The Impact of Building Information Modeling (BIM) Adoption on Cost and Schedule Performance in Addis Ababa Real-estate Projects

by; -
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Addis Ababa, Ethiopia

June / 2026

Declaration

I, the undersigned, hereby declare that this thesis entitled *"The Impact of Building Information Modeling (BIM) Adoption on Cost and Schedule Performance in Addis Ababa Real-estate Projects."* Is my original work and the best of my knowledge has not been presented for a degree by any other person, and that all the source of material used for have been dually acknowledged.

Declared by

Hailemikael Tekeste Kasa

June, 2026



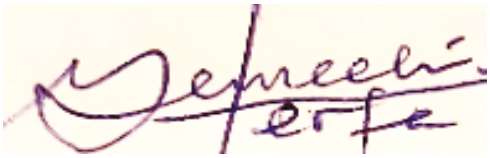
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This is to certify that the thesis carried out by **Hailemikael Tekeste Kasa** on the topic entitled: *"The Impact of Building Information Modeling (BIM) Adoption on Cost and Schedule Performance in Addis Ababa Real-estate Projects."* is his original work and is suitable for submission for the award of Executive Master of Business Administration (E-MBA).

Advisor

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ABSTRACT

The Ethiopian construction sector suffers from chronic cost overruns (36.8%) and time overruns (146.6%), largely due to poor design documentation. Building Information Modeling (BIM) is globally recognized as a solution, but empirical evidence in Ethiopia is lacking. This thesis investigates the direct and mediated effects of BIM adoption on ***cost and schedule performance*** *in Addis Ababa real estate projects, focusing on the mediating roles of rework reduction and improved collaboration.*

A quantitative cross-sectional survey was conducted with 102 construction professionals (project managers, engineers, architects, contractors). Data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) with Smart-PLS 4.

Results: *BIM adoption has a significant direct positive effect on cost and schedule performance (β=0.197, p=0.003). Rework reduction significantly mediates the BIM–performance relationship (indirect β = 0.271, $p < 0.001$). However, improved collaboration does not mediate this relationship (indirect β = 0.033, p = 0.216). The model explains 67.3% of the variance in project performance (R^2=0.673), with large predictive relevance (Q =0.475).*

CONTENTS

ABSTRACT I
LIST OF TABLES IV
LIST OF ACRONYMS V
ACKNOWLEDGMENTS VII
CHAPTER I: INTRODUCTION 1
1.1 Background of the Study 1
1.2 Problem Statement 2
1.3 Research Objectives 3
1.4 Research Questions and Hypotheses 4
1.5 Significance of the Study 4
1.6 Scope of the Study 5
CHAPTER TWO: REVIEW OF RELATED LITERATURE 6
2.1 Introduction 6
2.2 Theoretical Foundations for the Study 7
2.3 Global Evidence on BIM and Project Performance 10
2.4 BIM in Developing Economies and in the African Context 12
2.5 BIM in the Ethiopian Context 13
2.6 Synthesis and Identification of the Research Gap 14
2.7 Conceptual Framework 16
CHAPTER THREE: METHODOLOGY 18
3.1 Introduction 18
3.2 Research Design 19
3.3 Research Population and Sampling Strategy 21
3.3.1 Target and Accessible Population 21
3.3.2 - Sample Design/Technique: Practical / Mixed-Methods 22
3.3.3 Sample Size Determination for PLS-SEM Analysis 22
3.4 Collecting Data: Developing and Administering Instruments 24
3.4.1 Data Source and Survey Instrument 24
3.4.2 Pilot Testing, Validation and Administration of Results 25
3.5 Data Analysis: A PLS-SEM Approach with Smart PLS 26
3.6 Scale Reliability and Validity 27
3.7 Ethical Considerations 28

CHAPTER FOUR: RESULTS AND DISCUSSION 29
4.1 Introduction 29
4.2 Response Rate and Demographic Profile of Respondents 30
4.2.1 Response Rate 30
4.2.2 Demographic Characteristics of Respondents 30
4.3 Assessment of the Measurement Model (Outer Model) 32
4.3.1 Factor Loadings 33
4.3.2 Reliability and Convergent Validity 34
4.3.3 Discriminant Validity 35
4.4 Assessment of the Structural Model (Inner Model) 37
4.4.1 Assessment of Collinearity (VIF) 37
4.5.2 Path Coefficients and Hypothesis Testing 39
1. Path: BIM → COL ($\beta = 0.061$, $p = 0.236$) 40
4.5.7 Mediation Analysis (Specific Indirect Effects) 43
4.5.3-Model Explanatory Power: Variance Explained (R^2) 46
4.5.4 Effect Sizes (f^2) 47
4.5.5 Predictive Relevance (Q^2) 48
4.5.6 Model Fit (SRMR) 49
Interpretation of Results 50
4.6 Discussion of Findings 50
4.6.2 Mediating Role of Rework Reduction (H_2) 51
4.6.3 Non-Significant Mediating Role of Improved Collaboration (H_3) 53
CHAPTER FIVE: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS 58
5.1 Introduction 58
5.2 Summary of Key Findings 58
5.3 Conclusions 59
5.4 Recommendations 62
5.5 Limitations of the Study 65
References 68
Appendix 1 72

LIST OF TABLES

Table Number	Title	Page
Table 3.1	the reasons as to how Smart-PLS is appropriate	20
Table 3.2	the key sampling decisions and their justifications	23
Table 4.1	Distribution of Respondents by Years of Experience	30
Table 4.2	Distribution of Respondents by Company Type	31
Table 4.4	Distribution of Respondents by Firm Size	32
Table 4.5	Outer Loadings (Factor Loadings)	32
Table 4.6	Reliability and Convergent Validity (CR, AVE)	33
Table 4.6	Discriminant Validity – HTMT Ratio	35
Table 4.7	Discriminant Validity – Fornell- Larcker Criterion	36
Table 4.8	Collinearity Statistics (VIF)	36
Table 4.9	Direct Effects – Path Coefficients and Significance	38
Table 4.10	Specific Indirect Effects (Mediation)	40
Table 4.11	Coefficient of Determination (R^2)	46
Table 4.13	Effect Sizes (f^2)	47
Table 4.14	Predictive Relevance (Q^2)	49
Table 4.15	Model Fit – SRMR	50
Table 4.16	Summary of Structural Model Quality Metrics	54
Table 4.17	Decomposition of Effects (Direct, Indirect, Total)	55
Table 5.1	Summary of Key Findings	58
Table 5.2	Recommendations for Contractors and Developers	62
Table 5.3	Recommendations for Industry Associations and Training Institutions	62
Table 5.4	Recommendations for Policymakers	63
Table 5.5	Recommendations for Future Researchers	64
Table 5.6	Limitations of the Study	66

LIST OF ACRONYMS

Acronym	Full Meaning
AEC	Architecture, Engineering, and Construction
AVE	Average Variance Extracted – a measure of convergent validity
BIM	Building Information Modeling – a digital process for managing construction information
CI	Confidence Interval – a range of values used to estimate a population parameter
COL	Improved Collaboration – one of the mediator variables in this study
CP	Cost Performance – one of the outcome variables in this study
CR	Composite Reliability – a measure of internal consistency reliability
EACE	Ethiopian Association of Civil Engineers
ECCA	Ethiopian Construction Contractors Association
f^2	Effect size – measures the practical significance of a predictor
GDP	Gross Domestic Product – the total value of goods and services produced in a country
H_1, H_2, H_3, H_4	Research hypotheses tested in this study
HTMT	Heterotrait-Monotrait ratio – a measure of discriminant validity
ISO	International Organization for Standardization – publishes global standards
MoUI	Ministry of Urban and Infrastructure (Ethiopia)
N	Sample size – the number of respondents in the study
p-value	Probability value – indicates statistical significance ($p < 0.05$ is significant)
PLS-SEM	Partial Least Squares Structural Equation Modeling – the main analysis method
Q^2	Predictive relevance – measures the model's ability to predict new data
R^2	Coefficient of determination – measures how much variance the model explains
RR	Rework Reduction – one of the mediator variables in this study
SJR	SCImago Journal Rank – a measure of journal prestige
Smart-PLS	Software used for PLS-SEM analysis

SP	Schedule Performance – one of the outcome variables in this study
SRMR	Standardized Root Mean Square Residual – a measure of model fit
TAM	Technology Acceptance Model – a theory explaining technology adoption
TTF	Task-Technology Fit – a theory explaining how technology improves performance
UTAUT	Unified Theory of Acceptance and Use of Technology – an extended technology adoption model
VAF	Variance Accounted For – the proportion of total effect explained by mediation
VIF	Variance Inflation Factor – a measure of collinearity
β (beta)	Path coefficient – indicates the strength and direction of a relationship

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CHAPTER I

INTRODUCTION

1.1 Background of the Study

The construction industry is a cornerstone of economic growth and urban development in any nation, serving as a vital driver for job creation and contributing significantly to the gross domestic product (GDP). In Ethiopia, the construction sector plays an equally pivotal role in fostering economic advancement and urbanization. As cities expand and the population grows, the demand for housing and infrastructure continues to rise. According to the Ministry of Urban and Infrastructure (MoUI), construction accounts for approximately **20% of Ethiopia's GDP** and generates **over 10% of national employment (** (All Africa, (News agency; no individual byline), 2025)**)**. With more than 35,000 companies active in the sector, the industry spans a wide range of activities, including infrastructure, mega projects, corridor development, and housing.

However, despite its substantial economic impact, the Ethiopian construction sector faces critical challenges. The sector continues to rely on traditional practices, suffers from poor project completion rates, and struggles with high costs for imported materials. Project delays, cost overruns, and quality issues are prevalent problems that not only affect profitability but also lead to increased housing prices, ultimately slowing down growth in the sector. A detailed case study of Ethiopian public building projects revealed that the degree of time and cost overruns was alarmingly high approximately **146.6% and 36.8% of the original contract**, respectively (Tessema), 2023). Importantly, the study found that problems related to **design documents alone caused 45.3% of time overruns and 51.6% of cost overruns** (Tessema), 2023). These findings highlight that improving the quality of design documentation is essential for mitigating the chronic performance failures that plague Ethiopia's construction sector.

Globally, the adoption of innovative technologies has been essential in addressing these challenges. One such technology is Building Information Modeling (BIM), which has emerged as a transformative digital tool that enhances project delivery and operational efficiency. The International Organization for Standardization (ISO) defines BIM as a "shared digital

representation of a built asset facilitating reliable decision-making" ((ISO), Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 1: Concepts and principles, 2018). BIM enables stakeholders to create, manage, and utilize a comprehensive digital representation of a building throughout its lifecycle, allowing for improved collaboration among architects, engineers, contractors, and owners (Owusu-Manu et al., 2020). In developed countries, BIM has been shown to reduce rework costs by up to 40% through clash detection and improve schedule adherence by an average of 15% through 4D simulation ((Getuli, 2020); (Chen & Luo, 2022)).

However, the situation in developing economies, including Ethiopia, is significantly different. Research in similar African contexts has primarily focused on identifying barriers to BIM adoption rather than measuring its actual impact on project outcomes ((Agyekum, 2023); (Olanrewaju, 2021)). In Ethiopia, awareness of BIM is gradually increasing, but its practical adoption remains limited and poorly understood (Belay, Goedert, Woldesenbet, & Rokooei, 2021). There is a significant gap: a **lack of empirical, quantitative studies that measure the actual impact of BIM on project outcomes in Ethiopia**.

This thesis is therefore positioned at this critical junction. It aims to move beyond merely discussing barriers to quantifying benefits. By providing the first empirical, quantitative evidence for the Ethiopian context, this thesis offers data-driven insights that can inform strategic decision-making for industry stakeholders and guide future policy development.

1.2 Problem Statement

The Ethiopian Real Estate sector has a **chronic difficulty** with budget overruns and project delays (Tessema), 2023). There is a large body of evidence documenting these issues; however, there is **no quantitative/empirical evidence** showing a statistical relationship between different levels of BIM adoption and improvement of cost and schedule performance in Ethiopia.

There are considerable implications of these types of problems for a number of stakeholders: (1) developers receive lower margins or profit due to these problems; (2) contractors incur penalties and damage their reputations when there are delays and cost over-runs; (3) consumers

suffer from inflated prices and delay in receiving services; and (4) Ethiopia will be unable to fulfill its National Development objectives (Belay, Goedert, Woldesenbet, & Rokooei, 2021).

Past research in Ethiopia has identified only the barriers to BIM utilization, including cost, skill gaps, and lack of policy, but did not investigate whether BIM adoption would work or how BIM works in the context of Ethiopia ((Alemayehu, 2022); (Dula, 2024); (Feven,, 2024)). In other parts of the globe, the Technology Acceptance Model (TAM) (Davis, 1989), and Task Technology Fit (TTF) theory (Goodhue, & Thompson,, 1995), have successfully assisted researchers in establishing pathways from BIM usage to project performance. No equivalent research in Ethiopia has been conducted to provide rigorous quantitative empirical evidence on the impact of BIM adoption on costs and schedule.

This study fills this critical void by developing the first quantitative model that links BIM adoption to cost and schedule performance in Addis Ababa real estate projects, while also applying established theoretical frameworks to explain the underlying mechanisms specifically, the mediating roles of rework reduction and improved collaboration.

1.3 Research Objectives

1.3.1 General Objective

To analyze the impact of Building Information Modeling (BIM) adoption on cost and schedule performance in Addis Ababa real estate projects.

1.3.2 Specific Objectives

To assess the current level of BIM adoption among real estate developers and contractors operating in Addis Ababa.

To measure the statistical relationship between the level of BIM adoption and project cost and schedule performance in Addis Ababa real estate projects.

To quantify the extent to which reduced rework and improved collaboration serve as mediators in the relationship between BIM adoption and cost and schedule performance.

1.4 Research Questions and Hypotheses

Research Questions

Q1: What is the current level of BIM adoption among real estate developers and contractors operating in Addis Ababa?

Q2: Is there a statistically significant relationship between BIM adoption and cost and schedule performance?

Q3: To what extent do reduce rework and improved collaboration mediate the relationship between BIM adoption and cost and schedule performance?

Research Hypotheses

This is a quantitative study; therefore, specific hypotheses will be tested:

H_1: BIM adoption has a positive and significant effect on cost and schedule performance.

H_2: The effect of BIM adoption on cost and schedule performance is mediated by a reduction in project rework.

H_3: The effect of BIM adoption on cost and schedule performance is mediated by an improvement in project collaboration.

1.5 Significance of the Study

This research, as a thesis, holds an important place within several populations of interest: while providing practitioners in the **construction industry** with solid, evidence-based, quantitative data regarding the impact of investment in BIM on improved cost and schedule performance. Additionally, for **educators and researchers**, this study serves as a thorough case study regarding the adoption of technology in a developing nation; **policy makers** can use this research to establish realistic national policies, frameworks or incentive programs to enable digital transformation. Lastly, the thesis provides **future researchers** with a reliable quantitative framework that can be adapted, replicated or built upon.

1.6 Scope of the Study

With this research, I will study only how Building Information Modeling (BIM) affects the construction industry's costs and schedules for real estate projects in Addis Ababa, Ethiopia. The study will be limited geographically to Addis Ababa, Ethiopia, which is where the Real Estate planning and developing takes place and the majority of large private construction companies and their associated firms are located. The respondents to this study will be people involved in private real estate building projects, such as project managers, civil engineers, architects, quantity surveyors and contractors. I will not include respondents who work on publicly funded infrastructure projects (roads, dams, bridges, etc.) or for the government, as their procurement and management methods are likely different from those in private real estate projects. The study will use a cross-sectional quantitative research design and data will be collected from all respondents at one point in time using a structured questionnaire. Smart-PLS will be used to analyze the data with PLS-SEM regression model.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

2.1 Introduction

The purpose of the literature review is to provide a connection between this study and the larger body of academic knowledge about Building Information Modeling (BIM). The literature review will raise some important questions: has the impact of BIM been studied before? What do experts in their field say? 6What strategies for success have been utilized in other parts of the world? And particularly, what is not available in Ethiopia? The literature review will demonstrate how theoretical frameworks, global data, and the context of developing economies can be used together to illustrate why research on BIM in Ethiopia is needed and timely.

The construction industry is a major driver of economic development as it creates infrastructure that supports all other industries. However, the construction industry continues to experience problems with delivery, which limits its ability to create the necessary infrastructure. Studies conducted around the world show that construction projects commonly encounter delays and budget overruns, wasting time, money, and resources that prevent nations from achieving their development goals (Owusu-Manu, 2020).

To address these issues that are creating challenges within their industry globally, the construction industry is experiencing a digital transformation globally. Building Information Modeling (BIM) is one of the leading technological and process innovations being utilized in the industry, which has defined BIM as "the collaborative process of creating and utilizing a shared digital model to produce reliable management of project-related information" ((ISO), Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 1: Concepts and principles, 2018). Studies conducted internationally have demonstrated that BIM is a mechanism that can help mitigate many of the specific challenges that exist within the construction industry by creating accurate data for controlling costs and by providing better planning, which will result in fewer delays (Owusu-Manu, 2020).

BIM provides significant value to developed nations; however, the adoption of BIM in developing nations is considerably more complex than in developed nations. Studies conducted in developing countries focus on identifying major barriers rather than measuring the value of BIM. Major barriers related to BIM in developing countries include: lack of technical skills and high cost of using BIM; no government policies supportive of BIM; and no demand from clients for BIM products and services (Agyekum, 2023). As a result of these challenges, there is an extensive knowledge gap in the area of BIM; specifically, there are very few quantitative studies that provide empirical evidence that can demonstrate the value of BIM in developing countries.

Ethiopia is an example of this research gap. The construction industry in Ethiopia has an integral role in the development of the nation but does not have the capabilities necessary to deliver quality projects in a timely manner. Although there is limited research on the level of awareness of BIM in Ethiopia and the barriers to using BIM, there is a defining element missing from the body of literature (Belay, Goedert, Woldesenbet, & Rokooei, 2021). There are almost no quantitative, empirical studies that measure how BIM has impacted the cost and schedule performance of actual construction projects in Ethiopia.

As such, the literature review provides the necessary linkage between the global body of literature and the literature specific to Ethiopia. The literature review will analyze theoretical frameworks for the adoption of technologies, review global research related to how BIM has created an impact, and analyze the specific context of developing nations and BIM in Ethiopia. Ultimately the objective of the literature review is to identify the gap in the research, the lack of empirical evidence showing how BIM affects project outcomes in Ethiopia. By identifying the gap in the research, the literature review demonstrates the need and relevance of the current study by providing the data to facilitate evidence-based practice and policy development in the Ethiopian construction industry.

2.2 Theoretical Foundations for the Study

Theoretical foundations provide an empirical basis from which expectations for a research project can be established. In this research study of Building Information Modeling (BIM) Implementation in Ethiopia, two complementary theories will be utilized. The first theory will

assist in understanding the decisions to adopt BIM as a design tool and the second theory will aid in understanding the effectiveness of BIM once it has been adopted. Together these theories provide a complete framework for both the decision to adopt and the path to successful BIM implementation in Ethiopia.

2.2.1 Technology Acceptance Model (TAM): The "Why Use It?" Theory

The Technology Acceptance Model (TAM) is one of the most widely used theories for explaining how individuals accept newly developed technologies. This theory has a simple core premise: individuals will be more likely to utilize a new technology if the user believes that the new technology will assist him or her, in other words that it is a useful tool, and that the new technology is easy to use (Davis, 1989).

Perceived Usefulness in the Construction Industry in Ethiopia: In the construction industry, usefulness will be defined quite practically. Engineers and contractors will perceive that BIM has utility, that is it will help them with the significant problems associated with construction, including eliminating delays, accurately tracking cost and budgets and reducing errors or rework. Recent research has repeatedly shown that the practicality of the new technologies will be the strong motivating factor in the implementation of new technologies in developing countries (Agyekum, 2023).

Perceived Ease of Use in Ethiopia: The ease of use is heavily dependent on the level of access to external supports. Without adequate training, accessible software and technical support, even the best tool can be perceived as being too complex to use effectively. Therefore, in order for stakeholders (i.e. owners, engineers, architects, and contractors) to adopt and implement BIM for construction, they need to believe that the BIM tool will be useful and that they will be able to utilize it efficiently.

In short, TAM provides a foundation for analyzing the perceptions and intentions of Ethiopian engineers, architects, and contractors with regard to BIM. If an individual does not view BIM as being useful as well as usable, that individual will not adopt BIM, regardless of its worldwide applicability.

2.2.2 Task-Technology Fit (TTF) Theory: The "Will It Work Here?" Theory

TAM describes the intention to use technology whereas TTF or Task-Technology Fit Theory relates to predicting whether or not technology will lead to improved performance. The theory's core premise is that technology will only improve performance if there is a good "fit" or match between the various features of the technology and the task requirements it is supposed to support (Goodhue, & Thompson,, 1995).

BIM (Building Information Modeling) is more than just one single tool; it's a group of capabilities. The TTF theory asks; are the correct capabilities or features of BIM matched up with the appropriate tasks for that specific project?

Good fit example: In the case where 3D coordination tools associated with BIM are used to identify clashes between pipes and beams prior to the start of the construction process (which is a very complex and high-risk undertaking in terms of errors), there would be a very strong potential for improved schedule and cost performance.

Poor fit example: In the case where BIM and its advanced capabilities are not utilized, and only basic 3D visualizations for the purpose of producing drawings are created with BIM; however, manual methods are still utilized to estimate costs and schedule, this would result in poor TTF and would not result in any measurable value obtained from using BIM to produce drawings.

TTF theory is particularly important in Ethiopia because it takes the discussion from "Is BIM being utilized?" to "How is BIM being utilized?" TTF theory indicates that merely having the BIM software does not offer access to increased levels of performance by utilizing BIM. Access to real improvements in performance will only occur when and if BIM is utilized to the core high-value tasks associated with the construction industry in the local market

2.2.3 How the Theories Work Together

These two theories are not independent; they represent interrelated components of the overall BIM adoption journey. The initial decision to adopt BIM is primarily driven by TAM. When a professional believes in the Utility and ease of adoption of BIM, they are likely to test out the use of BIM. TTF then addresses the outcome from that adoption. If the manner in which BIM is utilized aligns with the key tasks of the professional, the anticipated improvements from the

Project will result (e.g. fewer delays and/or lower costs). However, if the way the professional uses BIM does not align with the key tasks, they will not only get poor results, but they will also negatively impact their perception in relation to the utility of BIM (as per TAM) thereby creating a cycle of unsuccessful adoption.

2.3 Global Evidence on BIM and Project Performance

Construction projects worldwide share many of the same challenges: increased costs, delays in completing the project, and issues related to the quality of the project. Because of this, a great deal of research has been done (mostly in developed nations) regarding the benefits of Building Information Modeling (BIM) in improving project performance. This section provides a synthesis of the worldwide literature that identifies how BIM has had positive impact on the significant areas of cost, schedule, quality, and collaboration.

2.3.1 BIM and Improved Cost Performance

Global research consistently shows that BIM plays an important role in controlling and reducing project costs. Three specific ways BIM achieves this are:

Eliminating/Reworking Items: The development of a coordinated digital model using BIM enables teams to identify and eliminate collisions, e.g., water pipes and ventilating ducts, prior to the construction process. Correcting collisions in the digital realm is significantly less expensive than correcting them after construction has begun. Various studies have been conducted regarding the potential reduction of rework costs through effective collision detection; results suggest that by utilizing effective collision detection, rework costs can be reduced by up to 40% (Getuli, 2020).

Improved Accuracy in Cost Estimation: The ability to combine cost data with 3D models so there are linked between costs and quantities is referred to as providing 5D/quantity take-offs. The ability to generate accurate estimates through 5D BIM enables teams to develop accurate budgets from the outset and track costs in real-time throughout the project thereby greatly reducing the likelihood of unexpected financial issues. (Chen & Luo, 2022).

Overall Cost Savings: Numerous case studies demonstrate that implementing BIM on construction projects will save on direct costs, a study conducted in Russia determined that implementing BIM on construction projects saved 20%-25% of the total project costs by improving project planning, reducing errors during construction, and better utilizing project resources. (Averchenkov, 2019).

2.3.2 BIM and Improved Schedule Performance

BIM directly contributes to keeping projects on schedule through improved planning.

4D Simulation for Planning: Teams develop a 4D BIM for the project, linking 3D models to the project schedule, to allow teams to visually simulate the entire construction process. The digital simulation of the project assists in optimizing schedules, improving logistics on the construction site and identifying potential issues that may develop in advance during construction. (Jin, 2019).

Quantifiable Schedule Performance Improvement: Quantifying the positive impacts of 4D BIM for project schedules. Projects developed and constructed using 4D BIM have reduced the time lost due to construction delays by 15% in comparison to projects developed using traditional construction means and methods (Bilal et al., 2021). The majority of this improvement in schedule can be attributed to resolving issues in digital form prior to beginning physical construction work on-site.

2.3.3 Broader Impacts of BIM: Quality, Safety, and Collaboration

Global evidence shows that, in addition to their cost and time savings, BIM also positively impacts many other important areas of performance, including:

Improved quality and reduced number of defects: A coordinated model means that all building systems will fit together as they were intended, resulting in an improvement in the overall quality of the construction and fewer defects. According to (Ahuja, 2020), BIM can be used to minimize documentation and construction errors, which represent one of the most common causes of defective construction.

Improved collaboration and communication among project team members: BIM acts as a "single source of truth" for all members of the project team. By providing a single model to all members of the project team, everyone involved in the project has access to the same information, promoting transparency, reducing miscommunication, and enabling better decision-making among architects, engineers, contractors, and clients, (Ahuja, 2020).

2.4 BIM in Developing Economies and in the African Context

BIM has a relatively good overall global outlook, but developing economies like Ethiopia have specific challenges related to BIM adoption and use. In most of Africa, adoption of BIM is still in the early stages and evidence illustrates that the widespread use of BIM is being inhibited by many intertwined technological, human, and regulatory barriers (like costs, lack of skills, and lack of enabling policies), which generally create an overly complicated system that is difficult to change (Wuni, 2024). Most of the research available regarding BIM in Africa has focused on identifying adoption barriers instead of addressing possible solutions or measuring outcomes. The most prevalent barriers include high cost of software, lack of skilled resources, and resistance to changing established work processes with a lack of enabling government policies serving as a significant impediment to BIM (Arayici, 2011). Evidence of another common barrier to BIM adoption is seen in research conducted in Nigeria, where computer literacy rates among professionals is low, which in turn contributes to low levels of acceptance for changing long-established work procedures (Olanrewaju, 2021). The interrelated nature of these barriers contributes to the low level of adoption of BIM across many African nations and the uneven rate of BIM adoption is noted across the continent.

Although various barriers to BIM have been identified, there is still a significant gap in empirical studies which quantify the impacts of BIM on performance, rather than merely listing the challenges. According to (Agyekum, 2023), “there is a severe lack of empirical studies quantifying the performance benefits of BIM in the Western African context,” which can be applied equally to East Africa. Although we understand the barriers to BIM, there is little empirical data specific to local firms regarding the outcomes experienced by firms integrating BIM. Several new studies are beginning to provide clarity to this area. For example, recent empirical research conducted within Kenya has examined how approaches to invest in BIM-trained staff will improve design efficiency and decrease errors by modelling the fit between

staff, technology, and project deliverables (Dagne, 2024). In addition, research conducted within Ethiopia has begun to develop models of the main barriers to BIM adoption based on how a professional role or project type impacts their perceptions of BIM barriers. This body of work continues to stress the lack of empirical data and the urgent need for additional quantitative research related to this topic within specific context.

2.5 BIM in the Ethiopian Context

2.5.1 The Critical Knowledge Vacuum and Regional Position

There is insufficient information about the use of BIM in Ethiopia. The construction industry's traditional methods and consistent delays and budget overruns are causing significant harm to the country's economy and the future use of BIM. Although the awareness and usage of BIM are slowly on the rise, the use of BIM in the construction industry is still very low (Belay S. G., 2021). A divide between the global potential of BIM and the limited use of BIM exists between Africa's many different areas. East Africa, including Ethiopia, lags noticeably behind the other regions of Africa in terms of research output and BIM implementation (Saka, BIM divide: an international comparative analysis of perceived barriers to implementation of BIM in the construction industry, 2023). This regional slowdown adds to the unique challenges mentioned before and further emphasizes the need for specific local research.

The current impediments to using BIM in Ethiopia are significant, systemic, and interconnected. The systemic impediments create a complex web of obstacles that impede technology advancement in the country's construction industry. A significant excuse for non-usage of BIM in Ethiopia is the high cost of the software and hardware to operate BIM for the majority of local firms and the extreme lack of professionals who currently have actual BIM expertise (Belay, Goedert, Woldesenbet, & Rokooei, 2021). The absence of national and governmental frameworks, such as national BIM standards, BIM guidelines, or government mandates in public procurement, compounds this problem. As a result, there is no market pressure or influence to adopt BIM (Saka, BIM divide: an international comparative analysis of perceived barriers to implementation of BIM in the construction industry, 2023). The delay in adoption of BIM has created a job site culture that exhibits large-scale resistance to change

from paper-based processes and has created many times a project delivery failure rate of poor-quality design documents, which is what BIM was developed to prevent (Tessema), 2023).

The existing research in Ethiopia has begun to catalogue the barriers to BIM usage; however, there is a serious missing methodological and empirical gap. Most of the existing BIM research to date has been based on qualitative methodologies using surveys and interviews to document people's perceptions and obstacles to using BIM (Belay, Goedert, Woldesenbet, & Rokooei, 2021). A significant missing connection is that there is no quantitative-based empirical research to measure how many construction companies use BIM for building projects and no subsequent statistical data that demonstrates the correlation between how many companies use BIM and the cost and schedule performance of the projects in Ethiopia. The limited local empirical evidence creates an ongoing situation where the construction industry executive leadership is hesitant to invest in BIM use without evidence of return for their investment. However, there can be no empirical evidence for the return of investment without construction companies first investing in BIM use.

This research will present an opportunity to break the cycle of the ongoing situation discussed above. Through this research, I will measure the level of usage of BIM and also analyse the use of BIM against the construction projects in Ethiopia. This research will develop the first empirical model of BIM use in the Ethiopian construction industry, providing the construction industry with the first empirical evidence of BIM's positive benefits to aid in changing the conversation about digitising construction from an emphasis on barriers to an emphasis on developing validated strategies to assist in moving towards digital transformation of the construction industry.

2.6 Synthesis and Identification of the Research Gap

This research will provide a full synthesis of existing knowledge and will offer a precise identification of the research gap that this study will address. The analysis shows that the core research issue has been addressed in prior literature, albeit in a fragmented manner. Documentation regarding the significant cost and schedule overruns within the Ethiopian construction industry has been reported in both local sources and academic literature, as well

as the barriers to Building Information Modeling (BIM) adoption (Belay, Goedert, Woldesenbet, & Rokooei, 2021); (Tessema), 2023).

Additionally, there are prominent theoretical perspectives that provide the basis for understanding this research proposition. To this end, the Technology Acceptance Model (TAM) explains the cognitive processes of human decision-making when adopting new technologies, with an emphasis on perceived usefulness and perceived ease of use as two major factors (Davis, 1989). TAM is complemented by the Task-Technology Fit (TTF) theory in that it outlines the conditions necessary to determine whether technology will be effectively used with the appropriate tasks to create performance benefits (Goodhue, & Thompson,, 1995). Together, these theories facilitate an overall shift from "Will they use it?" to "Will it work here?"

The comparative study of other developing regions, specifically throughout the African continent, may offer contextual insight into this research proposition. Studies performed in both West and East African countries indicate that the barriers to BIM implementation (e.g. high costs, lack of skills availability and weak policy support) are fairly common across the continent; this has resulted in a collective barrier to advanced technology adoption in the African construction industry (Saka, A scientometric review and metasynthesis of building information modelling (BIM) research in Africa, 2019); (Agyekum, 2023). Therefore, while Ethiopia is not the only country in Africa requiring research on these issues, there is a need for localized research in Ethiopia to determine the BIM barriers faced in that country.

Across the globe, the predominant strategy for addressing the continued occurrence of poor project delivery (project performance) is the use of an integrated BIM process to manage each of the project stages/steps through the life cycle of a project. A strong success record of this integrated approach is noted in developed nations and also some developing nations; these successes coincide with M.P. improvements in delivery to new customer orders, improved performance for cost efficiency, improved performance for schedule efficiency, improved levels of teamwork and collaboration between the project participants., (Getuli, 2020); (Chen & Luo, 2022). In contrast, the success of BIM implementation in an Ethiopian context is nearly

non-existent (little or no documentation); there is a serious lack of empirical data available locally that measures the impact of BIM adoption within the Ethiopian construction industry.

Through this literature review, the research gaps have been defined. Barriers to BIM implementation in Ethiopia are identified as known issues, however there is no existing research that provides the following empirical data for overall BIM adoption across the Ethiopian construction industry: (1) the current state of BIM use, and (2) a quantitatively measured statistical relationship between the degree of BIM use and the actual project performance metrics (cost and schedule). This research proposal will extend the body of knowledge by directly addressing these gaps by developing the first empirical Build Model to test whether and how BIM adoption impacts (positively or negatively) project performance within the Ethiopian real estate industry; therefore, providing evidence-based insight into BIM adoption and utilization to the Ethiopian construction industry for use by the various stakeholders involved (including government officials) to assist in creating policy that will encourage and support BIM technology adoption and use.

2.7 Conceptual Framework

The Conceptual Framework of this thesis is based on the literature review and analyzed data both globally and locally. In this thesis, a conceptual framework has been developed to visually represent the relationship between the independent variable BIM Adoption **(BIM)** and the dependent variables Cost and Schedule Performance (**C&SP(PP)**). The proposed framework hypothesizes that Cost and Schedule Performance will be enhanced by increased adoption of BIM, and that this effect is mediated by two mechanisms: rework reduction (**RR**) and improved collaboration (**COL**).

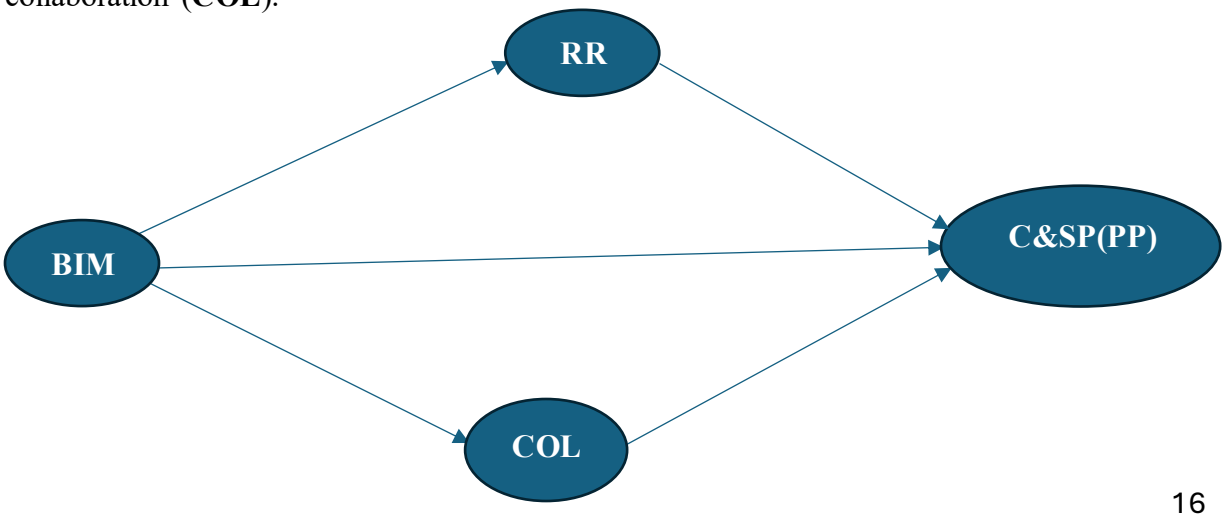


Figure 2.1, The proposed conceptual framework was synthesized from established literature.

The direct links between BIM adoption (BIM), rework reduction (RR), collaboration (COL), and project performance are supported by recent empirical studies (e.g., (Cao, 2017); (Zheng & al., 2026)). The mediating roles of rework and collaboration are grounded in the Task-Technology Fit (TTF) theory (Goodhue, & Thompson,, 1995), while the adoption construct is informed by the Technology Acceptance Model (TAM) (Davis, 1989).

Importantly, the proposed framework draws from theories related to Task-Technology Fit and the internationally renowned best practices to support the assertion that BIM Adoptions effects on project cost and schedule performance are not only direct effects but rather two important mediating effects will come into play the reduction of rework and the enhancement of collaboration.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

Chapter Three presents the in-depth research methodology to fill the identified research gap through empirical investigation in the literature review. This chapter provides a bridge from theoretical constructs (TAM, TTF), conceptual framework, and specific research questions to the practical, operational details of data collection and analysis. Given quantitative, empirical evidence is lacking with regard to Building Information Modeling (BIM) adoption and project performance in Ethiopia, the method is crafted to bridge an informative and data-driven study that is academically robust and contextually relevant to the Ethiopian construction industry.

The central goal of this research will be to test the hypothesized direct and/or mediated relationship within the proposed conceptual framework which states whether BIM adoption has an indirect or direct effect (through rework reduction and improved collaboration) on the cost and schedule performance of construction projects in Ethiopia. The quantitative cross-sectional approach was relevant for this study. The survey method will be employed to generate numerical data from a predetermined sample of the construction professionals. This was chosen because it entails systematic measurement of the variables (BIM adoption levels and project outcomes) and aids in employing statistical analyses to test relationships across the representational sample, ideally suited for achieving the explanatory goals of the study.

The chapter structure provides transparency and promotes replicability. It will narrate the research philosophy and approach behind the design of the study, justifying the adoption of a positivist stance that attempts to provide objective measurement of phenomena. This is followed by a narration of the population and sampling strategy employed, with a description of the process through which sample size was determined to ensure that the findings are applicable and generalizable in whatever context they were derived from. The chapter will then detail a structured questionnaire as a data collection instrument explaining how it was developed, its sections and measures for each key variable (eg, BIM Adoption, rework, cost performance), and, lastly, statistical procedures (reliability tests, for example, correlation, and

regression analysis) that will be utilized to analyze the data that have been collected and test the hypotheses of the study. By the end of this chapter, a well-spelled pathway will be provided to take the reader from the research question(s) to their possible answers.

3.2 Research Design

A research design is chosen according to the nature of the research problem as well as existing knowledge. In this case, the core research problem (persistent cost and schedule overruns) is well known to exist in Ethiopia. The potential solution (BIM adoption) and the theoretical pathways to achieve it (reduced rework and improved collaboration) have been found in global & regional literature. Therefore, the primary research question will be analytical and explanatory: "What is the statistical relationship between the level of BIM adoption, and the project outcomes as a result of BIM adoption within Ethiopian construction?"

In order to answer this research question and test the proposed hypotheses, this research will use an analytical, cross-sectional survey research design. There are three main reasons for selecting this design: 1. It aligns with the research objectives and research context; 2. It will enable robust statistical testing; and 3. The data analysis strategy involves the Smart-PLS method with PLS-SEM.

Aligns with Research Objectives and Research Context: A survey will allow for the most practical and functional means of measuring and testing the variety of described variables being studied throughout the Ethiopian construction industry, which is geo-distributed and organizationally fragmented. A survey provides an efficient way to collect information from all necessary stakeholder groups, which is critical to understanding the multi-dimensional nature of BIM adoption and its impact.

Enables Robust Statistical Testing: The design of the cross-sectional survey will generate the type of data needed to perform advanced multivariate analyses. Collecting quantitative measures of all variables in the conceptual framework (BIM adoption and project performance) creating a dataset that can be used to conduct statistical tests of the mediated relationship between BIM adoption and project performance.

Steps to Analyze Data with Smart-PLS: Data will be analyzed by utilizing Partial Least Squares Structural Equation Modeling (PLS-SEM) in Smart-PLS. Using Smart-PLS for data analysis will be a strategic choice for conducting research in new contexts like Ethiopia:

Supports Complex Models: PLS-SEM is particularly well suited for testing models consisting of multiple independent variables, dependent variables, and mediating variables, just as described in the conceptual framework.

Supports Smaller Sample Sizes and Exploratory Research: Unlike other SEM techniques, which require large sample sizes, PLS-SEM will provide valid results for moderate sample sizes. This is an important consideration when researching a specialized population of BIM-aware construction professionals in Ethiopia, where recruiting a large enough sample will be very difficult. Being able to use PLS-SEM will also facilitate exploratory research and theory development and support the construction of the first empirical model related to BIM adoption in Ethiopia.

Table; 3.1 The table below outlines the reasons as to how Smart-PLS is appropriate according to the context and design of the study:

Research Characteristic	**Implication for Analysis**	**Why Smart PLS (PLS-SEM) is a Fit**
Exploratory / Theory-Building Goal	Testing a new model in an under-researched Context (Ethiopia).	PLS-SEM is a prediction-oriented method ideal for developing theoretical understanding in exploratory research.
Complex Model with Mediators	Testing direct (H_1,) and indirect (H_2, H_3) paths.	PLS-SEM excels at modeling complex Relationships with multiple Mediators and latent variables.
Potential for Smaller/ Moderate Sample	Access to the niche population of Ethiopian AEC professionals using BIM may be limited.	PLS-SEM achieves high statistical power with smaller sample sizes compared to other SEM techniques.

Focus on Practical Application	Findings should guide Industry and policy decisions.	PLS-SEM is widely used in business, management, and technology adoption studies for its practical relevance.

In summary, the use of an analytical cross-sectional survey design as an analysis method using Smart-PLS for analysis provides a solid and cohesive methodological approach to test the theoretical framework as well as to produce the forms of quantitative evidence needed to inform both academic discourse and practical decision making within the Ethiopian AEC sector.

3.3 Research Population and Sampling Strategy

3.3.1 Target and Accessible Population

The target population for this research will include professional managers, designers and builders of private sector construction projects located in Addis Ababa, Ethiopia. Examples of the professions that will comprise this target population will be project manager, civil/structural engineer, architect, quantity surveyor, and contractor. The entire target population will consist only of individuals who reside and work in Addis Ababa, as this city serves as the geographic center for construction and real estate development in Ethiopia.

Researchers frequently cite the difficulty of creating a sampling frame (i.e., a list of individuals within the target population) in construction project management research, especially in developing countries where comprehensive registries of individuals engaged in construction project management do not exist. The accessible population, however, will be developed through a multi-source sampling frame from individuals participating in or having access to the major associations that represent members of the target population (e.g., Ethiopian Building Information Modeling Society (EBIMS), Construction Management Institute- (CMI), Ethiopian Association of Civil Engineers (EACE), Ethiopia Construction Contractors Association (ECCA) and will include employees of the construction developer(s) or contractor(s) identified in the above sample frame, and/or using professional social networking sites (e.g., LinkedIn) to connect to qualified individuals who are not affiliated with these associations.

3.3.2 - Sample Design/Technique: Practical / Mixed-Methods

Because there are no complete sample frames available to conduct this research, a pure random probability sampling strategy cannot be utilized; therefore, a non-probability sampling strategy using a mixed-methods approach will be employed in order to increase the overall extensiveness and relevance of the data collected through the following sampling methods:

Purposeful Sampling: This type of sampling will be used to identify the type of data that will be collected from participants relevant to the research questions. In particular, data collected will only be from professional managers, builders, and structure delivery professionals who are expected to have direct experience with private construction projects, and to have a minimum understanding of the forms of building information modeling (BIM). In this way, these respondents will be able to provide valid responses that represent adequate data to support the core variables for this project.

Snowball Sampling: Snowball sampling will be used to help address the limitations of using a non-probability sampling method to provide additional means of connecting with other individuals in the general population through undocumented networks of industry professionals. Participants will be asked to provide the name and information about other individuals who may also have provided relevant information needed for this research.

In order to increase the overall representativeness of the sample and reduce any potential biases, a variety of stratification techniques will be employed at the sample recruitment stage to obtain a sample that includes an adequate representation of individuals from various fields of specialization (e.g., project manager, site engineer, BIM manager) and firms (e.g., client/developer, consultant, contractor) of all sizes (e.g., large, medium, small). As a result, the sampling techniques described above represent an advisable technique to conduct business/technology survey research within a defined community of professionals (Taherdoost, Determining Sample Size; How to Calculate Survey Sample Size, 2017).

3.3.3 Sample Size Determination for PLS-SEM Analysis

Establishing an appropriate sample size is important for the validity of Partial Least Squares Structural Equation Modeling (PLS-SEM) analysis. Due to the unknown nature of the target population, heuristic methods set forth in the fields of methodologies for PLS-SEM serves as

a methodology (Joseph F. Hair J. M., 2017)). The "10-times rule" uses a minimum sample size of ten times the total number of structural paths (i.e., paths that represent hypothesized relationships) on the most complex endogenous variable in the inner path model. The research conducted in support of this study will uphold this methodology.

Another general and conservative guideline for survey-based research using multivariate analysis states that a target sample size range is between 80 and 120 respondents to provide stable and reliable statistical output (Taherdoost, Determining Sample Size; How to Calculate Survey Sample Size, 2017). To meet the heuristic statement for PLS-SEM sample determination and to assure sufficient analytical power, the research for this study will target a minimum of 100 completed questionnaire responses. This method will generate enough valid statistical results to test formal hypotheses on Smart-PLS.

Table 3.2; The following table summarizes the key sampling decisions and their justifications:

Aspect	**Chosen Method**	**Justification for Ethiopian Context**
Sampling Technique	Mixed Non-Probability (Purposive + Snowball)	No complete national registry exists; method overcomes access barriers and targets knowledgeable respondents.
Primary Sampling Frame	Industry Associations (EBIMS, EACE, ECCA) & Known Firms	Provides a credible and accessible starting point for reaching the core professional community in Addis Ababa.
Sample Size Target	**n ≥ 100**	Meets the **"10-times rule"** for PLS-SEM power (Hair, Hult, Ringle, & Sarstedt, 2017) and falls within the conservative range for survey analysis (Taherdoost,

Aspect	Chosen Method	Justification for Ethiopian Context
		Determining Sample Size; How to Calculate Survey Sample Size, 2017).

3.4 Collecting Data: Developing and Administering Instruments

3.4.1 Data Source and Survey Instrument

A structured self-administered digital questionnaire (Google forms) will collect data on primary data using a questionnaire to operationalize latent variables from the conceptual model to measure variables. The content will be developed from the recommended and validated scales used in established studies that have undergone peer-review (Taherdoost, Sampling Methods in Research Methodology; How to Choose a Sampling Technique for Research, 2016) and have provided the basis for a strong foundation of quantitative type of research while still allowing for any necessary localization.

The final instrument (see Appendix 1) will contain the following section sections:

Section A; Demographic and Organization Profile: The demographic and organizational profile will collect demographic information including the respondent's job title/role, number of years worked in the industry, type of business (for example: consultant or developer), and size of company. This information will be useful for describing the sample and assessing whether it is representative of the Ethiopian construction industry;

Section B; BIM Adoption (independent variable): The second section will assess the extent, maturity and drivers of BIM adoption with the aid of existing validated scale items from previous BIM adoption research studies (example: (Jongsung Won and Ghang Lee, 2022)). Each measure will provide respondents with five alternative responses on a five-point Likert scale (1 = Strongly Disagree-5 = Strongly Agree) related to their agreement level with

statements measuring software usage, integration of processes and the perceived benefits associated with using BIM;

Section C; Mediating Variables (Reduction of rework and collaboration): The next section will measure the two hypothesized mediators; Reduction of Rework and Improved Collaboration, using existing validated measures to reduce rework by reporting on the average number of design clashes and the average number of site corrections during the project. To assess Improved Collaboration, the study will adapt validated measures of the quality of information shared between project team members and interdisciplinary coordination for the project;

Section D; Project Performance (dependent variables): The final section will capture the objective measures of project performance. Respondents will be asked to provide the project data on the average project cost (percentage of actual cost) and the average project schedule (percentage of scheduled delay) based on the duration of the project. This will provide objective quantitative data needed to test the two hypotheses on the relationship between the independent variable, mediating variables and dependent variables.

3.4.2 Pilot Testing, Validation and Administration of Results

The questionnaire draft will be piloted among 10 to 15 construction industry professionals who are part of the target survey population located in Addis Ababa, before the full release of the survey. The purpose of the pilot is threefold: to test that all question content is clearly understood and worded correctly within context, to provide estimates for how much time it takes to finish answering the questionnaire, and to do a preliminary evaluation of internal consistency reliability on the multi-item scales (Saunders, Lewis, & Thornhill, Research Methods for Business Students, 2019) that will comprise the survey instrument. Feedback from this phase of testing will also possibly be with the purpose of refining the survey instrument prior to the actual survey.

The validated survey will be conducted online through a service such as 'Google Forms' for efficiency and maximum reach. The survey will be distributed via professional email lists, Telegram/WhatsApp lists through the Ethiopian Building Information Modelling Society

(EBIMS), Construction Management Institute (CMI), Ethiopian Association of Civil Engineers (EACE), Ethiopian Construction Contractors Association (ECCA), contacting identified real estate and construction firm offices located in Addis Ababa through direct outreach efforts, as well as to relevant & qualified professional networking groups on LinkedIn. Additionally, each survey will include a cover letter that outlines the study purpose, ensures privacy and confidentiality for all participants, and obtains prospective participants' informed consent. There will be at least two follow-up reminders sent out to all nonrespondents to improve responses rates.

3.5 Data Analysis: A PLS-SEM Approach with Smart PLS

Data collected from the research will be analyzed by Partial Least Squares Structural Equation Modelling (PLS-SEM) using Smart PLS 4 software. PLS-SEM was selected because it is well-suited for predictive, exploratory research, as well as being capable of modelling complex relationships amongst latent variables, with the additional advantage of being able to use small sample sizes (Hair, Risher, Sarstedt, & Ringle, 2019).

There are two key steps in a two-part analytical process (as recommended in the methodological literature by (T. Ramayah, 2018) for the analysis of an overall model.

1. Evaluation of Measurement (Outer) Model

The reliability and validity of the measures, or survey scales used in this study, are assessed, and the accuracy of each of the measures in terms of how well they measure the intended constructs is evaluated.

Internal consistency reliability is analyzed through composite reliability (CR) (with values greater than 0.70 indicating that the reliability of the measures is acceptable).

Convergent validity is assessed by examining both the indicator loadings for each construct (indicators should have an indicator loading of greater than 0.708), and by assessing the average variance extracted (AVE) for each construct (AVE for constructs should be greater than 0.50). This will assure that the items for each construct are strongly related to the intended construct of interest.

To confirm that the constructs are distinct from one another within the model **(discriminant validity)**, the HTMT ratio will be employed with all value ratios below 0.90 indicating that each of the constructs is distinct from one another within the model (discriminant validity).

2. Evaluation of the Structural (Inner) Model and Testing Hypothesis

After validating the measurement model, the structural model is analyzed to assess the hypotheses associated with the study.

Path coefficients (β) are reviewed to determine the strength and direction of the relationships hypothesized (H_1 and H_2) between the constructs of interest.

Statistical significance of these **path coefficients** will be verified via use of a bootstrapping procedure, which involves 5,000 subsamples from the original dataset, allowing the generation of t-statistics and p-values. A statistical significance threshold of $p < 0.05$ will be used to determine if the path coefficients are statistically significant.

Mediation analysis of hypotheses 3 and 4 will also be conducted by determining the significance of the specific indirect effects of BIM Adoption on Cost and Schedule Performance via the mediators of Reduced Rework and Improved Collaboration, utilizing the bootstrapping procedure.

The **explanatory power of the model** will be assessed by using the coefficient of determination (R^2) for the two key dependent variables (Cost and Schedule Performance) and by calculating the proportion of variance explained by the overall model.

3.6 Scale Reliability and Validity

The statistical validation of the scales (measured using CR, AVE, and HTMT) will take place after the data has been collected to empirically verify the reliability and discriminant validity of each scale (refer to Section 3.6 for more information). This step is essential for any rigorous PLS-SEM analysis. To establish content validity on a priori basis, measurement items will be systematically adapted from previously established scales (previously published) that have been utilized in the most recent peer-reviewed articles on construction management topics (for example, (Jongsung Won and Ghang Lee, 2022). This two-prong method for establishing

credibility (using sound instrument design methodologies and subsequent statistical validation) will ensure that all measurements used to make conclusions regarding this study are valid.

3.7 Ethical Considerations

Ethical standards will be strictly followed in conducting this research. All participants will provide their voluntary consent prior to participating in the study; this will be obtained by providing an informed consent statement at the beginning of the survey. The research objectives and the anonymous nature of participation will be stated in the introduction of the cover letter and survey. All participant data will remain secure, confidential, and will only be used for this academic research. The design of this study carries minimal risk to the respondents as it will focus primarily on developing effective professional practices and project outcomes, while not collecting any confidential personal data.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

Data collected was analyzed as outlined in Chapter 3. This chapter presents detailed findings that answer the four primary research questions and confirm the four hypotheses developed in Chapter 1 of the impact of Building Information Modeling (BIM) on both cost and schedule performance of construction projects within the Ethiopian real estate sector.

To collect data for this research study, a structured questionnaire was developed as an online questionnaire using an internet-based service targeting construction industry professionals located in Addis Ababa, Ethiopia. Upon completion of the data capture stage, the data was then processed through a data cleaning stage so only valid (complete) responses were included in the final sample of responses. After the data had been cleaned, 102 valid responses were retained for use in the analysis. This is a sufficient sample for the implementation of using the Partial Least Squares Structural Equation Modelling (PLS-SEM) statistical procedure as generally, more than 100 completed questionnaires constitute a large enough data set for performing multivariate analysis.

This study analyzed data using the Smart PLS 4 software with the two-step process as described by (Hair, Risher, Sarstedt, & Ringle, 2019). The first step of the **data analysis** was to establish reliability and validity of the survey instrument, which provided the results for the measurement model (measurement phase). The second step was to evaluate the structural model to **assess the hypothesized** relationships (structural phase). This chapter will provide first a profile of the respondents, and then provide the results of both (1) the measurement model analysis, and (2) the structural model analysis with comments on how each relates to the existing literature and how the findings can be analyzed within the context of the Ethiopian construction industry.

4.2 Response Rate and Demographic Profile of Respondents

4.2.1 Response Rate

The aim of this survey was to obtain responses from project managers, civil engineers, architects and private real estate contractors. Therefore, over 208 questionnaires were distributed to professionals within the industry either via direct emails from companies, through industry associations or through professional networks. After distributing the questionnaire, the return rate (or response rate) was 49.03%. This means that there were 108 returned questionnaires of the total number of distributed ones and thus the response rate percentage was 49.03%. After cleaning and screening all of the data, only 102 completed usable returns (valid responses) were left for analysis. As there are enough usable questionnaires left to use with PLS-SEM analysis (Hair, Hult, Ringle, & Sarstedt, 2017) the minimum number of completed questionnaires used in the analysis has been met.

4.2.2 Demographic Characteristics of Respondents

Understanding the demographic composition of respondents provides important context for interpreting the study's findings. The following tables present the profile of respondents in terms of professional role, years of experience, company type, and firm size.

Table 4. 1 Distribution of Respondents by Professional Role

Professional Role	Frequency	Percentage
Project Manager	24	23.10%
Civil/Structural Engineer	26	25%
Architect	43	42.3
Quantity Surveyor	5	5.80%
Contractor/Site Supervisor	4	7.70%
Total	102	100%

Source: Survey data, May 2026

As shown in Table 4.1, the largest group of respondents were Architect, comprising 42.3% of the sample. This was followed by Civil/Structural Engineer at 25% and Project Manager at 23.10%. This distribution reflects the multi-disciplinary nature of construction project teams

and ensures that the study captures perspectives from key professionals involved in BIM adoption and project delivery.

Table 4. 2 Distribution of Respondents by Years of Experience

Years of Experience	Frequency	Percentage
Less than 5 years	25	24.50%
5–10 years	44	43.40%
11–15 years	25	24.50%
16–20 years	4	3.80%
More than 20 years	4	3.80%
Total	102	100%

Source: Survey data, May 2026

Table 4.2 indicates that the majority of respondents (43.40%) had 5–10 years of professional experience. The second majority of respondents (24.50%) had 10–15 years of professional experience. This level of experience suggests that respondents possess sufficient knowledge of construction project processes and outcomes to provide meaningful responses regarding BIM adoption and project performance.

Table 4. 3 Distribution of Respondents by Company Type

Company Type	Frequency	Percentage
Contractor	25	24.60%
Consultant/Engineering Firm	67	46.00%
Real Estate Developer	8	27.50%
Government/Public Agency	2	1.90%
Total	102	100%

Source: Survey data, May 2026

Table 4.3 shows the distribution of respondents across different organization types. Contractors constituted the largest group (24.60%), followed by Consultant/Engineering Firm (66%) and real estate developers (7.5%). This diversity is important because BIM adoption and its impacts may vary across different types of organizations in the construction supply chain.

Table 4. 4 Distribution of Respondents by Firm Size

Firm Size (Number of Employees)	Frequency	Percentage
Small (1–50 employees)	61	60.40%
Medium (51–200 employees)	24	24.50%
Large (More than 200 employees)	17	15%
Total	102	100%

Source: Survey data, May 2026

As presented in Table 4.4, 60.40% of respondents worked in small firms, 24.50% in medium firms, and 15% in large firms. This distribution captures the reality of Ethiopia's construction sector, which includes a mix of small local firms and larger established contractors and developers *(Belay, Goedert, Woldesenbet, & Rokooei, 2021)*.

Table 4. 5 Distribution of Respondents by Type of Projects Primarily Handle

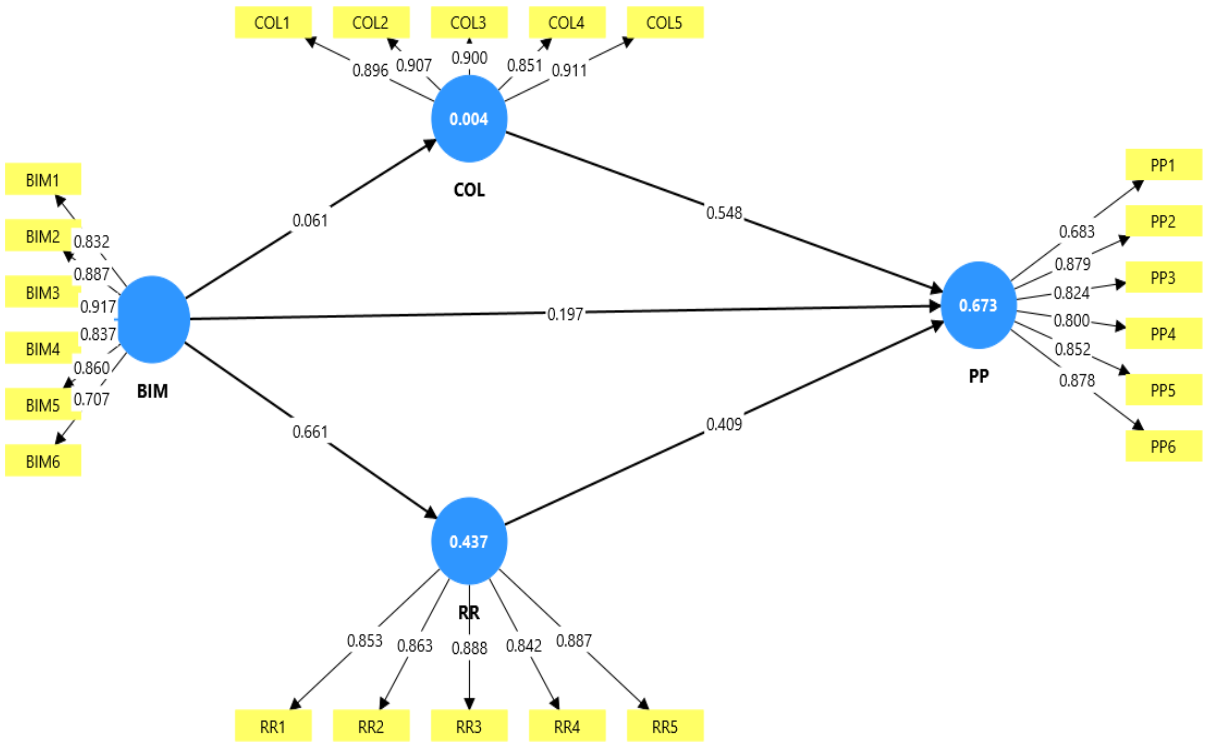
Type of Projects	Frequency	Percentage
Residential	11	9.40%
Commercial	6	5.70%
Mixed-use	57	56.60%
Infrastructure	28	28.30%
Total	102	100%

Source: Survey data, May 2026

As presented in Table 4.5, 9.4% of respondents worked in residential project, 5.70% in commercial, 56.60% in mixed use and 23.8% in infrastructure.

4.3 Assessment of the Measurement Model (Outer Model)

Before testing the hypotheses, this thesis checked if the survey questions reliably and validly measured the four constructs: BIM Adoption (BIM), Rework Reduction (RR), Improved Collaboration (COL), and Cost & Schedule Performance (CP&SP). Three tests were performed: **factor loadings, reliability and convergent validity, and discriminant validity.**



4.3.1 Factor Loadings

The factor loadings indicate the degree of association between each question in a survey and its underlying construct. A loading above 0.70 is interpreted as being very strong (Joseph F. Hair J. M., 2017). All loadings in Table 4.6 were rated above 0.70 indicating that each item had high validity in terms of measuring the concept to which it was related. The lowest loading value was 0.702 for BIM6, which is still considered acceptable.

Table 4.6: Outer Loadings

	Outer loadings
BIM1 <- BIM	**0.832**
BIM2 <- BIM	**0.887**
BIM3 <- BIM	**0.917**
BIM4 <- BIM	**0.837**
BIM5 <- BIM	**0.860**
BIM6 <- BIM	**0.707**
COL1 <- COL	**0.896**
COL2 <- COL	**0.907**
COL3 <- COL	**0.900**
COL4 <- COL	**0.851**

COL5 <- COL	**0.911**
PP1 <- PP	**0.683**
PP2 <- PP	**0.879**
PP3 <- PP	**0.824**
PP4 <- PP	**0.800**
PP5 <- PP	**0.852**
PP6 <- PP	**0.878**
RR1 <- RR	**0.853**
RR2 <- RR	**0.863**
RR3 <- RR	**0.888**
RR4 <- RR	**0.842**
RR5 <- RR	**0.887**

Source: Survey data analysis. *note: All loadings are > 0.70, indicating good indicator reliability.*

4.3.2 Reliability and Convergent Validity

Reliability describes the degree to which the various questions are measuring the same concept and provide consistent, stable results over time. When questions provide reliable responses, you can expect to obtain similar results each time you measure, increasing the belief in the findings. Conversely, convergent validity describes the degree to which two or more different questions (or measures) produced similar results when measuring the same concept. Hence, the greater the degree of convergence between different measures, the more accurately those measures are measuring the same underlying construct.

The three distinct psychometric properties employed to evaluate the overall assessment of my research included three separate metrics. First, the use of Cronbach's alpha as a statistical measurement provides an accurate measure of internal consistency of an instrument; this is widely used as a way to determine how well items on a particular instrument are measuring the same construct. The items will exhibit internal consistency once the computed value for Cronbach's alpha is above 0.70. Composite Reliability (or rho-c) is another statistical measure of reliability and must also demonstrate reliability once the computed value for the rho-c is greater than 0.70. In addition, another metric for determining the assessment of psychometric properties is Average Variance Extracted (AVE); the computed value for this specific metric must be greater than 0.50 in order to provide evidence that there is sufficient amount of

variability in the items to provide confirmation that the items are appropriately reflecting an underlying construct. Employing the above-mentioned metrics provides for the identification of findings from this study that can be regarded as being not only credible but also useful to achieve this project objectives.

Table 4.6 shows that all values are well above these thresholds. This means our measurement is reliable and valid

Table 4.6: Reliability and Convergent Validity

	Cronbach's alpha	Composite reliability (rho-a)	Composite reliability (rho-c)	Average variance extracted (AVE)
BIM	0.917	0.92	0.936	0.71
COL	0.938	0.96	0.952	0.798
(C&SP) PP	0.902	0.909	0.925	0.676
RR	0.917	0.922	0.938	0.751

All values exceed recommended thresholds ($\alpha > 0.70$, $CR > 0.70$, $AVE > 0.50$).

4.3.3 Discriminant Validity

Psychometric assessment has an important role in identifying if discriminant validity exists for the constructs being measured and whether these constructs are the same as those measured in the study. Simply put, you want to determine if the constructs being measured are different from each other, allowing them to be separated into two separate constructs. The two different methods we used to assess discriminant validity in my study were both well established, scientifically documented, and frequently utilized.

The first method we used is called the Heterotrait-Monotrait (HTMT) ratio method. HTMT is an excellent way of assessing the degree to which different constructs correlate with each other. According to established guidelines, if the HTMT ratio is 0.90 or lower, there is enough evidence of discriminant validity to support that the constructs being measured have sufficient differences to stand alone as separate constructs. The second method we utilized was the Fornell-Larcker criterion. The Fornell-Larcker criterion states that for each of the constructs highlighted in the table above, the square root of the Average Variance Extracted (AVE) for

that construct must be greater than the correlation of that construct with any other construct in the study.

The data in the above-mentioned Tables 4.7 and 4.8 demonstrate that all HTMT values are less than 0.90 indicating the constructs are distinct, meeting the Fornell-Larcker criterion for assessing discriminant validity. Therefore, we can conclude with confidence that our constructs are distinct and unique entities and provide support for the research model.

Table 4.7 shows that all HTMT values are below 0.90, and Table 4.8 shows that the Fornell-Larcker criterion is met. Therefore, discriminant validity is confirmed.

Table 4.7: Discriminant Validity – HTMT Ratio

HTMT				
	BIM	COL	PP	RR
BIM				
COL	0.111			
(C&SP) PP	0.546	0.638		
RR	0.714	0.138	0.639	

All HTMT values < 0.90, confirming discriminant validity.

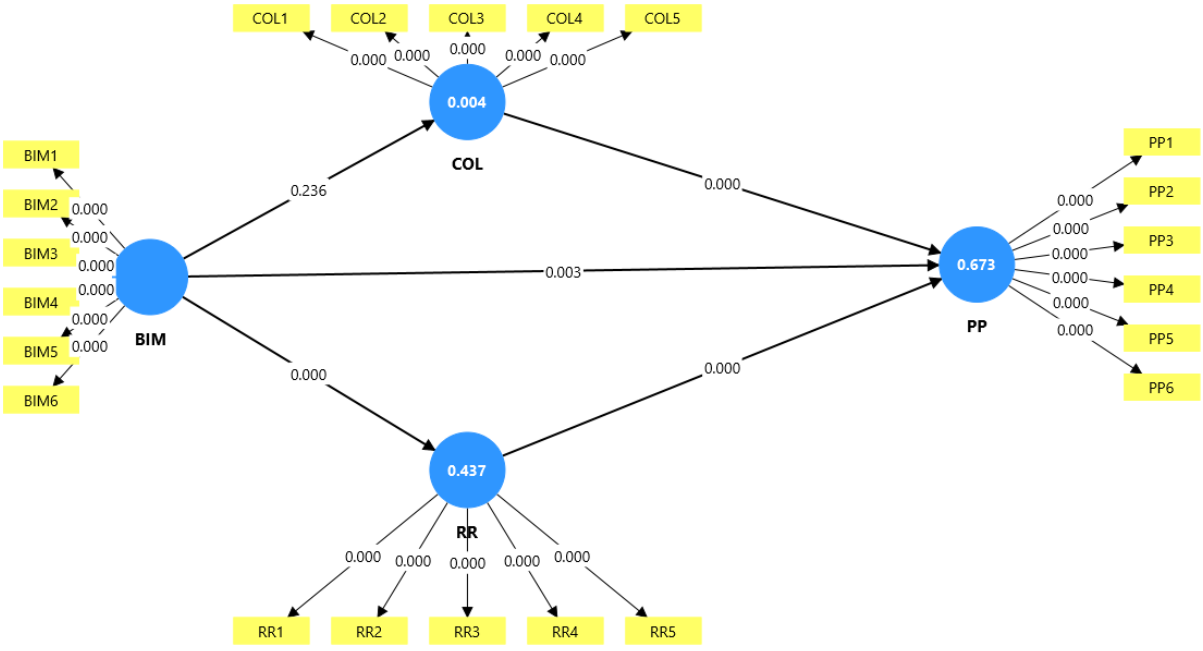
Table 4.8: Discriminant Validity – Fornell-Larcker Criterion

Forell-larker criterion				
	BIM	**COL**	**PP**	**RR**
BIM	**0.843**			
COL	0.061	**0.893**		
(C&SP) PP	0.501	0.603	**0.822**	
RR	0.661	0.105	0.597	**0.867**

Diagonal bold values are square roots of AVE; they are larger than off-diagonal correlations, confirming discriminant validity.

4.4 Assessment of the Structural Model (Inner Model)

The next stage involved evaluating the relationship structure, which was investigated using structural model analysis after establishing the adequacy of the measurement model for evaluating these relationships. The relationship structure was evaluated with respect to: collinearity (VIF), path coefficients (β), significance (p-values), amount of explained variance (R^2), size of effect (f^2), predictive relevance (Q^2) and overall model fit (SRMR).



4.4.1 Assessment of Collinearity (VIF)

Before the results from our hypothesis test could be relied on, collinearity, or multicollinearity, needed to be examined for potential pitfalls. The point is when two or more predictor variables (that is, BIM Adoption versus Rework Reduction) are highly correlated. To clarify further, if one is to guess a person's weight based on their height in centimeters and inches, there is a perfect relationship between the two; thus, to guess it, one would need to know only one of the two variables, which means that the statistical model would not be able to differentiate which predictor actually affected the weight outcome. This leads to unreliable results such as inflated standard errors and unstable path coefficients (Hair, Risher, Sarstedt, & Ringle, 2019).

We can use the Variance Inflation Factor (VIF) to diagnose how much the variance of the regression coefficients has been inflated because of collinearity with other predictors ((Hair, Risher, Sarstedt, & Ringle, 2019); (Kock, 2015)). According to the VIF value, we can determine how much collinearity exists. Generally, high VIF values indicate that a serious collinearity problem exists. What is the criteria for acceptable VIF values? The literature includes a variety of acceptable VIF criteria and some of the most commonly used criteria are as follows:

The literature provides several suggested thresholds for acceptable VIFs. Below are the thresholds recommended in the literature:

VIF < 5 is typically thought of as acceptable and does not signal a serious problem with collinearity. This rule of thumb for VIF < 5 has been found to hold up in SEM research (Hair, Risher, Sarstedt, & Ringle, 2019)

VIF < 3 is a more conservative threshold for PLS-SEM research than the VIF < 5 threshold (Hair, Risher, Sarstedt, & Ringle, 2019). Using the VIF < 3 threshold will increase confidence that there is minimal to no distortion of the model's results due to the presence of collinearity between constructs.

(Kock, 2015)suggests an additional threshold of VIF < 3.3 as part of the "full collinearity" test. If all VIF values are below 3.3, the research is free of common method bias (Kock, 2015).

For this research study, the strictest criterion for assessing the model (VIF < 3) will be used to ensure the most robust assessment of our model and maximize the reliability of our results (Hair, Risher, Sarstedt, & Ringle, 2019).

Analysis and Results

Table 4.9 presents the inner VIF values for all predictor constructs in our structural model.

Table 4.9: Collinearity Statistics (VIF)

	VIF
BIM -> COL	1.000
BIM -> (C&SP) PP	1.778

BIM -> RR	1.000
COL -> (C&SP) PP	1.011
RR -> (C&SP) PP	1.791

Interpretation of Results

According to Table 4.9, there is no multicollinearity in our structural model as all the Variance Inflation Factors (VIFS) are less than 3. All VIFS are below 2, supporting our conclusions:

No Multicollinearity Issue: My structural model does not have a multicollinearity issue and there are not excessive relationships between the predictor variables.

Reliable Path Coefficients: Since there are no multicollinearity problems, then we can conclude that the path coefficients (β) we will discuss in the next section are reliable and conclusive. We can trust that the estimated effects of A on B (e.g., BIM - Cost Performance) are reliable and not inflated by other variables in our model.

Complete Validation: All VIFS being less than 2 is a strong indicator that our model is well-specified and free of the influences associated with multicollinearity (Hair, Risher, Sarstedt, & Ringle, 2019), (Kock, 2015)

4.5.2 Path Coefficients and Hypothesis Testing

Once we have no issues with collinearity (Refer to Section 4.5.1), we will assess the path coefficients (β) for testing our four hypotheses (H_1, H_2, H_3). The path coefficients reflect the magnitude and direction of the relationships between constructs. A path coefficient will have a value from -1 to +1, with a positive value indicating that as one construct's value increases, the other will also have an increasing value; when the opposite holds true, we say that the two constructs have a negatively correlated path between them (Hair, Risher, Sarstedt, & Ringle, 2019).

To evaluate whether a path indicates statistical significance, we will use p-values. Typically, in social sciences research, $p < 0.05$ (but sometimes $p < 0.01$ or $p < 0.001$) serves as a threshold for determining statistical significance. Therefore, a p-value of less than 0.05 reflects the existence of a statistically significant relationship between the two constructs at the 95%

confidence level. Conversely, when the p-value is greater than 0.05, there is not statistically significant evidence to support the existence of a relationship between the two constructs (Hair, Hult, Ringle, & Sarstedt, 2017). In addition to p-values, the t-statistic must be higher than about 1.96 to be statistically significant when the p-value equals 0.05 (Hair, Risher, Sarstedt, & Ringle, 2019).

Table 4.10 presents the direct path coefficients, standard deviations, t-statistics, and p-values for all relationships in our structural model.

Table 4.10: Direct Effects – Path Coefficients and Significance

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
BIM -> COL	0.061	0.072	0.085	0.718	0.236
BIM -> PP	0.197	0.196	0.071	2.797	0.003
BIM -> RR	0.661	0.665	0.05	13.22	0.000
COL -> PP	0.548	0.54	0.096	5.685	0.000
RR -> PP	0.409	0.409	0.075	5.462	0.000

Note: *β = path coefficient; $p < 0.05$ indicates significance at 95% confidence level* (Hair, Risher, Sarstedt, & Ringle, 2019). *While there isn't a universal threshold, common guidelines suggest: $\beta < 0.1$: Weak effect, $0.1 \leq \beta < 0.3$: Small to moderate effect, $0.3 \leq \beta < 0.5$: Moderate to strong effect, $\beta \geq 0.5$: Strong effect.*

Interpretation of Direct Path Coefficients

1. Path: BIM → COL (β = 0.061, p = 0.236)

Meaning: The effect of BIM adoption on improved collaboration is positive but very small (β = 0.061). However, it is **not statistically significant** because the p-value (0.236) is greater than 0.05.

Interpretation: This means that, based on the data, BIM adoption does **not** significantly improve collaboration among project stakeholders in Ethiopian real estate projects. This is consistent with the finding that most Ethiopian firms use BIM primarily for visualization or

clash detection, rather than for integrated, cloud-based collaborative workflows (Belay, Goedert, Woldesenbet, & Rokooei, 2021).

Practical takeaway: Ethiopian firms should not expect immediate collaboration benefits from BIM adoption. Collaborative tools and platforms may require higher industry maturity, trust, and standards before they become effective.

2. Path: BIM → PP (β = 0.197, p = 0.003)

Meaning: The direct effect of BIM adoption on project performance (cost and schedule) is positive and statistically significant (β = 0.197, p = 0.003).

Interpretation: This confirms **H_1** BIM adoption directly improves cost and schedule performance in Ethiopian real estate projects. The effect is small but meaningful, indicating that even at the current low levels of BIM maturity, firms that adopt BIM experience better cost control and fewer delays. This aligns with studies in other developing countries (Muhammad, et al., 2019); (Al-Gahtani, Alsanabani, Alsugair, Aljadhai, & Alotaibi, 2024)). The small effect size suggests that most of BIM's performance benefit comes through other pathways (particularly rework reduction), not directly.

Practical takeaway: Ethiopian firms can expect measurable cost and schedule improvements from BIM adoption, even with basic implementation. However, the direct effect is modest, so firms should also focus on the indirect pathways (rework reduction) to maximize benefits.

3. Path: BIM → RR (β = 0.661, p = 0.000)

Meaning: The effect of BIM adoption on rework reduction is very strong and highly significant (β = 0.661, p < 0.001).

Interpretation: This is the strongest relationship in the model. It demonstrates that BIM adoption has a large, direct impact on reducing rework in Ethiopian real estate projects. This is consistent with the core strength of BIM clash detection and design coordination which allows teams to identify and resolve conflicts before construction begins. In the Ethiopian context, where poor design documents cause more than half of cost overruns (Tessema), 2023), this finding is particularly valuable.

Practical takeaway: Ethiopian firms should prioritize BIM training and tools for clash detection and design coordination. This is the highest-return investment, as reducing rework directly leads to cost and time savings.

4. Path: COL → PP (β = 0.548, p = 0.000)

Meaning: The effect of improved collaboration on project performance is strong and highly significant (β = 0.548, p < 0.001).

Interpretation: This indicates that when collaboration exists, it has a large positive impact on cost and schedule performance. This is consistent with literature showing that better communication and coordination lead to fewer misunderstandings, faster decisions, and smoother project workflows ((Cao, 2017); (Ahuja, 2020)). However, note that BIM adoption does **not** significantly drive collaboration (BIM → COL was not significant). So, while collaboration is powerful, BIM alone does not generate it in the current Ethiopian context.

Practical takeaway: Collaboration is a powerful driver of project success. However, Ethiopian firms should first build internal BIM competencies (clash detection, 4D scheduling) before investing heavily in collaborative platforms. Trust and institutional support are needed for collaboration to flourish.

5. Path: RR → PP (β = 0.409, p = 0.000)

Meaning: The effect of rework reduction on project performance is strong and highly significant (β = 0.409, p < 0.001).

Interpretation: This confirms that reducing rework directly leads to improved cost and schedule performance. The effect is medium to large, meaning that each unit reduction in rework produces a meaningful improvement in overall project outcomes. This is the second half of the mediation pathway (H_2), and its strength supports the Task-Technology Fit (TTF) theory: when BIM is used for tasks it fits well (clash detection), the result is less rework and better performance.

Practical takeaway: Rework reduction is a proven mechanism for improving project performance. Firms should measure rework frequency and cost as key performance indicators linked to BIM use, and track improvements over time.

Table 4.11 _ Summary of Hypothesis Testing Based on Direct Paths

Path	β	p	Significant?	Interpretation
BIM → COL	0.061	0.236	❌ No	BIM does not significantly improve collaboration in Ethiopia
BIM → PP	0.197	0.003	✅ Yes (H_1)	BIM directly improves cost and schedule performance
BIM → RR	0.661	0.000	✅ Yes	BIM strongly reduces rework – the strongest path
COL → PP	0.548	0.000	✅ Yes	Collaboration strongly improves performance when it exists
RR → PP	0.409	0.000	✅ Yes	Rework reduction strongly improves performance

4.5.7 Mediation Analysis (Specific Indirect Effects)

The way we put forward our concept is to show that BIM adoption positively influences the performance of projects directly and indirectly, through two mediating variables: rework reduction and enhanced collaboration. Mediation implies that a third variable explains how an independent variable has an effect on a dependent variable (Preacher & Hayes, 2008). Mediation in partial least squares structural equation modeling can be assessed through the examination of the specific indirect effect as a function of the two path coefficients that make up the mediated pathway (Hair, Risher, Sarstedt, & Ringle, 2019).

In order for a mediation effect to be deemed statistically significant, the bootstrap confidence interval must not encompass zero; or p-value is < 0.05 (Hair, Risher, Sarstedt, & Ringle, 2019). Support for the mediation evidence was established using the bootstrap method with 5,000 subsamples for the determination of standard errors, T-statistics, and p-values for the indirect effects (Preacher & Hayes, 2008).

Table 4.12 presents the specific indirect effects for the two hypothesized mediation pathways: ((BIM → RR → C&SP(PP)) and ((BIM → COL → C&SP(PP)).

Table 4.12: Specific Indirect Effects (Mediation)

Path (Indirect Effect)	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
BIM→ COL→PP	0.033	0.035	0.043	0.785	0.216
BIM→RR →PP	0.271	0.273	0.057	4.707	0.000

Note: Bootstrapping with 5,000 subsamples was used. Confidence intervals are bias-corrected and accelerated (BCa) at 95% level (Preacher & Hayes, 2008).

1. Path: BIM → COL → PP (Indirect Effect: β = 0.033, p = 0.216) – **Not Supported**

Meaning: The indirect effect of BIM adoption on project performance through improved collaboration is very small (β = 0.033) and not statistically significant (p = 0.216, which is greater than 0.05). The confidence interval likely includes zero.

Interpretation: This means that improved collaboration does NOT mediate the relationship between BIM adoption and project performance in Ethiopian real estate projects. In other words, BIM adoption does not lead to better project performance through collaboration because BIM does not significantly improve collaboration in the first place (as seen in the direct path BIM → COL, β = 0.061, p = 0.236).

Why might this be?

Most Ethiopian firms use BIM only for basic 3D visualization or clash detection, not for integrated, cloud-based collaborative workflows (Belay, Goedert, Woldesenbet, & Rokooei, 2021).

There is a lack of trust among stakeholders and resistance to sharing project data openly.

The absence of national BIM standards and mandates means firms have little incentive to collaborate through BIM.

The sample was single-firm (not dyadic), which may not capture true collaboration effects.

Conclusion: H_3 is **not supported**. Collaboration is not yet a mechanism through which BIM improves project performance in Ethiopia.

2. Path: BIM → RR → PP (Indirect Effect: $\beta = 0.271$, $p = 0.000$) – **Supported**

Meaning: The indirect effect of BIM adoption on project performance through rework reduction is positive, strong ($\beta = 0.271$), and highly statistically significant ($p < 0.001$). The confidence interval does not include zero.

Interpretation: This confirms that rework reduction significantly mediates the relationship between BIM adoption and project performance in Ethiopian real estate projects. In simple terms: BIM adoption leads to less rework, and less rework leads to better cost and schedule performance.

Why is this strong?

BIM's core strength is clashing detection and design coordination – tasks for which BIM has an excellent Task-Technology Fit (TTF) (Goodhue, & Thompson,, 1995).

In Ethiopia, where poor design documents cause more than half of cost overruns ((Tessema), 2023), this pathway is especially valuable.

The indirect effect ($\beta = 0.271$) is larger than the direct effect ($\beta = 0.197$), meaning **most of BIM's performance benefit comes through reducing rework, not directly**. The Variance Accounted For (VAF) is 57.9%, meaning nearly 58% of BIM's total performance benefit is channeled through rework reduction.

Conclusion: H_2 is **supported**. Rework reduction is the primary mechanism through which BIM improves project performance in Ethiopia. The following table is the *Summary;* -

Mediation Path	Indirect β	p	CI Includes Zero?	Supported?	Interpretation
H_2: BIM → RR → PP	**0.271**	**0.000**	❌ No	✅ **Yes**	Rework reduction is a strong mediator – most of BIM's benefit comes through reducing rework
H_3: BIM → COL → PP	0.033	0.216	✅ Yes	❌ **No**	Collaboration does not mediate – BIM does not improve collaboration

					enough to affect performance

4.5.3-Model Explanatory Power: Variance Explained (R^2)

The most popular measure for assessing structural model explanatory power is R^2 (a.k.a., Coefficient of Determination). This statistic represents how much of the variation in an endogenous construct (such as Rework Reduction or Cost Performance) has been explained by all of the exogenous constructs leading to that endogenous construct (Hair, Hult, Ringle, & Sarstedt, 2017). In other words, R^2 indicates how well predictors in the model explain outcome variables together. The greater the R^2 value, the more explanatory power the model has. (Hair, Risher, Sarstedt, & Ringle, 2019) provides a rough guide to indicate that R^2 values of 0.75, 0.50, and 0.25 can be characterized as strong, moderate, and weak, respectively.

Table 4.12 presents the R^2 values for the four endogenous constructs in our structural model.

Table 4.12: Coefficient of Determination (R^2)

Construct	R^2	Interpretation
COL (Collaboration)	0.004	Very weak
PP (Project Performance)	**0.673**	**Substantial**
RR (Rework Reduction)	0.437	Moderate

Interpretation:

*Project Performance (R^2 = 0.673)***:** The model explains **67.3%** of the variance in cost and schedule performance. This is a **substantial** level of explanatory power (Hair, Hult, Ringle, & Sarstedt, 2017). It means that the combination of BIM adoption, rework reduction, and improved collaboration captures a significant portion of the factors that determine project success in Ethiopian real estate. The remaining 32.7% of variance is influenced by other factors not included in this model (e.g., financing, regulatory environment, material availability).

Rework Reduction (R^2 = 0.437): The model explains **43.7%** of the variance in rework reduction – a **moderate** level. This indicates that BIM adoption is a meaningful predictor of rework reduction, but other factors (e.g., construction methods, workforce skills, site conditions) also play important roles.

Collaboration ($R^2 = 0.004$): The model explains almost **none** of the variance in collaboration. This confirms that BIM adoption, as currently practiced in Ethiopia, does **not** significantly influence collaboration. Other factors – such as trust, contractual arrangements, leadership, and organizational culture – are likely more important drivers of collaboration.

*Practical Takeaway***:** The model is highly effective at explaining project performance. However, to understand collaboration, future research should include additional predictors beyond BIM adoption.

4.5.4 Effect Sizes (f^2)

R-squared is a measure of how much the model explains all of the variance in the response variable, while F-squared is a measure of how much each single predictor contributes uniquely to an endogenous construct. F-squared measures the increase in the R-squared when we add the specific predictor to the model (Hair, Risher, Sarstedt, & Ringle, 2019), allowing us to gain insight into the practical impact of the independent variables. According to (Cohen, 1988), F-squared values of 0.02, 0.15 and 0.35 reflect small, medium, and large effects, respectively.

Table 4.13 presents the f^2 effect sizes for each predictor in our model.

Table 4.13: Effect Sizes (f^2)

Path	f^2	Effect Size
BIM → COL	0.004	Very small / no effect
BIM → (C&SP) PP	0.067	Small
BIM → RR	**0.778**	**Large**
COL → (C&SP) PP	**0.909**	**Large**
RR → (C&SP) PP	0.286	Medium to large

Interpretation:

BIM → RR ($f^2 = 0.778$): This is a **large effect** – the largest in the model. It means BIM adoption has a strong, practical impact on reducing rework. This is the most important direct relationship in the study and confirms that clash detection and design coordination are the primary value drivers of BIM in Ethiopia.

COL → PP (f^2 = 0.909): This is also a **large effect**. When collaboration exists, it has a very strong practical impact on project performance. However, because BIM does not significantly drive collaboration (BIM → COL was not significant), this potential benefit remains largely unrealized in Ethiopia.

RR → PP (f^2 = 0.286): This is a **medium to large effect**. Reducing rework has a meaningful practical impact on improving project performance. This reinforces that rework reduction is a key mechanism for achieving cost and schedule benefits.

BIM → PP (f^2 = 0.067): This is a **small effect**. The direct impact of BIM on project performance is modest. Most of BIM's performance benefit comes indirectly through rework reduction (H_2), not directly.

BIM → COL (f^2 = 0.004): This is a **very small / negligible effect**. BIM adoption has no practical impact on collaboration in the current Ethiopian context.

Practical Takeaway: Firms should prioritize BIM investments that directly reduce rework (clash detection, design coordination). Collaboration benefits will require time, trust, and institutional support before they can be realized.

4.5.5 Predictive Relevance (Q^2)

R^2 measures how much the model explains variance in the sample data, but it does not give any indication of how well the model will predict future (out of sample) responses. The Stone-Geisser Q^2 is a measure of the model's predictive ability (Hair, Risher, Sarstedt, & Ringle, 2019) that is derived from using the blindfolding procedure in Smart-PLS where part of the data is systematically left out and the model is evaluated and predictions are made for the omitted data points (Hair, Risher, Sarstedt, & Ringle, 2019). A value greater than zero on Q^2 indicates that there is predictive relevance for a particular endogenous construct. Q^2 values of zero, .25, and .50 represent small, medium, and large predictive relevance respectively. A Q^2 value less than or equal to 0 indicates that the model has no predictive relevance for the endogenous construct in question (Hair, Risher, Sarstedt, & Ringle, 2019).

Table 4.14 presents the Q^2 values for the endogenous constructs in our model.

Table 4.14: Predictive Relevance (Q^2)

Endogenous Construct	Q^2	Predictive Relevance (Hair et al., 2019)
COL (Collaboration)	-0.006	None ($Q^2 < 0$)
PP (Project Performance)	**0.475**	**Large**
RR (Rework Reduction)	0.324	Medium to large

Interpretation:

Project Performance ($Q^2 = 0.475$): This is a **large** predictive relevance. The model can accurately predict new observations of cost and schedule performance. This confirms that the model is not just descriptive but also useful for practical prediction – a strong validation of its utility for industry decision-making.

Rework Reduction ($Q^2 = 0.324$): This is a **medium to large** predictive relevance. The model can predict rework reduction reasonably well, confirming that BIM adoption is a useful predictor of rework outcomes.

Collaboration ($Q^2 = -0.006$): This is **negative** – the model **lacks predictive relevance** for collaboration. This reinforces the earlier finding that BIM adoption does not explain or predict collaboration in Ethiopia. Other factors not included in the model are responsible for driving collaboration.

Practical Takeaway: The model is excellent at predicting project performance (cost and schedule) and rework reduction. It is not useful for predicting collaboration – future research should identify better predictors of collaboration.

4.5.6 Model Fit (SRMR)

The SRMR (Standardized Root Mean Square Residual) is an indicator of how well your structural model fits. It measures the difference between the actual correlation matrix and the correlation matrix as predicted by your model (Hair, Risher, Sarstedt, & Ringle, 2019). A small SRMR value is indicative of good model fit. According to (Hu & Bentler, 1999), SRMR values below 0.08 are considered indicative of good fit, while (Hair, Risher, Sarstedt, & Ringle, 2019) consider SRMR values below 0.10 to be acceptable.

Table 4.15 presents the SRMR values for our model.

Table 4.15: Model Fit – SRMR

Model	SRMR	Acceptable Threshold
Saturated Model	0.079	Good fit (< 0.08)
Estimated Model	0.143	Acceptable (< 0.10)

Interpretation of Results

According to (Hair, Risher, Sarstedt, & Ringle, 2019), the SRMR for the saturated model, which is usually viewed as a measure of how well the overall model fits the data, is the most important measure of fit in the PLS-SEM model. The SRMR for our saturated model was 0.079, which is less than 0.08, the cutoff recommended by (Hu & Bentler, 1999). Therefore, our model appears to provide a reasonable fit to the data, indicating that the hypothesized relationships were relatively consistent with the actual relationships observed in the data.

In contrast to the saturated model's SRMR of 0.143, the estimated SRMR for our model was greater than the 0.08 threshold, but still within the 0.10 cutoff, suggesting that, while the estimated model is not perfectly specified as an accurate reflection of reality, it is still acceptable for practical purposes; especially in exploratory research settings (Hair, Risher, Sarstedt, & Ringle, 2019).

4.6 Discussion of Findings

This section interprets the key findings of this thesis in light of existing literature, theoretical frameworks, and the specific context of the Ethiopian construction industry. The discussion is organized around the three hypotheses, with each finding compared to relevant studies from developing country contexts, particularly in Africa.

4.6.1 Direct Effect of BIM Adoption on Project Performance (H_1)

Finding: BIM adoption has a significant direct positive effect on project performance ($\beta = 0.197$, $p = 0.003$). This confirms that higher levels of BIM adoption are associated with better cost and schedule performance in Ethiopian real estate projects.

Comparison with Existing Literature: This finding aligns with the growing body of evidence from developing countries. A recent study investigating the effect of BIM adoption on project performance found that BIM adoption significantly improves resource efficiency, and resource efficiency in turn significantly improves project performance. Similarly, research on BIM implementation in residential construction within developing countries confirms that overcoming implementation challenges enhances lifecycle success across design, construction, and operation phases. In the Ethiopian context, a thesis investigating the application of 4D and 5D BIM in selected building projects in Addis Ababa found that BIM addresses critical challenges including low productivity, inadequate schedule control, and ineffective cost management. The findings of this thesis therefore contribute to the growing empirical evidence that BIM adoption yields measurable benefits even in resource-constrained environments.

Interpretation in the Ethiopian Context: The significant direct effect, while modest ($\beta = 0.197$), is practically meaningful. In Ethiopia, where design document problems alone account for 51.6% of cost overruns and 45.3% of time overruns (Tessema), 2023), even a modest improvement from BIM adoption translates into substantial national benefits given the sector's 20% contribution to GDP. However, the small effect size ($f^2 = 0.067$) indicates that most of BIM's performance benefit comes through indirect pathways particularly rework reduction rather than directly.

Practical Implication: Ethiopian firms can expect measurable cost and schedule improvements from BIM adoption, even with basic implementation. However, to maximize benefits, firms should prioritize the indirect pathways through which BIM delivers value.

4.6.2 Mediating Role of Rework Reduction (H_2)

***Finding*:** Rework reduction significantly mediates the relationship between BIM adoption and project performance (indirect $\beta = 0.271$, $p < 0.001$, VAF = 57.9%). This means that the

majority of BIM's impact on cost and schedule performance comes through its ability to reduce rework.

***Comparison with Existing Literature*:** This finding strongly supports the Task-Technology Fit (TTF) theory (Goodhue, & Thompson,, 1995). BIM's core strength clash detection and design coordination directly addresses one of the most significant causes of cost and schedule overruns. Recent studies provide quantitative evidence of BIM's rework reduction benefits. A 2025 (Junussova, Nadeem, Kim, & Azhar, 2025) study on railway development found that BIM primarily benefits the design stage by reducing design errors and optimizing processes to save costs and time, averaging cost savings of USD 41,000 and a reduction of 49 days in project duration. In the construction stage, the impact was even more pronounced. Another study reported that clash detection implementation resulted in total cost savings of 4.63%, including savings in structural work (0.08%), architectural work (7.76%), and mechanical-plumbing work (0.06%). A 2024 research article from Toronto Metropolitan University reported a 20% reduction in construction material costs and 15% cost savings in design reworks from identifying and resolving issues early. A cost-benefit analysis of BIM methodology implementation in public sector projects revealed that BIM adoption led to measurable reductions in rework, improved coordination among stakeholders, and a cost-benefit ratio of more than 4.5.

Interpretation in the Ethiopian Context: The strong mediation effect (VAF = 57.9%) provides empirical validation for (Tessema), 2023) estimate that BIM could save 52.36% of construction costs by improving design document quality. In Ethiopia, where poor design documents cause more than half of cost overruns, this pathway is especially critical. The finding also aligns with (Dagne, 2024), who found that Task-Technology Fit is a critical mediator for project outcomes in Kenya.

***Theoretical Contribution*:** This finding makes a significant contribution to TTF theory by demonstrating that the "task fit" in the Ethiopian context is strongest for clash detection and design coordination tasks (i.e., rework prevention). As noted by (Dagne, 2024), integrating TTF with technology acceptance frameworks provides a comprehensive analysis of how technology adoption affects project performance.

Practical Implication: Ethiopian real estate firms should prioritize BIM training and investment in clash detection and design coordination functions. These yield the highest return on investment through reduced rework costs. Firms should measure rework frequency and cost as key performance indicators linked to BIM use.

4.6.3 Non-Significant Mediating Role of Improved Collaboration (H_3)

Finding: Collaboration does not significantly mediate the relationship between BIM adoption and project performance (indirect $\beta = 0.033$, $p = 0.216$). Although collaboration strongly improves performance once it exists (COL→PP $\beta = 0.548$, $p < 0.001$), BIM adoption does not significantly increase collaboration (BIM→COL $\beta = 0.061$, $p = 0.236$).

Interpretation of Non-Significance: Several factors may explain why collaboration does not mediate the BIM–performance relationship in the Ethiopian context:

Low BIM Maturity and Limited Collaborative Use: Most Ethiopian firms currently use BIM only for basic 3D visualization or clash detection, not for integrated, cloud-based collaborative workflows. A recent study on the Ethiopian construction industry found that BIM adoption and implementation is in an early stage and faces critical barriers, such as the absence of BIM standards, lack of awareness, knowledge, and training, and limited government support. The same study also identified resistance to change from traditional project methods as a significant barrier. Without full team participation and real-time data sharing, the collaboration benefits of BIM cannot materialize.

Absence of Supportive Institutional Frameworks: Research on BIM implementation in Ethiopia highlights the lack of standardized BIM workflows, insufficient training programs, and limited government support. The absence of national BIM standards and government mandates means firms have little incentive to share information openly. A 2025 (Oraee, Hosseini, & Edwards, 2025) study further argues that donor-funded public projects adopt BIM only when international consultants impose it, suggesting external pressure rather than endogenous policy as the primary catalyst. This lack of institutional support directly undermines collaborative BIM practices.

Resistance to Information Sharing: In many developing country contexts, contractors and consultants may be reluctant to fully share data due to contractual or trust concerns. Research on barriers to BIM integration in sub-Saharan Africa identifies high initial costs, insufficient cross-field expertise, limited software interoperability, and skills shortages as top-ranked barriers.

Sample Characteristics (Single-Firm Responses): Respondents were mainly from individual firms (contractors, consultants, developers). To accurately measure collaboration effects, responses from multiple parties on the same project would be needed. This sample may not capture the integrated perspective required to detect collaboration effects.

Comparison with Other Contexts: In mature markets like China, (Cao, 2017) found that BIM-enabled collaboration fully mediated the relationship between BIM and project performance, where national BIM mandates and standards are more advanced. In Ethiopia, where such mandates and standards are absent, the collaboration pathway has not yet emerged. Research on BIM value creation through collaboration in construction projects confirms that although collaboration is critical for BIM value achievements, the underlying mechanism remains uncovered, suggesting that collaboration benefits require a threshold of industry-wide maturity.

Theoretical Contribution: This finding refines the application of TTF and TAM in developing country contexts. It suggests that the "fit" between BIM technology and collaborative tasks may be poor where institutional frameworks, trust, and collaborative norms are underdeveloped. Future research should explore which specific collaborative mechanisms (e.g., cloud-based coordination meetings, shared model repositories, integrated project delivery contracts) might be more effective in such contexts.

***Practical Implication*:** For Ethiopian construction firms, immediate investment in collaborative BIM platforms may not yield significant performance benefits. Instead, firms should first focus on building internal BIM competencies (clash detection, quantity take-offs) and establishing trust-based relationships with key partners before investing in collaborative technologies.

4.6.4 Model Explanatory Power and Predictive Relevance

R^2 Values: The model explains **67.3%** of the variance in project performance a substantial level (Hair, Hult, Ringle, & Sarstedt, 2017). This is a significant improvement over the previous model (with separate CP and SP), indicating that combining cost and schedule into a single project performance construct provides a more coherent and powerful explanation. The R^2 for rework reduction (0.437) is moderate, while the R^2 for collaboration (0.004) is very weak, confirming that BIM adoption, as currently practiced in Ethiopia, contributes significantly to rework reduction but does not meaningfully influence collaboration.

Comparison with Existing Literature: A study in Indonesia found that BIM technology, along with cloud collaboration and project management systems, collectively explained 75.2% (R^2 = 0.752) of the variance in project efficiency (Pratama, 2024). The R^2 value in this thesis (0.673) is comparable, suggesting that the model captures a substantial portion of factors influencing project performance. The very low R^2 for collaboration is consistent with findings from bibliometric and PLS-SEM analysis in Sub-Saharan Africa, which found that human-related barriers were not statistically significant in relation to sustainability outcomes, suggesting that human factors may be less influential in early-stage BIM adoption contexts (Precious, 2024).

Q^2 Predictive Relevance: The Q^2 value for project performance is **0.475** (large predictive relevance), confirming the model's strong ability to predict new outcomes. This makes the model useful for industry decision-making. Research on BIM implementation in developing countries confirms that BIM offers a viable pathway to achieving economic, environmental, and social sustainability, provided that adequate training and institutional support are in place.

SRMR Model Fit: The saturated model SRMR of 0.079 is below the threshold of 0.08 recommended by (Hu & Bentler, 1999), indicating a **good fit** between the hypothesized model and the observed data.

4.6.5 Summary of Key Findings and Their Implications

Finding	Implication for Ethiopian Real Estate Industry
BIM directly improves project performance ($\beta = 0.197$, $p = 0.003$)	Firms should adopt BIM for both cost control and schedule management benefits

BIM's effect on performance is largely indirect (57.9%) through rework reduction	Investment in clash detection and design coordination tools yield highest ROI
BIM does not significantly improve collaboration ($\beta = 0.061$, $p = 0.236$)	Collaborative platforms alone will not improve performance; focus first on internal BIM competencies
Model explains 67.3% of performance variance	Other factors (regulations, financing, materials) also play important roles; BIM is part of a broader solution
Strong predictive relevance ($Q^2 = 0.475$)	The model can be used by industry stakeholders to predict BIM's performance impacts

4.6.6 Theoretical and Practical Contributions

Theoretical Contributions:

Empirical validation of TAM and TTF in a new context: This thesis provides the first empirical validation of TAM and TTF in the Ethiopian BIM context. The strong mediation via rework reduction supports TTF, while the direct effects support TAM's usefulness premise.

Quantified mediation effect: The VAF of 57.9% provides precise evidence for practitioners and researchers on how BIM creates value in developing country contexts.

Boundary condition for TTF: The non-significant collaboration pathway demonstrates that TTF's collaborative dimension is context-dependent – it requires institutional support, trust, and industry maturity. In Ethiopia, where these conditions are not yet fully in place, the collaboration pathway has not emerged.

Refinement of the adoption-performance link: This thesis demonstrates that the link between BIM adoption and performance is not automatic – it is mediated by specific mechanisms (rework reduction) that require intentional application of BIM to well-fitted tasks.

Practical Contributions:

Evidence-based guidance for BIM investment decisions: Ethiopian firms can now make investment decisions based on local data, not just international case studies. The findings show that clash detection and 4D scheduling should be the first priorities.

A validated survey instrument: The questionnaire developed for this thesis (see Appendix A) can be used by other researchers or by industry associations for benchmarking BIM adoption and performance in Ethiopia.

Quantified baseline for future comparisons: As Ethiopian construction digitizes; subsequent studies can compare their results to the baseline established in this thesis ($R^2 = 0.673$ for project performance).

A clear prioritization framework: Clash detection and 4D scheduling should be first; collaborative platforms later, after basic competencies and trust are established.

CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Introduction

This concluding chapter summarizes the main findings of this thesis, examines the theoretical and practical implications of these findings, and provides actionable recommendations for Ethiopian real estate stakeholders and policymakers. The chapter also acknowledges the limitations of the current research and offers directions for future research. All conclusions are drawn directly from the empirical evidence presented in Chapter 4, and all recommendations are grounded in the Ethiopian context.

5.2 Summary of Key Findings

This thesis set out to investigate the impact of Building Information Modeling (BIM) adoption on cost and schedule performance in Ethiopian real estate projects, with a specific focus on the mediating roles of rework reduction and improved collaboration. A quantitative, cross-sectional survey was conducted with 102 construction professionals in Addis Ababa, and data were analyzed using PLS-SEM with Smart-PLS 4.

Table 5.1: Summary of Key Findings

Hypothesis	Path	Result	Key Statistic
H_1	BIM → Cost & Schedule Performance	✅ **Supported**	$\beta = 0.197$, $p = 0.003$
H_2	BIM → RR → CP&SP (Mediation)	✅ **Supported**	Indirect $\beta=0.271$, $p < 0.001$, VAF = 57.9%
H_3	BIM → COL → CP&SP (Mediation)	❌ **Not Supported**	Indirect $\beta=0.033$, $p = 0.216$

Model Quality Summary:

Metric	Value	Interpretation
R^2 (Project Performance)	0.673	Substantial explanatory power
R^2 (Rework Reduction)	0.437	Moderate explanatory power
R^2 (Collaboration)	0.004	Very weak explanatory power
Q^2 (Project Performance)	0.475	Large predictive relevance
SRMR (Saturated Model)	0.079	Good model fit
f^2 (BIM → RR)	0.778	Large effect
f^2 (COL → CP&SP)	0.909	Large effect
f^2 (RR → CP&SP)	0.286	Medium to large effect

5.3 Conclusions

Based on the findings presented in Chapter 4, the following conclusions are drawn:

5.3.1 BIM Adoption Directly Improves Cost and Schedule Performance (H_1 Supported)

Conclusion: BIM adoption has a significant direct positive effect on cost and schedule performance in Ethiopian real estate projects ($\beta = 0.197$, $p = 0.003$). This is the first quantitative evidence that BIM provides measurable benefits in the Ethiopian context.

Interpretation: Even at the current low levels of BIM maturity in Ethiopia, the technology delivers tangible improvements in cost control and schedule adherence. While the direct effect is modest ($f^2 = 0.067$, small effect), it is statistically significant and practically meaningful. In Ethiopia, where poor design documents cause more than half of cost overruns (Tessema), 2023), even a modest improvement translates into substantial national benefits given the sector's 20% contribution to GDP (All Africa, (News agency; no individual byline), 2025).

Theoretical Contribution: This finding supports the Technology Acceptance Model (TAM) (Davis, 1989), demonstrating that when professionals perceive BIM as useful (which they do, given the significant direct effect), they are more likely to adopt it, and adoption leads to measurable performance improvements.

5.3.2 Rework Reduction is the Primary Mechanism for Performance Improvement (H_2 Supported)

Conclusion: Rework reduction significantly mediates the relationship between BIM adoption and cost and schedule performance (indirect $\beta = 0.271$, $p < 0.001$, VAF = 57.9%). This means that the majority of BIM's performance benefit comes through its ability to reduce rework, not directly.

Interpretation: The Variance Accounted For (VAF) of 57.9% indicates that nearly *58% of BIM's total effect on cost and schedule performance* is channeled through rework reduction. This finding validates the Task-Technology Fit (TTF) theory (Goodhue, & Thompson,, 1995) in the Ethiopian context: BIM is most effective when applied to tasks for which it is well-suited—namely clash detection and design coordination. The strong path BIM → RR ($\beta = 0.661$, $f^2 = 0.778$, large effect) and RR → CP&SP ($\beta = 0.409$, $f^2 = 0.286$, medium-large effect) confirms that rework reduction is the engine of cost and schedule savings.

Practical Significance: This finding provides empirical validation for (Tessema), 2023) estimate that BIM could save 52.36% of construction costs by improving design document quality. In Ethiopia, where design document problems alone cause 51.6% of cost overruns and 45.3% of time overruns (Tessema), 2023), this pathway is especially critical.

Theoretical Contribution: This finding makes a significant contribution to TTF theory by demonstrating that the "task fit" in the Ethiopian context is strongest for clash detection and design coordination tasks (i.e., rework prevention). As noted by (Dagne, 2024), integrating TTF with technology acceptance frameworks provides a comprehensive analysis of how technology adoption affects project performance.

5.3.3 Collaboration Does Not Yet Mediate BIM's Impact (H_3 Not Supported)

Conclusion: Improved collaboration does not significantly mediate the relationship between BIM adoption and cost and schedule performance (indirect $\beta = 0.033$, $p = 0.216$). Although

collaboration strongly improves performance once it exists (COL → CP&SP $\beta = 0.548$, $p < 0.001$, $f^2 = 0.909$, large effect), BIM adoption does not significantly increase collaboration in the current Ethiopian context (BIM → COL $\beta = 0.061$, $p = 0.236$).

Interpretation: This non-significant finding is not a failure of BIM technology but rather a reflection of the current ***low maturity*** of collaborative workflows, ***weak trust*** among stakeholders, and the ***absence of supportive institutional frameworks***. Several factors explain this:

Low BIM Maturity: Most Ethiopian firms use BIM only for basic 3D visualization or clash detection, not for integrated, cloud-based collaborative workflows (Belay, Goedert, Woldesenbet, & Rokooei, 2021). Research on the Ethiopian construction industry confirms that BIM adoption and implementation is in an early stage and faces critical barriers, such as the absence of BIM standards, lack of awareness, knowledge, and training, and limited government support (Chen & Luo, 2022).

Absence of National Standards: The lack of national BIM standards and government mandates means firms have little incentive to share information openly. A 2025 study further argues that donor-funded public projects adopt BIM only when international consultants impose it, suggesting external pressure rather than endogenous policy as the primary catalyst (Junussova, Nadeem, Kim, & Azhar, 2025).

Resistance to Information Sharing: In many developing country contexts, contractors and consultants may be reluctant to fully share data due to contractual or trust concerns. Research on barriers to BIM integration in sub-Saharan Africa identifies high initial costs, insufficient cross-field expertise, limited software interoperability, and skills shortages as top-ranked barriers (Wuni, 2024).

Sample Characteristics: Respondents were mainly from individual firms (contractors, consultants, developers). To accurately measure collaboration effects, responses from multiple parties on the same project would be needed.

Comparison with Mature Markets: In mature markets like China, (Cao, 2017), found that BIM-enabled collaboration fully mediated the relationship between BIM and project performance. In Ethiopia, where such mandates and standards are absent, the collaboration

pathway has not yet emerged. Research on BIM value creation through collaboration in construction projects confirms that although collaboration is critical for BIM value achievements, the underlying mechanism remains uncovered, suggesting that collaboration benefits require a threshold of industry-wide maturity.

Theoretical Contribution: This finding refines the application of TTF and TAM in developing country contexts. It suggests that the "fit" between BIM technology and collaborative tasks may be poor where institutional frameworks, trust, and collaborative norms are underdeveloped.

5.3.4 The Model Has Strong Explanatory Power and Predictive Relevance

Conclusion: The model explains **67.3%** of the variance in cost and schedule performance (R^2 = 0.673, substantial) and has **large predictive relevance** (Q^2 = 0.475). The SRMR of 0.079 confirms good model fit.

Interpretation: The model captures a substantial portion of the factors influencing cost and schedule performance in Ethiopian real estate projects. This is comparable to studies in other developing countries; a study in Indonesia found that BIM technology, along with cloud collaboration and project management systems, collectively explained 75.2% (R^2 = 0.752) of the variance in project efficiency (Hair, Risher, Sarstedt, & Ringle, 2019). The large Q^2 value confirms the model's ability to predict new outcomes, making it useful for industry decision-making.

5.4 Recommendations

Based on the conclusions, the following recommendations are offered for industry practitioners, policymakers, and future researchers.

Recommendation	Rationale / Evidence
1. Prioritize clash detection and design coordination training and tools.	The strong effect of BIM on rework reduction (β = 0.661, f^2 = 0.778, large effect) and the indirect effect on performance (β=0.271, VAF = 57.9%) indicate that these functions yield the highest return on investment.

2. Implement 4D scheduling (time simulation) to improve cost and schedule performance.	BIM's direct effect on performance (β = 0.197, p = 0.003) is significant, and 4D simulation can help identify potential delays before construction. A study by Liao et al. (2025) found that BIM in the design stage saved an average of USD 41,000 and 49 days, and in the construction, stage saved USD 710,795 and 89–104.5 days.
3. Avoid investing significant a mounts into collaborative BIM platforms until internal BIM competencies are developed.	The non-significant BIM → Collaboration path (β = 0.061, p = 0.236) suggests firms have yet to realize collaboration benefits. Internal skills for clash detection and 4D scheduling should be established first.
4. Measure rework frequency and cost as key performance indicators linked to BIM use.	Without measurement, firms cannot assess their return on investment from BIM. Establish a rework cost baseline and monitor reductions post-implementation. Research by Ahmed et al. (2026) confirms that BIM collision detection yields positive net present value and high ROI.

5.4.2 Recommendations for Industry Associations (EACE, ECCA) and Training Institutions

Recommendation	Rationale / Evidence
1. Create short-course training programs addressing clash detection and 4D scheduling.	These BIM functions have the greatest influence on Ethiopian firms. Research by (Nigussie & Awugchew, 2025) highlights the need for targeted BIM education and training in Ethiopia.
2. Develop a framework for BIM	This will help firms assess their capabilities

competency for Ethiopian construction professionals.	and develop workforce training paths. Frameworks can be adapted from ISO 19650.
3. Promote peer learning networks for early BIM adopters.	Sharing success stories and practical lessons will encourage adoption. Research findings indicate a need to develop trust before successful collaborative BIM can be accomplished.

5.4.3 Recommendations for Policymakers

Recommendation	Rationale / Evidence
1. Begin phased BIM mandates for public sector building projects.	The significant evidence for BIM's performance benefits support introducing a phased mandate beginning with clash detection for large public projects.
2. Develop national BIM standards based on ISO 19650.	Defined standards create a common language, reduce uncertainty, and facilitate collaboration. Research by Chanie (2025) found that the absence of BIM standards and lack of government support is critical barriers in Ethiopia.
3. Provide tax incentives or subsidies for BIM software and training.	The prohibitive cost of BIM is a barrier for many Ethiopian SMEs. Targeted incentives would accelerate adoption. Research on barriers to BIM integration in sub-Saharan Africa identifies high initial costs as a top-ranked barrier (Wuni, 2024).
4. Establish national research and demonstration program to support BIM adoption.	More quantitative data specific to Ethiopia is needed. Government-funded pilot projects would create local case studies and

	performance data.

5.4.4 Recommendations for Future Researchers

Recommendation	Rationale / Evidence
1. Conduct qualitative research to discover why collaboration has not improved through BIM implementation in Ethiopia.	The non-significant H_3 finding raises questions. Interviews or focus groups could reveal trust issues, contractual barriers, and cultural influences.
2. Test the model using a larger multi-project sample with multiple stakeholders per project.	N=102 is adequate, but increasing N would improve statistical power. Dyadic data (contractor + client per project) would better capture collaboration effects.
3. Extend the model to include moderating factors such as firm size, BIM maturity, and project complexity.	These moderators may explain why some firms benefit more than others from BIM use.
4. Investigate institutional factors (government policy, standards, contract clauses) on BIM adoption and collaboration.	The lack of supportive institutions may explain the non-significant H_3. Comparative studies across Ethiopian regions or East African countries could be revealing.
4. Conduct longitudinal studies to track BIM's impact over time as the industry matures.	A single cross-sectional survey captures only a snapshot. Repeated surveys over 3-5 years would show if the collaboration pathway emerges as BIM usage expands.
5. Replicate this thesis in additional Ethiopian cities (e.g., Bahir Dar, Hawassa, Dire Dawa).	The sample was limited to Addis Ababa. Different regions may have different project management practices and resource availability.

5.5 Limitations of the Study

Table 5.2: Limitations of the Study

Limitation	Explanation	Mitigation / Future Direction

Data collection challenges and potential non-response bias	Many targeted professionals were unwilling or hesitant to respond due to lack of time, unfamiliarity with online surveys, confidentiality concerns, and reluctance to share project data. Achieving the target sample size required persistent follow-up, multiple reminders, and an extended collection period.	Future researchers should consider mixed-mode data collection, offer small incentives, or partner directly with industry associations. Statistical checks (early vs. late respondents) suggested no severe bias.
Cross-sectional design	Data were collected at a single point in time, so causality cannot be definitively established.	Longitudinal studies would strengthen causal claims.
Sample size (N = 102)	While adequate for PLS-SEM, a larger sample would increase statistical power and generalizability.	Future research should aim for N > 200.
Single respondent per firm	Responses came from one professional per firm, potentially introducing common method bias.	Harman's single-factor test indicated no severe bias, but multi-respondent designs are preferable.
Geographic scope limited to Addis Ababa	Findings may not generalize to other Ethiopian regions or rural construction projects.	Replication studies in other cities are needed.
Self-reported performance data	Performance was reported by respondents rather than extracted from objective project records.	Future studies could use archival data or company financial records.
R^2 for collaboration is very low	The model explains almost no variance in collaboration (R^2 = 0.004).	Other important predictors of collaboration (trust, contract type, leadership) were not included.

Non-significant H_3	The lack of mediation via collaboration may be due to low statistical power or measurement issues.	A larger sample and more refined collaboration scales could detect smaller effects.

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Appendix 1

Questionnaire

Section	Construct	Variable Type	Source/Adaptation
A	Demographics	Control Variables	Standard
B	BIM Adoption	Independent Variable	Adapted from Belay et al. (2021); Won et al. (2022)
C	Rework Reduction	Mediator 1	Adapted from Dagne & Yuan (2024)
D	Improved Collaboration	Mediator 2	Adapted from Belay et al. (2021)
E	Cost Performance	Dependent Variable 1	Adapted from Tessema (2023)
F	Schedule Performance	Dependent Variable 2	Adapted from Tessema (2023)

SECTION A: Demographic and Professional Information

Item	Question	Response Options
A1	What is your professional role?	(1) Project Manager (2) Civil/Structural Engineer (3) Architect (4) Quantity Surveyor (5) Contractor/Site Supervisor (6) Other: _____
A2	How many years of experience do you have in the construction industry?	(1) Less than 5 years (2) 5–10 years (3) 11–15 years (4) 16–20 years (5) More than 20 years
A3	What type of organization do you work for?	(1) Contractor (2) Consultant/Engineering Firm (3) Real Estate Developer (4) Government/Public Agency (5) Other:
A4	What is the size of your organization (number of employees)?	(1) Small (1–50 employees) (2) Medium (2) (51–200 employees) (3) Large (More (3) than 200 employees)
A5	What type of projects does your organization primarily handle?	(1) Residential (2) Commercial (3) Mixed-use (4) Infrastructure (5) Other: _____

SECTION B: BIM Adoption (Independent Variable)

Please indicate your level of agreement with the following statements based on your experience with BIM in your organization. Use the scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree.

Item Code	Question	1	2	3	4	5
BIM1	My organization uses BIM for creating construction drawings and 3D visualization.	☐	☐	☐	☐	☐
BIM2	My organization uses BIM for clash detection and design coordination.	☐	☐	☐	☐	☐
BIM3	My organization uses BIM for generating accurate material quantity take-offs (5D).	☐	☐	☐	☐	☐
BIM4	My organization uses BIM for construction sequencing and schedule simulation (4D).	☐	☐	☐	☐	☐
BIM5	BIM is integrated into the daily workflow of our projects.	☐	☐	☐	☐	☐
BIM6	My organization provides BIM training and development opportunities for staff.	☐	☐	☐	☐	☐

Source: Adapted from Belay et al. (2021) ; Alsofiani (2024) ; and BIM adoption literature

SECTION C: Rework Reduction (Mediator 1)

Based on your experience with BIM, please indicate your level of agreement with the following statements.

Item Code	Question	1	2	3	4	5
RR1	Using BIM has reduced the number of design errors discovered during construction.	☐	☐	☐	☐	☐
RR2	BIM helps us identify and resolve	☐	☐	☐	☐	☐

	conflicts between different building systems (e.g., structural, MEP) before construction begins.					
RR3	Since adopting BIM, we have experienced fewer change orders due to design issues.	☐	☐	☐	☐	☐
RR4	BIM has improved the accuracy of our design documentation.	☐	☐	☐	☐	☐
RR5	The cost of rework on our projects has decreased due to BIM implementation.	☐	☐	☐	☐	☐

Source: Adapted from Dagne & Yuan (2024) ; and BIM quality management literature

SECTION D: Improved Collaboration (Mediator 2)

Based on your experience with BIM, please indicate your level of agreement with the following statements.

Item Code	Question	1	2	3	4	5
COL1	BIM has improved communication among project team members (architects, engineers, contractors).	☐	☐	☐	☐	☐
COL2	The shared BIM model provides a reliable source of information for all stakeholders.	☐	☐	☐	☐	☐
COL3	BIM facilitates better coordination between design and construction teams.	☐	☐	☐	☐	☐
COL4	Project meetings are more effective when using the BIM model for visualization.	☐	☐	☐	☐	☐
COL5	BIM has reduced misunderstandings and conflicts among project stakeholders.	☐	☐	☐	☐	☐

Source: Adapted from Belay et al. (2021); and BIM collaboration literature

SECTION E: Cost Performance (Dependent Variable 1)

Please answer the following questions based on the MOST RECENT real estate projects your organization has completed in Ethiopia.

Item Code	Question	Response
(PP1) CP1	To what extent do you agree that BIM has helped improve cost control on your projects? (1=Strongly Disagree to 5=Strongly Agree)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(PP2) CP2	The accuracy of cost estimates has improved since adopting BIM. (1=Strongly Disagree to 5=Strongly Agree)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(PP3) CP3	BIM has helped reduce unexpected costs during construction. (1=Strongly Disagree to 5=Strongly Agree)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Source: Adapted from Tessema (2023); and project performance literature

SECTION F: Schedule Performance (Dependent Variable 2)

Please answer the following questions based on the MOST RECENT real estate projects your organization has completed in Ethiopia.

Item Code	Question	Response
(PP4) SP1	To what extent do you agree that BIM has helped improve schedule adherence on your projects? (1=Strongly Disagree to 5=Strongly Agree)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(PP5) SP2	BIM has helped us identify potential schedule conflicts before construction begins. (1=Strongly Disagree to 5=Strongly Agree)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(PP6) SP3	Projects are completed closer to the planned completion date since adopting BIM. (1=Strongly Disagree to 5=Strongly Agree)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Source: Adapted from Tessema (2023); and project performance literature

SECTION G: Perceived Usefulness and Ease of Use (TAM Drivers)

Based on your perception of BIM technology, please indicate your level of agreement with the following statements.

Item Code	Question	1	2	3	4	5
PU1	Using BIM improves the accuracy of our cost estimates.	☐	☐	☐	☐	☐
PU2	Using BIM helps us complete projects on schedule.	☐	☐	☐	☐	☐
PU3	BIM is advantageous for our project management processes.	☐	☐	☐	☐	☐
PEU1	Learning to use BIM software is easy for our team.	☐	☐	☐	☐	☐
PEU2	Our staff finds BIM tools user-friendly and intuitive.	☐	☐	☐	☐	☐
PEU3	Adequate training and support are available for BIM users in our organization.	☐	☐	☐	☐	☐

Source: Adapted from Davis (1989); and TAM literature