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Solomon Belay

James D. Goedert

Asregedew Woldesenbet

Saeed Rokooei3

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Enhancing BIM implementation in the Ethiopian public construction sector: An empirical study

Solomon Belay[1*], James Goedert[2], Asregedew Woldesenbet[2] and Saeed Rokooei[3]

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*Corresponding author: Solomon Belay, Civil and Water Resources Engineering, Bahir Dar University, Bahir Dar, Ethiopia
E-mail: solomon.melaku@bdu.edu.et

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Additional information is available at the end of the article

Abstract: Recently, the popularity of BIM has grown rapidly in the public construction sector. However, only a few studies so far have been seeking to address the BIM adoption benefits and barriers in developmental public projects across the low-income countries. Thus, the study aims to investigate the benefits and barriers of BIM adoption in the context of the Ethiopian infrastructure market. To achieve the objectives, a comprehensive systematic literature review was conducted to identify BIM adoption benefits and barriers in developing countries. Then, a structured questionnaire survey was conducted to collect data from various professionals working in organizations including client, consultant, and contractor. The results indicate that Insufficient IT Infrastructure, Poor Government Help, and Lack of BIM Researches & Courses in Universities are the top ranked BIM adoption barriers in infrastructure projects. Whereas, Improved Communication Among Parties, Early Multidisciplinary Coordination, and 3D visualization perceived as the major benefits of BIM adoption in the Ethiopian context. The findings provide empirical evidences to professionals,

ABOUT THE AUTHOR

Solomon Belay Solomon Belay is a lecturer at the Bahir Dar Institute of Technology, Bahir Dar University. He is currently a PhD candidate in Construction Engineering and Management. He received his BSc. Degree in Civil Engineering at Jimma University and received his MSc. Degree in Civil Engineering at Bahir Dar University. His research interest includes Building Information Modeling (BIM), construction technology, and sustainability.

James Goedert James Goedert is an emirates professor at the University of Nebraska-Lincoln, USA; and an adjunct professor at Bahir Dar University. His research interest includes critical success factors in construction projects, project management, BIM.

Asregedew Woldesenbet Asregedew Woldesenbet is an adjunct professor at Bahir Dar Institute of Technology, Bahir Dar University. His research interest includes asset management, construction technology, building information modeling.

Saeed Rokooei Saeed Rokooei is an assistant professor at the Mississippi State University. His research interest includes education, project management, data analytics, BIM, community resilience, simulation and visualization, and sustainability.

PUBLIC INTEREST STATEMENT

The study explored the advantages and the challenges of adopting building information modeling, also commonly known as BIM in the Ethiopian public construction sector. BIM is a technology-driven process that has the potential to improve the overall performance of construction projects. The result reveals that BIM has the potential to enhance collaboration and communication between major players in the construction sector; although, the limited IT infrastructure could deter its wider diffusion in infrastructure construction projects. The findings provide practical application and an insight into the key focus areas of improvement to ensure successful BIM adoption in construction firms, as well as at the project and industry levels.

business CEOs and policy makers for the development of future BIM adoption policy in the Ethiopian construction sector. Further, insightful recommendations were forwarded to enhance the current BIM uptake in various construction projects.

Subjects: Engineering Management; Engineering Project Management; Civil, Environmental and Geotechnical Engineering

Keywords: BIM adoption; readiness; infrastructure projects; developing countries

1. Introduction

Infrastructure projects are generally considered as the fundamental structures, facilities, and systems that impact the public at large (Babatunde et al., 2012; Sinesilassie et al., 2017). This in turn makes these projects unique from their technical and financial point of view (Abd et al., 2017; Ozorhon & Karahan, 2017). Infrastructure construction projects involve multiple stakeholders throughout the project life cycle. The coordination and communication between these stakeholders are essential to enhance project management and ensure success of infrastructure projects (Chileshe et al., 2020). In this context, the planning, design, construction and delivery of infrastructure projects become complex when it comes to low-income countries (Kekana et al., 2020; Porwal & Hewage, 2013).

According to the World Bank report, the delivery of infrastructure projects in several sub-Saharan African countries lacks efficiency; and are normally knotted with delay, cost overrun, low productivity, and dispute among stakeholders (Calderon et al., 2018). As a result, construction firms become less profitable and incompetent. In addition, literature highlighted that the application of change orders due to design errors, and use of old construction techniques in developing countries are thought as the major causes of poor performance in public infrastructure projects (Ismail et al., 2017; Koops et al., 2016).

One of the ways to overcome the aforementioned problems is by introducing new technological innovations and processes such as Building Information Modeling (BIM) in the construction business operations (Ahn & Kim, 2016; Olanrewaju et al., 2020). BIM is a technological advancement which revolutionizes the technical, managerial, as well as business aspects of the construction industry. Developed nations, in particular the European countries, USA, Australia and Hong Kong enjoyed the variety of BIM benefits over the past decade (Chan et al., 2019; Ullah et al., 2019). These countries formulated and endorsed national BIM policies and standards to enhance the adoption and diffusion of BIM across the construction sector (Kassem & Succar, 2017).

In recent years, BIM has also gained a widespread acceptance across developing countries, despite its low adoption rate in developmental infrastructure projects (Ismail et al., 2017; Olawumi & Chan, 2019). For instance, Ismail et al. (2017) reported an improvement in overall BIM uptake across the Asian developing countries although suggested for further extended studies. Similarly, Murphy and Nahod, (2017) call for an in-depth investigation of BIM adoption in public construction projects for a successful BIM adoption and diffusion.

Moreover, recent studies revealed that there are only very few studies conducted in sub-Saharan African countries regarding BIM adoption in public infrastructure projects. Thus, to fill this gap, this study aims to explore the extent of BIM adoption readiness, including the benefits and barriers of adopting BIM in infrastructure projects. The study also examines the level of agreement between various respondent groups such as client, consultant, and contractor on each identified benefit and barrier. Further, the study provides key recommended actions to improve BIM diffusion across the construction market based on the findings from the factor analysis.

This study contributes to the Ethiopian construction sector by (1) for the first time providing a set of potential benefits and critical hindrance of adopting BIM particularly in public construction projects, (2) highlighting thoughtful practical implications and recommendations to enhance the current BIM uptake in construction organizations. The findings of this study will help construction business CEOs and management team to concentrate on the key areas of improvement in the organizational structure. Moreover, government officials and policy makers will be beneficial in their quest to develop a national BIM adoption standard for the Ethiopian construction sector.

2. Literature review

This section provides a background of BIM adoption in developing countries including the desk study techniques employed to select relevant papers for the analysis.

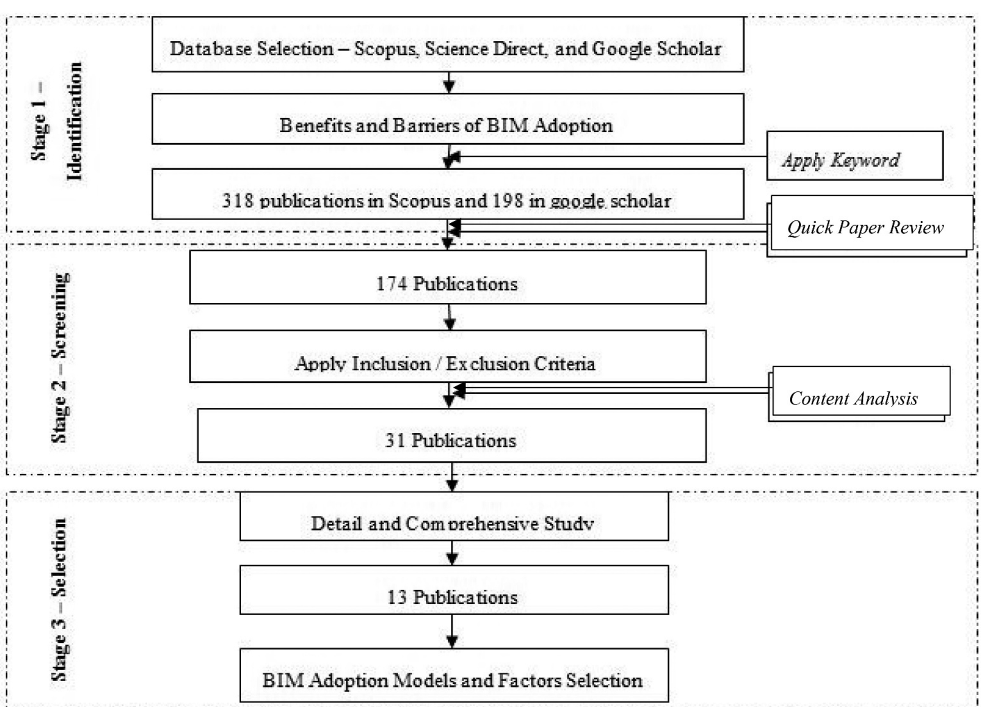
2.1. Systematic literature review

A Systematic Literature Review (SLR) is a technique which is used to identify and appraise relevant studies following clearly defined criterions/guidelines in order to answer a research question (Ahmed & Kassem, 2018). This review technique has been applied in several BIM-related studies. A few examples include, Charef et al., (2019a), Samimpay & Saghatforoush, (2020), and Abanda et al., (2015). The purpose of this review was to identify the potential benefits and barriers of BIM adoption in emerging markets.

The SLR for this paper was conducted in three major stages using online research databases including Scopus and Google Scholar. The first stage of the SLR, key words such as “BIM Adoption” and “Benefits” and “Barriers” were used. The return was 318 publications in Scopus and Science Direct, and 198 in Google Scholar. After a quick review, a total of 253 papers were kept for further scrutiny.

In the second stage, inclusion/exclusion criteria were set for content analysis. These criteria include publication Year (between 2012 and 2020), relevancy, location, and language. This time, 174 papers were selected from both databases. Finally, a total of 31 valid conference and journal publications were selected after an in-depth review of studies that are focusing on developing countries. From these, 13 publications were filtered for questionnaire preparation, abandoning the

Figure 1. Systematic literature review flow chart.



remaining papers that have similarity to the research output, and non-rigorous data analysis. Figure 1 presents the systematic literature review flow chart adopted for this study.

2.2. BIM adoption in developing countries

Several construction organizations, professional associations, and government agencies have advocated the use of BIM in the AEC industry to improve project management and facilitate coordination among stakeholders in construction projects (Chan et al., 2019). Although the extent of BIM implementation varies around the world, developed nations such as the United States (Cheng & Lu, 2015), Australia (Kassem & Succar, 2017), and few European countries (Charef et al., 2019b) have led to the rapid diffusion of BIM across the AEC industry. These countries in particular utilized several in-depth research projects and strategies in certain knowledge areas to ensure effective adoption in both the public and private sectors (Chong et al., 2016).

In recent years, however, several developing countries have been trying to catch up and improve the current level of BIM uptake across the construction industry (Olawumi & Chan, 2019). Indeed, the potential benefits such as, improved architectural visualization (Chan et al., 2019), collaboration among parties (Husain et al., 2018), and effective asset management (Ahn et al., 2016) are some of the major driving factors that persuade BIM adoption in these construction markets. In contrast, prior studies also highlighted challenges and barriers of BIM adoption in low-income countries, despite the efforts by governments and respective stakeholders in the construction sector (Amuda-Yusuf, 2018; Olanrewaju et al., 2020). These hindrances are ranging from problems associated with low IT infrastructure, financial competency of construction firms, poor collaboration, lack of BIM courses in universities, and cultural barriers (Ghaffarianhoseini et al., 2017; Kekana et al., 2020).

Globally, most BIM related empirical studies in developing countries have been centered on three themes: (1) BIM benefits, (2) BIM barriers, and (3) BIM readiness (Abubakar et al., 2014; Chan et al., 2019; Olanrewaju et al., 2020). These studies examined the critical BIM attributes including at the pre and post adoption stages across the construction sectors. Meanwhile, there is also a growing interest in BIM implementation to the public infrastructure construction sector either in the design, construction, and asset management of road and water works (Ahuja et al., 2020). In such a case, management and utilization of project data pertinent to project life cycle are a few of the center of focus in the public infrastructure sector (Chong et al., 2016). More so, the gap in the economic development of countries and the differences in rate of BIM adoption across various disciplines have led to the notion that several researches are needed to contextualize the benefits and barriers of BIM in different geographical locations around the world. Thus, the current study aims to continue the rigorous efforts being taken towards the exploration of the key BIM attributes to enhance BIM implementation in the public sector

3. Methodology

This section discusses the research design, and data analysis techniques employed in the current research.

3.1. Research design

The study employed a structural questionnaire survey designed using the SLR and a mini Delphi study for contextualizing the pre-selected CSFs. The first draft of the structured questionnaire was designed based on an extensive systematic literature review to choose the potential benefits and critical barriers of BIM adoption in public infrastructure projects. Then, the draft questionnaire was then sent to three experienced professionals; two from the industry, and one from academia for content analysis prior to data collection. These experts have more than 15 years of professional's experience in the construction sector. Using the mini two-stage Delphi survey, the experts were initially asked to evaluate the pre-selected 28 benefits and 20 barriers. After qualitative examination of the responses, the first stage of the mini Delphi survey resulted in 18 benefits and 19 barriers. During the second stage, the experts were able to re-evaluate their first assessment and

Table 1. Summary of benefits of BIM adoption identified from literature

Item	BIM Adoption Benefits	(Shaaban	(Ahn &	(Akerele	(Jin et	(Husain et	(Antwi-	(Chanet
BBN1	3D Visualization	√	√	√		√	√	
BBN2	Building Lifecycle Data		√	√	√		√	√
BBN3	On Time Project Completion	√		√				√
BBN4	Clash Detection	√			√	√		
BBN5	Asset Management	√	√			√	√	
BBN6	Effective Scheduling and Material Delivery	√		√	√		√	√
BBN7	Better and Efficient Design Alternatives		√	√		√		√
BBN8	Reduce Rework and Wastage				√			
BBN9	Accurate Quantities & Geometrical Representation	√						
BBN1	Improved Communication Among Parties		√	√	√	√	√	
BBN1	Early Multidisciplinary Coordination			√		√	√	
BBN1	Better Quality Assurance	√	√			√		√
BBN1	Lesser Claims and Disputes		√	√			√	

(*Continued*)

Table 1. (*Continued*)

Item	BIM Adoption Benefits	(Shaaban	(Ahn &	(Akerele	(Jin et	(Husain et	(Antwi-	(Chanet
BBN1	Better Rate of Investment		√	√	√	√	√	√
BBN1	Minimize Construction Risks	√	√		√		√	√
BBN1	Improved Productivity	√				√	√	
BBN1	Good Working Environment Among Professionals	√		√	√	√		

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Table 2. Summary of barriers to BIM adoption identified from literature

Item	BIM Adoption Barriers	(Ghaffarianh	(Ahuja	(Ismail et al.,	(Tan et	(Charef	(Kekana et al.,
BBR	Lack of Resources		√	√	√	√	
BBR	Complexity of BIM Software						
BBR	Poor Communication Among Major Parties	√	√	√			√
BBR	Lack of Standard Form of Contracts for BIM	√					
BBR	Lack of BIM Regulations, Guidelines and Standards	√	√	√	√	√	√
BBR	BIM Model Ownership Rights		√		√	√	
BBR	Lack of Insurance Applicable to BIM			√			
BBR	Traditional Procurement and Delivery Methods	√				√	
BBR	Poor Government Support	√	√	√	√		√
BBR	Insufficient Internet Infrastructure		√			√	√
BBR	Lack of BIM Researches and Courses in University	√			√		
BBR	Inclusion of BIM Protocols in contracts		√		√		
BBR	High Initial Cost for BIM Implementation			√		√	√

(*Continued*)

Table 2. (Continued)

Item	BIM Adoption Barriers	(Ghaffarianh	(Ahuja	(Ismail et al.,	(Tan et	(Charef	(Kekana et al.,
BBR	Lack of Training for Professionals	√		√	√		
BBR	Difficulty of workflow due to changes in Roles	√	√	√		√	√
BBR	Lack of Awareness		√		√		
BBR	Complications of the BIM Process		√			√	
BBR	Resistance to Change (due to Culture)	√	√	√		√	√
BBR	BIM Misunderstanding				√		√

respond back in a week's time. Finally, the experts sent a revised 20 benefits and 17 barriers of BIM adoption. Tables 1 and 2 summarize the common benefits and barriers of BIM adoption used in the present study based on the systematic literature review.

The final structured questionnaire draft was then prepared to collect data among professionals working in public infrastructure projects across the Ethiopian construction sector. The target respondents comprised from organizations including client, consultant, and contractor. The questionnaire draft has three sections. The first section of the questionnaire solicited to acquire general demographic information of respondents including organization profile of experts. Whereas, the second and third sections of the questionnaire comprised the potential benefits and barriers of BIM adoption in infrastructure projects. The responses were collected using a 5-point Likert scale, ranging in ascending order from 1 = Strongly Disagree to 5 = Strongly Agree. It's also common to use a 5-point Likert scale in previous studies.

3.2. Data collection

Due to the emerging nature of the topic, purposive sampling was employed to minimize bias and collect a reliable data. Further, the present study employed triangulation technique to achieve consistency through the use of different statistical tools (Chan et al., 2019). The respondents were selected based on their involvement and prior experience in public infrastructure projects. A priori analysis was run to estimate the number of responses required for this study to specify the sample size by using the population proportion. With the assumptions of the confidence interval of 95% ($Z\alpha/2 = 1.96$), the margin of error of 10% ($\varepsilon = 0.10$), and the limited amount of information regarding the resulting data distribution, the maximum proportion of respondents was used ($p = 50\%$). Consequently, the expected sample size for the study was 96 subjects. In this regard, a total of 148 questionnaires were distributed and 106 responses were returned; representing 72% response rate. From these, 13 of the responses were incomplete, and the remaining 93 valid responses comply with the required sample size and were further considered for the analysis. The demographic summary of respondents is shown in Table 3.

3.3. Data analysis

In order to avoid bias by the respondents, the current study utilized triangulation method to achieve some measures of objectivity through the use of several statistical procedures. This technique has also long been emphasized by prior studies such as (Chan et al., 2019). In this respect, the study adopted a total of six common non-parametric statistical measures including, Cronbach's alpha and Kolmogorov-Smirnov test, Mean Score, Chi square test, Spearman's Rank Correlation test, and Factor Analysis.

Table 3. Demographic profile of respondents

Variables	No of Respondents	Percentage
Gender		
Male	78	84%
Female	15	16%
Experience (Year)		
0–5	9	10%
6–10	47	51%
11–15	27	29%
> 15	10	10%
Organization		
Client	18	19%
Design & Consulting	43	46%
Contractor	32	35%

4. Findings

This section discusses the analysis of data collected through questionnaire survey and presents the results of the statistical tools adopted in the current study. The responses were carefully analyzed using the statistical software package IBM SPSS V23, and the findings are illustrated in the following subsections.

4.1. Normality and reliability tests

The Kolmogorov-Smirnov test was used to test the normality of data. The test result indicated a non-normal distribution; so, non-parametric statistical tests will be conducted further. Similarly, the Cronbach's alpha reliability test is employed to test the internal consistency of the questionnaire items. The larger the α-value, the higher the reliability. If the α-value ≥ 0.7, the measurement scale is considered to be reliable (Charef et al., 2019b). In the current study, a Cronbach's alpha of 0.702 for benefits and 0.736 for barriers of BIM adoption were recorded; and both are in the acceptable range.

4.2. Benefits of BIM Adoption in public projects

4.2.1. Mean score ranking (Benefits)

Mean score (M) utilizes the average (mean) of survey responses which were filled using a 5-point Likert's scale. As shown in equation 1, M is calculated by averaging all responses in an item.

$$M = \frac{\sum^{f} \times S}{N}, (0<\text{M} \leq \ 5) \tag{1}$$

Where: f is the frequency of responses, and S is the score given to each attribute by a respondent from 1 to 5.

Based on the survey results of the rankings as shown in Table 4, the top three significant benefits of BIM adoption are: "Improved Communication Among Parties", "Early Multidisciplinary Coordination", and "Good Working Environment Among Professionals" with a mean score ranking (M) with value of 4.26, 4.01 and 3.83 respectively. Whereas, experts perceived that "Lesser Claims and Disputes" (M = 3.05), "Clash Detection" (M = 2.96), and "Better Quality Assurance" (M = 2.88) scored the lowest mean score values of BIM adoption benefits.

Most of the experts agreed that collaboration between the project team is a significant factor that affects the integration of technology innovation in projects. This integration could be achieved through regular meetings and communication among the project team. Prior studies also reported that the success of construction projects depends on the extent of flow of information and communication among professionals and stakeholders (Chan et al., 2019; Ma et al., 2020). In contrast, the majority of respondents perceived that clash detection of BIM models and quality assurance issues might not be noteworthy in the current construction business environment. This arises from the fact that the Ethiopian construction industry is in the early stages of BIM implementation.

4.2.2. Analysis of agreement within the rankings of participant groups

The level of agreements or disagreements within the rankings of participants were analyzed using Kendall's coefficient of concordance (W). The range of values of Kendall's coefficient of concordance (W) is from 0 to 1. However, if the number of items that are going to ranked are larger than 7, chi square test will be used (Chan et al., 2019). W can be calculated using the following formula.

$$W = \frac{\sum_{i=1}^{n} (R1 - R2)^2}{n(n^2 - 1)/12} \tag{2}$$

Table 4. Mean score ranking of benefits of BIM adoption in Ethiopia

Benefits of BIM Adoption in Ethiopia	All Respondents		Client		Contractor		Consultant	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Improved Communication Among Parties	4.26	1	4.56	1	4.21	1	4.18	1
Early Multidisciplinary Coordination	4.01	2	3.81	4	4.04	2	4.09	2
Good Working Environment Among Professionals	3.83	3	3.78	6	3.99	3	3.86	3
3D Visualization	3.63	4	3.83	3	3.55	4	3.60	5
Effective Scheduling and Material Delivery	3.53	5	3.89	2	3.32	6	3.56	7
Better and Effective Design	3.46	6	3.44	10	3.50	5	3.43	10
Improved Productivity	3.41	7	3.17	14	3.24	7	3.66	4
Building Lifecycle Data	3.38	8	3.56	7	3.05	12	3.59	6
Asset Management	3.35	9	3.55	8	3.16	9	3.45	9
Accurate Quantities & Geometrical Representation	3.32	10	3.50	9	3.17	10	3.48	8
Minimize Construction Risks	3.28	11	3.39	11	3.13	11	3.36	13

(*Continued*)

Table 4. (*Continued*)

Benefits of BIM Adoption in Ethiopia	All Respondents		Client		Contractor		Consultant	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Better Rate of Investment	3.34	12	3.78	5	2.84	15	3.41	12
On Time Project Completion	3.20	13	3.28	12	3.16	8	3.32	14
Reduce Rework and Wastage	3.10	14	2.94	16	2.82	16	3.43	11
Lesser Claims and Disputes	3.05	15	2.92	17	3.03	13	3.11	15
Clash Detection	2.96	16	3.17	13	2.87	14	2.95	17
Better Quality Assurance	2.88	17	3.06	15	2.55	17	3.09	16

Table 5. Mean score ranking of barriers of BIM adoption in Ethiopia

Barriers of BIM Adoption in Ethiopia	All Respondents		Client		Contractor		Consultant	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Insufficient IT Infrastructure	4.22	1	3.72	2	4.42	1	4.23	1
Poor Government Support	4.14	2	3.61	5	4.39	3	4.14	2
Lack of BIM Researches & Courses in Universities	3.99	3	3.39	11	4.41	2	3.91	3
Resistance to Change	3.86	4	3.69	4	4.12	4	3.73	4
Lack of BIM Expertise	3.84	5	4.06	1	3.97	5	3.66	5
High Initial Cost for Implementation	3.60	6	3.48	7	3.55	7	3.64	6
Lack of Standard Form of Contract for BIM Adoption	3.54	7	3.50	6	3.61	6	3.55	7
Lack of Insurance for to BIM Adoption	3.44	8	3.22	14	3.42	12	3.93	8
Inclusion of BIM Protocols in Contracts	3.44	9	3.22	15	3.52	8	4.00	11
Lack of BIM Regulations and Standards	3.40	10	3.33	12	3.36	14	3.55	10
Lack of Resources	3.38	11	2.89	18	3.45	11	3.48	9

(*Continued*)

Table 5. (Continued)

Barriers of BIM Adoption in Ethiopia	All Respondents		Client		Contractor		Consultant	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
Traditional Procurement Methods	3.36	12	3.39	10	3.48	10	3.63	13
Lack of Awareness	3.34	13	3.72	3	3.42	13	3.41	20
BIM Misunderstanding	3.32	14	3.50	8	3.50	9	3.23	18
Poor Collaboration Among Major Parties	3.24	15	3.44	9	3.09	16	3.39	14
Complexity of the BIM Process	3.21	16	3.22	16	2.91	18	3.50	12
Lack of Training for professionals	3.20	17	3.28	13	3.27	15	3.11	19
Difficulty of Workflow Due to Change in Role	3.06	18	3.00	17	2.94	17	3.43	16
BIM Model Ownership Rights	2.84	19	2.39	20	2.45	19	3.22	15
Complexity of BIM Software	2.78	20	2.78	19	2.30	20	3.18	17

4.3. Where n = number of items to be ranked; R = average of ranked assigned to all items
Similarly, the chi-square values with degree of freedom (n-1) are calculated as follows:

$$\varphi^2 = k(\mathrm{n} - 1)\mathrm{W} \quad (3)$$

4.4. Where k = number of respondents ranking the items; n = number of items to be ranked
The rule is that if the chi-square values of benefits and barriers of BIM adoption are larger than the critical value reading from the chi square significance level table and the given degrees of freedom (df) value, then the null hypothesis (Ho) will be rejected.

The null hypothesis (Ho) is: *There is no relationship within the rankings of each participant groups.*

The Kendall's coefficient of concordance (W) is computed to be, for all respondents (0.101), client (0.172), consultant (0.075), and contractor (0.132). Significant values for all group of respondents is calculated to be 0.000 which is less than the allowable significance level (0.05 or 5%). Correspondingly, the chi square values for all respondents, client, consultant, and contractor are 160.824, 49.529, 52.711, and 80.450 respectively. From the chi square table, the critical value of degree of freedom (df) = 16 and p = 0.05 is 26.30. Hence, since the calculated chi square values of all group of respondents are larger than the critical value, it can be concluded that there is indeed a relationship within rankings of each respondent group; and then the null hypothesis is rejected.

4.4.1. Analysis of agreement between participant groups
Spearman's rank correlation coefficient (r_s) was adopted to test the correlation between group of respondents on the sets of rankings. Normally, Spearman's rank correlation coefficient ranges from −1 to +1. The higher the positive/negative value of r_s, the stronger positive/negative linear correlation (relationship). In contract, if r_s = 0, there is no linear relationship between two sets of rankings at all (Chan et al., 2019). The rule is that if r_s is statistically significant at a predetermined significance level (i.e. 5%), the null hypothesis (Ho) will be rejected.

The null hypothesis (Ho) in this is: *There is no correlation between the sets of rankings among participant groups.*

$r_s$can be computed using the following formula:

$$r_s = \frac{6\sum^{d^2}}{n(n^2 - 1)} \quad (4)$$

Where d = the difference between ranking of two groups in the same item; n = total number of responses for an item

The r_s values for benefits of BIM adoption at the significant level of 0.05; a) between clients and contractor group, b) client and consultants, d) consultant and contractor are 0.696, 0.672, and 0.799 respectively. Similarly, the significant levels for the pair between client and contractor, client and consultant, and consultant, and contractor are 0.002, 0.003, and 0.000 respectively. All the calculated ρ values are less than the threshold value 0.05. Hence, the null hypothesis will be rejected. Which means that there is a significant correlation between client and contractor group, and client and consultant group on the overall ranking of BIM benefits in the Ethiopian public construction sector.

4.5. Barriers of BIM Adoption in public projects

4.5.1. Mean score ranking (Barriers)
The barriers of BIM adoption in the public construction sector were computed using mean score. The result reveals that the top three ranked BIM adoption hindrances in the Ethiopian public

construction sector are “Insufficient IT Infrastructure” with a value of mean M = 4.22, “Poor Government Support” M = 4.14, and “Lack of BIM Researches & Courses in Universities” with a mean score value of M = 3.99. In contrast, barriers such as, “Difficulty of Workflow Due to Change in Role” (M = 3.06), “BIM Model Ownership Rights” (M = 2.84), and “Complexity of BIM Software” (M = 2.78) had the lowest mean ranks, as shown in Table 5.

The result coincides with the findings of (Abubakar et al., 2014), which emphasized that internet and other related infrastructures and poor government initiatives to integrate BIM in the construction sector are the major hindrances of BIM implementation in the developing nations. This problem is even challenging when it comes to the East African region where poor infrastructure network hampers technology and innovation adoption in the construction industry.

4.5.2. Agreement of ranks within participant groups

After computation, the calculated values of Kendall’s coefficient of concordance (W) are for all respondents (0.118), clients (0.103), consultants (0.098), and contractors (0.259). Significant values for all group of respondents is calculated to be 0.000, which is less than the allowable significance level 0.05.

Similarly, the chi square values were computed and the results for overall respondents, client, consultant, and contractor are 212.942, 35.079, 81.960, and 162.402 respectively. From chi square table, the critical value of degree of freedom (df) = 19 and p = 0.05 is 30.14; Hence, since the calculated chi square values of all groups of respondents are higher than the critical value, the null hypothesis is rejected.

4.5.3. Analysis of agreement between participant groups

The Spearman rank correlation coefficient (r_s) analysis for the barriers of BIM adoption reveals that the correlation between client and contractor group is $r_s = 0.548$ with a corresponding significant level of 0.046. In which case, the null hypothesis is rejected. Similarly, between client and consultant group ($r_s = 0.723$, $\alpha = 0.000$), and contractor and consultant group ($r_s = 0.797$, $\alpha = 0.000$); the null hypothesis is rejected. Therefore, there is a correlation among all the pairs of respondent groups on the rankings of barriers of BIM adoption in the Ethiopian construction industry.

5. Principal component analysis

The current paper employed Principal Component Analysis (PCA), also known as factor analysis to examine and cluster the benefits and barriers of BIM adoption in the Ethiopian construction sector based on latent component factors. The principal component analysis findings for this study are discussed below.

5.1. BIM Benefits

In the case of BIM benefits, the PCA analysis converged to five latent components during the first round of varimax rotation. The result indicated that all the BIM adoption benefits had higher factor loadings when compared with the minimum value of 0.5. The model validity fitness was evaluated using the Kaiser-Meyer-Olkin (KMO) and Bartlett’s tests. The result reveals that the KMO is 0.616, which is larger than the minimum acceptable limit of 0.6 (Olanrewaju et al., 2020). Similarly, the computed significance level of Bartlett’s test is 0.000 with $\chi(93)$ is 619.769, which indicates the independence of the BIM benefit factors. Table 6 reveals five latent components which point to Project Management, Technical, Economic, Lifecycle, and Contractual Benefits.

The first identified BIM benefit component is Project Management. The factors associated with this component are: *Improved Productivity, Effective Scheduling and Material Delivery, Lesser Claims and Disputes, and Better-Quality Assurance*, with factor loadings of 0.867, 0.828, 0.699, and 0.540 respectively. All these BIM benefits focus on the advantages related to project success and delivery. Hence, the component is named, project management benefits. Shaaban and Nadeem (2015) reported the application of BIM in enhancing the overall productivity in the project life cycle of Qatari construction projects.

Table 6. BIM benefits component matrix

Code	BIM Benefits	Component				
		1	2	3	4	5
	Project Management Benefits					
BBN16	Improved Productivity	0.867				
BBN6	Effective Scheduling and Material Delivery	0.828				
BBN13	Lesser Claims and Disputes	0.699				
BBN12	Better Quality Assurance	0.540				
	Technical Benefits					
BBN9	Accurate Quantities & Geometrical Representation		0.880			
BBN2	Building Lifecycle Data		0.821			
BBN1	3D Realistic Visualization		0.667			
BBN4	Clash Detection		0.640			
	Economic Benefits					
BBN14	Better Rate of Investment (Profit)			0.889		
BBN8	Reduce Rework and Wastage			0.869		
BBN15	Minimize Construction Risks			0.600		
	Lifecycle Benefits					
BBN7	Better and Effective Design				0.846	
BBN3	Enhanced Project Delivery				0.784	

(*Continued*)

Table 6. (*Continued*)

Code	BIM Benefits	Component				
		1	2	3	4	5
BBN5	Asset Management Benefits				0.768	
	Contractual Benefits					
BBN11	Allows Early Multidisciplinary Integration					0.863
BBN17	Good working Environment Among Professionals					0.760
BBN10	Improved Communication b/n Parties					0.593

The second component is Technical benefits. The factors associated with this component are: *Accurate Quantities & Geometrical Representation (0.880), Building Lifecycle Data (0.821), 3D Realistic Visualization (0.667), and Clash Detection (0.640)*. A closer look into these factors reveals the technical aspect of BIM. Similarly, Economic benefits is the third component of the PCA. The factors associated with this component are: Better Rate of Investment (0.889), Reduce Rework and Wastage (0.869), and Minimize Construction Risks (0.600). As a business model, firms typically concentrate their effort in improving efficiency, reducing rework and risk, to get the utmost profit in the construction business environment. Thus, it's imperative to cluster these factors as economic related benefits.

In addition, the fourth identified component, Lifecycle benefits is comprised of factors such as *Better and Effective Design (0.846), Enhanced Project Delivery (0.784), and Asset Management Benefits (0.768)*. These benefits are closely related to the project lifecycle aspect of the BIM process. Further, *Allows Early Multidisciplinary Integration (0.863), Good working Environment Among Professionals (0.760), and Improved Communication b/n Parties (0.593)* are associated with the fifth principal component, Contractual benefits. Prior studies reported the interoperability aspect of BIM and the benefit of early collaboration of design professionals and stakeholders through the use of various BIM models using Industry Foundation Class (IFC) platform (Azhar et al., 2012; Ghaffarianhoseini et al., 2017).

5.2. BIM Barriers

The PCA for the BIM barriers converged in two rounds of varimax rotation. During the first round, BBR2, 14, and 16 had factor loadings of below the threshold value of 0.5, and was discarded. Then, the second round of the PCA was conducted and showed a satisfactory result, with the KMO value of 0.7 and Bartlett's significant test result of 0.000 with $\chi(93)$ is 1042.004. As shown in Table 7, the final PCA result for BIM barriers comprised four principal components: Legal and Contractual, Process, Cultural and Organizational, and Government Related barriers.

5.3. Component 1—legal and contractual related barriers

Although the concise benefits and hindrances of BIM integration in organizational structures have been advocated in the AEC industry, it's imperative to evaluate the project-specific legal risks and uncertainties associated intuitive BIM implementation (Tan et al., 2019). As a technological collaborative process, the adoption BIM requires legal feasibility and contractual obligations among stakeholders. The Legal and Contractual Component in this study is comprised of four factors: Lack of a Standard Form of Contracts for BIM Adoption, Lack of BIM Regulations and Standards, Inclusion of BIM Protocols in Contracts, and Lack of Insurance Applicable to BIM Implementation; with factor loadings of 0.895, 0.879, 0.869, and 0.845 respectively. This component accounts for 26.48% of the total variance of BIM adoption barriers. This component aligns with previous findings such as (Gardezi et al., 2014) in Malaysia, (Arshad et al., 2019) in Pakistan, and (Amuda-Yusuf, 2018) in Nigeria. For instance, Gardezi et al. (2014) reported that lack of determination of ownership of the BIM model information, including model copyright protection laws and liability of the model data entry are the critical legal and contractual risks in the Malaysian construction sector. Whereas, Arshad et al. (2019) analyzed the legal aspect of BIM adoption with respect to the conventional project delivery method, Design-Bid-Build (DBB).

Moreover, studies that focused on developing countries, especially in the sub-Saharan African region demonstrated the limitation of BIM-related standards and guidelines to provide legal ground for BIM enabled projects across the construction sector (Olanrewaju et al., 2020). To reinforce this, Olatunji and Sher (2010) highlighted the legal implications arising from BIM implementation in construction projects and the need for contractual frameworks to accommodate those challenges. The authors reported that BIM-related legal insinuations are a major concern which slows down the adoption and diffusion process. Generally, it is important to note that most previous studies, including the present study agreed that in order to have a concise and all rounded standard

Table 7. BIM barriers component matrix

Code	BIM Barriers	Component			
		1	2	3	4
	Legal and Contractual Related Barriers				
BBR5	Lack of a Standard Form of Contracts for BIM Adoption	0.895			
BBR6	Lack of BIM Regulations and Standards	0.879			
BBR13	Inclusion of BIM Protocols in Contracts	0.869			
BBR8	Lack of Insurance Applicable to BIM Implementation	0.845			
	Process Related Barriers				
BBR3	Complexity of BIM software		0.876		
BBR7	BIM Model Ownership Rights		0.818		
BBR4	Poor Collaboration Among Major Parties		0.773		
BBR18	Complexity of BIM Process		0.748		
BBR9	Traditional Procurement Methods		0.603		
	Cultural and Organizational Related Barriers				
BBR20	BIM Misunderstanding			0.900	
BBR17	Lack of Awareness			0.895	
BBR15	Lack of Training for Professionals			0.743	
BBR1	Lack of BIM Expertise			0.715	
BBR19	Resistance to Change			0.686	

(*Continued*)

Table 7. (*Continued*)

Code	BIM Barriers	Component			
		1	2	3	4
	Government Related Barriers				
BBR11	Insufficient IT Infrastructure				0.943
BBR10	Poor Government Support				0.889
BBR12	Lack of BIM Researches & Courses in Universities				0.737

form of contracts for a successful BIM adoption in developing countries, there has to be a collaborative effort between all major stakeholders across the industry.

5.4. Component 2—process related barriers

BIM is recognized as a technology-based process which needs the attention and understanding of practitioners to function smoothly. In this respect, all key stakeholders are responsible to harmonize the working environment for a successful project delivery. The Process component accounts for 18.61% of the total variance of BIM adoption barriers in the Ethiopian context. The factors fall within the theme of process-related barriers are *Complexity of BIM software, BIM Model Ownership Rights, Poor Collaboration Among Major Parties, Complexity of BIM Process, and Traditional Procurement Methods* with factor loadings 0.876, 0.818, 0.773, 0.748, and 0.603 respectively. A closer look at these factors reveals that they are related to software application and integration themes. To reinforce the findings, (Olatunji & Sher, 2010) highlighted that although BIM software models and the overall process are associated with collaboration among stakeholders within a project, ownership of the final software output belongs to the owner rather than consulting firms individual ownership right of design models in the conventional delivery methods. This position is aimed at strengthening owner's rights and fostering collaboration amongst owner and project teams throughout the project lifecycle (Porwal & Hewage, 2013). Nevertheless, other studies disagree with this philosophy, and argued that this could result in certain unsatisfactory consequences to the owner, and this in turn is detrimental to the project itself (Arshad et al., 2019). Hence, it's eminent to develop clear and concise BIM-based procurement and contract liability guidelines prior to project commencement.

5.5. Component 3—cultural and organizational-related barriers

It's a well-known fact that having a smooth working environment and early stage coordination among major parties in construction projects leads to ultimate project success. This notion is the center focus strategy of BIM implementation in the construction sector. When it comes to the sub-Saharan African region (of which Ethiopia is situated), the private sector is more lean-to pertaining BIM adoption in construction projects. This "bottom-up" approach in the absence of government involvement tends to constrain the diffusion process across and pushes the implementation of BIM through inter-sectorial specific strategies (Kekana et al., 2020)

This component is composed of five factors: *BIM Misunderstanding (0.900), Lack of Awareness (0.895), Lack of Training for Professionals (0.743), Lack of BIM Expertise (0.715), and Resistance to Change (0.686)*. This component accounts for 13.686% of the total variance of BIM adoption barriers. Ahuja et al. (2020) in India, which is a developing country like Ethiopia, indicated that social and cultural barriers are prominent challenges which lead to low BIM implementation in the construction sector. Olanrewaju et al. (2020) further reinforced that findings by compounding the effect of low BIM awareness and misunderstanding on the level of BIM diffusion in Nigeria.

In addition, Shaikh et al., (2016) observed the lack of BIM expertise and professional's resistance to equip themselves with the BIM environment as critical factors that account for the failure of BIM in the Saudi Arabia construction sector.

5.6. Component 4—government related barriers

Literature summarized BIM as a digital data-based modeling, analysis and simulation process which requires the integration of information technology infrastructure to utilize the method in construction projects (Ahuja et al., 2020). However, the major challenges that hinder the adoption BIM in developing countries are often related to poor information technology infrastructure network and the lack of government initiative to provide sufficient internet access to the public (Abubakar et al., 2014). These challenges further highlight the government's role in low-income economies with regard to facilitating BIM adoption through infrastructure development. In the present study, component 4 is comprised of three factors: *Insufficient IT Infrastructure (0.943), Poor Government Support (0.889), and Lack of BIM Researches & Courses in Universities (0.737)*. The result coincides with the findings of (Olanrewaju et al., 2020); and (Abubakar et al., 2014) which revealed that the governments in developing countries play a vital role to emanate BIM adoption policies and guidelines which enables the environment for disseminating BIM knowledge to practitioners, as well as a successful implementation of BIM in AEC firms operating in those emerging markets (Bui et al., 2016).

In addition, Ismail et al. (2017) highlighted that government's initiative and mandate is a significant driver to encourage firms effectively accept, manage, and corroborate BIM adoption in construction practices. It is worth noting that, despite the problems envisaged in the Ethiopian construction sector, policy makers including agencies and the regulatory body collaboration with the private sector through PPP schemes and networks is a better alternative to encourage the implementation of BIM and tackle the identified adoption challenges.

6. Practical implications and recommendations

Based on the empirical findings, thoughtful practical implications and recommendations are highlighted for professionals, key stakeholders, policy makers and regulatory body. Understanding the potential benefits and challenges of BIM adoption in the Ethiopian construction sector will help practitioners to be in a better position to adopt BIM in public housing projects arising from the increased understanding of the BIM benefits and barriers. For instance, for the government, when it comes to public condominium housing and other public projects plays a vital role to achieve the second Growth and Transformation Plan (GTP). Hence, the results of this paper could be used by policy makers and the regulatory body to put more emphasis on creating a healthy environment to encourage the private sector to be informed about BIM.

Recently, the Ethiopian Project Management Institute (ECPMI, 2018) published a 5-year roadmap to improve the current BIM uptake, and encourage stakeholders to adopt BIM in public construction projects throughout the country. This roadmap acknowledges the adoption of BIM within the construction sector to enhance project delivery and improve the overall construction process. In this regard, the current study provided a set of comprehensive benefits and barriers of BIM adoption to demonstrate critical gaps and area of improvement for projects in the Ethiopian context. More so, the findings are believed to help local construction organizations to cope up with international firms operating in the Ethiopian public sector.

In addition, this study evaluated the relationship between the experts' ranking on the potential benefits and barriers of BIM adoption using Kendall's coefficient of concordance, and Spearman rank correlation. The result indicated that there is a good consensus among client. consultant, and contractor. The results coincide with the findings of (Chan et al., 2019; Jin et al., 2017). This agreement and consensus between the stakeholders will pave the way for professionals, top management team and business CEOs to collaborate on BIM-based projects across the private and public sectors.

Further, the findings of the PCA offers comprehensive and empirical-based evidences that can be utilized to close underlying the gap regarding the critical challenges and barriers of BIM adoption in the Ethiopian context. This in turn will enable the experts in the construction sector to acquire sufficient awareness and common understanding in relation to BIM Adoption. Table 8 illustrates the key recommended actions highlighted in relation to the four critical BIM adoption barrier components in the Ethiopian construction sector.

7. Conclusion

The current study outlined the potential benefits and associated barriers of BIM adoption in projects from the international research community; and ranked their criticality based on different empirical techniques in the Ethiopian public construction sector. The paper also compared the empirical findings with studies in other developing regions to contextualize the results.

Table 8. Recommended actions to enhance BIM adoption in the Ethiopian construction sector

BIM Adoption Barriers	Recommended Actions
Legal and Contractual	▪Develop sector specific BIM policies, and regulations to facilitate BIM adoption across the Ethiopian AEC industry ▪In conformity with international codes, develop a standard form of contract with an inclusion of BIM protocols ▪Establish legal provisions and rules to resolve any claims, disputes which may arise during the project lifecycle
Process	▪Develop project specific guidelines to ease BIM implementation ▪Ensure the use of BIM compatible procurement and delivery methods ▪Acquire Pre and post BIM capability assessment tools to evaluate the performance of construction firms ▪Develop clear BIM related contractual roles, responsibilities and obligations for each party
Cultural & Organizational	▪Government in collaboration with universities and professional associations, should organize regular BIM trainings, seminars, and workshops to enhance the current level of awareness and understanding ▪Assess social, cultural, political, and technical viability of BIM adoption
Government Related	▪Develop a comprehensive Strategy to facilitate implementation of BIM across public and private projects ▪Establish public—private partnerships (PPP) oriented construction policy schemes and initiatives to improve the current IT infrastructure. ▪Devise financial support mechanisms, including loans to withstand the high cost of implementation ▪Encourage higher education institutions to include BIM related courses and research-based projects in curriculums

Furthermore, the opinions of the different parties (owner, consultant, and contractor) were compared to investigate the discrepancy of their assessment.

Meanwhile, the PCA result found five latent BIM benefit components: *Project Management, Technical, Economic, Lifecycle, Contractual Benefits*; and four latent barrier components: *Legal and Contractual, Process, Cultural and Organizational, and Government Related Barriers*. Both findings reveal the relationship among certain factors and functionalities in the context of public construction projects as a contribution to the BIM body of knowledge. Similarly, the highlighted factors disclose the need for salient BIM adoption strategy to utilize the potential benefits and improve the major hinderances of BIM in the Ethiopian construction industry.

The findings of this study, for the first time provide empirical evidences of the potential benefits and barriers of BIM adoption in the context of the Ethiopian public construction sector. This paper also provides practical insights and key recommendations to tackle the aforementioned barriers and enhance the current BIM uptake in public infrastructure projects. More so, the principal component analysis and discussion reveals that BIM adoption in construction projects is context based. Hence, this study identifies the country-wide practice or culture so as to improve the status-quo and help major stakeholders with a basis in the establishment of BIM policies and guidelines.

The study has few limitations. (1) Although prior studies, including this study employed quantitative data analysis techniques, the authors believe that using qualitative measures could also provide additional perspectives on the subject matter; and (2) the study considered the generalized construction project concept to alleviate the systematic adoption of BIM in the Ethiopian construction sector. Such type of understanding is common in similar studies such as (Bosch-Sijtsema et al., 2019; Chan et al., 2019; Ma et al., 2020)), although the benefits and hindrances may differ according to the variability of projects. such as road, water, or residential. Further studies can be explored on BIM case studies and comparative evaluation of BIM strategies with regard to organizational basis and types of projects.

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Author details
Solomon Belay[1]
E-mail: solomon.melaku@bdu.edu.et
ORCID ID: http://orcid.org/0000-0002-5931-9089
James Goedert[2]
Asregedew Woldesenbet[2]
Saeed Rokooei[3]
[1] Faculty of Civil and Water Resources Engineering, Bahir Dar University, Bahir Dar, Ethiopia.
[2] Durham School of Architectural Engineering and Construction, University of Nebraska-Lincoln, the Peter Kiewit Institute, 1110 S 67th St., Omaha, NE 68182-0816, USA.
[3] College of Architecture, Art and Design, Mississippi State University, 123 – D Howell Building, Starkville, MS 39759, USA.

Conflicts of interest
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