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Building information modelling adoption in Uganda's construction industry

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ABSTRACT

Building Information Modelling (BIM) has gained traction over the last decade seeing several countries making BIM mandatory. Projects using BIM have enjoyed better quality, reduced costs, and duration. However, its adoption remains low in developing nations like Uganda. This study assessed the state of BIM and its feasibility in Uganda's construction industry. Data was collected using a structured online survey from 162 registered Architecture, Construction, and Engineering professionals. The analysis applied statistical tests like One-way non-parametric ANOVA, pairwise post hoc dunn and Mann-Whitney tests to assess relationships between profession, work experience, role in the supply chain, involvement in academia, against the awareness, BIM tools used, BIM functions, perceived benefits of BIM, and barriers to BIM adoption. Enhanced productivity was the highest benefit of BIM, along with complete project information and improved design quality. Acquisition and training costs were the top barriers to adoption. The ANOVA test showed those in academia had better understanding of BIM concepts, implying academia's importance in promoting BIM while work experience influenced BIM functions used and awareness of BIM tools. Different professions had varied understanding of some BIM concepts.

KEYWORDS

Software; technology adoption; Uganda; virtual construction

1. Introduction

Globally, the construction industry is essential for economic development accounting for over 6–8% of the employed labour force (Rhodes 2019; Thakurta 1970; UBOS 2020). Despite its importance, this industry is fraught with deep-rooted problems, including inefficient processes, fragmentation leading to delays, and inadequate training, amongst others (Hardi and Pittard 2015; Latham 1994). Processes like Building Information Modelling (BIM) provide possible solutions to these problems (Azhar et al. 2012; Lee and Borrmann 2020) and have now become the 'gold standard' of the Construction industry (BIM Africa 2020; Zhao et al. 2015).

BIM technology simulates virtual models of a structure, known as building information models, which are constructed digitally containing geometry and data needed to support the fabrication, construction, and operation activities. BIM, therefore, provides the potential for more efficient design and construction methods (Zhang et al. 2018) and greater integration of the roles in a project team. BIM also provides the ability to model the structure's life-cycle. When adopted well, BIM facilitates an integrated design and construction process resulting in better-quality buildings at lower cost and reduced project duration (Eastman et al. 2008).

Recognising the potential benefits, countries like Britain, Singapore, and Finland have made BIM mandatory for public infrastructure projects (Edirisinghe and London 2015). However, adoption of BIM in Africa's construction industry remains low (BIM Africa 2020). BIM adoption faces many obstacles like insufficient training, high execution costs, and low awareness (BIM Africa 2020; Ogwueleka and Ikediashi 2017). Successful

adoption of BIM requires understanding the obstacles and strategies to reduce them.

Uganda is like most African countries regarding adopting BIM processes and technologies. The rate of innovation and technology utilisation in most developing countries like Uganda is low (Alinaitwe et al. 2006; Masood et al. 2014). It is usually characterised by heavy reliance on labour for productivity, leaving the employers in a precarious position of employing work intensification to increase productivity (Calderon et al. 2018, World Bank 1984), which in most cases results in minor improvements. In addition, a 2018 report indicated that East Africa has the largest number of construction projects in the continent (Deloitte 2018). Therefore, there is a need for BIM adoption in Uganda's construction industry to realise productivity gains in the sector. It is becoming a common belief that BIM will improve efficiency by virtually identifying clashes and potential issues during the early stages of the project before physical construction, resulting in a reduction in wastage from rework.

This paper aimed at investigating the status, benefits, and barriers of adopting BIM in Uganda's construction industry, by answering the following questions: (i) what is the level of BIM awareness and use in Uganda? (ii) what are the perceived benefits of using BIM? and (iii) what are the barriers to BIM use in Uganda's construction industry?

2. Literature review

2.1. BIM adoption

The global construction industry has embraced BIM-based practice, with a general upward trend (McGraw-Hill Construction

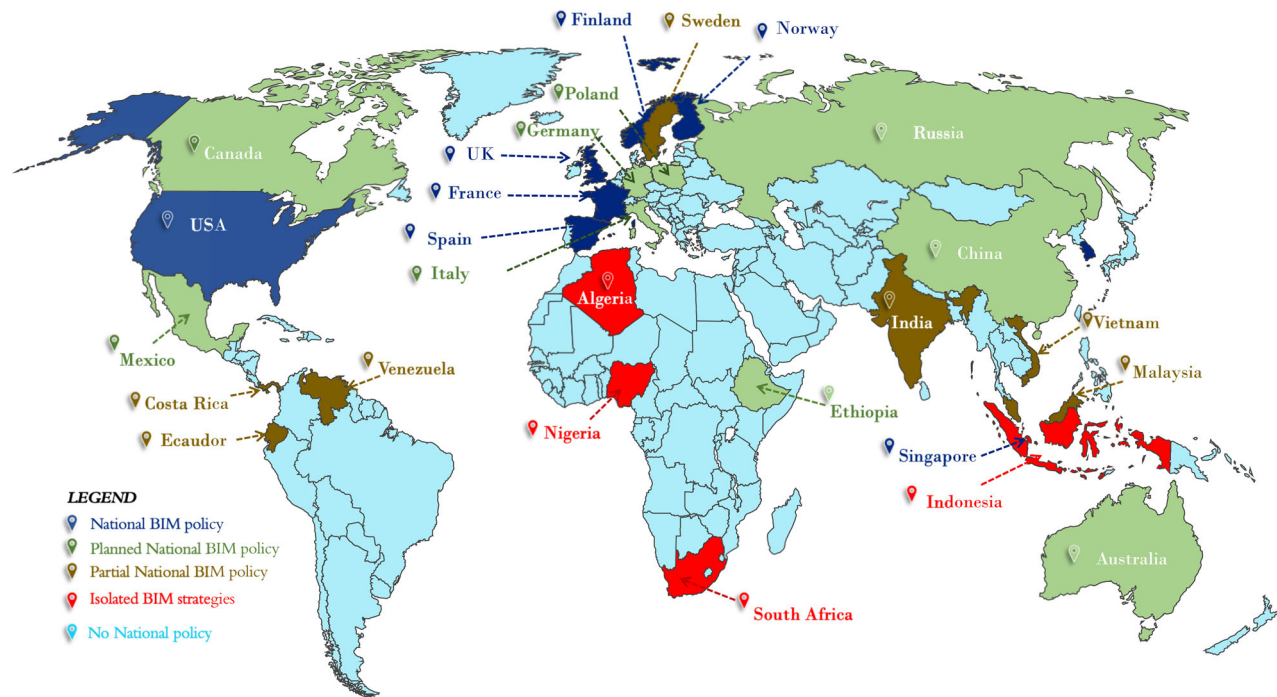


Figure 1. Global adoption of BIM policies.

Source: Authors' construct from data available at (Edirisinghe and London 2015; Hamma-Adama and Kouider 2019; Ismail et al. 2017; Burgess et al. 2018; Newton and Chileshe 2012; RIBA Enterprises Ltd 2017; Shimonti 2018; United BIM 2020).

2009; Rokoeei 2015). However, it is frequently observed that the sheer size of the construction sector in populous countries like the United States, China, and India makes the likelihood of widespread acceptance of BIM in the short term difficult and, therefore, unlikely (Brewer et al. 2012). Therefore, it is posited that countries with a smaller construction industry such as Finland, Sweden, Norway, Australia, and Canada represent the forefront of BIM software. On the other hand, the construction industry in developing countries in Eastern Europe, the Middle East, and Africa (presented in Figure 1) are not likely to match the pace of adoption as that witnessed in the developed countries until BIM has become standard practice in the leading regions.

There are no National policies for BIM in any African country. However, there have been strategies for implementing BIM in particular projects. In South Africa, Nigeria and Algeria, there are projects where BIM has been employed for collaboration and design (BIM Africa 2020) and in Ethiopia, there is a plan for a National BIM policy (Belay et al. 2021).

2.2. Benefits of BIM

One of the earliest examples of using BIM technology was clash identification between building elements and the associated productivity benefit (Jalaei et al. 2021; Mohandes and Omrany 2013). Using BIM, an asset can be built twice: once digitally to fix all constructability issues and second, physically on-site (Drees&Sommer 2020; SPIE 2017). Before the advent of BIM, modifying one building element required changing several drawings, which was time-consuming for the designers and drafting technicians. BIM does the modifications to all the dependent elements automatically resulting in time savings. With increasing use of BIM in conceiving, designing, constructing, and operating buildings and other infrastructure, studies have reported the benefits of using BIM (refer to Table 1).

A BIM model is more than a 3D model. Therefore, by adding data dimensions, it is possible to get a fuller understanding of the structure, including planning, design, construction, and facility operation processes. The system modifies dimensions whenever the drafters add specific information to the model. These further applications can deal with various types of information and data and have led to a reference to terms such as 4D (adding time to the model), 5D (adding quantities and cost of materials), and 6D (adding facilities management/project lifecycle management aspects) and so on (Abbasnejad and Moud 2013). When applied to its full potential; BIM can be used to provide benefits in all stages of construction.

2.3. Barriers to BIM adoption

Despite all the potential benefits from BIM, its full potential may not be realised with limited use (Abbasnejad and Moud 2013). Adopting any new technology requires overcoming barriers and challenges, some of which are presented in Table 2. Slow penetration of technology is not only attributable to technical aspects of a novel approach (Babič and Rebolj 2016), whilst superiority of a technical solution does not warrant replacing existing solutions. Therefore, a culture and mindset shift should precede an overall technological change, confirming that 'BIM utopia' and hype framing of BIM benefits have not helped foster its full adoption (Fox 2014; Miettinen and Paavola 2014). Further to this, governments need to implement initiatives for BIM adoption (Faisal Shehzad et al. 2020).

2.4. Methodologies to assess BIM adoption

There have been several studies looking at the implementation of BIM in the construction industry (Edirisinghe and London 2015; Hamma-Adama and Kouider 2019; Ismail et al. 2017; Burgess et al. 2018; Sadeh et al. 2021), the perceived benefits of BIM

Table 1. Perceived BIM Benefits.

Item	BIM Benefits	Source
1	Improved design quality	(Ahankoob et al. 2019; Azhar et al. 2012; Brewer et al. 2012; Dodge Data and Analytics 2015; Sacks et al. 2018)
2	Enhanced project predictability due to reduced variations	(Ahankoob et al. 2019; AGC 2006; Holzer 2016; Olawumi and Chan 2019)
3	Low financial risks due to reliable cost estimates	(AGC 2006; Brewer et al. 2012; Suermann 2009; SUN et al. 2015)
4	Enhanced energy efficiency and sustainability features to predict environmental performance	(Azhar et al. 2012; Dodge Data and Analytics 2015; Raouf and Al-Ghamdi 2019; RIBA Enterprises Ltd 2017; Suermann 2009; Wang, Wu, and Zhang 2016)
5	Completeness of project information in a single file for operations and facilities management	(Ahankoob et al. 2019; Azhar, Khalfan, and Maqsood 2009; Dodge Data and Analytics 2015; Hooper 2015)
6	Early forensic analysis for potential failures and design errors, through clash detections	(Ahankoob et al. 2019; AGC 2006; Lu et al. 2018; Nasila and Cloete 2018; Ogwueleka and Ikediashi 2017; Suermann 2009; SUN et al. 2015)
7	Improved construction planning leading to increased speed and reduced overall project durations	(AGC 2006; Azhar, Khalfan, and Maqsood 2009; Brewer et al. 2012; Dodge Data and Analytics 2015; Hartmann and Fischer 2008)
8	Reduced safety risks through improved site safety planning and management	(Clevenger et al. 2012; Dodge Data and Analytics 2015)
9	Quick and accurate production of shop and fabrication drawings	(Ahankoob et al. 2019; AGC 2006; Azhar, Khalfan, and Maqsood 2009)
10	Simplification of measurements and cost calculations through automated quantities from CAD files	(Barison and Santos 2010; Lu et al. 2018)
11	Reduced claims, disputes and conflicts	(Ahankoob et al. 2019; Suermann 2009)
12	Improved project communication and coordination resulting from enhanced team collaboration	(Hooper 2015; McGraw-Hill Construction 2008, McGraw-Hill Construction 2009)
13	Better marketing of projects to new and existing clients	(AGC 2006; Azhar, Khalfan, and Maqsood 2009; Hartmann and Fischer 2008)
14	Reduced rework during construction	(Dodge Data and Analytics 2015; Nasila and Cloete 2018)
15	Improved visualisation	(Nasila and Cloete 2018)

Table 2. Perceived BIM implementation barriers.

Item	Barriers to BIM Implementation	Source
1	Lack of sufficient training opportunities and technical support	(Abdul 2016; Brewer et al. 2012; Demian and Walters 2014; Gardezi et al. 2014; Ma et al. 2020; Morrison 2010)
2	Prevalence of an inadequately trained workforce	(Brewer et al. 2012; Gardezi et al. 2014; Ma et al. 2020; Morrison 2010)
3	Interoperability Issues (the inability to exchange data between applications)	(Abdul 2016; Brewer et al. 2012; Demian and Walters 2014; Gardezi et al. 2014; Kurul et al. 2013; Ma et al. 2020; Migilinskas et al. 2013; Morrison 2010)
4	Software malfunctions and data misuse	(Kurul et al. 2013)
5	BIM data ownership, copyright issues and misuse of intellectual property	(Miettinen and Paavola 2014; Morrison 2010)
6	BIM Licensing issues for proprietary designs	(Morrison 2010)
7	Industry resistance to process change and preference to traditional project delivery methods	(Abdul 2016; Amin and Abanda 2019; Gardezi et al. 2014; Morrison 2010)
8	Unawareness of the benefits BIM can bring to projects and organisations/ lack of immediate benefits to designers	(Abdul 2016; Ahuja et al. 2020; Kurul et al. 2013)
9	Not enough demand from clients and/or other project participants	(Abdul 2016; Gardezi et al. 2014; Ma et al. 2020; Sadeh et al. 2021)
10	Financial constraints for upfront costs for software, hardware upgrades, training and support	(Ahuja et al. 2020; AGC 2006; Brewer et al. 2012; Faisal Shehzad et al. 2020; Gardezi et al. 2014; Kurul et al. 2013; Morrison 2010; Okakpu et al. 2020)
11	Lack of BIM Standards and collaborative work processes for model integration and management	(Gardezi et al. 2014)
12	Lack of legal and contractual agreements	(Brewer et al. 2012; Kurul et al. 2013)

(Ahankoob et al. 2019; Azhar et al. 2012; Sacks et al. 2018) and the barriers to BIM adoption (Ahuja et al. 2020; Faisal Shehzad et al. 2020; Okakpu et al. 2020; Ma et al. 2020).

Most of the studies employed survey questionnaires to answer their research questions (Ahuja et al. 2020; Sadeh et al. 2021; Ma et al. 2020). The analysis of the results used inferential statistics, descriptive statistics (Ahuja et al. 2020) and hypothesis testing to analyse associations between variables (Sadeh et al. 2021) by either using the Wilcoxon Signed-Rank test (Sadeh et al. 2021), Mann-Whitney U test (Sadeh et al. 2021). In addition, in some

cases, cluster analysis was used to process the data and infer relationships (Sadeh et al. 2021).

2.5. Theories of technology adoption

Technology is a crucial contributor to the growth of the construction industry through improved productivity, quality, and safety (Masood et al. 2014; Sepasgozar and Bernold 2013), nonetheless, technology adoption in developing nations is often

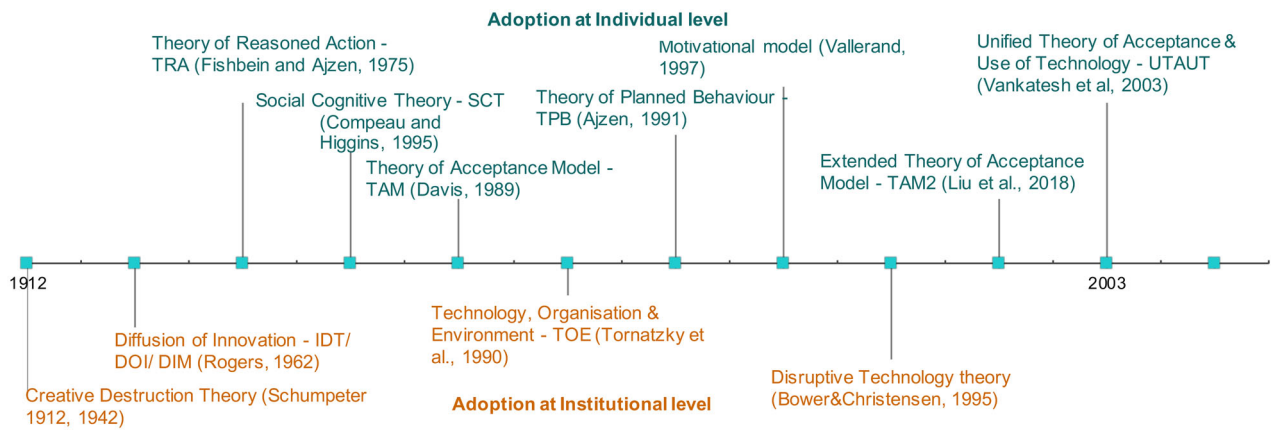


Figure 2. Evolution of technology adoption theories (authors' construct from (Ahuja et al. 2020; Aldhaban 2012; Hillmer 2009; Momani and Jamous 2017; Taherdoost 2018)).

limited (Alinaitwe et al. 2006; Masood et al. 2014). Furthermore, technology adoption is a complex concept that is affected by the efficiency of the technology and other factors like user characteristics, management styles, environment, regulation, and other causal factors (Ahuja et al. 2020; Sepasgozar and Bernold 2013; Taherdoost 2018). Several technology-adoption theories have been developed over the years, focusing on adoption at the individual or institutional/organisational level, as presented in Figure 2.

While BIM is a process rather than a technology, its adoption in the construction industry hinges on the use of BIM technology efficiently to experience the benefits of BIM. Therefore, under-utilisation of BIM technology may hinder its growth, and the complexities of technology adoption may affect the development of appropriate solutions. A review of common BIM technology adoption theories presented in Table 3 demonstrates that technology adoption depends on various factors, including user interest, cognitive ability, management interest, strategic organisational interest, technology, and the environment (Ahuja et al. 2020; Hillmer 2009; Taherdoost 2018), however with majority of scholars employing a Technology Acceptance Model (TAM)-based adoption theory.

3. Materials and methods

3.1. Theoretical framework

Following the reviewed literature in Sections 2.4 and 2.5, the theoretical model for this research was hinged on the Extended Technology Acceptance Model (TAM 2) with constructs: understanding BIM concepts, processes and tools; application of BIM; BIM benefits; and barriers to BIM adoption in Uganda's construction industry. Consequently, the study identified nine variables (*profession, role in academia, role in the supply chain, work experience, understanding of BIM, BIM functions used, level of awareness and use of BIM tools & vendors, perceived benefits of BIM, and perceived barriers to BIM adoption*). Study hypotheses were formulated and are presented in Table 4.

3.2. Survey questionnaire development

The survey questionnaire was designed to measure nine variables that would answer the main research question on evaluating the status of BIM adoption in Uganda's construction industry. The research established that the appropriate independent variables

would be; profession, role in academia, role in the supply chain, and work experience. These independent variables would be assessed to identify their relationship or impact on the dependent variables, which were selected as; understanding of BIM, BIM functions used, level of awareness and use of BIM tools, perceived benefits of BIM and perceived barriers to BIM adoption which were selected from a bibliography review.

The instrument included four sections presented in Table 5. The first section captured the profile information of the respondents. This section included questions with dichotomous answers (yes/no) and demographic questions. The second section focused on understanding of BIM concepts and use of BIM tools. This section used matrix questions following a Likert scale of 1-5 (Jamieson 2004). The third section addressed the respondents' perception of the benefits of BIM to construction projects based on 13 benefit categories adopted from literature. The final section assessed the respondent's perception of the barriers to BIM adoption in Uganda's construction industry and had 14 barriers to BIM adoption obtained from the literature following a Likert scale of 1-5.

A preliminary questionnaire was piloted for two weeks to ascertain data validity and reliability. It was then shared with two construction-industry professionals and four academics to establish content and face validity and minimise double-barreled questions. Subsequently, the survey questions were modified, and the survey was refined to capture relevant data. Consequently, the piloting exercise refined the questions on the benefits of BIM and barriers to BIM adoption. The benefits on rework and reduced delays were combined as enhanced productivity. Two additional barriers on prevalence of unregulated construction projects and potential conflict of interest amongst project participants were also included in the survey.

3.3. Data collection

A structured online survey was administered for four months, from February 2020 to May 2020, through SurveyMonkey. The study population was defined as professionals in the Architecture Engineering and Construction (AEC) industry registered with a relevant accrediting or professional body in Uganda. As of February 2020, the total study population comprised 950 professionals with 525 Registered Engineers, 165 Registered Architects, 80 Registered Valuation Surveyors, 57 Registered Quantity Surveyors, and 123 Registered Land Surveyors.

Table 3. Review of literature on technological theories on BIM adoption.

Reference	Technology theory	Research area	Acceptance	Behavioural intention	Behaviour control	Belief in benefits	Client requirement	Compatibility	Complexity	Computer anxiety	Cost	Demonstrability	Environment	Expertise	Image	Job relevance	Facilitating conditions	Influence	Management support	Perceived ease of use	Perceived enjoyment	External control	Personal competency	Regulatory support	Self-efficacy	Subjective norms	Trade partner readiness	Use	Quality of output	Voluntariness
Lee et al. (2012)	TAM2 and PBC	BIM-based FM	✓	✓				✓																						
Lee et al. (2015)	TAM-based	BIM acceptance model						✓																						
Ahuja et al. (2020)	TOE	BIM adoption factors in emerging markets						✓																						
Liu et al. (2018)	TAM2	Smart construction systems						✓																						
Eishafey et al. (2020)	TAM3	BIM integration in the construction industry						✓																						
Sorce and Issa (2021)	TAM2	ICT in the Construction industry						✓																						

The Professionals falling under the target study population were contacted via email through their respective accrediting and professional bodies. The survey was programmed so that respondents could only take the survey once. Respondents were categorised according to profession, supply chain role, and working experience. A further category sought to establish if the respondents were involved in teaching at higher institutions of learning to compare the perceptions of those in academia against practitioners outside the academia. The survey targeted professionals in the professions of Quantity Surveying, Architecture, Civil/Structural Engineering, Geomatics/Land Surveying, Construction Management, Valuation Surveying/Land Economics/Property Valuer/Estate Management, and Mechanical and Electrical Engineering.

The final survey tool, consent forms, and questionnaires were prepared and submitted to the Makerere University Research and Innovation Institutional Review Board for approval, which provided exemption since the survey was not collecting sensitive data. However, informed consent was included in the survey questionnaire indicating the level of data protection. Electronically signed 'informed consent' was obtained from the respondents before attending the online survey questionnaire. At the closure of the survey, data were downloaded and exported to IBM SPSS version 17 software for data cleaning, coding, and analysis. The data analysis was performed in IBM SPSS version 17 and STATA MP version 13.

3.4. Data analysis

The data was analysed according to the flow chart presented in Figure 3.

3.4.1. Data cleaning

Responses from individuals outside the target population were eliminated. These included responses from administrators and business development officers in the various institutions. The data cleaning process also eliminated responses where straight lining occurred, and the respondents selected only one response irrespective of the question.

3.4.2. Diagnostic tests for multicollinearity

Diagnostics tests were performed to check for multicollinearity and Normality. The multicollinearity tests were performed using the Variance of Inflation test for independent variables (VIF) to ensure that the variables were not closely correlated. The tests considered that a low correlation exists where the VIF does not exceed 4 and an acceptable level of correlation for VIF values less than 10 (Hair et al. 1995; Marquardt 1970; Mason et al. 1989; O'Brien 2007).

3.4.3. Diagnostic tests for normality

The data was checked for normality to determine the best statistical method for analysis. A combination of the Shapiro-wilk test and a graphical plot of the histogram and normal distribution curve were applied to check for normality (Masood et al. 2014). For the Shapiro-wilk test, the p-values greater than 0.05 were taken to follow a normal distribution.

Table 4. Null hypotheses tested in the study.

S/N	Null hypothesis
H1 ₀	BIM in Uganda is employed at level 01
H2 ₀	There is a significant relationship between one's profession and awareness of BIM software
H3 ₀	The respondents' profession has no correlation with one's understanding of BIM processes, concepts and tools
H4 ₀	The respondents' profession has a correlation with the BIM functions employed
H5 ₀	The respondents' profession has a correlation with one's use of different BIM software
H6 ₀	The Work experience has a positive correlation with the awareness and use of BIM software
H7 ₀	The Work experience has a correlation with the BIM functions employed
H8 ₀	The respondents' work experience has a positive correlation with one's understanding of BIM processes, concepts and tools
H9 ₀	The role in the supply chain has a positive correlation with the awareness and use of BIM software
H10 ₀	The role in the supply chain has a correlation with the BIM functions employed
H11 ₀	The respondent's role in the supply chain has a positive correlation with one's understanding of BIM processes, concepts and tools
H12 ₀	The role in academia has no correlation with the awareness and use of BIM software
H13 ₀	The role in academia has a correlation with the BIM functions employed
H14 ₀	The respondent's role in academia has a correlation with one's understanding of BIM processes, concepts and tools

Table 5. Structure of research questionnaire.

Section	Focus	Source
1. Respondents Profile	1.1 Profession 1.2 Role in supply chain 1.3 Experience 1.4 Role in academia	
2. Understanding of BIM concepts	2.1 Level of understanding of BIM concepts, tools and processes 2.2 Awareness of BIM tools and vendors	
3. Application of BIM	3.1 Use of BIM software 3.2 BIM functions employed	
4. Benefits of BIM	4.1 Perceived benefits of BIM	(Ahankoob et al. 2019; AGC 2006; Azhar, Khalfan, and Maqsood 2009)
5. Barriers of BIM adoption	5.1 Perceived barriers to BIM	(Abdul 2016; Brewer et al. 2012; Demian and Walters 2014; Gardezi et al. 2014; Kurul et al. 2013; Ma et al. 2020; Migilinskas et al. 2013; Morrison 2010)

3.4.4. Reliability and validity tests

The data was analysed for validity and reliability of the four measures of understanding BIM concepts, BIM application, the perceived benefits of BIM, and barriers to BIM adoption. The Cronbach's alpha (CA) was used to assess the internal consistency of the questionnaire items. A higher alpha (α) value indicated higher reliability, with values greater than 0.7 considered acceptable (DeVellis 2017). In addition, the Composite reliability test was also used to assess the reliability of the questionnaire items, with acceptable ranges taken to be between 0.70 and 0.95 (Fornell and Larcker 1981).

Construct validity was checked through Convergent validity (using Average Variance Extracted) and Discriminant validity (using Fornell-larcker and cross-loading) (Fornell and Larcker 1981). The acceptable ranges for average variance extracted were those above 0.50 (Fornell and Larcker 1981).

3.4.5. Statistical tests and analysis

The diagnostic tests on normality determined that non-parametric statistical tests would be most suitable. One-way non-parametric ANOVA (Hammad et al. 2020; Hosseini et al. 2015) and Mann-Whitney tests (Sadeh et al. 2021) were performed to assess the relationships between profession, role in supply chain, work experience, involvement in education against awareness and use of BIM, understanding of the BIM concepts, BIM functions in use, level of importance of BIM benefits, and the level of importance of the BIM barriers. Thereafter, pairwise post-hoc dunn tests were performed to establish the statistical significance between groups within the independent variables; profession, role in supply chain, work experience, involvement in education on the determined dependent variables.

4. Results

4.1. Diagnostic tests

4.1.1. Multicollinearity

The multicollinearity test (refer to Appendix 1) shows that for all dependent variables, the VIF for the independent variables were within acceptable limits with values less than 4 (O'Brien 2007); and the average VIF for all the independent predictors did not exceed a value of 4 (Hair et al. 1995; Marquardt 1970; Mason et al. 1989). Therefore, the independent variables did not exhibit multicollinearity and considered as reliable to answer the research questions.

4.1.2. Normality

The Shapiro-Wilk test for normality indicated that majority of the data violates the normality assumptions with p-values less than 0.05 (refer to Appendix 2) and graphical analysis using histograms and normal distribution curves revealed that all the dependent variables followed a non-normal distribution as presented in Figure 4.

Therefore, the data was analysed using non-parametric tests. The dependent variables with binary dichotomous responses were not tested for normality.

4.2. Reliability and validity tests

4.2.1. Reliability tests

The reliability of the four measures of the level of BIM adoption in Uganda was tested using Cronbach's alpha (CA) and Composite Reliability (CR). The Cronbach's alpha (CA) for all four measures ranged from 0.86 to 0.98, (Table 6) above the acceptable level of 0.70 (DeVellis 2017).

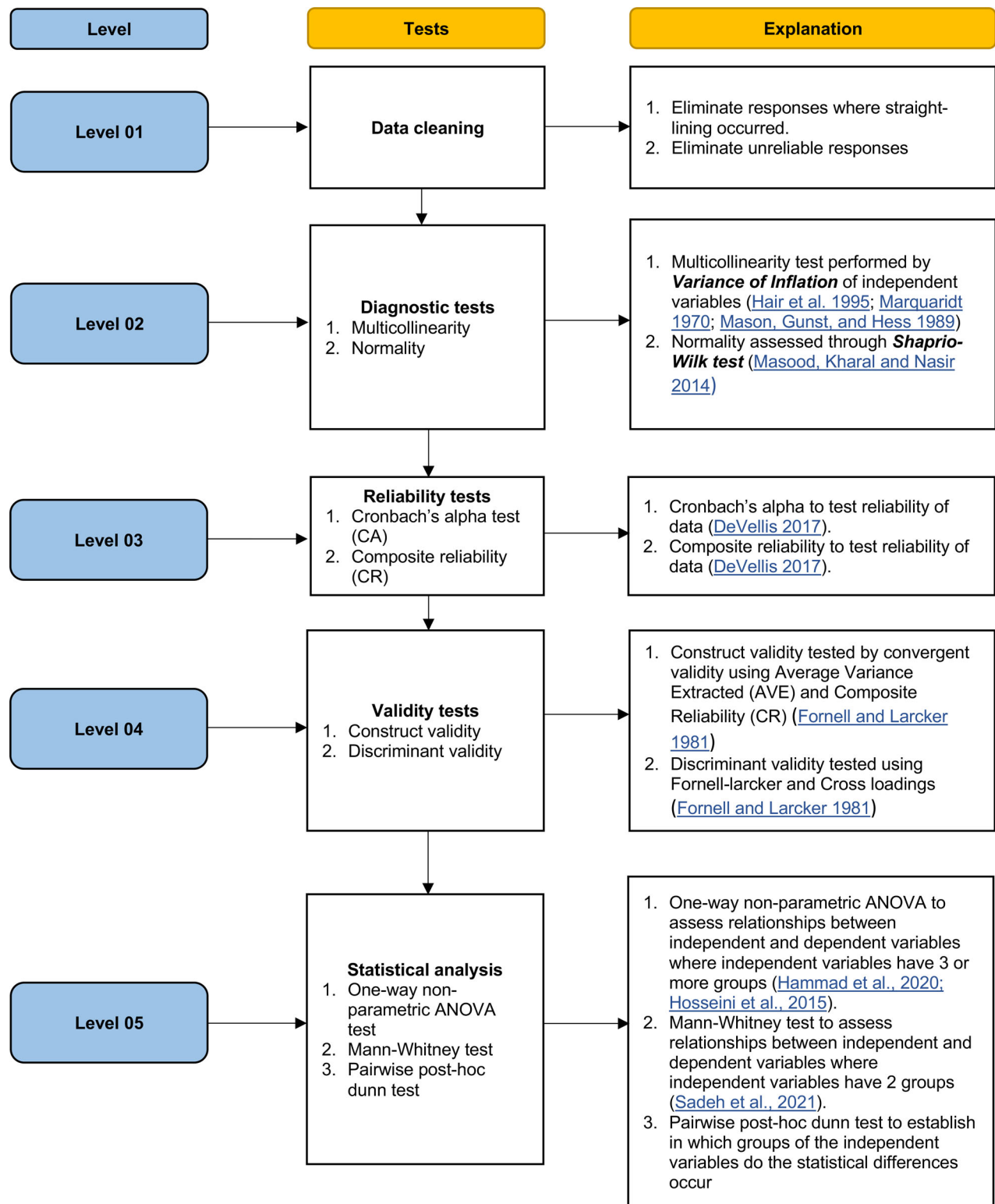


Figure 3. Flow chart of the data analysis process.

The composite reliability (CR) for all four measures was also above the acceptable level of 0.60 (Fornell and Larcker 1981), ranging between 0.88 and 0.98 (Table 7) indicating that the measures had a high degree of internal reliability.

4.2.2. Validity tests

The measures were tested for construct validity and discriminant validity. The construct validity was tested using the average

variance extracted (AVE). The average variance extracted (AVE) for 'awareness and use of BIM tools and platforms' and for 'Understanding of BIM concepts' was found to be 67% and 57%, respectively, which is above the acceptable level of 50% (Fornell and Larcker 1981). However, the AVE for 'BIM benefits' and 'BIM implementation barriers' were below the acceptable level at 41% and 37%, respectively. Fornell and Larcker (1981) posit that since the AVE may be a more conservative method of estimating

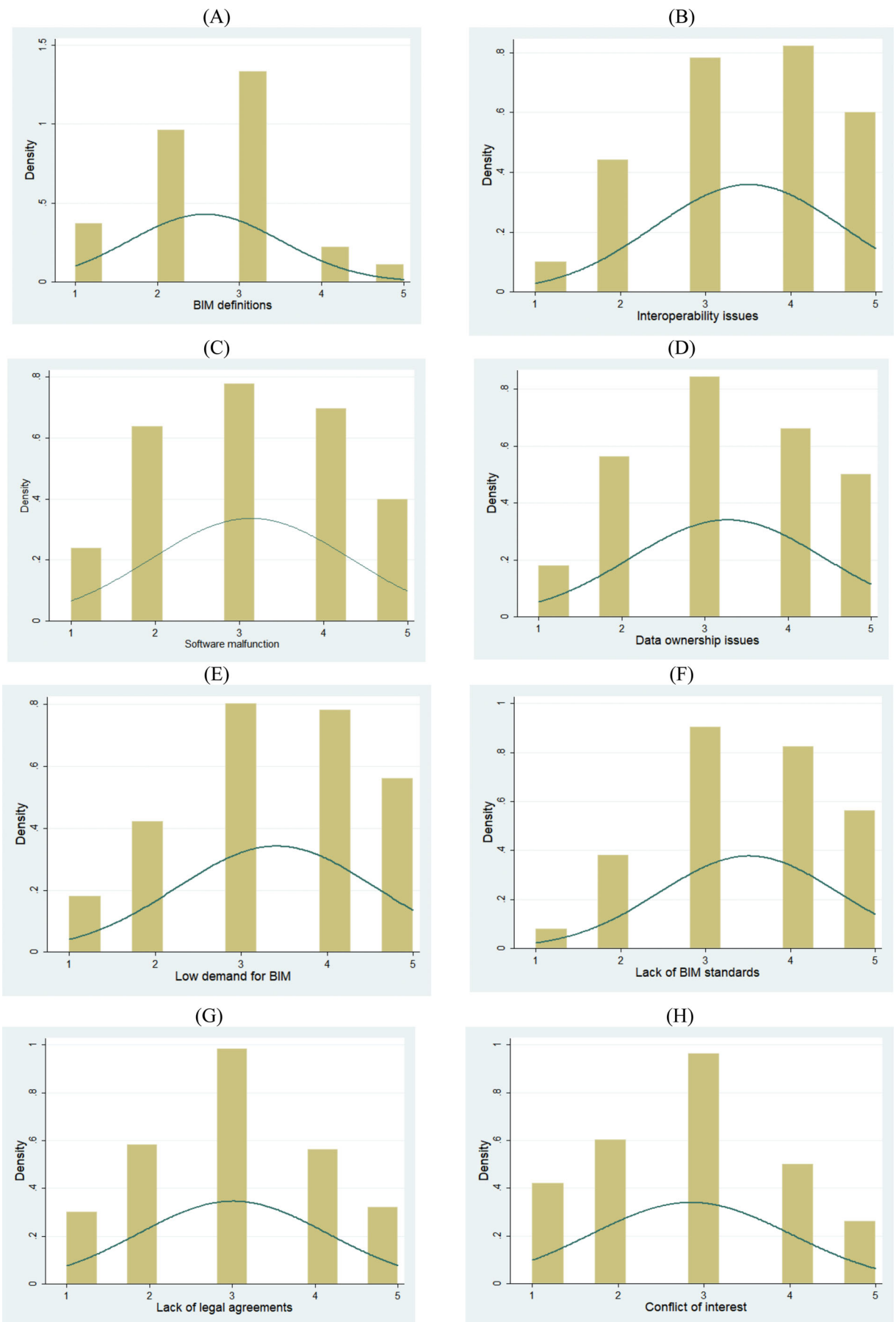


Figure 4. (A-H): Histogram for dependent variables showing normalcy.

Table 6. Reliability results using Cronbach alpha.

Key research parameter	Cronbach's Alpha	Cronbach's Alpha Based on Standardised Items	No. of Items
Application of BIM	0.971	0.976	22
Understanding of BIM concepts	0.919	0.921	9
BIM benefits	0.920	0.921	13
BIM implementation barriers	0.864	0.863	14

Table 7. Reliability results using composite reliability.

Key research parameter	Composite Reliability
Application of BIM	0.978
Understanding of BIM concepts	0.923
BIM benefits	0.890
BIM implementation barriers	0.883

Table 8. Construct validity test results for the four measures.

Key research parameter	Composite Reliability	Average Variance Extracted
Awareness and Use of BIM Tools and Platforms	0.978	0.672
Understanding of BIM concepts	0.923	0.574
BIM benefits	0.890	0.405
BIM implementation barriers	0.883	0.367

Table 9. Fornell-Larcker analysis for discriminant validity.

	Awareness and use of BIM tools	Understanding of BIM concepts	Perceived benefits of BIM	Perceived barriers to BIM adoption
Application of BIM	0.8197			
Understanding of BIM concepts	-0.1335	0.7578		
Perceived benefits of BIM	0.0300	0.0636	0.6261	
Perceived barriers to BIM adoption	0.1244	0.0575	0.3429	0.6061

validity, an acceptable CR value can warrant a verdict of convergent validity. Since the CR values for the four measures were above the acceptable value, the convergent validity was considered adequate based on the composite reliability (Table 8).

The discriminant validity was determined using the Fornell-Larcker criteria and cross-loadings, as demonstrated in Table 9 and Appendix 3. The comparison of loadings and cross-loadings (Appendix 3) shows that the factor loading indicators on the assigned constructs are higher than all loadings of other factor loading indicators. The Fornell-Larcker analysis criterion was satisfied with the square root of the AVE of each construct being higher than the assigned constructs correlation as demonstrated in Table 9.

4.3. Profile of respondents

A total of 950 respondents were identified however, the survey was only able to contact 671 respondents resulting in a contact rate of 71%. From the 671 email invitations sent out, 212 responses were received, resulting in a 31.6% response rate. However, only 162 responses were substantially responsive to the critical survey questions, which reduced the total response rate to an actual response rate of 24%. The responses that were substantially responsive were determined as those responses that had completed the questions on the; (i) profile of the respondent, (ii) level of awareness of BIM, (iii) work experience of BIM tools and functions, (iv) perceived benefits of BIM and (v) barriers to BIM adoption in Uganda's construction industry. Research by Nulty (2008), considered a response rate between 3% and 41% for a population of 1,000 under liberal and stringent conditions respectively. Therefore, this research considered the response rate of 24% reliable (Figure 5).

4.4. Level of knowledge of BIM concepts, processes and tools

The One-way non-parametric ANOVA test (Hammad et al. 2020; Hosseini et al. 2015) was performed to establish the statistical difference between the groups in the independent variables (Profession, Role in supply chain, and Experience) when compared against the understanding of BIM concepts and awareness of BIM software (refer to Appendices 4–6). A pairwise post-hoc Dunn test was performed to establish the groups in the independent variables that possessed the statistical relationships. For the case of the independent variable, 'involvement in academia', the one-way non-parametric ANOVA test was found to be inappropriate as the variable contained only two categories, therefore the Mann-Whitney test (Sadeh et al. 2021) was performed to assess any statistical significance in the understanding of BIM concepts and awareness of BIM software.

4.4.1. Level of understanding of BIM concepts

The respondent's profession was found to significantly influence their understanding of BIM processes ($p = 0.0272$). In addition, the involvement in academia demonstrated a strong relationship with one's knowledge of BIM definitions ($p = 0.0121$), maturity levels ($p = 0.0089$) and BIM dimensions ($p = 0.0229$), (refer to Appendix 4).

Pairwise post-hoc comparisons using Dunn's test indicated that knowledge of BIM processes was significantly dispersed with Architects and Geomatic surveyors ($p = 0.0166$), Civil Engineers and Quantity Surveyors ($p = 0.0192$), Civil Engineers and Geomatics ($p = 0.0051$) and Construction Managers and Geomatic surveyors ($p = 0.0153$).

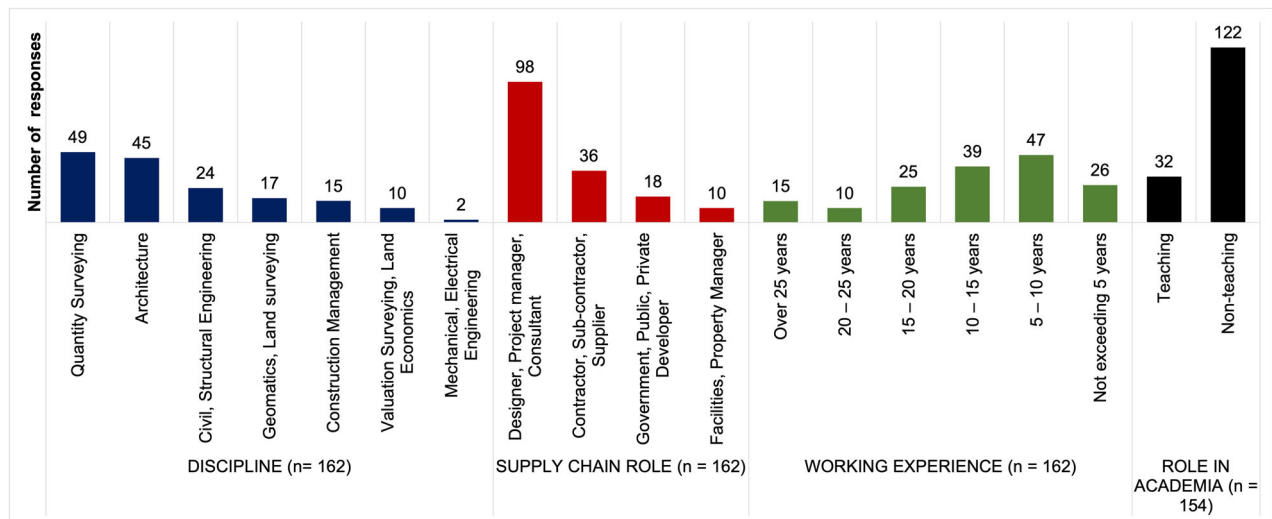


Figure 5. Categorisation of respondents.

4.4.2. Level of awareness of BIM tools

The statistical test presented (refer to Appendix 5) showed a significant difference in the awareness of ArcGIS, Bentley, CostX, Masterbill, Revit and Trimble as a BIM software and the six groups of the respondent's profession with p-values less than 0.05. It also demonstrated a significant relationship between the four groups of the respondent's role in the supply chain and the awareness of ALLPLAN, Astapowerpoint, CostX and Vico. In addition, the work experience had a significant impact on the awareness of ALLPLAN, Asite and Masterbill.

A further analysis using the dunn test (refer to Appendix 6) demonstrated that Geomatics and Valuation Surveyors were more aware of ArcGIS as compared to the other professionals while for the cost and measurement software (CostX and Masterbill), the Quantity Surveyors were more aware as compared to the other professions. In the case of Bentley microstation; Civil Engineers and Geomatics Surveyors were aware of this software as a BIM tool and Geomatics and Valuation Surveyors had more knowledge of Trimble as compared to other professions. All professions except for Valuation Surveyors were aware of Revit.

4.5. Application of BIM

4.5.1. Use of BIM tools

The statistical test (refer to Appendix 7) showed that one's profession had a statistical significance on the use of; ArcGIS, Astapower project, AutoCAD, Bentley Microstation, COINS, Innovaya, Newforma and Vico. At the same time, involvement in academia influenced the use of Digital Project, and Tekla structures.

These influences were further assessed in Appendix 8 and revealed that except for the Geomatics Surveyors (73%), the use of ArcGIS amongst the professions is low. In addition, all professions use AutoCAD except for Architects recording a 37.5% use. On the other hand, Astapower project was not used by any of the professions aside from the Geomatics Surveyors (10%) and Quantity Surveyors (3%).

4.5.2. BIM functions in use

A One-way non-parametric ANOVA analysis established that the BIM functions used by the industry practitioners showed no statistical significance amongst the different groups of professions ($p=0.234$), role in the supply chain ($p=0.4492$), and;

involvement in academia ($p=0.5448$). However, the work experience showed a strong relationship with the BIM functions one would use ($p=0.0084$).

4.6. Perceived benefits of BIM

The test revealed statistical significance between the profession and the perception that BIM ensures early forensic analysis. Similarly, involvement in academia influenced the perception that BIM enhances energy efficiency (refer to Appendix 9).

A further analysis using pairwise post-hoc dunn test showed that the perception that BIM enhances early forensic analysis was statistically significant amongst Architects and Geomatic Surveyors ($p=0.044$), Architects and Valuation Surveyors ($p=0.010$), Civil Engineers and Geomatic Surveyors ($p=0.005$), Quantity and Geomatic Surveyors ($p=0.009$), Architects and Geomatic Surveyors ($p=0.044$), and Valuation and Geomatic Surveyors ($p=0.001$).

4.7. Perceived barriers to adoption of BIM

The perceived barrier on interoperability issues showed strong relationships with the respondent's role in the supply chain. The other perceived barriers did not show statistical significance amongst the different professions, role in the supply chain, work experience or involvement in academia (refer to Appendix 10). It was deduced that irrespective of profession, role in the supply chain, work experience, or involvement in academia, the respondents held the same perception of the barriers to BIM adoption.

The perception on interoperability issues had a strong relationship amongst the Consultant and Contractor ($p=0.001$), Client and Contractor ($p=0.002$), and Facilities Manager and Contractor ($p=0.032$).

5. Discussions

5.1. Level of knowledge of BIM concepts, processes and tools

5.1.1. Understanding of BIM concepts

The study sought to answer the hypothesis on the level of BIM adoption in Uganda by assessing the respondents' level of

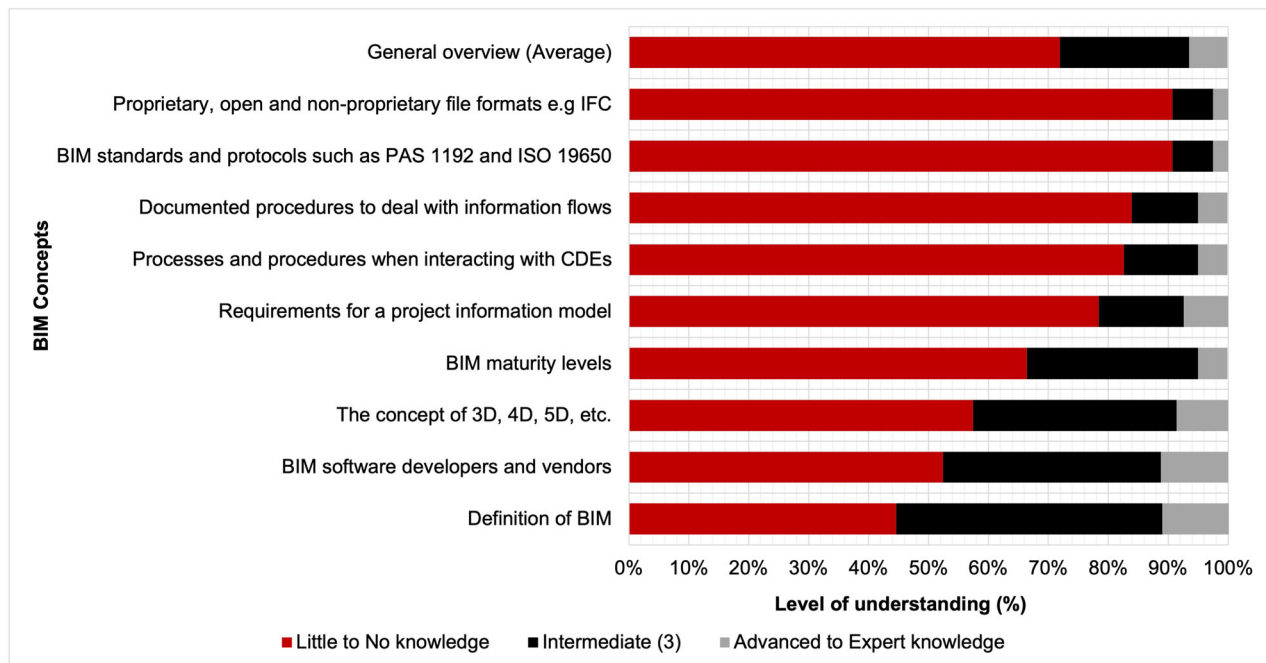


Figure 6. Level of understanding of BIM concepts, tools, and processes (percentage distribution).

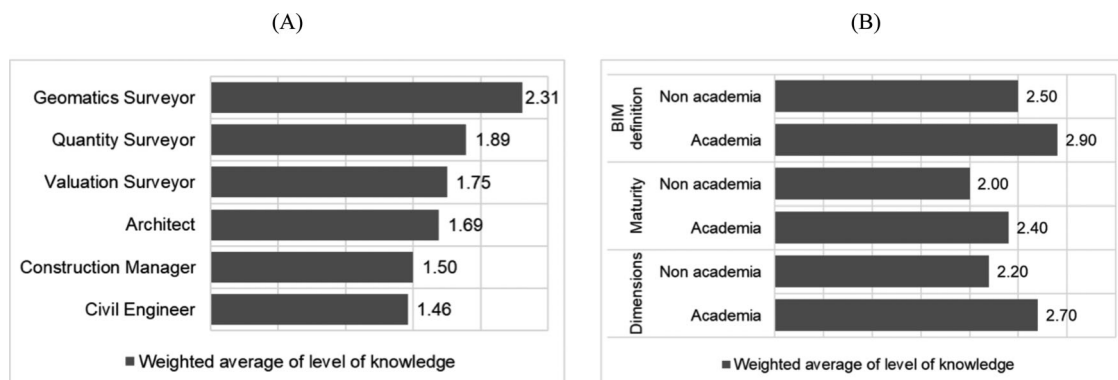


Figure 7. (A) Variation of knowledge of BIM processes amongst the different professions; (B) Variation of BIM knowledge according to involvement in academia.

understanding of BIM concepts and their awareness of BIM tools and vendors. As demonstrated in Figure 6, the survey established that most respondents (71.9%) have limited-to-no knowledge of the concept and processes of BIM. The results further indicate that while BIM knowledge is still limited, respondents are familiar with the BIM definitions, software vendors, and the concept of BIM dimensions. Further to this, the analysis demonstrated that the industry practitioners have limited knowledge of the requirements of a project information model, which are some of the essential aspects of applying BIM. This research demonstrates the need for BIM training to enhance the knowledge of BIM processes for improved delivery of construction projects. The respondents were aware of the BIM tools with limited knowledge of the BIM processes and concepts. Since BIM is more than the technology, for the industry to fully experience the benefits of BIM, it is imperative that the industry's understanding of BIM processes and concepts is improved.

5.1.2. Relationship between profession and academia on the understanding of BIM

An analysis of knowledge of BIM processes amongst the different professions demonstrates that Geomatics Surveyors possess better

knowledge on BIM processes than the other professionals with a weighted average of 2.31, as presented in Figure 7(A). It can therefore be deduced that the respondents' profession has a correlation with one's knowledge of BIM processes, concepts and tools since some professions have begun to embrace BIM at a greater level.

These findings are contrary to previous studies where Architects and Civil Engineers were found to have better knowledge of BIM (Alufohai 2012). These differences could be attributed to the exclusion of Geomatic Surveyors in previous surveys as well as increased exposure to BIM processes in their work due to the accelerated adoption of digital technologies like the use of Unmanned Aerial Vehicles (UAVs) and Geographical Information Systems (GIS), in current surveying practice.

Further analysis in Figure 7(B) revealed that those involved in academia have better knowledge of BIM definitions, maturity levels, and dimensions, perhaps because universities are now developing BIM curricula to promote BIM adoption in the industry. Such interventions are necessary to improve the adoption of BIM in Uganda.

5.1.3. Awareness of BIM tools

The analysis on the awareness of BIM tools presented in Figure 8 demonstrated that professionals in the construction industry in

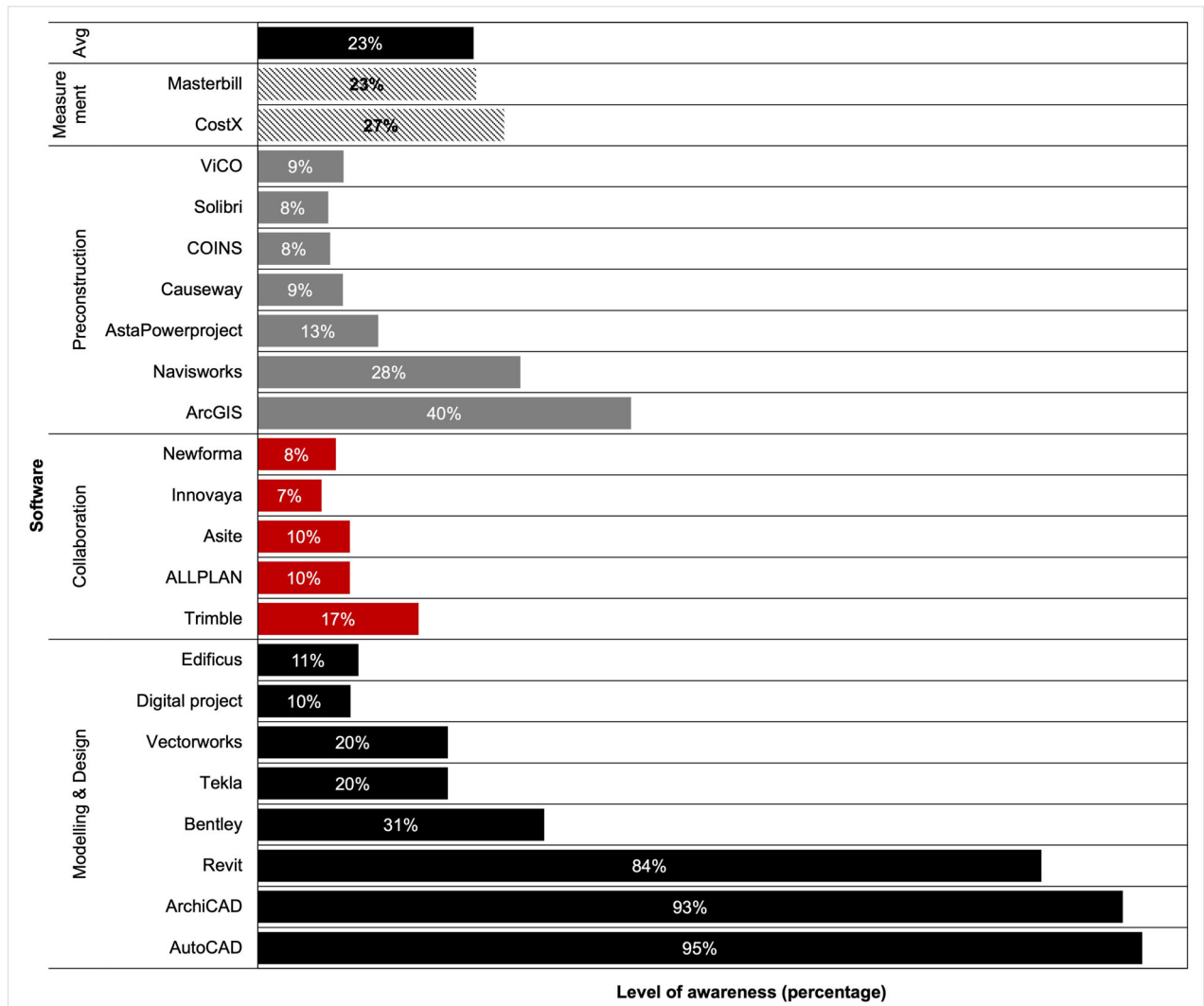


Figure 8. Awareness of BIM software.

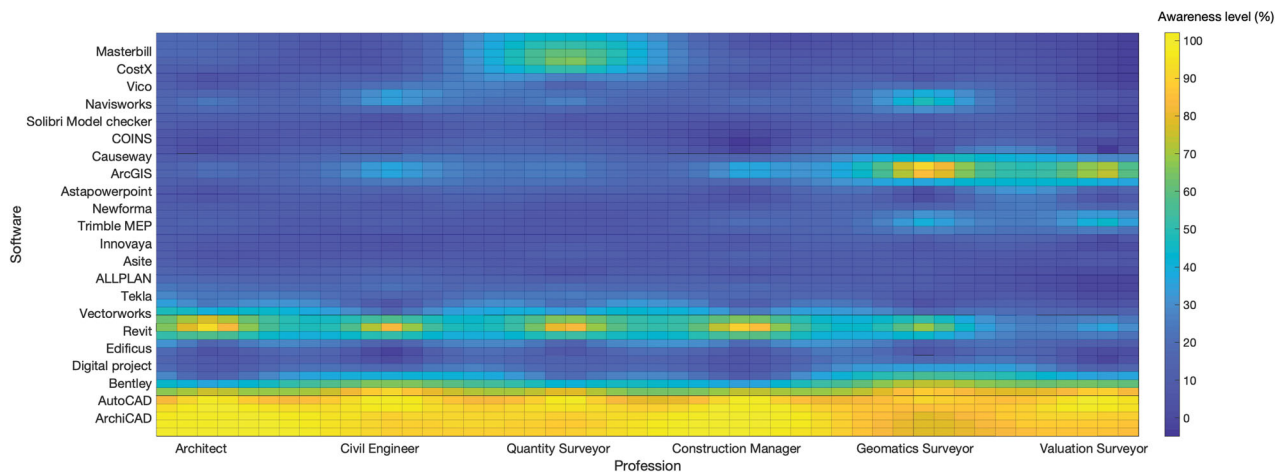


Figure 9. Variation of awareness of various software by profession.

Uganda are more aware of modelling software, with 95%, 93% and 84% showing awareness of AutoCAD, ArchiCAD and Revit, respectively, implying that modelling software is more prevalent in use than other aspects of BIM such as collaboration, preconstruction, and measurement. This further substantiates the hypothesis that BIM is employed in Uganda's construction industry at Level 1.

5.1.4. Relationship between profession and awareness of BIM

Further analysis of the awareness of BIM software across various professions as presented in Figure 9 shows that architects, civil engineers, and construction managers are more aware of modelling software, with the majority having knowledge of ArchiCAD, AutoCAD and Revit. However, Geomatics and Valuation surveyors demonstrated awareness in modelling (ArchiCAD, AutoCAD) and preconstruction software (ArcGIS) while Quantity Surveyors indicated awareness in modelling (ArchiCAD, AutoCAD & Revit) and measurement software (CostX).

This variation could be arising from the nature of work that these professions perform in the construction industry, with Architects, Civil Engineers, Construction Managers and Quantity Surveyors usually taking up roles as designers, consultants and contractors. However, it was noted that, in as much as the Architects, Civil Engineers, Construction Managers and Quantity Surveyors in most cases take up roles as project managers where collaboration and review was necessary, their knowledge of collaboration and preconstruction software was limited.

5.1.5. Relationship between experience level and awareness of BIM

A detailed analysis of the impact of work experience as demonstrated in Figures 10(A)–(D) shows that for Asite, ALLPLAN and Masterbill, an additional five-year experience has a 4%, 6% and 8% respective positive influence on the level of awareness of the software. However, the other software showed a 0–2% influence on the level of awareness between the different groups of Work experience.

Furthermore, the analysis demonstrates that the awareness of modelling and preconstruction software is not influenced by the work experience in the industry. The level of awareness of ArchiCAD, AutoCAD, and Revit was outstanding across all experience groups. At the same time, Bentley, Edificus, Tekla Digital project, Vectorworks was low across all experience groups. On the other hand, the awareness of preconstruction software was low for all the experience groups, as presented in Figure 10(B). This analysis may explain the common BIM tools in Uganda's construction industry.

5.2. Application of BIM

5.2.1. Use of BIM tools

The survey identified and listed 22 possible BIM tools and software and required the respondents to establish their level of awareness and use of these BIM tools and software. This approach made it possible to establish awareness and usage amongst stakeholders in the construction industry, as presented in Figure 11.

Apart from ArcGIS, AstaPower project and AutoCAD, there was no statistical significance between the use of the BIM software and the profession. As presented in Figure 12, a detailed analysis also demonstrated that most professions use modelling software like AutoCAD and Revit.

5.2.2. BIM functions in use

Although BIM tools and software have several functions, only two out of 15 functions identified, were reported to be in use by over 50% of the respondents. Most respondents use BIM software for creating drawings, (Figure 13) as reported by 83% of the respondents, which correlates with at least 67.6% using modelling software (from Figure 11) while 50% of the respondents use BIM for site planning. BIM at maturity level 1 involves the use of modelling and documentation with limited collaboration between stakeholders (Abbasnejad and Moud 2013). BIM adoption has been recommended at level 2 with collaboration and interoperability (Khosrowshahi and Arayici 2012). From this survey, it can be deduced that Uganda uses BIM at level 1.

5.3. Perceived BIM benefits

BIM benefits are all highly regarded as important (Figure 14), with an average weighted rating scale of 3.98 out of a potential maximum scale of 5.0. Like previous studies, the study respondents perceive the most important benefits of BIM as enhanced productivity, access to complete project information, and an improved design (Azhar et al. 2012; Brewer et al. 2012; Dodge Data and Analytics 2015; Hooper 2015; Paik et al. 2020; Rosayuru et al. 2019; Sacks et al. 2018).

The tests showed a strong relationship between the perceived benefit of early forensic analysis and the profession of the respondent; and the perception of better marketing and enhanced energy efficiency as a highly regarded benefit amongst those involved in academia. The study found no relationship between the perceived benefits and work experience, contrary to a study by (Ahankoo et al. 2019) that found a strong relationship between the work experience in BIM perception of BIM benefits.

Whilst the benefits of BIM can be realised across all phases of a construction project, it is not ambitious to suggest that such benefits can only accrue when the whole project team uses standard processes and protocols for exchanging information at critical stages, which requires an entirely different way of working and procuring assets. This cannot happen with technologies alone and, above all, without a change in the culture and mindset of the construction industry.

5.4. Perceived BIM barriers

The survey identified the most highly regarded barriers as; the lack of sufficient training opportunities and financial constraints for upfront costs, as summarised in Figure 15. The results correlate with findings from other researchers (Abdul 2016; AGC 2006; Brewer et al. 2012; Gardezi et al. 2014; Kurul et al. 2013; Morrison 2010; Okakpu et al. 2020; Rosayuru et al. 2019) and therefore, suggest the need for all industry players to support the integration of BIM in designing solutions to these challenges.

The One-way non-parametric ANOVA test found a correlation between the role in the supply chain and the perceived barrier of interoperability issues. A further analysis revealed that the Consultants, Clients and Property/Facility Managers regarded interoperability issues as an important barrier with a weighted mean of 3.6, 3.8 and 3.8 respectively while Contractors found interoperability issues not to be an important barrier with a weighted mean of 2.6.

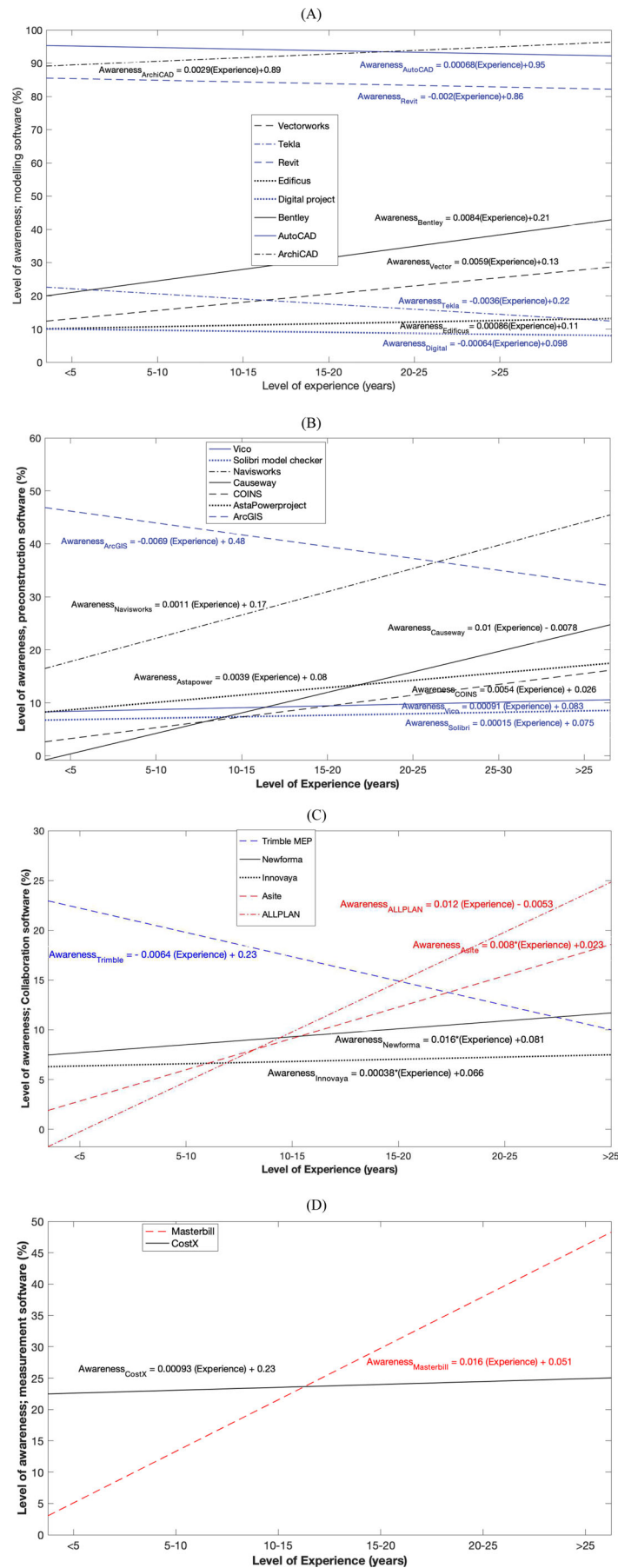


Figure 10. (A) variation of awareness of modelling BIM software against work experience; (B) variation of awareness of preconstruction BIM software against work experience; (C) variation of awareness of collaboration BIM software against work experience; (D) variation of awareness of measurement BIM software against work experience.

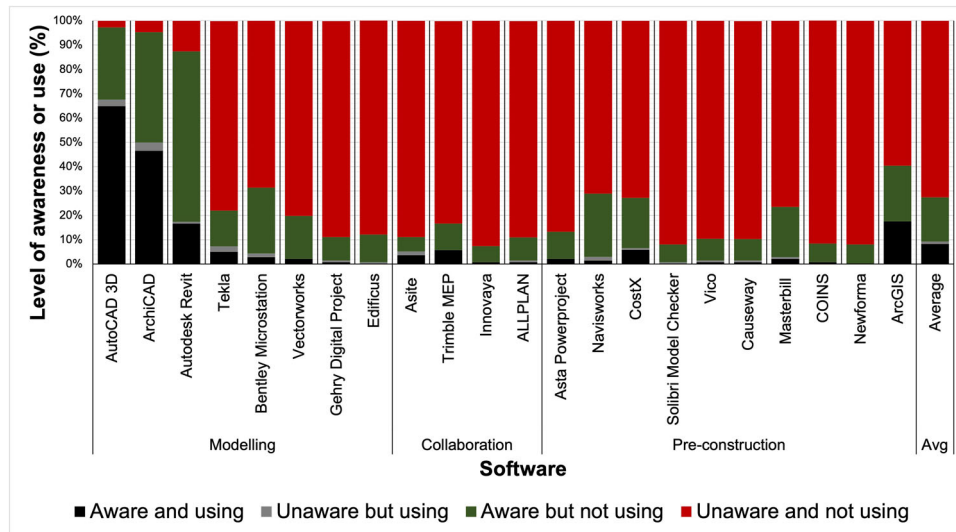


Figure 11. Level of awareness and use of popular BIM software and tools.

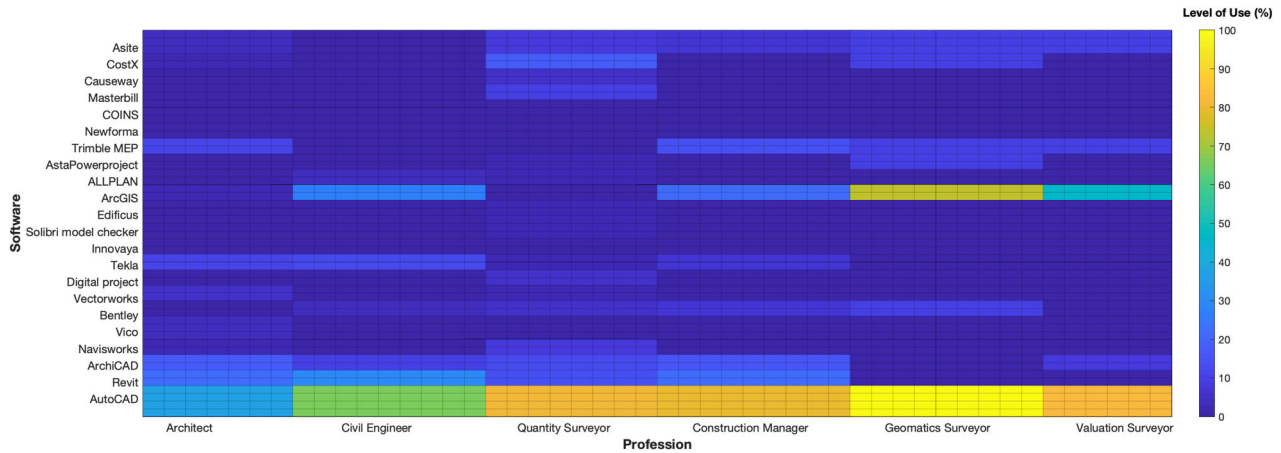


Figure 12. Variation in the use of BIM software amongst the different professions.

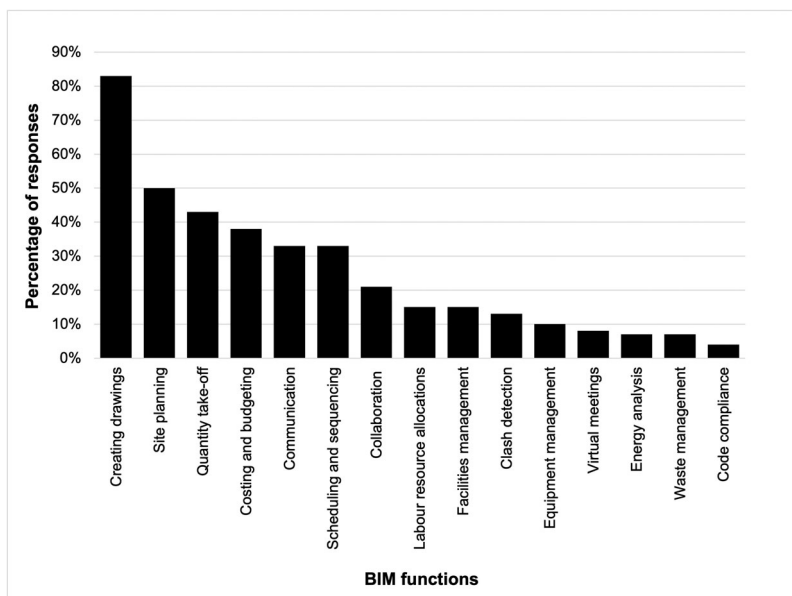


Figure 13. Common BIM functions in use in Uganda's construction industry.

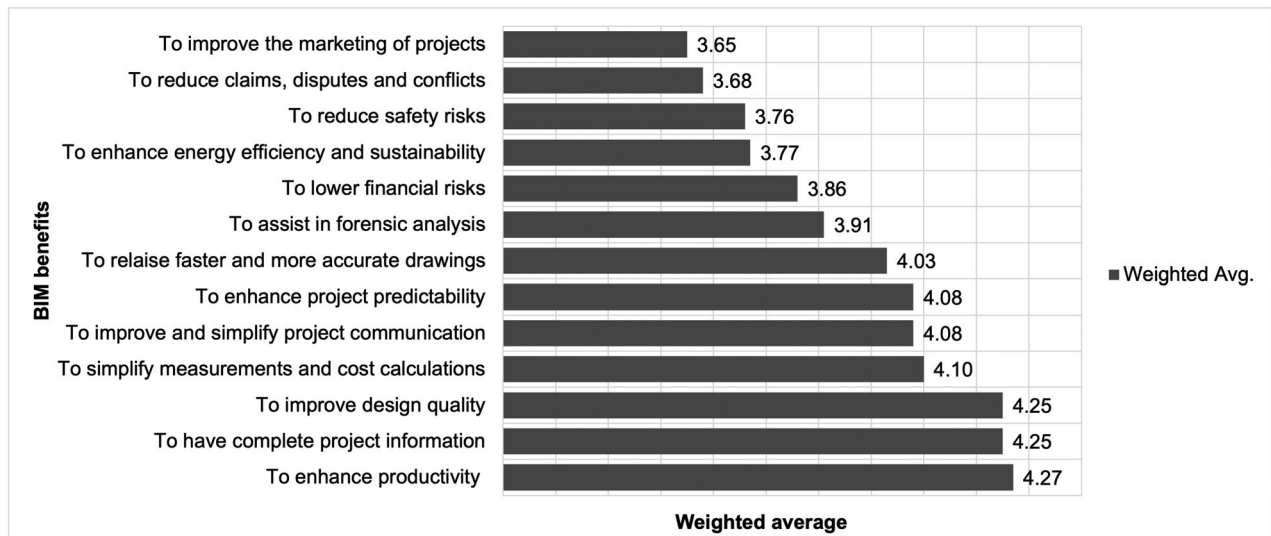


Figure 14. Relative importance of BIM benefits (weighted averages).

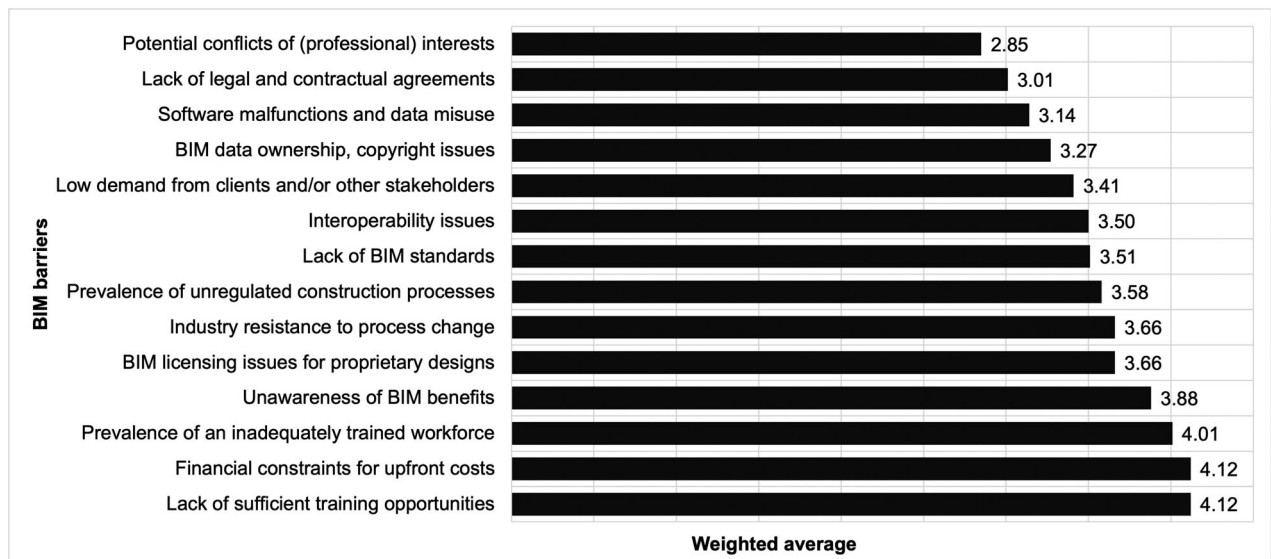


Figure 15. Weighted average of significant barriers to BIM adoption in Uganda.

6. Conclusion

BIM adoption in Uganda is at an infancy stage, with most professionals using BIM software primarily for modelling with limited use of collaboration or preconstruction software. Majority of the respondents were aware of modelling software especially; AutoCAD, Revit and ArchiCAD. Nonetheless, professionals do appreciate the importance of BIM and considered some of its most important benefits as enhanced productivity, access to complete project information, and an improved design. This presents an opportunity for BIM adoption in Uganda.

To enhance the adoption of BIM in Uganda's construction industry, our study recommends concerted effort towards the training of professionals on the concepts, benefits, and use of BIM. The respondents cited financial constraints and lack of training opportunities as the top barriers to BIM adoption in the industry. A collaborative effort between academia to train BIM professionals, industry to collaborate on projects, accrediting bodies for continued vocational training, and legislative arm of Government to make BIM mandatory will enhance the incorporation and adoption of BIM in industry.

This research had some limitations since it focused on professionals in the Architecture, Engineering, and Construction industry and identified the total population as those registered with the accrediting and professional bodies. This eliminated professionals who are still at the graduate level or not registered. Therefore, future research will need to incorporate the contribution of unregistered professionals with accrediting and professional bodies.

Further research will be necessary to establish the possible strategies for implementing BIM in construction education, emphasising the best approaches for the different Architecture, Engineering, and Construction industry professions.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Data collected for this study are available from the author upon request.

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Authors' contributions

Pamela Opio Acheng will be the first author and correspondence author as she made substantial contributions to the conceptualization, development, and design of the manuscript. She contributed largely to the data collection, selection of analysis tools and methods, and performed the analysis. In addition, Pamela wrote the paper and made the necessary revisions arising from the comments raised by the reviewers. Finally, she prepared the proposal that attracted the funding for the project.

Dr. Nathan Kibwami and Tom Mukasa will be the second authors because they assisted in the conceptualization and development of the manuscript; including, a review of the data analysis tools and results from the analysis. Further to this, they reviewed the draft papers to develop a final manuscript for submission.

Billy Brian Odongkara, Semanda Julius, and Birungi Rachel will be the third authors as they participated in the data collection, analysis, and presentation of findings.

Dr. Manga Musa will be the last and correspondence author as he participated in data analysis, interpretation, and review of the findings. He offered substantial support in the development of the final revised manuscript and co-wrote the paper.

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Appendix 1. Multicollinearity tested using the variance of inflation for independent variables.

Dependent variable	Profession	Role in supply chain	Experience	Academia	Average
1. Understanding of BIM					
<i>1.1 Level of understanding of BIM concepts, tools and processes</i>					
BIM definition	1.11	1.07	1.03	1.02	1.06
Maturity levels	1.11	1.07	1.03	1.02	1.06
BIM dimensions	1.11	1.07	1.03	1.02	1.06
BIM Standards	1.11	1.07	1.03	1.02	1.06
File formats	1.11	1.07	1.03	1.02	1.06
Processes	1.11	1.07	1.03	1.02	1.06
Requirements	1.11	1.07	1.03	1.02	1.06
Documentation	1.11	1.07	1.03	1.02	1.06
<i>1.2 Awareness of BIM software</i>					
ALLPLAN	1.14	1.11	1.02	1.02	1.07
ArchiCAD	1.12	1.09	1.04	1.01	1.06
ArcGIS	1.12	1.09	1.02	1.02	1.06
Astapower project	1.14	1.10	1.02	1.02	1.07
Asite	1.14	1.11	1.02	1.02	1.07
AutoCAD	1.11	1.07	1.03	1.02	1.06
Bentley microstation	1.12	1.10	1.02	1.02	1.07
Causeway	1.14	1.11	1.02	1.02	1.07
COINS	1.15	1.12	1.02	1.02	1.08
CostX	1.14	1.10	1.03	1.02	1.07
Digital Project	1.14	1.10	1.02	1.02	1.07
Edificus	1.14	1.10	1.02	1.02	1.07
Innovaya	1.14	1.11	1.02	1.02	1.07
Masterbill	1.15	1.12	1.02	1.02	1.08
Navisworks	1.13	1.10	1.02	1.02	1.07
Newforma	1.14	1.11	1.02	1.02	1.07
Revit	1.13	1.09	1.03	1.02	1.07
Solibri Model checker	1.13	1.09	1.02	1.02	1.06
Tekla Structures	1.13	1.09	1.02	1.02	1.06
Trimble MEP	1.13	1.09	1.03	1.02	1.07
Vectorworks (Nemetschek)	1.15	1.12	1.02	1.02	1.08
ViCO awareness&use	1.14	1.11	1.03	1.02	1.07
2. Application of BIM					
<i>2.1 Use of BIM software</i>					
ALLPLAN	1.14	1.11	1.02	1.02	1.07
ArchiCAD	1.12	1.09	1.04	1.01	1.06
ArcGIS	1.12	1.09	1.02	1.02	1.06
Astapower project	1.14	1.10	1.02	1.02	1.07
Asite	1.14	1.11	1.02	1.02	1.07
AutoCAD	1.11	1.07	1.03	1.02	1.06
Bentley microstation	1.12	1.10	1.02	1.02	1.07
Causeway	1.14	1.11	1.02	1.02	1.07
COINS	1.15	1.12	1.02	1.02	1.08
CostX	1.14	1.10	1.03	1.02	1.07
Digital Project	1.14	1.10	1.02	1.02	1.07
Edificus	1.14	1.10	1.02	1.02	1.07
Innovaya	1.14	1.11	1.02	1.02	1.07
Masterbill	1.15	1.12	1.02	1.02	1.08
Navisworks	1.13	1.10	1.02	1.02	1.07
Newforma	1.14	1.11	1.02	1.02	1.07
Revit	1.13	1.09	1.03	1.02	1.07
Solibri Model checker	1.13	1.09	1.02	1.02	1.06
Tekla Structures	1.13	1.09	1.02	1.02	1.06
Trimble MEP	1.13	1.09	1.03	1.02	1.07
Vectorworks (Nemetschek)	1.15	1.12	1.02	1.02	1.08
ViCO awareness&use	1.14	1.11	1.03	1.02	1.07
<i>2.2 BIM functions employed</i>					
BIM functions used	1.11	1.09	1.03	1.01	1.06
3. Perceived Benefits of BIM					
Better Marketing					
Improved productivity	1.12	1.08	1.04	1.01	1.06
Improved design quality	1.12	1.08	1.04	1.01	1.06
Enhanced predictability	1.12	1.08	1.04	1.01	1.06
Lower financial risks	1.12	1.08	1.04	1.01	1.06
Enhanced energy efficiency	1.12	1.08	1.04	1.01	1.06
Complete project information	1.12	1.08	1.04	1.01	1.06
Early forensic analysis	1.12	1.08	1.04	1.01	1.06
Reduced safety risks	1.12	1.08	1.04	1.01	1.06
Accurate drawings	1.12	1.08	1.04	1.01	1.06
Simplified measurements	1.12	1.08	1.04	1.01	1.06
Reduced claims	1.12	1.08	1.04	1.01	1.06
Improved communication	1.12	1.08	1.04	1.01	1.06

(continued)

Appendix 1. Continued.

Dependent variable	Profession	Role in supply chain	Experience	Academia	Average
4. Perceived Barriers to BIM adoption					
Lack of training opportunities	1.13	1.09	1.05	1.01	1.07
Inadequately trained staff	1.13	1.09	1.05	1.01	1.07
Interoperability issues	1.13	1.09	1.05	1.01	1.07
Software malfunction	1.13	1.09	1.05	1.01	1.07
Data ownership issues	1.13	1.09	1.05	1.01	1.07
BIM licensing issues	1.13	1.09	1.05	1.01	1.07
Industry resistance	1.13	1.09	1.05	1.01	1.07
Unawareness of benefits	1.13	1.09	1.05	1.01	1.07
Low demand	1.13	1.09	1.05	1.01	1.07
Financial constraints	1.13	1.09	1.05	1.01	1.07
Lack of BIM standards	1.13	1.09	1.05	1.01	1.07
Lack of legal agreements	1.13	1.09	1.05	1.01	1.07
Conflict of interest	1.13	1.09	1.05	1.01	1.07
Unregulated constructions	1.13	1.09	1.05	1.01	1.07

Appendix 2. Shapiro-wilk tests for normality of dependent variables.

1. Awareness of BIM concepts, tools & processes			2. Application of BIM		
1.1 Level of understanding of BIM			2.1 BIM functions		
Variable	W	p-value	Variable	W	p-value
BIM definition	0.99019	0.32547	BIM functions used	0.96984	0.00186
Maturity levels	0.95900	0.00011			
BIM dimensions	0.97627	0.00691			
BIM Standards	0.89945	0.00000			
File formats	0.89549	0.00000			
Processes	0.93768	0.00000			
Requirements	0.94829	0.00001			
Documentation	0.93487	0.00000			
3. Perceived benefits			4. Perceived barriers		
Variable	W	p-value	Variable	W	p-value
Better Marketing			Lack of training opportunities	0.90730	0.00000
Improved productivity	0.88282	0.00000	Inadequately trained staff	0.97389	0.00946
Improved design quality	0.92475	0.00000	Interoperability issues	0.98907	0.35685
Enhanced predictability	0.93677	0.00000	Software malfunction	0.99744	0.99809
Lower financial risks	0.96696	0.00137	Data ownership issues	0.99658	0.98800
Enhanced energy efficiency	0.96705	0.00146	BIM licensing issues	0.97807	0.02630
Complete project information	0.90257	0.00000	Industry resistance	0.97864	0.02910
Early forensic analysis	0.95811	0.00021	Unawareness of benefits	0.95749	0.00030
Reduced safety risks	0.97313	0.00574	Low demand	0.99294	0.73137
Accurate drawings	0.94228	0.00001	Financial constraints	0.94604	0.00004
Simplified measurements	0.93738	0.00000	Lack of BIM standards	0.98857	0.31972
Reduced claims	0.97560	0.01045	Lack of legal agreements	0.99940	1.00000
Improved communication	0.93667	0.00000	Conflict of interest	0.99748	0.99838
			Unregulated constructions	0.97909	0.03356

Appendix 3. Key Research Measurement items.

		Factor loadings
Awareness and Use of BIM Tools and Platforms (Alpha = 0.98, CR = 0.98, AVE = 0.67)		
1	Autodesk Revit (Architecture, Structures, MEP)	0.640
2	Autodesk AutoCAD 3 D	0.654
3	ArchiCAD	0.529
4	Autodesk Navisworks	0.863
5	Vico	0.929
6	Bentley systems (Microstation)	0.801
7	Nemetschek (Vectorworks)	0.762
8	Gehry Digital Project	0.929
9	Tekla	0.842
10	Innovaya	0.891
11	Solibri Model Checker	0.929
12	ACCA S.p.A Edificus	0.910
13	Esri ArcGIS	0.583
14	ALLPLAN	0.905
15	Elecosoft Asta Powerproject	0.796
16	Trimble	0.638
17	Newforma	0.892
18	COINS	0.816
19	Masterbill microsystems	0.847
20	Causeway Technologies	0.938
21	Exactal (CostX Estimating software)	0.842
22	Asite (Document Management)	0.900
Understanding of BIM concepts (Alpha = 0.92, CR = 0.92, AVE = 0.57)		
1	Definiton of BIM	0.719
2	BIM Maturity levels such as Level 0, Level 1, Level 2 and Level 3	0.775
3	The concept of 3 D, 4 D, 5 D, 6 D, nD, etc	0.723
4	BIM software developers and vendors such as Autodesk, Graphisoft, Bentley, etc	0.661
5	BIM Standards and Protocols such as PAS 1192 and ISO 19650	0.768
6	The difference between proprietary, open and non-proprietary file formats	0.660
7	Processes and procedures to be used by project participants when interacting	0.810
8	Requirements for a Project Information Model	0.822
9	Documented procedures to deal with information flows during Collaborative BIM	0.856
BIM benefits (Alpha = 0.92, CR = 0.89, AVE = 0.41)		
1	To improve marketing of projects to new and existing clients*	0.472
2	To enhance productivity through improved construction planning	0.654
3	To improve design quality, such as elimination of clashes between designers	0.591
4	To enhance project predictability due to reduced variations	0.663
5	To lower financial risks due to reliable cost estimates	0.679
6	To enhance energy efficiency and sustainability features to predict environmental performance	0.564
7	To have complete project information in a single file for operations and facilities management	0.663
8	To assist in early forensic analysis for potential failures and design errors, through clash detections	0.633
9	To reduce safety risks through improved site safety planning and management	0.651
10	To realise faster and more accurate production of shop and fabrication drawings	0.646
11	To simplify measurements and cost calculations through automated quantities from CAD files	0.709
12	To reduce claims, disputes and conflicts	0.501
13	To improve and simplify project communication and coordination because of enhanced team collaboration and lead to better decision	0.666
BIM implementation barriers (Alpha = 0.86, CR = 0.88, AVE = 0.37)		
1	Lack of sufficient training opportunities and technical support	0.771
2	Prevalence of an inadequately trained workforce	0.807
3	Interoperability Issues (the inability to exchange data between applications)*	0.477
4	Software malfunctions and data misuse	0.614
5	BIM data ownership, copyright issues and misuse of intellectual property, fear of losing competitive advantage and marketability by sharing knowledge to a Common Data Environment	0.545
6	BIM Licensing issues for proprietary designs*	0.381
7	Industry resistance to process change and preference to traditional project delivery methods*	0.419
8	Unawareness of the benefits BIM can bring to projects and organisations	0.540
9	Low demand from clients and/or other project participants*	0.353
10	Financial constraints for upfront costs for software applications, hardware upgrades, training and support*	0.450
11	Lack of BIM Standards and collaborative work processes for model integration and management	0.640
12	Lack of legal and contractual agreements	0.814
13	Potential conflicts of (professional) interests among project participants	0.865
14	The prevalence of unregulated/ uncoordinated construction processes through the informal sector*	0.484

Notes: *Insufficient values of factor loadings therefore eliminated from analysis

Appendix 4. One-way non-parametric ANOVA test (p-value) of significance for the level of understanding of BIM concepts.

Variable	Profession	Role in supply chain	Experience	Academia
1. Understanding of BIM concepts, processes and tools				
<i>1.1 Level of understanding of BIM concepts</i>				
BIM definition	0.3864	0.5019	0.3864	0.0121
Maturity levels	0.9454	0.3741	0.2524	0.0089
BIM dimensions	0.3620	0.5092	0.9542	0.0229
BIM Standards	0.5560	0.1156	0.3848	0.0940
File formats	0.5692	0.0666	0.8866	0.9789
Processes	0.0272	0.3914	0.9783	0.1879
Requirements	0.4386	0.3571	0.9658	0.3048
Documentation	0.5397	0.3329	0.9831	0.4363

Appendix 5. One-way non-parametric ANOVA test (p-value) for the awareness of BIM software.

Variable	Profession	Role in supply chain	Experience	Academia
1. Understanding of BIM				
<i>1.2 Awareness of BIM software</i>				
ALLPLAN	0.2854	0.0099	0.0157	0.9401
ArchiCAD	0.4075	0.5224	0.8644	0.2729
ArcGIS	0.0001	0.0548	0.1067	0.0694
Astapower project	0.4610	0.0031	0.4705	0.5440
Asite	0.9583	0.6008	0.0297	0.1866
AutoCAD	0.8286	0.9059	0.3415	0.7728
Bentley microstation	0.0081	0.2019	0.1272	0.6460
Causeway	0.0838	0.1230	0.0661	0.9381
COINS	0.4008	0.0789	0.2422	0.7082
CostX	0.0001	0.0295	0.1371	0.9243
Digital Project	0.2506	0.6063	0.6595	0.5590
Edificus	0.7492	0.1430	0.7685	0.6296
Innovaya	0.3561	0.2338	0.6901	0.5402
Masterbill	0.0001	0.1804	0.0081	0.9367
Navisworks	0.3367	0.8422	0.4740	0.9182
Newforma	0.9995	0.7684	0.0692	0.2762
Revit	0.0002	0.3051	0.4189	0.4462
Solibri Model checker	0.8776	0.6534	0.2108	0.5307
Tekla Structures	0.5596	0.6811	0.4441	0.5897
Trimble MEP	0.0362	0.9724	0.4577	0.9114
Vectorworks (Nemetschek)	0.2252	0.2380	0.2156	0.9818
ViCO	0.2054	0.0061	0.6012	0.4472

Appendix 8. Pairwise post-hoc dunn test results (p-value) for use of BIM software.

Software		Profession				
		ARC	CIV	CM	GS	QS
ArcGIS	CIV	0.01				
	CM					0.04
	GS	0.00	0.00	0.00		0.00
	QS		0.01			
	VS	0.00				
Astapower project AutoCAD	CIV	0.01				
	CM	0.00				
	GS	0.00	0.02			
	QS	0.00				
	VS	0.00				
Innovaya	CM	0.00	0.00			0.00
	GS					0.00
	QS					
	VS					0.00
Newforma	GS	0.03				
	VS		0.00	0.00	0.02	0.00

Appendix 9. One-way non-parametric ANOVA test (p-values) of significance for the perceived benefits of BIM.

Variable	Profession	Role in supply chain	Experience	Academia
3. Perceived Benefits of BIM				
Better Marketing	0.122	0.065	0.123	0.0780
Improved productivity	0.4478	0.6050	0.4626	0.1726
Improved design quality	0.4757	0.5988	0.9284	0.5939
Enhanced predictability	0.6056	0.2018	0.9520	0.9371
Lower financial risks	0.1389	0.6928	0.0992	0.2124
Enhanced energy efficiency	0.3214	0.0731	0.1589	0.0492
Complete project information	0.8550	0.6172	0.4184	0.4918
Early forensic analysis	0.0324	0.1594	0.9743	0.3210
Reduced safety risks	0.0898	0.2322	0.0659	0.1987
Accurate drawings	0.6695	0.9517	0.8006	0.6017
Simplified measurements	0.3887	0.9656	0.4143	0.4918
Reduced claims	0.0735	0.2022	0.2982	0.6477
Improved communication	0.2068	0.2670	0.5979	0.8072

Appendix 10. One-way non-parametric ANOVA test (p-values) of significance for the perceived barriers to BIM adoption.

Dependent variable	Profession	Role in supply chain	Experience	Academia
Perceived Barriers to BIM adoption				
Lack of training opportunities	0.5941	0.5679	0.4665	0.6823
Inadequately trained staff	0.9096	0.8454	0.3997	0.4066
Interoperability issues	0.3662	0.0090	0.6240	0.6187
Software malfunction	0.8191	0.6744	0.7462	0.3702
Data ownership issues	0.2742	0.9558	0.9201	0.6556
BIM licensing issues	0.2020	0.9038	0.5535	0.3472
Industry resistance	0.1123	0.8926	0.8044	0.7249
Unawareness of benefits	0.8182	0.7360	0.9820	0.9104
Low demand	0.9017	0.9006	0.3073	0.5554
Financial constraints	0.2707	0.1783	0.6902	0.4792
Lack of BIM standards	0.0607	0.0986	0.7990	0.0931
Lack of legal agreements	0.8867	0.7254	0.6289	0.6675
Conflict of interest	0.2971	0.4190	0.9648	0.3620
Unregulated constructions	0.9890	0.5094	0.8435	0.5633