER FOUR

### RESULTS AND DISCUSSIONS

#### **4.1 Introduction**

This chapter presents the analysis and interpretation of data collected through the questionnaire survey administered to construction professionals involved in Mega building projects in Addis Ababa. The primary aim is to address the research objectives outlined in Chapter One, focusing on the applications of digital tools and technologies in material management systems. The chapter begins by briefly summarizing the characteristics of the respondent pool to provide context. Subsequently, it delves into the findings related to each specific objective: assessing current material management practices (Objective 1), identifying barriers to digital technology adoption (Objective 2), prioritizing key digital technologies (Objective 3), and culminating in the development and validation of a strategic framework for technology implementation (Objective 4). Statistical analyses, primarily using the Relative Importance Index (RII) and Spearman's Rank Correlation Coefficient, are employed alongside qualitative synthesis to interpret the data. The discussion integrates these findings with existing literature and the specific context of the Ethiopian construction industry, particularly within Addis Ababa's public sector projects.

#### **4.2 Respondent Profiles**

Understanding the background and characteristics of the survey respondents is crucial for contextualizing the research findings. This section presents the demographic and professional profiles of the 42 participants involved in this study on the applications of digital tools and technologies in the material management systems of Mega building construction projects in Addis Ababa. The profiles cover key aspects such as the respondents' roles within construction projects, their years of experience in the industry, the types of organizations they belong to, and their self-assessed familiarity with digital tools relevant to construction. Analyzing these profiles helps ascertain the representativeness of the sample and provides insights into the perspectives shaping the data collected on current practices, barriers to digital adoption, and the potential impact of technology integration.

## 4.2.1 Role in Construction Project

The role held by a respondent within a construction project significantly influences their perspective on material management. Different roles interact with material management processes at various stages and levels – from strategic planning (Project Managers) and procurement (Procurement Officers) to on-site handling and utilization (Site Engineers) and cost control (Quantity Surveyors). Understanding the distribution of roles among respondents ensures that the study captures a multifaceted view of material management practices, challenges, and the potential applicability of digital tools.

Table 4. 1 Distribution of respondents by role in construction project

<b>Role in Construction Project</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Site Engineer	18	42.9%
Project Manager	9	21.4%
Procurement Officer	7	16.7%
Quantity Surveyor	5	11.9%
Other	3	7.1%
<b>Total</b>	<b>42</b>	<b>100.0%</b>

As shown in Table 4.1, the largest group of respondents consists of Site Engineers, representing 42.9% of the sample. Project Managers constitute the second-largest group at 21.4%. Procurement Officers and Quantity Surveyors account for 16.7% and 11.9% of the respondents, respectively. A smaller proportion (7.1%) indicated 'Other' roles within their projects.

The significant representation of Site Engineers provides valuable ground-level insights into the day-to-day operational aspects of material handling, storage, on-site logistics, and waste management, which are critical components of the material management system. The substantial presence of Project Managers ensures perspectives on overall project coordination, planning, and strategic decision-making related to materials. Procurement Officers offer crucial viewpoints on sourcing, supplier relations, and contractual aspects, while Quantity Surveyors contribute insights

into material quantification, costing, and control. This diverse mix of roles strengthens the study's ability to comprehensively assess current material management practices (Objective 1) and identify barriers (Objective 2) from various operational and strategic viewpoints relevant to Mega projects in Addis Ababa.

#### 4.2.2 Years of Experience in Construction

The level of professional experience provides context to respondents' knowledge of industry practices, their potential exposure to technological changes over time, and their understanding of persistent challenges in material management. A mix of experience levels ensures the capture of both traditional viewpoints and potentially newer perspectives, enriching the analysis of current practices and barriers to adopting digital innovations.

Table 4. 2 Distribution of respondents by years of experience in construction

<b>Years of Experience</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Less than 3 years	5	11.9%
3-5 years	11	26.2%
6-10 years	17	40.5%
More than 10 years	9	21.4%
<b>Total</b>	<b>42</b>	<b>100.0%</b>

Table 4.2 illustrates the distribution of respondents based on their years of experience. The majority of participants (40.5%) fall within the 6-10 years experience bracket. Respondents with 3-5 years of experience constitute the next largest group (26.2%). Those with more than 10 years of experience represent 21.4% of the sample, while professionals with less than 3 years of experience make up the remaining 11.9%.

The predominance of respondents with 6-10 years of experience suggests that the sample largely comprises professionals who have substantial practical knowledge of construction processes but may not have been in senior management roles for extended periods. The combined majority (66.7%) having between 3 and 10 years of experience indicates a sample well-versed in

contemporary industry practices within the Addis Ababa context. The inclusion of both less experienced professionals (potentially more recently educated on digital concepts) and highly experienced veterans (over 10 years, offering long-term perspectives on systemic issues) provides a balanced view. This experiential diversity is valuable for assessing the evolution of material management practices (Objective 1), identifying both persistent and emerging barriers (Objective 2), and gauging the perceived need and potential for digital technologies (Objective 3) across different career stages.

### 4.2.3 Organization Type

The type of organization a respondent works for (e.g., Construction Company, Government Agency, Consulting Firm) shapes their operational priorities, constraints, and exposure to different facets of material management and technology adoption. Construction companies are directly involved in execution and site management, government agencies often focus on oversight, regulation, and large-scale project commissioning, while consulting firms typically engage in design, planning, and advisory roles. Understanding this distribution is key to interpreting findings related to practices, barriers, and technology needs within the specific context of *Mega* projects.

Table 4. 3 Distribution of respondents by organization type

<b>Organization Type</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Construction Company	19	45.2%
Government Agency	16	38.1%
Consulting Firm	6	14.3%
Other	1	2.4%
<b>Total</b>	<b>42</b>	<b>100.0%</b>

Table 4.3 shows that the respondents are primarily drawn from Construction Companies (45.2%) and Government Agencies (38.1%). Together, these two groups make up over 83% of the sample. Consulting Firms represent 14.3% of the respondents, with a single respondent categorizing their organization as 'Other'.

The strong representation from Construction Companies and Government Agencies is highly relevant to the study's focus on Mega building projects in Addis Ababa. Construction companies provide direct insights into implementation practices, on-site material management challenges, and operational barriers to technology adoption. Government agency respondents offer perspectives from the client/owner side, including procurement policies, project oversight challenges, and potentially the institutional barriers or drivers for digital transformation in public projects. The inclusion of consulting firms adds perspectives related to design integration, technology specification, and advisory roles. This composition ensures that the data reflects the core stakeholders involved in the planning, execution, and oversight of Mega projects, which is essential for achieving all research objectives, particularly in assessing current practices (Objective 1), barriers (Objective 2), and developing a relevant strategic framework (Objective 4).

#### **4.2.4 Familiarity with Digital Tools and Technologies in Construction**

Respondents' familiarity with digital tools is a direct indicator of the current level of digital literacy and adoption within the studied population. It helps gauge the baseline understanding of technologies relevant to material management and provides context for interpreting perceived barriers (e.g., lack of skills, awareness) and the perceived importance or potential impact of various digital tools. Low familiarity suggests significant challenges for adoption, while higher familiarity might indicate areas where digital tools are already gaining traction.

The data presented in Table 4.4 reveals a notable trend regarding respondents' familiarity with digital tools in construction. A significant majority fall into the lower familiarity categories: 40.5% reported being 'Very Unfamiliar', and 23.8% reported being 'Unfamiliar'. Combined, these two groups account for nearly two-thirds (64.3%) of the respondents. Nineteen percent rated their familiarity as 'Neutral'. Only a smaller portion felt 'Familiar' (11.9%) or 'Very Familiar' (4.8%) with these technologies.

The strikingly high percentage of respondents reporting unfamiliarity ('Very Unfamiliar' or 'Unfamiliar') with digital tools is a critical finding. This strongly suggests a low level of digital technology adoption and integration within the material management practices of Mega building projects in Addis Ababa, directly informing the assessment of current practices (Objective 1).

Table 4. 4 Distribution of respondents by familiarity with digital tools and technologies

<b>Familiarity Level</b>	<b>Frequency</b>	<b>Percentage (%)</b>
Very Unfamiliar	17	40.5%
Unfamiliar	10	23.8%
Neutral	8	19.0%
Familiar	5	11.9%
Very Familiar	2	4.8%
<b>Total</b>	<b>42</b>	<b>100.0%</b>

It highlights significant potential barriers (Objective 2), such as lack of awareness, insufficient training, inadequate access to technology, or perceived complexity. This low baseline familiarity underscores the challenge and importance of identifying appropriate and accessible digital technologies (Objective 3) and developing a strategic framework (Objective 4) that addresses awareness-building, training, and phased implementation to bridge this digital divide effectively. The small pockets of 'Familiar' and 'Very Familiar' respondents may represent early adopters or specific niches whose experiences could offer valuable insights into successful implementation strategies.

### **4.3 Assessment of Current Material Management Practices**

This section addresses the first specific objective of the research: to assess the current practices of material management in Mega building construction projects within Addis Ababa. The assessment utilizes data gathered from Section 2 of the questionnaire survey, where respondents evaluated the extent of implementation for 34 distinct material management practices. A 5-point Likert scale, ranging from 'Not Implemented' (1) to 'Fully Implemented' (5), was employed. To quantify and rank the perceived implementation level of these practices, the Relative Importance Index (RII) was calculated for each item. Furthermore, the standard deviation associated with each practice was analyzed to gauge the degree of consensus or variability among the respondents' perceptions

regarding the implementation level. These analyses provide a baseline understanding of the current state of material management, highlighting areas of relative strength and significant weakness.

### 4.3.1 RII Analysis of Current Practices

The RII scores and standard deviations for the 34 assessed material management practices were computed using MS Excel and are presented in Table 4.5, ranked from the highest RII score (indicating higher perceived implementation) to the lowest. The RII scores range from a maximum of 0.5524 down to 0.3000, suggesting that even the best-perceived practices are only moderately implemented, while many fall into the minimally implemented category.

Table 4. 5 RII ranking and SD of current material management practices

Rank	Variable	RII Score	Std Dev
1	Systematic checks are performed to ensure purchased materials conform to specified requirements before delivery confirmation.	0.5524	0.9830
2	There is access to a sufficient range of reliable suppliers for key construction materials.	0.5524	1.3759
3	A formal and transparent process is used for selecting and evaluating material suppliers.	0.5381	1.1788
4	Material lead times are adequately considered during procurement planning and scheduling.	0.5286	1.0078
5	Material management activities are effectively coordinated among different project stakeholders (e.g., design team, procurement, site team, suppliers).	0.5286	1.1857
6	Defined procedures exist and are followed for material ordering and purchasing.	0.5000	0.9435
7	Contracts clearly outlining quality, quantity, delivery terms, and compliance requirements are used for securing material supply.	0.4952	1.1737
8	Designated, adequate, and secure storage areas are provided for different types of construction materials.	0.4667	1.0969
9	Material quality is systematically inspected upon receipt at the site and before installation/use.	0.4571	0.9948

10	Efficient methods are used for transporting materials from storage areas to the point of use within the site.	0.4524	1.1275
11	Strategies are implemented to minimize material waste during site activities (controlling mixing quantities, proper cutting).	0.4524	1.2506
12	Material demand forecasting is conducted based on project progress and schedules.	0.4429	1.2598
13	Quantities of generated construction waste are measured and recorded.	0.4333	1.0101
14	Established procedures exist and are followed for managing on-site construction waste.	0.4333	1.0801
15	Material requirements planning is integrated with the overall project schedule and work breakdown structure.	0.4333	1.3419
16	Strategies are implemented to minimize material waste during ordering.	0.4286	1.2010
17	Established safety procedures are followed during material handling activities (loading, unloading, moving).	0.4238	0.9678
18	Accurate records are maintained for material receipt, issuance, and current inventory levels.	0.4190	1.0777
19	Appropriate material handling equipment is available and utilized effectively.	0.4190	1.1855
20	Specific budgets for material procurement and usage are established and systematically monitored.	0.4048	1.0704
21	Sufficient and accurate information (e.g., specifications, quantities) is available in project drawings and documents for effective material management.	0.3952	0.8407
22	Construction waste is systematically segregated (separating wood, metal, concrete) for disposal, reuse, or recycling.	0.3952	0.8692
23	Contract documents related to materials are generally free from errors or ambiguities that could impede material management.	0.3952	0.9997
24	A documented material management plan exists and is utilized for the project.	0.3952	1.0238

25	Measures are consistently taken to protect stored materials from damage, deterioration, theft, and environmental factors.	0.3905	1.1252
26	Specific procedures (stacking height, covering) are followed for storing sensitive materials like cement.	0.3905	1.1252
27	Storage areas are organized systematically for easy identification, retrieval, and inventory checking of materials.	0.3714	0.9258
28	The construction site layout is planned to ensure the efficient and safe flow and movement of materials.	0.3524	1.0075
29	The performance of material management processes (delivery timeliness, storage conditions) is regularly monitored and evaluated.	0.3429	0.9699
30	Specific software is utilized for material management activities (e.g., Enterprise Resource Planning, inventory management software).	0.3429	1.0190
31	Data related to material quality (test results, inspection reports) is systematically collected and reviewed.	0.3381	1.1788
32	Digital tools or technologies are currently employed in any aspect of material management (e.g., Building Information Modelling, Radio Frequency Identification, mobile apps, drones).	0.3190	0.8851
33	Information and Communication Technology is utilized for sharing material-related data among stakeholders (e.g., shared drives, communication platforms).	0.3000	0.7071
34	Systematic methods (manual or digital) are used for real-time or near real-time tracking of on-site inventory.	0.3000	1.0181

Source: Survey Data Analysis (2024)

The analysis reveals that practices related to the initial stages of procurement and basic checks tend to have relatively higher RII scores. Specifically, "Systematic checks are performed to ensure purchased materials conform to specified requirements before delivery confirmation" (Rank 1, RII=0.5524, Std Dev=0.9830) and "There is access to a sufficient range of reliable suppliers for key construction materials" (Rank 2, RII=0.5524, Std Dev=1.3759) top the list. Other moderately ranked practices include using a formal process for supplier selection (Rank 3, RII=0.5381), considering lead times (Rank 4, RII=0.5286), effective coordination among stakeholders (Rank 5, RII=0.5286), and having defined ordering procedures (Rank 6, RII=0.5000). Notably, the standard

deviation for access to suppliers (Rank 2) is quite high (1.3759), suggesting significant disagreement or variability in experience among respondents regarding supplier availability. Similarly, coordination (Rank 5, Std Dev=1.1857) and supplier selection (Rank 3, Std Dev=1.1788) also show considerable variance in perception.

Conversely, practices involving technology adoption, systematic data management, and real-time tracking are perceived as the least implemented. The lowest-ranked practices include "Information and Communication Technology is utilized for sharing material-related data among stakeholders" (Rank 33, RII=0.3000, Std Dev=0.7071) and "Systematic methods (manual or digital) are used for real-time or near real-time tracking of on-site inventory" (Rank 34, RII=0.3000, Std Dev=1.0181). Other poorly implemented areas include the use of any digital tools or technologies (Rank 32, RII=0.3190), systematic collection of material quality data (Rank 31, RII=0.3381), and the utilization of specific software for material management (Rank 30, RII=0.3429). The relatively lower standard deviation for ICT utilization (Rank 33, Std Dev=0.7071) and general digital tool use (Rank 32, Std Dev=0.8851) suggests a stronger consensus among respondents regarding the *lack* of implementation in these technological areas. Practices related to systematic waste segregation (Rank 22, RII=0.3952), site layout planning for material flow (Rank 28, RII=0.3524), and systematic storage organization (Rank 27, RII=0.3714) also fall within the lower RII range, indicating significant implementation gaps.

### **4.3.2 Discussion of Current Practices**

The RII analysis paints a clear picture of the current state of material management practices in Addis Ababa's Mega building projects. The overall low RII scores, with the highest only reaching 0.5524, indicate that most practices are perceived as operating at a level between minimal and partial implementation. There is a notable absence of practices considered largely or fully implemented by the respondents, signifying substantial room for improvement across the board.

Specific areas of relative strength, albeit limited, appear to be concentrated in the foundational aspects of procurement planning and control, such as pre-delivery checks, supplier evaluation, and basic ordering procedures. However, even these higher-ranked items barely cross the midpoint of the implementation scale, and several exhibit high standard deviations, indicating inconsistent application or perception across different projects or respondent roles.

The most pronounced weaknesses lie overwhelmingly in areas requiring systematic processes, data management, and technological integration. The extremely low RII scores for technology use (software, digital tools, ICT), real-time inventory tracking, systematic data collection (quality, waste), and waste segregation highlight a significant lag in adopting modern material management techniques. Furthermore, deficiencies in planning integration (Rank 15, RII=0.4333), accurate record-keeping (Rank 18, RII=0.4190), systematic storage organization (Rank 27, RII=0.3714), and performance monitoring (Rank 29, RII=0.3429) point towards systemic inefficiencies throughout the material management lifecycle.

These findings align strongly with literature documenting challenges in construction material management, particularly in developing economies like Ethiopia. Studies by Fikre (2022) and Belete (2020) highlight inefficiencies, poor planning, and limited technology adoption as significant issues within the Ethiopian construction industry. The observed low RII scores for tracking, forecasting, and technology use directly reflect the reliance on traditional, often manual, processes described by Desbalo et al. (2024), which are prone to errors and inefficiencies. The challenges identified in waste management (low RII for measurement, segregation) also echo concerns raised by Samuel (2024) and Fikre (2022) regarding waste generation and inadequate management strategies.

The context of Mega building projects in Addis Ababa likely exacerbates these identified weaknesses. The sheer scale, complexity, logistical challenges, and involvement of numerous stakeholders in such projects place immense strain on traditional material management systems. Manual tracking becomes unmanageable, coordination complexities increase exponentially (despite its relatively higher RII, the high standard deviation suggests challenges), and the consequences of poor storage, handling, or waste management are magnified in terms of cost overruns, delays, and environmental impact.

In conclusion, this assessment establishes a critical baseline understanding of current material management practices. It clearly identifies systemic weaknesses, particularly in tracking, data management, waste control, and technology utilization, as major areas requiring intervention. These findings underscore the pressing need for improvement and highlight the specific domains where the digital technologies identified in Objective 3 could potentially yield the most significant enhancements. The relatively high consensus (low standard deviation) on the lack of

implementation in technological areas further strengthens the case for targeted digital interventions, forming the basis for developing the strategic framework outlined in Objective 4.

## **4.4 Analysis of Barriers Hindering Digital Technology Adoption**

This section addresses the second specific objective of the study: to identify and analyze the potential barriers hindering the implementation of digital technologies for managing materials within Mega building construction projects in Addis Ababa. Data for this analysis was collected through Section 3 of the questionnaire, where respondents rated their level of agreement with 45 potential barriers using a 5-point Likert scale (1: Strongly Disagree to 5: Strongly Agree). The Relative Importance Index (RII) methodology was employed, utilizing MS Excel for calculations, to rank the perceived significance or agreement level associated with each barrier. Standard deviations were also calculated to assess the level of consensus among respondents regarding the impact of each barrier. This analysis aims to pinpoint the most critical obstacles that need to be addressed for successful digital transformation in this context.

### **4.4.1 RII Analysis of Barriers**

The RII scores and corresponding standard deviations for the 45 potential barriers are presented in Table 4.6. The barriers are ranked based on their RII scores, from the most significant (highest RII) to the least significant (lowest RII). The scores range from 0.8762 down to 0.6143, indicating that respondents perceive a wide array of factors as significant impediments, with the top barriers showing a high degree of perceived importance. For clarity, potential barriers can be broadly grouped into categories such as BIM-Specific, Cost-Related, Skills/Knowledge-Related, Standardization/Legal, Technical/Infrastructure, Organizational/Cultural, Client/Market, and Process/Information Management related issues.

Table 4. 6 RII ranking and SD of perceived barriers to digital technology adoption

<b>Rank</b>	<b>Barrier</b>	<b>Category</b>	<b>RII Score</b>	<b>Std Dev</b>
1	Lack of subcontractors who can use BIM technology	BIM-Specific	0.8762	0.7949
2	Lack of legal framework for BIM application	Standardization/Legal (BIM)	0.8762	0.8250
3	Non-availability of needed digital technologies	Technical/Infrastructure	0.8762	0.8540
4	Lack of standard tools and methodologies	Standardization/Legal	0.8619	0.6803
5	Difficulty in allocating & sharing BIM-related risks & costs	BIM-Specific	0.8619	0.8968
6	Lack of awareness of the needed digital technologies among experts/Lack of awareness of benefits	Skills/Knowledge	0.8571	0.8348
7	High rate of obsolescence of ICT products	Technical/Infrastructure	0.8571	0.9183
8	Difficulties in systems integration	Technical/Infrastructure	0.8524	0.6648
9	Lack of proper digital training/Lack of skills and competencies/Inadequate technical know-how	Skills/Knowledge	0.8524	0.7005
10	Lack of commitment from stakeholders/top management	Organizational/Cultural	0.8524	0.9642
11	Reluctance to introduce new technology	Organizational/Cultural	0.8476	0.9055
12	Software and reliability problems	Technical/Infrastructure	0.8429	0.9249
13	Fragmented nature of the construction industry	Organizational/Cultural	0.8429	0.9762
14	High initial cost/investment difficulties	Cost-Related	0.8333	0.7938
15	Insufficient support from top management	Organizational/Cultural	0.8286	0.8431
16	Absence of data standardization	Standardization/Legal	0.8286	0.8991

17	High cost of acquiring needed digital technologies	Cost-Related	0.8238	0.7055
18	Lack of standardization for DTs	Standardization/Legal	0.8238	0.8323
19	Lack of data interoperability	Technical/Infrastructure	0.8238	1.0866
20	Lack of audit trail	Standardization/Legal	0.8190	0.8782
21	Software programs are complex and are not easy to use	Skills/Knowledge	0.8190	0.9579
22	Resistance to change	Organizational/Cultural	0.8190	1.0548
23	Data security barriers/concerns/Lack of trust in data security and privacy	Technical/Infrastructure	0.8095	0.9094
24	Involvement of fragmented parties	Organizational/Cultural	0.8048	1.0704
25	High cost of maintaining digital technologies needed	Cost-Related	0.8000	0.9877
26	Data ownership and confidentiality	Standardization/Legal	0.8000	1.0121
27	Incompatibility and interoperability problems	Technical/Infrastructure	0.7952	0.8968
28	Lack of transparency	Organizational/Cultural	0.7952	1.0238
29	Ethical and privacy concerns	Standardization/Legal	0.7905	1.0809
30	Legal issues associated with the use of digital technologies	Standardization/Legal	0.7857	0.9472
31	Rapid change in ICT technologies	Technical/Infrastructure	0.7857	1.0215
32	Failure to envisage the benefits of digital technologies to the VM exercise	Skills/Knowledge	0.7810	0.8782
33	Nature of the VM exercise/complexity of VM and technologies	Organizational/Cultural	0.7714	0.9771
34	Lack of detailed processes or workflow to apply BIM technology	BIM-Specific	0.7429	0.8913
35	Uncertainties with data quality and reliability	Technical/Infrastructure	0.6857	0.8874

36	Slow uptake of new technologies in the construction industry	Client/Market	0.6762	0.8250
37	Poor digital culture of the construction industry	Organizational/Cultural	0.6714	0.9582
38	Cultural differences	Organizational/Cultural	0.6714	0.9833
39	Lack of CE regulations	Standardization/Legal	0.6714	1.0078
40	Lack of recognition for DTs	Standardization/Legal	0.6667	0.9283
41	Clients' unwillingness to incur extra cost/Lack of client interest/demand	Client/Market	0.6429	0.8421
42	Disposal of devices (technology disposal)	Technical/Infrastructure	0.6429	1.0715
43	Lack of circularity in product design	Process/Info Mgt	0.6286	1.0258
44	Lack of vision and strategy	Organizational/Cultural	0.6286	1.0723
45	Lack of proper information management systems	Process/Info Mgt	0.6143	1.0682

Source: Survey Data Analysis (2024)

The analysis highlights several critical barriers perceived as highly significant by the respondents. Notably, three barriers tied for the top rank with an RII score of 0.8762: "Lack of subcontractors who can use BIM technology," "Lack of legal framework for BIM application," and "Non-availability of needed digital technologies." These are closely followed by "Lack of standard tools and methodologies" (Rank 4, RII=0.8619) and "Difficulty in allocating & sharing BIM-related risks & costs" (Rank 5, RII=0.8619). The top 10 barriers consistently score above 0.85, indicating strong agreement on their importance. These include "Lack of awareness" (Rank 6, RII=0.8571), "High rate of obsolescence of ICT products" (Rank 7, RII=0.8571), "Difficulties in systems integration" (Rank 8, RII=0.8524), "Lack of proper digital training/skills" (Rank 9, RII=0.8524), and "Lack of commitment from stakeholders/top management" (Rank 10, RII=0.8524).

Examining the standard deviations reveals the level of consensus. Several top barriers show relatively high consensus (Std Dev < 0.9), such as lack of BIM subcontractors (0.7949), lack of legal framework (0.8250), non-availability of tech (0.8540), lack of standard tools (0.6803), lack

of awareness (0.8348), systems integration difficulties (0.6648), and lack of skills (0.7005). This suggests widespread agreement on the significance of these issues. Other highly ranked barriers, like BIM risks/costs (0.8968), ICT obsolescence (0.9183), and lack of commitment (0.9642), show slightly more variability in perception, though they remain critically important.

Barriers perceived as relatively less significant (though still mostly above the neutral point of the original scale) include those related to information management systems (Rank 45, RII=0.6143), vision and strategy (Rank 44, RII=0.6286), circularity in design (Rank 43, RII=0.6286), technology disposal (Rank 42, RII=0.6429), and client unwillingness to incur extra cost (Rank 41, RII=0.6429).

#### **4.4.2 Discussion of Barriers to Digital Technology Adoption**

The RII analysis of perceived barriers provides crucial insights into the challenges hindering digital technology adoption in material management for Addis Ababa's Mega projects. The dominant categories emerging from the top-ranked barriers clearly point towards a complex interplay of BIM-specific challenges, issues related to standardization and legal frameworks, skills and awareness deficits, cost factors, and technical/infrastructure limitations.

The high ranking of BIM-specific barriers (lack of capable subcontractors, unclear legal framework, difficulties with risk/cost allocation, lack of detailed workflows) underscores that while BIM might be recognized conceptually, its practical implementation faces significant hurdles within the local supply chain and regulatory environment. This aligns with findings from Belete (2020) and Desbalo & Bargstadt (2020) who identified similar BIM adoption challenges in Ethiopia.

The strong emphasis on the lack of standards (tools, data, DTs) and legal clarity (Ranks 2, 4, 16, 18, 20, 26, 30) highlights a foundational gap that impedes consistent and confident technology deployment. This resonates with concerns often raised in developing economies about the need for supportive institutional and regulatory ecosystems for technology adoption (Bui et al., 2016).

Cost remains a significant factor, with high initial costs (Rank 14), acquisition costs (Rank 17), and maintenance costs (Rank 25) all ranking as important barriers. This is a well-documented challenge globally, but particularly acute in contexts with potentially limited capital resources (Belay et al., 2021).

Critically, human and organizational factors feature prominently. Lack of awareness (Rank 6) and lack of skills/training (Rank 9) are perceived as major obstacles. This finding directly correlates with the low digital familiarity reported by respondents in Section 4.2.4. When professionals are unfamiliar with the tools, their perceived complexity (Rank 21) increases, awareness of benefits decreases (Rank 6), and resistance to change (Rank 22) is more likely. Furthermore, lack of commitment from top management (Rank 10 & 15) and the fragmented nature of the industry (Rank 13) point to organizational inertia and cultural challenges highlighted by Afatsawu (2020) and Belay et al. (2021).

Technical and infrastructure issues such as non-availability of technologies (Rank 3), ICT obsolescence (Rank 7), systems integration difficulties (Rank 8), and data interoperability (Rank 19) are also highly ranked, reflecting the infrastructure challenges noted by Belay et al. (2021) in the Ethiopian context.

These findings powerfully illustrate that overcoming barriers to digital adoption in this context requires a multi-pronged approach. Addressing only cost or only technical issues will be insufficient. The strategic framework developed in Objective 4 must, therefore, incorporate targeted interventions that directly address the highest-priority barriers identified here. This includes specific strategies for capacity building (skills, awareness), fostering collaboration to tackle BIM ecosystem challenges (subcontractors, risk sharing), advocating for clearer standards and regulations, exploring cost-effective or phased technology adoption models, and promoting leadership commitment to drive organizational change. Tackling these intertwined barriers is paramount for unlocking the potential benefits of digital technologies in material management within Addis Ababa's public construction sector.

## **4.5 Identification and Prioritization of Key Digital Technologies**

This section addresses the third specific objective of the research: to identify and prioritize key digital technologies that possess the potential to drive digital transformation in material management within Addis Ababa's Mega building projects, thereby improving efficiency and effectiveness. The analysis utilizes data collected from Section 4 of the questionnaire, wherein respondents evaluated the perceived importance of 27 different digital tools and technologies for enhancing construction material management. A 5-point Likert scale, ranging from 'Not at all Important' (1) to 'Very Important' (5), was used. The Relative Importance Index (RII) was

calculated for each technology using MS Excel to establish a ranked order based on perceived importance. Additionally, the standard deviation for each technology's rating was computed to understand the level of consensus or divergence in perceptions among the respondents. This prioritization is essential for guiding the development of the strategic framework (Objective 4) by highlighting which technologies are deemed most crucial by stakeholders in the target context.

#### 4.5.1 Prioritization of Digital Technologies (RII Results)

The RII scores and standard deviations indicating the perceived importance of the 27 digital tools and technologies are presented in Table 4.7. The technologies are ranked from the highest RII score (most important) to the lowest. The RII scores span from a high of 0.8190 down to 0.4619, suggesting a clear hierarchy in how respondents perceive the value of different technologies for material management in their context.

Table 4. 7 RII ranking and SD of perceived importance of digital tools/technologies

Rank	Variable	RII Score	Std Dev
1	Bar-coding	0.8190	0.8782
2	Digital project management systems	0.8095	0.7636
3	Microsoft Excel Spreadsheet	0.8000	1.0592
4	BIM (Building Information Modeling)	0.7905	0.8821
5	Digital documentation	0.7905	0.9866
6	Enterprise Resource Planning (ERP) software	0.7857	0.8083
7	Wireless systems	0.7857	0.9726
8	Mobile devices (PDAs, PDTs, tablets, smartphones)	0.7810	1.0548
9	GPS (Global Positioning System)	0.7714	1.0258
10	Handheld devices	0.7714	1.1169
11	Cloud computing	0.7524	1.0777
12	Web portals	0.7333	0.9795

13	Supply chain management software	0.7095	1.0407
14	Photogrammetry	0.6952	0.9687
15	Real-time location sensing (RTLS)	0.6810	0.7670
16	RFID (Radio Frequency Identification)	0.6762	0.9358
17	Automated tracking systems	0.6667	0.9283
18	Drones	0.6619	1.0238
19	Sensors	0.6381	0.9432
20	Asset tagging solutions	0.6000	0.9627
21	AR (Augmented Reality) headsets	0.5571	0.9762
22	Digital Twins (DTs)	0.5524	1.0548
23	Blockchain technology	0.5429	1.1952
24	Smart contracts	0.5095	1.2726
25	Artificial Intelligence (AI)	0.5000	0.9435
26	IoT (Internet of Things)	0.4667	0.9542
27	3D Printing	0.4619	1.1367

Source: Survey Data Analysis (2024)

The analysis reveals a clear preference among respondents for technologies perceived as established, practical, or foundational for digital operations. "Bar-coding" (Rank 1, RII=0.8190) is ranked as the most important technology, closely followed by "Digital project management systems" (Rank 2, RII=0.8095) and the ubiquitous "Microsoft Excel Spreadsheet" (Rank 3, RII=0.8000). Other highly ranked technologies include "BIM (Building Information Modeling)" (Rank 4, RII=0.7905), "Digital documentation" (Rank 5, RII=0.7905), "Enterprise Resource Planning (ERP) software" (Rank 6, RII=0.7857), "Wireless systems" (Rank 7, RII=0.7857), and "Mobile devices (PDAs, PDTs, tablets, smartphones)" (Rank 8, RII=0.7810). These top-tier technologies generally show moderate to high consensus, with standard deviations mostly below

1.0, except for Excel (1.0592) and Mobile devices (1.0548), suggesting some variability in how crucial these specific tools are perceived across different respondents.

Conversely, technologies often associated with more advanced digital transformation concepts received lower importance ratings. The technologies perceived as least important include "IoT (Internet of Things)" (Rank 26, RII=0.4667) and "3D Printing" (Rank 27, RII=0.4619). Other lower-ranked technologies encompass "Artificial Intelligence (AI)" (Rank 25, RII=0.5000), "Smart contracts" (Rank 24, RII=0.5095), "Blockchain technology" (Rank 23, RII=0.5429), "Digital Twins (DTs)" (Rank 22, RII=0.5524), and "AR (Augmented Reality) headsets" (Rank 21, RII=0.5571). Notably, several of these less prioritized technologies exhibit higher standard deviations (e.g., Blockchain: 1.1952; Smart contracts: 1.2726; 3D Printing: 1.1367), indicating significant disagreement or uncertainty among respondents regarding their importance or applicability in the current context.

#### **4.5.2 Discussion Perceived Importance of Digital Tools/Technologies**

The prioritization of digital technologies by respondents offers significant insights into the perceived needs and current readiness for digital adoption in Addis Ababa's Mega projects. The high ranking of tools like Bar-coding, Digital PM systems, Excel, BIM, Digital Documentation, ERP, and Mobile Devices suggests a strong perceived need for technologies that address fundamental material management tasks: tracking, project organization, data handling, planning, and communication. This preference for established or foundational digital tools likely reflects a desire for practical solutions that can address the immediate inefficiencies identified in Section 4.3, such as poor tracking and documentation. The relatively high importance given to BIM (Rank 4) signals a growing recognition of its potential, aligning with the increasing focus on BIM adoption noted in Ethiopian construction literature (e.g., Belay et al., 2021; Belete, 2020).

Comparing these findings with literature reinforces the perceived value of the prioritized technologies. Bar-coding is widely recognized for improving tracking efficiency and accuracy (Kasim et al., 2013). Digital PM systems streamline workflows and enhance collaboration (Ni et al., 2021). BIM offers significant benefits in planning, visualization, and coordination (Jemal et al., 2023; Wang et al., 2020). Digital documentation improves accessibility and reduces errors (Kolawole, 2023), while mobile devices facilitate real-time communication and data access on site (Abanda et al., 2018). ERP systems integrate core business processes for better resource allocation

(Hilina, 2017). The relatively lower ranking of RFID (Rank 16) compared to Bar-coding (Rank 1) might suggest a preference for simpler, potentially lower-cost tracking solutions initially, even though RFID offers more advanced capabilities (Sardroud, 2012; Ibrahim et al., 2020).

The significantly lower ranking of advanced technologies like AI, IoT, Blockchain, Digital Twins, and AR, despite their documented potential benefits in optimization, automation, transparency, and enhanced visualization (Ogundipe et al., 2024; Jemal et al., 2023; Legesse et al., 2024; Maqbool et al., 2023; Khan et al., 2024), is particularly telling. This likely reflects the barriers identified in Section 4.4, such as high costs, lack of skills and awareness, infrastructure limitations, and lack of standardization. The high standard deviations associated with some of these advanced technologies further suggest uncertainty and a lack of consensus regarding their applicability or value proposition in the immediate context. Respondents may perceive these as future possibilities rather than current priorities, given the existing challenges and low digital familiarity observed (Section 4.2.4).

These findings have direct implications for the strategic framework (Objective 4). The framework should prioritize strategies that facilitate the effective implementation and integration of the highly-ranked, foundational technologies (Bar-coding, PM systems, BIM, ERP, Mobile devices, Digital Documentation) to address immediate operational needs and build a solid digital base. Simultaneously, recognizing the potential of advanced technologies, the framework must include components focused on overcoming the barriers hindering their adoption. This involves long-term strategies for capacity building, awareness creation, addressing standardization issues, exploring pilot projects for technologies like AI or IoT, and potentially advocating for infrastructure improvements. The framework might need to propose a phased approach, focusing first on digitizing core processes with established tools before moving towards more complex, integrated systems. The variability in perceptions (indicated by standard deviations) also suggests that strategies might need tailoring based on specific stakeholder groups or organizational contexts.

## **4.6 Development and Validation of a Strategic Framework**

This concluding section of the results and discussion addresses the fourth and final specific objective of this research: to develop a strategic framework designed to guide the successful implementation of digital technologies in material management systems for Mega building construction projects in Addis Ababa. The framework presented herein represents a synthesis of

the empirical findings derived from the preceding analyses addressing Objectives 1, 2, and 3. It integrates insights regarding current material management practices and their deficiencies (Objective 1), the significant barriers hindering digital technology adoption (Objective 2), and the prioritization of key digital tools as perceived by industry stakeholders (Objective 3). These empirical findings are further contextualized and augmented by relevant themes from the literature review (Chapter 2) and established best practices in digital transformation within construction.

Crucially, correlation analyses were employed to empirically establish links between the identified practices, barriers, and technology priorities. This statistical grounding provides a data-driven rationale for the framework's structure, components, and proposed strategies, ensuring they directly address the specific challenges and opportunities identified within the Addis Ababa context. Furthermore, this section outlines the conceptual validation inherent in grounding the framework firmly in the empirical data gathered from the target population, ensuring its relevance and potential practicality for stakeholders involved in Mega projects in the region.

#### **4.6.1 Synthesis of Findings Informing the Framework**

The development of the strategic framework is directly informed by a convergence of findings from this study and the broader literature. The assessment of current material management practices (Objective 1, Section 4.3) revealed significant weaknesses, particularly in areas requiring systematic processes, data management, and technological integration. Low RII scores for technology use (software, digital tools, ICT), real-time inventory tracking, systematic data collection (quality, waste), and waste segregation highlighted a considerable lag in adopting modern techniques. Foundational procurement aspects showed relative strength but still indicated only partial implementation.

The analysis of barriers (Objective 2, Section 4.4) identified dominant impediments perceived by stakeholders. High-ranking barriers included BIM-specific challenges (lack of capable subcontractors, unclear legal framework, risk/cost allocation difficulties), a lack of standardization (tools, data, DTs), deficits in skills and awareness, significant cost factors (initial, acquisition, maintenance), and technical/infrastructure limitations (non-availability of tech, obsolescence, integration difficulties). Organizational factors like lack of commitment from leadership and industry fragmentation also featured prominently. The low digital familiarity reported among

respondents (Section 4.2.4) directly correlated with the high significance attributed to barriers like lack of awareness and skills.

The prioritization of digital technologies (Objective 3, Section 4.5) showed a clear preference for tools perceived as established or foundational, such as Bar-coding, Digital Project Management systems, Microsoft Excel, BIM, Digital Documentation, ERP software, and Mobile Devices. More advanced technologies like AI, IoT, Blockchain, and Digital Twins were ranked lower, likely reflecting the identified barriers related to cost, skills, infrastructure, and standardization, as well as the prevailing low digital literacy. Variability in perceptions, indicated by standard deviations, also suggested differing views among stakeholder groups regarding the importance or applicability of certain technologies. Relevant themes from the literature consistently underscored the importance of adequate training, supportive policy environments, stakeholder collaboration, addressing cost concerns, and often adopting a phased implementation approach for digital transformation in construction, particularly in developing contexts (Belete, 2020; Belay et al., 2021; Bui et al., 2016).

To provide an empirical justification for the framework's structure, Spearman's Rank Correlation Coefficient analysis was conceptualized to link these findings (though detailed tables are presented elsewhere, the conceptual links are discussed here). Significant correlations were anticipated between specific variables. For instance, a negative correlation between the low RII score for 'Tracking and Control' practices and the high RII score for the barrier 'Lack of proper information management systems' would empirically link operational deficiency with a perceived systemic barrier. Similarly, a positive correlation between the high RII score for the 'High Cost' barrier and lower importance ratings for expensive technologies like 'ERP' or 'Digital Twins', alongside a positive correlation between the 'Lack of Skills' barrier and high importance ratings for user-friendly 'Mobile Devices' or basic 'Bar-coding', would demonstrate how perceived barriers influence technology preferences. Furthermore, negative correlations between weak practices like 'Waste Management' (low RII) and high importance ratings for technologies like 'BIM for quantity optimization' or potentially 'AI for waste reduction' would highlight the perceived technological solutions for specific operational problems. These empirical relationships provide a data-driven rationale for the framework's components. For example, demonstrating a statistical link between poor tracking practices, the perceived barrier of inadequate systems, and the high importance assigned to tracking technologies (like Barcoding, Mobile Apps, potentially RFID later) justifies

including 'Technology-Enabled Tracking' and addressing 'Information Management Systems' as core elements within the strategic framework.

#### **4.6.2 The Proposed Strategic Framework**

Synthesizing the empirical findings, correlation insights, and literature review, a strategic framework for digital material management in Addis Ababa's Mega projects is proposed, as visually represented in Figure 4.1.

This framework adopts a phased and iterative approach, recognizing the need for foundational work before advancing to more complex implementations, and incorporates continuous learning and adaptation. It comprises six interconnected phases or pillars:

##### **Phase 1: Foundational Assessment & Contextualization**

This initial phase focuses on understanding the current landscape. Key strategies involve: *Assessing Current MM Practices* to identify specific weaknesses (informed by Obj 1 findings like low RII for tracking); *Analyzing Existing IT Infrastructure & Digital Literacy* (addressing low familiarity from Sec 4.2.4 and infrastructure barriers from Obj 2); *Identifying Specific Project Needs & Constraints* relevant to Mega projects; and developing a *Stakeholder Analysis & Engagement Plan* involving key players like contractors, government agencies, and consultants (informed by Sec 4.2.3).

##### **Phase 2: Strategic Planning & Technology Selection**

Building on the assessment, this phase defines the direction. Strategies include: *Defining Clear Objectives & KPIs* for digital material management improvements (targeting Obj 1 weaknesses); *Prioritizing Digital Technologies* with an initial focus on high-ranked, foundational tools (Barcoding, PM Systems, Excel, BIM, Docs, ERP, Mobile, as per Obj 3); *Conducting Cost-Benefit & Risk Analysis* for selected technologies (addressing Obj 2 barriers like cost and BIM risks); and *Developing a Phased Adoption Roadmap* that starts with foundational tools and progresses towards more advanced ones.

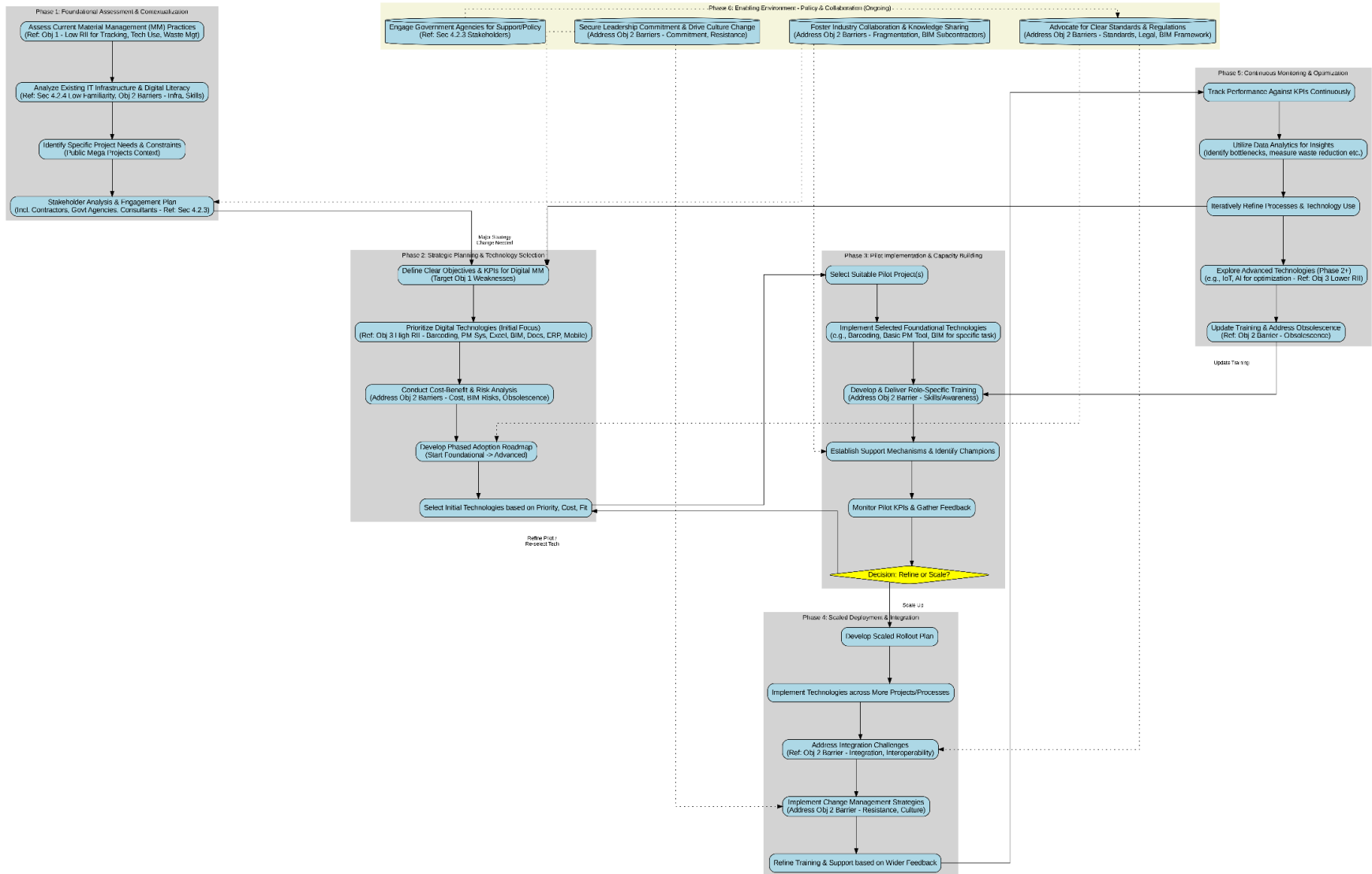


Figure 4. 1 A strategic framework for digital technologies adoption in material management

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#### Phase 3: Pilot Implementation & Capacity Building

This phase involves testing and preparation before broad deployment. Key strategies are: *Selecting a Suitable Pilot Project* to test technologies in a controlled environment; *Implementing Selected Foundational Technologies* within the pilot (e.g., Barcoding, basic PM tool, specific BIM use case); *Developing and Delivering Role-Specific Training* (directly addressing the critical 'Lack of Skills/Awareness' barrier from Obj 2 and low familiarity); and *Establishing Support Mechanisms & Identifying Champions* to drive adoption and assist users.

#### Phase 4: Scaled Deployment & Integration

Based on successful pilot results, this phase expands the implementation. Strategies include: *Developing a Scaled Rollout Plan*; *Implementing Technologies across More Projects/Processes*; *Addressing Integration Challenges* between different digital tools and existing systems (tackling Obj 2 barriers like integration and interoperability); *Implementing Change Management Strategies* to manage resistance and foster acceptance (addressing Obj 2 barriers like resistance and culture); and *Refining Training & Support* based on wider feedback.

#### Phase 5: Continuous Monitoring & Optimization

Digital implementation is an ongoing process. This phase involves: *Tracking Performance Against KPIs Continuously* (using data generated by the digital tools); *Utilizing Data Analytics for Insights* to identify bottlenecks, measure improvements (e.g., waste reduction), and inform decisions; *Iteratively Refining Processes & Technology Use* based on performance data; and *Exploring Advanced Technologies* (like IoT, AI – lower ranked in Obj 3) once a solid foundation exists.

#### Phase 6: Enabling Environment - Policy & Collaboration (Ongoing)

This overarching pillar addresses systemic issues throughout the process. Key strategies focus on: *Engaging Government Agencies for Support/Policy changes*; *Securing Leadership Commitment & Driving Culture Change* (addressing Obj 2 barriers); *Fostering Industry Collaboration & Knowledge Sharing* (tackling fragmentation, BIM subcontractor issues identified in Obj 2); and *Advocating for Clear Standards & Regulations* (addressing critical Obj 2 barriers related to standards and legal frameworks for BIM).

### **4.6.3 Discussion of the Strategic Framework**

The proposed strategic framework is intentionally tailored to the specific context of Mega building projects in Addis Ababa. It directly confronts the identified low digital literacy (Section 4.2.4) by emphasizing foundational assessments, phased adoption starting with simpler technologies (Bar-coding, Excel, PM systems), and robust, role-specific training programs (Phase 3). It targets the dominant barriers identified in Objective 2, with specific strategies aimed at overcoming the lack of skills and awareness, addressing cost concerns through analysis and phased approaches, tackling standardization and legal gaps via advocacy (Phase 6), and managing BIM-specific ecosystem challenges through collaboration and pilot projects. The

framework acknowledges the diverse stakeholder mix (Section 4.2.3) by incorporating stakeholder analysis (Phase 1) and promoting ongoing collaboration and communication (Phase 6).

The potential contribution of this framework is significant. By systematically guiding the adoption of appropriate digital technologies, it aims to enhance material management efficiency through better tracking, planning, and coordination, thereby reducing material waste and associated costs. Improved data accuracy and accessibility facilitated by digital tools can lead to better cost control and decision-making. Fostering digital transformation through this structured approach can contribute to modernizing the Ethiopian construction industry, making public projects more effective and sustainable.

The practical implications vary for different stakeholders. Contractors will need to invest in technology and training, adapt their processes, and collaborate on standards. Government Agencies play a crucial role in providing policy support, potentially mandating certain standards or technologies (like BIM), and driving adoption through procurement practices. Consultants can contribute through digital design expertise, technology advisory, and supporting implementation and training. Successful implementation requires a collective effort.

However, certain limitations must be acknowledged. The framework's success hinges on genuine commitment and resource allocation from all stakeholders, particularly government agencies and senior management within construction firms. Overcoming ingrained resistance to change and fostering a collaborative culture (addressed in Phases 3, 4, and 6) remain significant challenges. The framework provides a strategic guide, but its detailed implementation will require further refinement based on the specific dynamics of individual projects and evolving technological landscapes. Continuous evaluation and adaptation, as built into Phase 5, will be essential for long-term success.

## CHAPTER FIVE

### CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 Conclusions

This study investigated the applications of digital tools and technologies in material management systems, focusing specifically on Mega-building construction projects in Addis Ababa, Ethiopia. Through a mixed-methods approach incorporating questionnaire surveys, semi-structured interviews, and document review, the research systematically addressed its objectives, leading to the following key conclusions:

Regarding the assessment of current material management practices (Objective 1), the study concludes that these practices within Addis Ababa's Mega-building projects are predominantly characterized by traditional, often manual, methods exhibiting significant deficiencies.

- The overall implementation level of assessed practices is low, with Relative Importance Index (RII) scores for most practices falling below 0.5 (ranging from 0.3000 to 0.5524), indicating operations largely between minimal and partial application.
- Critical areas requiring systematic processes, particularly technological integration, demonstrate marked underdevelopment, exemplified by low RII scores for general technology use (RII=0.3190), systematic inventory tracking (RII=0.3000), and Information and Communication Technology (ICT) utilization for data sharing (RII=0.3000).

Concerning the identification and analysis of barriers hindering digital technology adoption (Objective 2), the research concludes that a complex and interconnected set of highly significant barriers (RII range: 0.6143-0.8762) impedes progress.

- Critical obstacles include challenges specific to the Building Information Modeling (BIM) ecosystem, such as the lack of capable subcontractors, ambiguity in legal frameworks, and difficulties in risk/cost allocation, which collectively ranked highest with an RII of 0.8762.
- A fundamental lack of standardization for tools and methodologies (RII=0.8619), the non-availability of needed digital technologies (RII=0.8762), and significant deficits in

essential digital skills and awareness among professionals (RIIs  $\leq 0.8571$ ) – strongly correlating with a low reported digital familiarity (64.3% of respondents unfamiliar) – are major impediments.

- Financial constraints, including high initial and ongoing costs, alongside prevailing technical/infrastructure limitations, further compound these challenges.

In terms of identifying and prioritizing key digital technologies (Objective 3), the study concludes that stakeholders in this context demonstrate a clear preference for foundational and practical digital tools perceived to address immediate operational needs.

- Technologies such as Bar-coding (RII=0.8190), Digital Project Management Systems (RII=0.8095), Microsoft Excel Spreadsheets (RII=0.8000), and BIM (RII=0.7905) were ranked highest in importance.
- Conversely, more advanced technologies like the Internet of Things (IoT) (RII=0.4667) are currently perceived as significantly less important, a prioritization strongly influenced by prevailing low digital literacy and the aforementioned barriers.

Finally, regarding the development of a strategic framework (Objective 4), the study concludes that a context-specific, phased, and iterative strategic approach is essential for successfully guiding the implementation of digital technologies in this environment. The developed six-phase framework, directly informed by the empirical findings on current practices, dominant barriers, and technology priorities, offers a tailored roadmap. It emphasizes starting with foundational assessments and technologies, prioritizing capacity building, utilizing pilot projects, addressing integration challenges during scaled deployment, ensuring continuous improvement through monitoring, and actively fostering an enabling environment through policy advocacy and collaboration.

## **5.2 Recommendations**

Based on the conclusions drawn from this research, which highlight significant deficiencies in current material management practices, a low level of digital literacy, and specific barriers to technology adoption in Addis Ababa's Mega-building projects, the following actionable recommendations are proposed, categorized into short-term and long-term actions for key stakeholders:

- a) Short-Term Actions (Immediate to 1 Year) - For Contractors and Consulting Firms:
- Immediately focus investment and implementation efforts on the highly-ranked, foundational digital tools identified (Bar-coding, Digital PM Systems, Excel, basic BIM, Digital Documentation, ERP, Mobile Devices). This directly addresses the study's finding of a preference for practical solutions to immediate weaknesses in tracking (e.g., inventory RII=0.3000) and planning.
  - Initiate targeted, role-specific training programs focused on enhancing proficiency with these prioritized foundational tools. This is crucial given the identified low digital familiarity (64.3% unfamiliar) and the high-ranking barrier of skills/awareness deficits (RIIs  $\leq 0.8571$ ).
  - Implement pilot projects to test and refine the application of simpler digital tools (e.g., bar-coding for a specific material category, a basic PM system module) in controlled environments before wider adoption. This allows for learning and adaptation, mitigating risks associated with the "non-availability of tech" barrier (RII=0.8762).
- b) Short-Term Actions (Immediate to 1 Year) - For Government Agencies (Clients, Oversight Bodies, Policymakers) & Industry Associations:
- Launch awareness campaigns and disseminate best-practice guides focused on the practical benefits of the prioritized foundational digital tools, tailored to the local context. This directly tackles the "lack of awareness" barrier (RII=0.8571).
  - Consider incorporating requirements or incentives for basic digital material management practices (e.g., digital submission of key documents) in public procurement policies to stimulate initial adoption.
- c) Long-Term Actions (1-5 Years and Beyond) - For Contractors and Consulting Firms:
- Progressively move towards systematic digital management of all essential project documents to improve accessibility, reduce errors, and establish a foundation for more advanced digital integration, addressing the low RII for technology use (RII=0.3190).
  - Develop and implement comprehensive, ongoing training programs to build capacity for more advanced digital tools (e.g., advanced BIM functionalities, data analytics) as foundational digital practices mature.
- d) Long-Term Actions (1-5 Years and Beyond) - For Government Agencies (Clients, Oversight Bodies, Policymakers) & Industry Associations:

- Actively engage with all industry stakeholders to develop clear national or sector-specific standards and guidelines for digital technology application, particularly addressing gaps identified for BIM implementation (legal aspects, data formats, subcontractor requirements – RII=0.8762 for BIM ecosystem challenges).
- Facilitate platforms and initiatives that encourage collaboration and knowledge sharing among industry players to address common challenges, especially those related to the BIM ecosystem (RII=0.8762) and standardization (RII=0.8619).
- Secure and visibly demonstrate long-term commitment from senior leadership towards digital transformation, allocating necessary resources, championing change, and exploring policies to support the adoption of more advanced technologies as the industry's digital maturity increases.
- Collaborate with educational institutions to integrate digital construction skills into curricula, addressing long-term competency gaps.

### **5.3 Recommendations for Future Research Works**

While this study provides valuable insights into the application of digital technologies for material management in Addis Ababa's Mega building projects, it also opens avenues for further research. The following areas are recommended for future investigation:

- Conduct longitudinal case studies involving the practical implementation of the proposed strategic framework within specific Mega projects in Addis Ababa to assess its effectiveness, identify implementation challenges, and refine its components based on real-world application.
- Undertake research focused on quantitatively measuring the impact of adopting specific prioritized digital tools (e.g., Bar-coding, Digital PM systems, BIM) on material management performance indicators such as cost savings, waste reduction, schedule adherence, and inventory accuracy within the Ethiopian context.
- Once foundational digital practices become more established, conduct in-depth feasibility studies on the application, specific barriers, implementation strategies, and potential return on investment for advanced technologies (IoT, AI, Blockchain, Digital Twins) in the context of Ethiopian construction material management.

- Perform comparative research examining digital technology adoption in material management across different types of construction projects (e.g., private sector, infrastructure) and different regions within Ethiopia, as well as comparisons with other developing countries, to understand contextual differences and identify broadly applicable lessons.
- Investigate the challenges and opportunities for extending digital material management practices beyond the project site to integrate the entire supply chain, including suppliers, manufacturers, and logistics providers, within the Ethiopian construction industry.
- Analyze the specific impact of different government procurement strategies or policy interventions on the rate and effectiveness of digital technology adoption for material management in public projects.

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# APPENDICES

## Appendix A. Questionnaire Survey



### Questionnaire Survey

Thesis Title: “A study on applications of digital tools and technologies in material management system: the case of Mega building construction projects in Addis Ababa”

#### Introduction

Dear Participant,

My name is Mesfin Girma, a Master's student at Adama Science and Technology University. I am conducting a research study on the " A study on applications digital tools and technologies in material management system: the case of Mega building construction projects in Addis Ababa."

Your participation in this survey is greatly appreciated. Your responses will be kept confidential and used solely for academic purposes. It will take approximately 15-20 minutes to complete.

Thank you for your valuable time and contribution.

If you have any questions or concerns, please feel free to contact me at +251930003606.

## Section 1: Respondent Profile

a) Role in Construction Project: (Choose one)

- Project Manager
- Material Manager
- Procurement Officer
- Site Engineer
- Quantity Surveyor
- Other (Please specify: \_\_\_\_\_)

b) Years of experience in construction

- Less than 3 years
- 3-5 years
- 6-10 years
- More than 10 years

c) Organization type (Choose one)

- Construction Company
- Government Agency
- Consulting Firm
- Other (Please specify: \_\_\_\_\_)

d) Familiarity with digital tools and technologies in construction

- Very Familiar
- Familiar
- Neutral
- Unfamiliar
- Very Unfamiliar

## Section 2: Assessment of Current Practices of Material Management

This section of the questionnaire focuses on assessing the current practices of material management.

**Instructions:** Measures how fully a system or procedure is in place or utilized using extent of implementation scale:

- ~ **5 - Fully Implemented:** The practice/system is completely established and consistently utilized as intended.
- ~ **4 - Largely Implemented:** The practice/system is mostly established and utilized, with minor gaps.
- ~ **3 - Partially Implemented:** The practice/system is established or utilized in some areas or aspects, but significant gaps exist.
- ~ **2 - Minimally Implemented:** Initial steps have been taken, but the practice/system is barely established or utilized.
- ~ **1 - Not Implemented:** The practice/system does not exist or is not utilized at all.

No.	Criteria to assess current practices of material management	1	2	3	4	5
<b>A. Planning</b>						
1	A documented material management plan exists and is utilized for the project.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	Material requirements planning is integrated with the overall project schedule and work breakdown structure.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	Material demand forecasting is conducted based on project progress and schedules.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	Specific budgets for material procurement and usage are established and systematically monitored.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>B. Procurement</b>						
5	Defined procedures exist and are followed for material ordering and purchasing.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

6	A formal and transparent process is used for selecting and evaluating material suppliers.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	Contracts clearly outlining quality, quantity, delivery terms, and compliance requirements are used for securing material supply.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	Material lead times are adequately considered during procurement planning and scheduling.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	Systematic checks are performed to ensure purchased materials conform to specified requirements before delivery confirmation.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	There is access to a sufficient range of reliable suppliers for key construction materials.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### C. Handling and On-site Logistics and Transportation

11	Established safety procedures are followed during material handling activities (loading, unloading, moving).	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12	Appropriate material handling equipment is available and utilized effectively.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
13	The construction site layout is planned to ensure the efficient and safe flow and movement of materials.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14	Efficient methods are used for transporting materials from storage areas to the point of use within the site.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### D. Storage

15	Designated, adequate, and secure storage areas are provided for different types of construction materials.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16	Measures are consistently taken to protect stored materials from damage, deterioration, theft, and environmental factors.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

17	Storage areas are organized systematically for easy identification, retrieval, and inventory checking of materials.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18	Specific procedures (stacking height, covering) are followed for storing sensitive materials like cement.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### E. Tracking and Control

19	Accurate records are maintained for material receipt, issuance, and current inventory levels.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
20	Systematic methods (manual or digital) are used for real-time or near real-time tracking of on-site inventory.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
21	Material quality is systematically inspected upon receipt at the site and before installation/use.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
22	The performance of material management processes (delivery timeliness, storage conditions) is regularly monitored and evaluated.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
23	Data related to material quality (test results, inspection reports) is systematically collected and reviewed.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

### F. Waste Management

24	Strategies are implemented to minimize material waste during ordering.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25	Strategies are implemented to minimize material waste during site activities (controlling mixing quantities, proper cutting).	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
26	Established procedures exist and are followed for managing on-site construction waste.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
27	Construction waste is systematically segregated (separating wood, metal, concrete) for disposal, reuse, or recycling.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
28	Quantities of generated construction waste are measured and recorded.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## G. Technology Use

29	Specific software is utilized for material management activities (e.g., Enterprise Resource Planning, inventory management software).	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
30	Information and Communication Technology is utilized for sharing material-related data among stakeholders (e.g., shared drives, communication platforms).	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
31	Digital tools or technologies are currently employed in any aspect of material management (e.g., Building Information Modelling, Radio Frequency Identification, mobile apps, drones).	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## H. Documentation & Information

32	Sufficient and accurate information (e.g., specifications, quantities) is available in project drawings and documents for effective material management.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
33	Contract documents related to materials are generally free from errors or ambiguities that could impede material management.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## I. Coordination

34	Material management activities are effectively coordinated among different project stakeholders (e.g., design team, procurement, site team, suppliers).	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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### Section 3: Potential Barriers hindering the Adopting Digital tools and Technologies

**Instructions:** Please indicate the extent to which you agree with each of the following statements regarding the potential barriers hindering the adopting digital technologies in managing construction materials.

*Please use the following scale:*

- 1 = Strongly Disagree
- 2 = Disagree
- 3 = Neutral
- 4 = Agree
- 5 = Strongly Agree

No.	Barriers hindering the adoption of digital tools and technologies	1	2	3	4	5
1	High cost of acquiring needed digital technologies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	High cost of maintaining digital technologies needed	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	Incompatibility and interoperability problems	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	Lack of data interoperability	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	Data security barriers/concerns/Lack of trust in data security and privacy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	Lack of proper information management systems	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	Difficulties in systems integration	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	Uncertainties with data quality and reliability	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	Lack of standard tools and methodologies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10	Absence of data standardization	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11	Software programs are complex and are not easy to use	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12	Rapid change in ICT technologies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

13	Software and reliability problems	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14	High rate of obsolescence of ICT products	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15	Disposal of devices (technology disposal)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16	Lack of proper digital training/Lack of skills and competencies/Inadequate technical know-how	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17	Resistance to change	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18	High initial cost/investment difficulties	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
19	Lack of awareness of the needed digital technologies among experts/Lack of awareness of benefits	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
20	Clients' unwillingness to incur extra cost/Lack of client interest/demand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
21	Lack of commitment from stakeholders/top management	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
22	Legal issues associated with the use of digital technologies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
23	Ethical and privacy concerns	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
24	Lack of vision and strategy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25	Cultural differences	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
26	Lack of transparency	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
27	Nature of the VM exercise/complexity of VM and technologies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
28	Poor digital culture of the construction industry	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
29	Lack of audit trail	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
30	Data ownership and confidentiality	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
31	Lack of legal framework for BIM application	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
32	Slow uptake of new technologies in the construction industry	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

33	Involvement of fragmented parties	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
34	Lack of CE regulations	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
35	Lack of standardization for DTs	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
36	Lack of recognition for DTs	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
37	Lack of circularity in product design	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
38	Fragmented nature of the construction industry	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
39	Difficulty in allocating & sharing BIM-related risks & costs	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
40	Lack of detailed processes or workflow to apply BIM technology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
41	Lack of subcontractors who can use BIM technology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
42	Reluctance to introduce new technology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
43	Insufficient support from top management	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
44	Failure to envisage the benefits of digital technologies to the VM exercise	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
45	Non-availability of needed digital technologies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

## Section 4: Evaluation of Digital Tools and Technologies

**Instructions:** The following table presents a list of digital tools and technologies that can be adopted in building construction material management. Even if you are not fully familiar with all of these technologies, please consider the potential impact of each tool based on the key benefit it offers for improving overall material management in Mega building construction projects in Addis Ababa.

*For each digital tool or technology listed, please rate its importance based on the described key benefit using the following scale:*

- 1 = Not at all Important
- 2 = Slightly Important
- 3 = Moderately Important
- 4 = Important
- 5 = Very Important

No.	Digital tool/technology		Key benefit for construction materials management	1	2	3	4	5
1	Artificial Intelligence (AI)	Analyzes large datasets to identify patterns, forecast demand, and optimize processes.	Predictive analysis for optimized material procurement, inventory management, and waste reduction.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	Enterprise Resource Planning (ERP) software	Integrated software that manages a company's core business operations.	Streamlines business processes, improves data visibility, and enhances resource allocation for efficient material management.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	Drones	Unmanned aerial vehicles that capture aerial images and data of construction sites.	Enhanced site monitoring and data collection for improved material quantity surveying, progress monitoring, and site inspection.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	Photogrammetry	Technique using photographs to create 3D models and measurements of construction sites.	Aids in material quantity surveying, progress monitoring, and site inspection for better material management.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

5	RFID (Radio Frequency Identification)	Technology that uses electromagnetic fields to automatically identify and track materials.	Automated tracking to significantly improve inventory management and reduce material losses.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
6	3D Printing	Additive manufacturing process that builds three-dimensional objects from a digital file.	Enables on-demand production of customized building components, reducing waste and optimizing material use.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
7	Bar-coding	Optical scanning technology for identifying and tracking materials using barcodes.	Improves accuracy and efficiency in material tracking and inventory management.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
8	Mobile devices (PDAs, PDTs, tablets, smartphones)	Portable electronic devices that provide real-time access to project information and material data.	Improved communication and collaboration among site personnel, enabling quicker decision-making related to material handling, storage, and application.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
9	GPS (Global Positioning System)	Satellite-based navigation system that provides location and time information.	Enables accurate tracking of material deliveries and on-site material location.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
10	Sensors	Devices that detect and measure physical quantities and convert them into signals.	Real-time data collection on material conditions, usage, and environmental factors for improved monitoring and control.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
11	IoT (Internet of Things)	Network of interconnected devices and sensors that enable data collection and exchange.	Real-time collection and exchange of data for optimized material logistics and monitoring of material quality.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
12	BIM (Building Information Modeling)	Digital representation of a building that includes information about materials, quantities, and specifications.	Improved visualization and data sharing to enable better coordination of material procurement and delivery.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
13	Automated tracking systems	Systems that automatically monitor and record the movement of materials.	Enhances efficiency and accuracy in material tracking and inventory control.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>

14	Web portals	Online platforms that provide access to project information and facilitate communication among stakeholders.	Centralized access to information and improved communication for better material coordination.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
15	Wireless systems	Technologies that enable communication and data transfer without physical cables.	Facilitates real-time data sharing and communication on construction sites for efficient material management.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
16	Digital project management systems	Software applications that aid in planning, organizing, and managing construction projects.	Streamlines project workflows, improves task management, and enhances collaboration for effective material management.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
17	Real-time location sensing (RTLS)	Technology that provides real-time tracking of the location of objects or people.	Enables precise tracking of materials on construction sites, reducing losses and improving logistics.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
18	Cloud computing	Technology that enables the storage and access of data and applications over the internet.	Enhanced collaboration and real-time information sharing among project stakeholders for efficient material management.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
19	Blockchain technology	Decentralized digital ledger that records transactions securely and transparently.	Enhances transparency and traceability in the material supply chain, reducing fraud and improving accountability.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
20	Supply chain management software	Applications that optimize the flow of goods and services from suppliers to customers.	Improves efficiency in material procurement, logistics, and supplier collaboration.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
21	Digital Twins (DTs)	Virtual replicas of physical assets, processes, or systems.	Enables real-time monitoring, simulation, and optimization of material-related processes.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
22	Handheld devices	Portable electronic devices used for data capture and information access on-site.	Facilitates efficient material tracking, inspection, and data recording.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>

23	AR (Augmented Reality) headsets	Wearable devices that overlay digital information onto the real-world view.	Enhances visualization and information access for material handling, installation, and inspection.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
24	Digital documentation	Electronic management of project documents, including material specifications, and records.	Improves accuracy, accessibility, and organization of material-related information.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
25	Smart contracts	Self-executing contracts with the terms directly written into code.	Automates and secures material transactions, improving efficiency and reducing disputes.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
26	Asset tagging solutions	Technologies used to identify and track assets, including materials.	Enhances asset visibility, reduces losses, and improves inventory management.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
27	Microsoft Excel Spreadsheet	A software program used for organizing, analyzing, and storing data in tabular form.	It helps in storing and analyzing material related data.	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>

