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Building information modeling (BIM) adoption for enhanced legal and contractual management in construction projects

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ABSTRACT

Building information modeling (BIM) adoption offers significant benefits for construction projects, including enhanced collaboration and legal/contractual management. However, the impacts of BIM deployment on construction contracts and dispute resolution remain unclear. This research analyzed the regulatory and legal implications of BIM adoption in construction industry via a framework evaluating Contractual Frameworks (CF), Dispute Resolution (DR), Legal Awareness (LA), and Risk Management (RM). Fifteen qualitative interviews with construction industry experts provided key insights. The results showed CF, DR, and LA have a large positive impact on BIM adoption, while RM has a smaller effect. Specifically, clearly defined BIM protocols in contracts, efficient dispute resolution mechanisms, and legal knowledge of BIM are essential to ensure effective deployment. These findings imply construction project managers should proactively address contractual and legal factors to manage risks, encourage collaboration, and adhere to regulations when implementing BIM. This research makes a significant contribution by addressing the lack of empirical insights on the contractual and legal aspects of BIM adoption. The qualitative methodology provides in-depth perspectives from experienced industry practitioners. The findings offer valuable insights for stakeholders worldwide seeking to leverage BIM. Further comparative research across regions and industries would continue to advance comprehension of the legal implications of BIM adoption.

1. Introduction

Building Information Modelling (BIM) in construction initiatives has increased significantly recently. According to a survey conducted by Dodge Data & Analytics 2020, approximately 68 % of respondents reported using BIM on more than half of their projects, demonstrating the industry's increasing prevalence of BIM adoption [1,2]. BIM has several benefits, including improved cooperation, better visualization, and quicker project completion. However, because to the widespread use of BIM, it is necessary to assess the legal and commercial ramifications of its application [3].

The already complex legal and contractual environment of building projects is further complicated by the advent of BIM. Only 31 % of architects, according to a 2019 American Institute of Architects (AIA) research, were confident in their understanding of the legal ramifications of BIM [4]. This shows that in order to guarantee BIM's effective integration into construction activities, a serious knowledge shortage must be addressed [5].

It is crucial that all parties involved, including business owners, contractors, architects, and solicitors, understand the legal and contractual implications of adopting BIM [6]. It includes intellectual property rights, data ownership and liability, standard form agreements, and risk allocation among project participants. Adequately address these legal aspects during project execution to avoid disputes, delays, and increased costs [7,8].

Even though BIM has become widely used in the construction sector,

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there is still a dearth of thorough knowledge regarding the legal and contractual ramifications of BIM deployment [9]. Prior studies have emphasized the need for more research into best practices for risk mitigation as well as the contractual and regulatory issues raised by this technology [10,11]. This knowledge gap is problematic because it can hinder the effective implementation of BIM, create disagreements, and keep stakeholders from fully realizing the benefits of BIM due to unclear contractual norms and unresolved legal issues [12]. In order to close this knowledge gap, this study examines industry standards, legal frameworks, and case studies [13]. It does so by highlighting important risk factors, offering insights into the legal and contractual obstacles associated with BIM adoption, and pinpointing opportunities to foster effective BIM integration. The views of Malaysian industry practitioners are specifically highlighted in order to clarify the unique problems encountered in this situation [14,15].

The objective of this research is to enable project stakeholders to proactively negotiate the legal difficulties of BIM, foster collaborative relationships, and optimize project outcomes by providing clarity on the regulatory environment and contractual matters related to BIM[16]. Structural equation modelling is utilized to thoroughly examine the intricate links among legal considerations, contracts, and BIM adoption. With its focus on the construction industry and its use of this advanced analytical method, the study significantly advances our knowledge of both the academic and practical elements of managing the contractual and legal aspects of BIM implementation.

2. Literature review

The building industry could undergo a major transformation because of the rapidly evolving technology known as building information modelling (BIM). It is a 3D model-based technique that combines data from various disciplines, including construction, engineering, and architecture [10,17]. With the use of this information, project stakeholders may collaborate better, communicate better, run less risks of mistakes and omissions, and work more productively. Around the world, numerous construction firms have already embraced BIM [18]. For instance, 73 % of businesses in the UK were utilizing BIM in their projects by 2020 [5,19]. Additionally, BIM has reportedly been shown to lower risks, save costs, and increase project profitability. Before BIM can be fully embraced by the construction industry, there are a few legal issues that must be resolved [12,20]. The lack of clarity and uniformity in the contractual agreements that specify the roles, obligations, and risks of the parties participating in BIM is one of the major issues. For instance, it is not always obvious who owns the BIM model, oversees ensuring the accuracy of the data and is the owner of the BIM model's intellectual property. Liability concerns and disagreements may result from this. In the context of integrated project delivery (IPD) and interoperability, protecting model ownership, data reliability, and intellectual property rights is another difficulty [15,21]. IPD is a team-based approach to project delivery that makes use of BIM. IPD, however, may present some legal issues, such as responsibility and risk allocation. For instance, when numerous parties are participating in the project, it is not always obvious who is accountable for errors and omissions in the BIM model [22,23]. A few issues relating to professional liability, insurance, and dispute resolution are also brought up by BIM. For architects, engineers, and other construction industry professionals, BIM may enhance their risk of professional liability. This is due to the possibility that BIM could facilitate mistakes. The price of insurance for construction projects may potentially rise because of BIM. This is so because BIM may make claims more likely. Finally, BIM may make it more challenging to settle disagreements [6,14]. This is because BIM projects frequently involve more complicated data. The construction sector can guarantee that BIM is utilized safely and successfully by resolving these legal challenges. It is crucial to take action to guarantee that BIM is utilized appropriately because it has the potential to completely transform the building sector [24,25].

The primary notion of the study was established through conceptualization. After that, during the exploratory stage, the BIM project team was contacted to polish the idea and the research design.[26] During the systematic evaluation of the literature, papers on BIM legal and contractual concerns were found using Scopus, a database of academic journals and conferences. 28 BIM factors discovered from a literature analysis were used to evaluate a case study project's contract provision. The evaluation's results, which are shown in Table 1, revealed that the case study contract agreement did not completely address all of the BIM concerns brought up in previous studies. This implies that more research is required to fully understand the contractual and legal implications of BIM.

BIM is a platform that eliminates task duplication while enabling the sharing of data and models across several stakeholders and disciplines. Interoperability, standardization, regulatory frameworks, and legal restraints are a few of the challenges it faces [7,31]. Table 2 outlines the advantages and cons of using BIM in a variety of domains, including legal and legally binding, management of risks, mediation, and contractual frameworks. It also provides some statistical proof to back up the assertions. The table outlines how BIM might be used for contingency planning, risk identification and assessment, communication, accountability, and transparency. The necessity for clear and uniform legal frameworks, enhanced responsibility for contractors that engage in design or use the template to acquire materials, and possible disputes over model maintenance, verification, or ownership are some of the issues it does bring up [5,10].

The information also looks at a few legal issues that have been discussed extensively in the literature, such as construction documents, standards of care, ownership protection for contractual models, interoperability, and the legalities of using sensitive data. It also looks at expert design responsibility and accountability. It also discusses potential implications for protection, risk-sharing, and task allocation that may result from these challenges [19,20]. However, it also acknowledges that these issues may increase security, traceability, and error-correction functionality. The data suggests that a common data environment (CDE) and a BIM execution plan (BEP) can promote data sharing and collaboration [12,15]. It also identifies two main challenges for optimizing BIM benefits: the absence of standard BIM contractual documents and the lack of research on the use of BIM as a collaborative framework. It highlights the importance of developing a value-based procurement model that can facilitate data-sharing and collaborative work through BIM [21,22].

Strong security and traceable access to an asset's origin are implied by the tracking requirement, which may also be used to define criteria for new assets. Receiving data from handed-over paper documents may improve preventive maintenance schedules, increasing FM efficiency by preventing incorrect or unavailable information [6,14]. The ability of a party to control and absorb risks where the responsible professional indicates compliance and acceptance of their responsibility is covered by a clear delineation in the contract that documents responsibility based on the benefits a party will receive from BIM. Even though IP rights influence data interoperability, most contract forms do not explicitly identify or describe them [24,25]. For project participants to ascertain whether circumstances call for the control of IP ownership in connection to BIM, IP coverage is crucial. The file format for an integrated system, sensitive data, construction methods, the sequential embedding of data in a certain manner, and other key elements that may be regarded as trade secrets should all be included in an IP framework [1,3]. The complexity of IP allocation grows as the need for BIM rises and more finesse is required when IP is utilized in a shared context [11,26]. In order to minimize inefficiencies and conflicts that might lead to legal problems, this research foresees that it is essential to explain and solve the BIM-related concerns as part of the creation of BIM frameworks in a digital context [32,33].

The literature analysis highlights the necessity for a comprehensive approach to deal with the many problems caused by contemporary

Table 1
Summary of the BIM contract content analysis in the case study.

Concerns with the law and contracts	Overview	Description	Concerned group	Potential solutions	Risk level	References
Refund and recognition	Specify the requirements for the costs, schedules, and functions of BIM.	There is nothing spelt out in the contract.	Project owner	Define the scope of BIM services and the payment terms in the contract	High	[27,28]
Conditions of the Agreement	Timing of delivery, format, and type of electronic platform have all been met about the design's content.	Notifying the manager or appropriate participants of model errors	Architect	Incorporate BIM standards and protocols into the contract	Medium	[12,21]
Data security	Concerns from project participants about inspection protocols and preserving sensitive information	Lack of risk management and clear criteria for rework brought on by data loss or corruption	General contractor	Establish data security policies and procedures, and assign responsibilities for data backup and recovery	High	[24,25]
ICT protocols	Prioritize the BIM administrative procedures using the contract languages	Participants in the project will create a modelling protocol	BIM manager	Make use of a common data environment (CDE) and a BIM execution plan (BEP) to promote data sharing and cooperation	Low	[7,8]
Intellectual property	Specifications for on-going intellectual property and copyright ownership when the model is created	The individual designer will continue to be the owner of the copyrights	Project owner	In the contract, agree on intellectual property rights and licenses for the usage of the model.	Medium	[29,30]
Interoperability	Members must pay close attention to the recording and auditing processes to keep track of any data changes and communications among project participants	The file transfer protocol will be provided by the contractor	Manager of facilities for the business that owns you	Adopt compatible software platforms and formats, and document the data changes and exchanges in a model log	Low	[1,3]

Table 2
A overview of the advantages and disadvantages of BIM in many sectors of building projects.

Category	Aspect	Advantages	Disadvantages	Validity	Statistical Data
Legal and contractual	Communication	Improved communication between stakeholders	None	✔	None
Legal and contractual	Errors and omissions	Reduced risk of errors and omissions	None	✔	None
Legal and contractual	Transparency and accountability	Increased transparency and accountability	None	✔	None
Legal and contractual	Dispute resolution	Facilitated dispute resolution	Potential disputes over model management, verification, or ownership.	×	The mean rating of BIM-related contractual and legal risks among stakeholders was 3.67/5
Risk management	Identification and assessment of risks	Improved identification and assessment of risks	None	✔	BIM can reduce rework by up to 40 % by eliminating design errors.
Risk management	Mitigation and contingency planning	Enhanced mitigation and contingency planning	None	✔	BIM can reduce project duration by up to 7 % by improving coordination and collaboration.
Risk management	Claims and litigation	Reduced likelihood of claims and litigation	Higher liability for contractors using BIM.	×	The mean rating of contractors' BIM-related risks was 3.50/5.
Dispute resolution	Early identification and resolution of disputes	Facilitated early identification and resolution of disputes	None	✔	None
Dispute resolution	Costs and delays associated with disputes	Reduced costs and delays associated with disputes	None	✔	None
Dispute resolution	Mutually agreeable outcome	Improved chances of reaching a mutually agreeable outcome	None	✔	None
Contractual frameworks	Flexibility and adaptability	Increased flexibility and adaptability	None	✔	None
Contractual frameworks	Transaction costs	Reduced transaction costs	High cost of BIM software.	×	BIM software cost: 500–10,000/user/year.
Contractual frameworks	Alignment of interests between stakeholders	Improved alignment of interests between stakeholders.	Need for clear and consistent contractual frameworks.	×	UK's BIM maturity index gauges collaboration and integration

urbanization. This is due to the fact that urbanization is a complicated and constantly changing event that impacts every area of society [34]. To guarantee that all important elements are examined and that the results are trustworthy and genuine, a thorough and systematic approach is required [7,8]. The study examines numerous aspects of urban expansion by fusing studies of cities, environmental dynamics, and sociopolitical concerns. The research uses a combination of methods to investigate both concealed weaknesses and visible trends in modern urban settings. This section includes quantitative models as well as qualitative case studies [4,28]. The study also involves a range of stakeholders using surveys, interviews, and interactive workshops to collect intuitive knowledge and grassroots viewpoints. This holistic strategy makes it possible to fully understand urban issues and makes it easier to develop interventions that are contextually aware. Therefore, this methodology is suitable for this study since it provides a comprehensive understanding of the complexities of urbanization.

3. Research framework methodology

The literature analysis highlights the need for a comprehensive, multi-faceted approach to examine the complex legal and contractual implications of BIM adoption. To develop such an approach, this study conducted 15 in-depth qualitative interviews with experienced industry professionals including project managers, architects, legal experts, and seasoned BIM practitioners [17,23]. The diverse professional perspectives provided critical insights that informed the creation of a robust research framework for evaluating the key factors impacting BIM adoption. Specifically, the interview findings enabled the identification and inclusion of the most salient legal and contractual considerations into the framework. The experts provided real-world guidance on issues, obstacles, and recommendations based on their firsthand knowledge of BIM implementation. By synthesizing these qualitative insights with the existing literature, the comprehensive research framework incorporates crucial contractual, legal, risk management, and dispute resolution elements that influence BIM adoption outcomes [35]. This integration of Mult perspective interview data with previous theoretical findings demonstrates how the literature review directly informed the methodological approach of this study. The qualitative interviews are built upon literature to elucidate nuanced real-world factors for analysis using the tailored research framework. This approach aligns with calls in the literature for holistic, context-sensitive techniques to investigate the multifaceted impacts of BIM adoption [21,28]. These interviews assisted in developing a comprehensive research framework for evaluating the Legal and Contractual Implications of BIM Adoption in Construction Projects. The interviewers utilized their expertise to meticulously analyses the interview data and identify recurring themes, obstacles, and suggestions related to BIM implementation. This procedure modified and refined the research framework to incorporate the most pertinent legal and contractual factors. The identified implications of BIM variables are shown in Table 3.

Unwanted or less significant variables were systematically categorized and eliminated to ensure a focused and reliable research methodology. Combined with the researchers' industry experience, the qualitative interview data contribute to the profundity and credibility of this study [11,28]. The resulting research framework provides valuable insights into the legal and contractual implications of BIM adoption and provides stakeholders in the construction industry with actionable recommendations [7,32]. Fig. 1 presents the hypothesized framework of this study constructed on the basis of identified factors and their corresponding constructs.

H1. Contractual Frameworks have significant relation with the implications of BIM in the construction industry.

H2. Dispute Resolution has a significant relation with the implications of BIM in the construction industry.

H3. Legal Awareness has a significant relation with the implications of BIM in the construction industry.

H4. Risk Management has a significant relation with the implications of BIM in the construction industry.

4. Investigational methodology

This study quantitatively analyzed the Legal and Contractual Implications of BIM Adoption in Construction Projects. Focusing on the construction industry, the study was conducted. Email distribution and manual administration to local experts were used to acquire data from industry professionals. Fig. 2 indicates the flow of the study in a step-by-step manner.

4.1. Questionnaire and data collection

The survey questionnaire was developed based on previous studies addressing comparable research topics and was tailored to the Perak context of BIM adoption. Respondents were asked to indicate their agreement or disagreement with statements regarding the legal and contractual implications of BIM adoption on a 5-point Likert scale [4,33,42].

The questionnaire was sent to 200 respondents to comprehend their perspectives and experiences thoroughly. 133 responses out of the total received were deemed legitimate and included in the analysis [30,31]. This corresponds to a response rate of 66.5 percent (133 valid responses from 200 survey recipients). The survey responses were thoroughly evaluated and analyzed to identify patterns, trends, and significant insights regarding the research objectives. Statistical techniques such as descriptive and inferential analysis (if applicable) were applied to the data to draw meaningful conclusions [12,23].

To support the adequacy of the sample size for this study, comparable sample sizes from prior research in comparable contexts have been cited. These studies have demonstrated the viability and dependability of similar sample sizes for investigating the legal and contractual implications of BIM adoption in construction projects [1,22]. Using a Likert scale questionnaire and a quantitative analysis approach, this study aims to provide valuable insights into the legal and contractual implications of BIM adoption in the Perak construction industry based on the perspectives and experiences of regional industry professionals.

4.2. EFA analysis

Exploratory Factor Analysis (EFA) was performed to validate and refine the categorization of variables utilized in the study. The decision to use EFA is supported by previous research in the field that

Table 3
Identified and modified variables from literature and qualitative interviews.

Cluster	Assigned Code	Description	Reference
Risk Management	BIM-RM1	BIM enables early identification and mitigation of risks through sophisticated visualization and conflict detection.	[36,37,38]
	BIM-RM2	BIM's enhanced coordination and communication reduce the likelihood of mistakes and misunderstandings, improving risk management.	[28,30,39]
	BIM-RM3	BIM facilitates the making of informed decisions and the implementation of effective risk mitigation strategies.	[4,32]
Dispute Resolution	BIM-DR1	BIM encourages improved collaboration and communication, which reduces the likelihood of disputes and expedites their resolution.	[2,18]
	BIM-DR2	BIM's three-dimensional models serve as visual evidence for presenting arguments and evaluating the impact of proposed changes.	[31,37]
	BIM-DR3	BIM's exhaustive documentation and audit trail provide a transparent record of actions and responsibilities, thereby facilitating the resolution of disputes.	[18,20]
Legal Awareness	BIM-LA1	Legal consciousness in BIM ensures comprehension of legal obligations about data ownership, liability, intellectual property rights, and contract performance.	[19,36]
	BIM-LA2	Legal savvy clarifies contractual provisions and reduces the likelihood of ambiguities and disputes.	[23,33]
	BIM-LA3	Legal awareness safeguards the intellectual property rights of BIM models and data.	[17,24]
	BIM-CF1	Contractual awareness of BIM ensures a better understanding of the specific contractual requirements and provisions related to BIM adoption.	[26,29]
	BIM-CF2	It enables stakeholders to draft and negotiate more effective contracts that address BIM-specific obligations and rights.	[22,40]
	BIM-CF3	It facilitates improved project communication and collaboration by including provisions that promote effective information-sharing and decision-making processes.	[30,32,41].

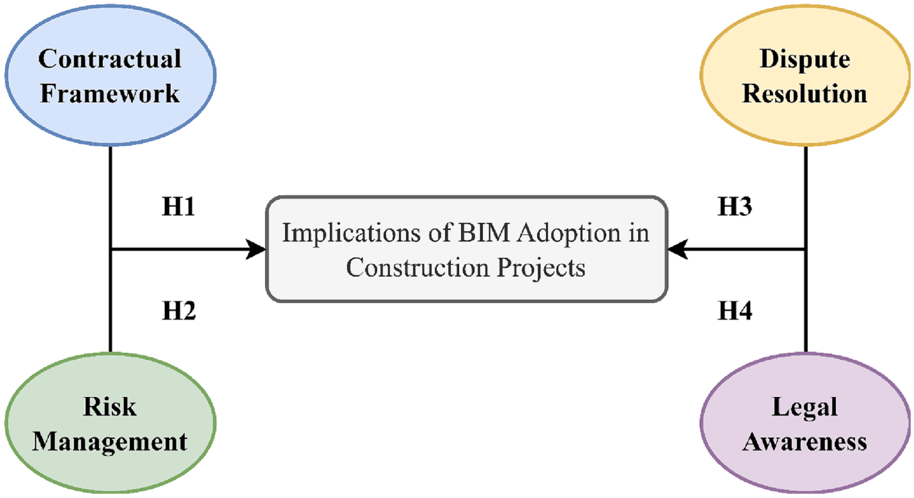

Fig. 1. Research Hypothesis.

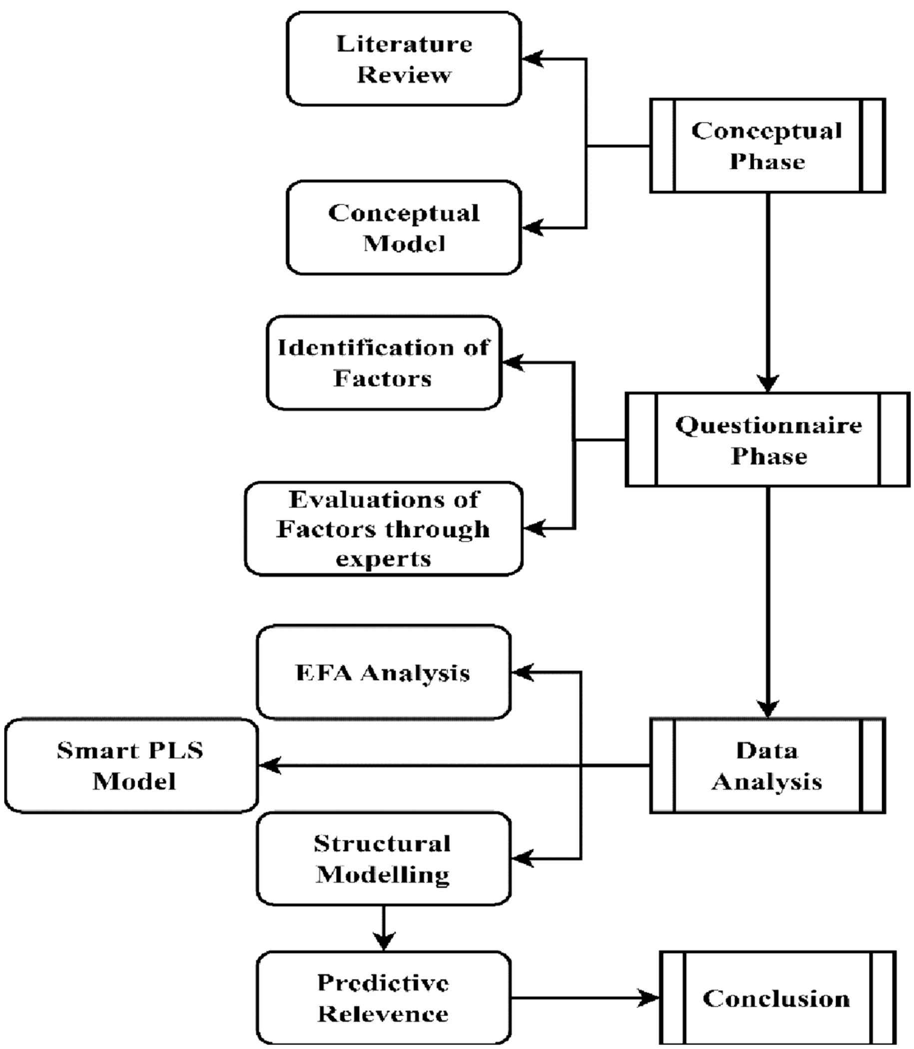

Fig. 2. Flow chart of the study.

recommends its application for categorizing and identifying underlying factors in similar contexts [10,15]. The EFA used a principal component approach with a Varimax rotation algorithm to find latent components and correct group data. This analytical approach has been widely used in prior studies to analyze the dimensionality of constructs and the interrelationships between variables [12,21]. This study aimed to offer a robust and extensive data analysis using EFA, hence improving understanding of the interactions between variables and assuring the reliability of the research results.

4.3. PLS-SEM algorithm

Using the SmartPLS 4 program and the Partial Least Squares Structural Equation Modelling (PLS-SEM) technique, data were analyzed for this inquiry. The PLS-SEM study comprised both convergent and discriminant validity assessments. Cronbach's alpha, composite reliability, and average variance extracted (AVE) were used to assess convergence validity. Cronbach's alpha and composite reliability were used to assess the internal consistency and reliability of the measurement items for each construct [4,33]. Instead, the AVE computed the construct's variance in proportion to the measurement error.

Numerous techniques, such as the Heterotrait-Monotrait (HTMT) analysis, the Fornell-Larcker criteria, and cross-loadings, were used to evaluate discriminant validity[43]. By ensuring that the correlation between constructs was lower than the correlation within constructs, the degree of discriminant validity between constructs was determined [28,36]. The Fornell-Larcker criterion compared the square roots of the AVE to the correlations between constructs to validate their uniqueness. Cross-loadings were analyzed to confirm that each indicator primarily loaded on its corresponding construct instead of other constructs [31,44].

By conducting these validity tests, including Cronbach's alpha, composite reliability, AVE, HTMT analysis, Fornell-Larcker analysis, and cross-loadings, the study ensured the internal consistency, distinctiveness, and validity of the measurement constructs, thereby enhancing the credibility and rigor of the research findings [45].

4.4. Structural model analysis

This study's structural model analysis utilized bootstrap analysis to assess the five hypotheses formulated. The bootstrap analysis is a resampling technique that permits the estimation of standard errors, t-statistics, and p-values to determine the significance of the relationships between constructs [10,20]. From the original sample data, many resamples were generated for the analysis. The structural model was re-estimated for each resample, and the parameters of relevance, including path coefficients, were determined. Through repeated this procedure, a distribution of parameter estimates was generated.

The distribution of parameter estimates was used to calculate the mean (M) and standard deviation (STDEV). These statistics revealed the mean and variance of the estimated parameters [46]. The t-statistics were then calculated by dividing the mean by the standard deviation, enabling the significance of the estimated parameters to be determined [6,23]. Comparing the t-statistics to the appropriate critical values for the intended significance level yielded the p-values. This made it possible to determine whether the observed effects were statistically significant or the result of random chance [30,37].

Using bootstrap analysis, this study assured a robust evaluation of the hypothesized relationships between constructs. Using t-statistics and p-values enhanced the overall validity and reliability of the structural model analysis by providing valuable insights into the significance of these relationships.

4.5. Predictive relevance

Predictive significance Q2 evaluates the research model's ability to predict and explain the outcome variable(s)[47]. Calculating the coefficient of determination (R-squared) between observed and predicted values measures the accuracy of the model's predictions. A higher Q2 value indicates a more substantial predictive relevance, indicating that the model can explain and predict the outcome variable(s).

5. Results and analysis

5.1. Demographic details

Participants' demographic information provides insight into their professional background, organization type, industrial experience, and BIM knowledge, as shown in Table 4. The most prevalent professions among the participants were civil engineers (24.0 %), architects (17.1 %), and project managers (15.0 %). The preponderance of participants (32.6 %) were contractors, followed by consultants (24.6 %) and consumers (18.2 %).

Regarding industrial experience, the participants' backgrounds were diverse. The largest group had 0 to 5 years of experience (26.9 %), followed by 6 to 10 years (20.6 %), 11 to 15 years (14.9 %), 16 to 20 years (5.7 %), and over 20 years (8.0 %). Regarding BIM knowledge, most respondents (69.1 %) reported having BIM knowledge, while a lesser percentage (6.9 %) reported having no ambiguous knowledge.

These demographic details provide a variegated representation of professionals from various backgrounds and organizations, thereby contributing to a thorough comprehension of the legal and contractual implications of BIM adoption in construction projects.

5.2. EFA test

Exploratory Factor Analysis (EFA) was performed to investigate the fundamental factor structure of the study's variables. Principal Component Analysis was utilized as the extraction technique, and Varimax rotation with Kaiser normalization was utilized as the rotation method[48]. The EFA revealed that the eigenvalues of the factors were more significant than 1, indicating the existence of distinct factors [18,40]. Based on the factor loadings, which assess the intensity of the relationship between variables and factors, it was determined that the variables' loadings on their respective factors were more outstanding than 0.6, indicating favorable factor loadings shown in Table 5. BIM-CF3 was eliminated from further analysis because its loading was less than 0.6, indicating a feeble relationship with the underlying factor [3,23]. The remaining variables were categorized into three factors: BIM-RM (Reliability and Maintenance), BIM-DR (Design and Documentation), and BIM-LA (Legal Awareness). The calculated Cronbach's alpha values for each factor indicate adequate internal consistency reliability.

Each of the variables had a clear factor structure, according to the EFA analysis, and each component was highly influenced by each variable. This research sets the framework for a more in-depth investigation of the connections between the variables and their effects on understanding the legal and contractual effects of BIM adoption in building projects.

Table 4
Demographic details of respondents.

Category	Classification	Frequency	%
Profession	Quantity Surveyor	18	10.3
	Architect	30	17.1
	Civil Engineer	42	24.0
	M&E Engineer	7	4.0
	Project Manager	27	15.4
	Other	9	5.1
Organization	Contractor	57	32.6
	Consultant	43	24.6
	Client	33	18.9
Industrial Experience	0–5 Years	47	26.9
	6–10 Years	36	20.6
	11–15 Years	26	14.9
	16–20 Years	10	5.7
	Over 20 Years	14	8.0
BIM Knowledge	Yes	121	69.1
	No/Maybe	12	6.9

Table 5
EFA Analysis.

Variables	Component				Cronbach Alpha
	1	2	3	4	
BIM-RM1	.858				.821
BIM-RM2	.812				
BIM-RM3	.655				
BIM-DR1		.811			.815
BIM-DR2		.778			
BIM-DR3		.653			
BIM-LA1			.783		.761
BIM-LA2			.750		
BIM-LA3			.698		
BIM-CF1				.762	769
BIM-CF2				.704	
BIM-CF3*					

"Extraction Method: Principal Component Analysis."
"Rotation Method: Varimax with Kaiser Normalization."
"Variable BIM-CF3 excluded because of loading less than 0.6.".

5.3. PLS-SEM model development

Table 6 indicates the convergent validity results, according to which the high factor loadings of BIM-RM1 (0.981) and BIM-RM2 (0.968) for the Risk Management cluster indicate a strong relationship between these elements and the underlying construct [24,49]. The variance inflation factor (VIF) values fall within a permissible range, indicating that multicollinearity is not an issue. The composite reliability (CR) value of 0.948 indicates a high level of internal consistency, and the average variance extracted (AVE) value of 0.85 indicates that the construct explains a substantial quantity of the measurement items' variance. BIM-DR1 (0.983) and BIM-DR2 (0.983) have high factor loadings within the Dispute Resolution cluster, indicating a significant relationship with the underlying construct. Additionally, the VIF values fall within an acceptable range. The CR value of 0.965 indicates high internal consistency, and the AVE value of 0.866 suggests that the construct explains a substantial amount of variance in the measurement items. Concerning the Legal Awareness cluster, BIM-LA1 (0.802), BIM-LA2 (0.759), and BIM-LA3 (0.713) have moderate to high factor loadings, indicating a moderately strong relationship with the underlying construct—the values of the VIF fall within a permissible range [1,18]. The CR value of 0.803 suggests good internal consistency, and the AVE value of 0.803 indicates that the construct explains a substantial portion of the variance in the measurement items. BIM-CF1 (0.887) and BIM-CF2 (0.903) have high factor loadings within the Contractual Frameworks cluster, indicating a significant relationship with the underlying construct. The values of the VIF fall within a permissible range. The CR value of 0.89 indicates high internal consistency, and the AVE value of 0.80 suggests that the construct explains a substantial amount of variance in the measurement items. Fig. 3 presents the loadings chart of variables where most of the variables have high factor loading. While Fig. 4 only presents the model reliability statistics where Cronbach alpha, composite reliability and AVE are shown for each construct.

Table 6
Convergent validity analysis.

Cluster	Assigned Code	Loadings	VIF	CA	CR	AVE
Risk Management	BIM-RM1	0.981	1.247	0.948	0.874	0.85
	BIM-RM2	0.968	1.223			
	BIM-RM3	Deleted	1.249			
Dispute Resolution	BIM-DR1	0.983	1.167	0.965	0.883	0.866
	BIM-DR2	0.983	2.048			
	BIM-DR3	Deleted	1.974			
Legal Awareness	BIM-LA1	0.802	2.864	0.803	0.776	0.803
	BIM-LA2	0.759	2.151			
	BIM-LA3	0.713	2.338			
	BIM-CF1	0.887	2.382	0.753	0.89	0.801
	BIM-CF2	0.903	2.551			

Discriminant validity results as indicated in Table 7 Values closest to zero indicate greater discriminant validity. In this analysis, the values below the diagonal represent HTMT ratios between distinct constructs, whereas those on the diagonal are inapplicable because they represent HTMT ratios within the same construct [32,33]. The results show that the HTMT ratios for the off-diagonal values are comparatively low, indicating that the constructs have good discriminant validity [50]. For instance, the HTMT ratio between Contractual Frameworks (CF) and Dispute Resolution (DR) is 0.347 %, indicating a relatively distinct relationship between these concepts. Similarly, the HTMT ratio between Legal Awareness (LA) and Risk Management (RM) is 0.214, suggesting that these constructs have a relatively distinct relationship. Fig. 5 presents the HTMT statistics of the constructs more clearly.

It can be seen from the results in Table 8 that the diagonal values are more significant than the correlations with other constructs, providing evidence for discriminant validity [51]. The AVE for Contractual Frameworks (CF) is 0.895 %, which is greater than its correlations with Dispute Resolution (DR), Legal Awareness (LA), and Risk Management (RM). Similarly, the AVE for Risk Management (RM) is 0.975 %, significantly higher than its correlations with the other constructs. The Fornell-Larcker analysis validates the discriminant validity of the study's constructs [4,28]. The diagonal AVE values are more significant than the correlations with other constructs, suggesting that each construct encompasses a unique portion of the variance and is distinct from the others. Fig. 6 presents the correlation graph of constructs.

According to the results in Table 9, each variable predominantly loads onto its designated construct, while loadings on other constructs are lesser. For instance, BIM-CF1 has a high weighting on Contractual Frameworks (CF) (0.887) and relatively reduced weightings on Dispute Resolution (DR), Legal Awareness (LA), and Risk Management (RM). This indicates that BIM-CF1 has limited influence on the other constructs and is primarily associated with CF.

Similarly, BIM-DR1 and BIM-DR2 have higher loadings for Dispute Resolution (DR) (0.983) than for the other constructs. BIM-LA1, BIM-LA2, and BIM-LA3 emphasize Legal Awareness (LA), whereas BIM-RM1 and BIM-RM2 emphasize Risk Management (RM).

Overall, the cross-loading results indicate that the variables correspond to their designated constructs, thereby supporting the discriminant validity of the constructs [28,30,52]. This analysis guarantees that each variable measures the intended construct and does not contribute significantly to other constructs [8]. Fig. 8 adequately present the chart of cross loadings of the model variables.

5.4. Structural model development

Table 10 and Fig. 7 in this study depict each hypothesis's bootstrap analysis results. This study's hypotheses (H1, H2, H3, and H4) are all accepted based on the results presented in this table. The data acquired for this study indicates a statistically significant relationship between the independent variables (CF, DR, LA, RM) and the dependent variable (BIM). In this study, the (O) values represent the original sample values, while the (M) values represent the sample mean values [4,31,9]. The T statistics and p-values provide additional evidence that the relationships are significant.

The study's T-statistics values, item loadings, and construct-to-concept relationships. It illustrates the significance and strength of the relationships between the constructs and their respective objects as in Fig. 8. The T-statistics values indicate these relationships' statistical significance and magnitude [26,33]. The loadings of the items on their respective constructs, representing the intensity of the item's relationship with its construct. The higher the payload, the stronger the association between the item and the construct [11,18].

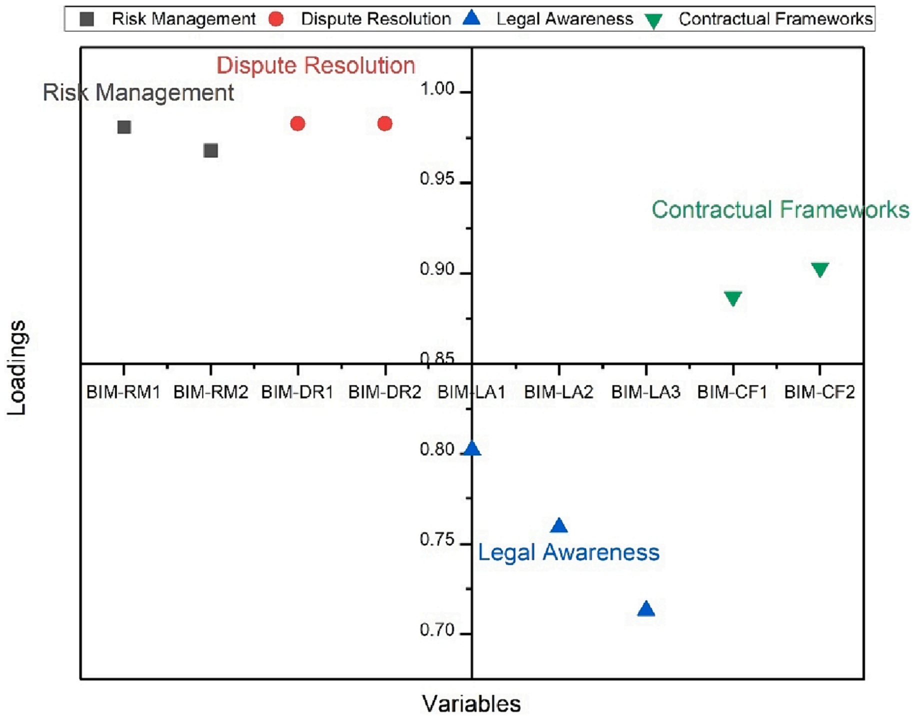

Fig. 3. Variables vs loadings chart.

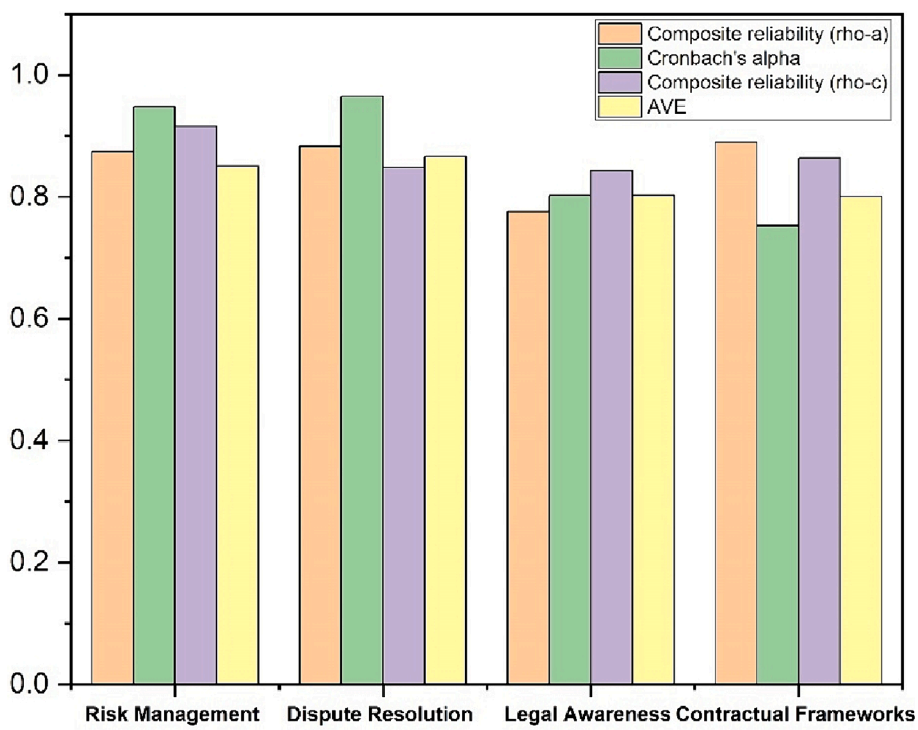

Fig. 4. Reliability statistics of the model.

Table 7
HTMT analysis for discriminant validity.

Constructs	CF	DR	LA	RM
Contractual Frameworks = CF				
Dispute Resolution = DR	0.347			
Legal Awareness = LA	0.318	0.235		
Risk Management = RM	0.086	0.018	0.214	

5.5. Predictive relevance Q^2

The value of Q2 is 0.155, which is calculated as 1 minus the ratio of SSO to SSE. This coefficient of determination indicates the veracity of the model's predictions. A higher Q2 value indicates better predictive performance, indicating that the independent variables included in the model have a plausible capacity to explain and predict the effects of BIM adoption on construction projects [15,20]. As indicated by Table 11, Q2

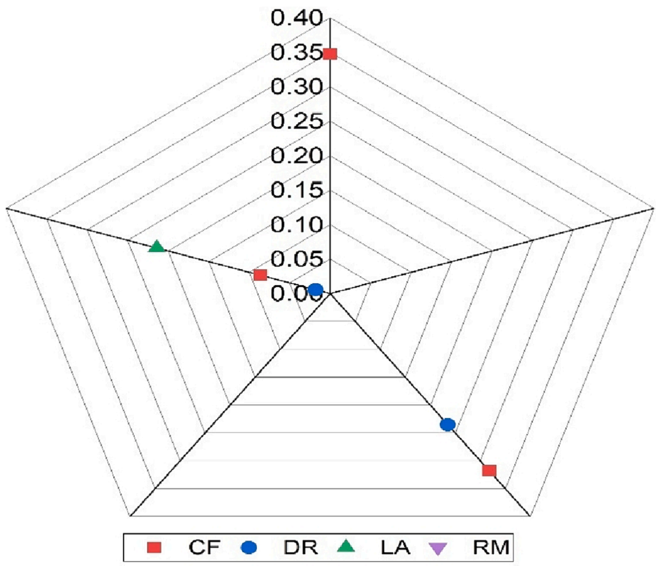

Fig. 5. Radar graph of the constructs indicating HTMT statistics.

Table 8
Fornell lacker criterion analysis for discriminant validity.

Constructs	CF	DR	LA	RM
Contractual Frameworks = CF	0.895			
Dispute Resolution = DR	0.295	0.983		
Legal Awareness = LA	0.236	0.215	0.759	
Risk Management = RM	0.077	−0.001	0.171	0.975

value of 0.155, the results of the predictive relevance analysis indicate that the model has some predictive power in comprehending the implications of BIM adoption in construction projects.

6. Discussion

The emphasis of the discussion portion of the manuscript is on interpreting and discussing the results of the hypothesis testing. Also highlighted are the significance and practical implications of each variable concerning the implications of BIM adoption in construction projects.

The first hypothesis (H1) stated that Contractual Frameworks (CF) and BIM have a significant relationship. According to the results, the path loading for CF –> BIM in the original sample is 0.466, and the sample mean is 0.461. This indicates that CF has a significant positive effect on the adoption of BIM in construction projects. The low standard deviation (0.031) indicates the relationship's stability. The high T statistics (15.133) and significant p-value (0) indicate that H1 should be accepted [10,22]. This emphasizes the significance of having well-defined contractual frameworks to facilitate the successful implementation and adoption of BIM in construction projects.

Likewise, the second hypothesis (H2) investigates the connection between Dispute Resolution (DR) and BIM. In the original sample, the path loading is 0.436, while the sample mean is 0.431. This indicates a positive correlation between disaster recovery and BIM adoption. The significant T statistics (9,933) and p-value (0) support the hypothesis H2. Effective dispute-resolution mechanisms play a crucial role in fostering collaboration, minimizing conflicts, and boosting the overall success of BIM implementation in construction projects [3,6].

The third hypothesis (H3) emphasizes the relationship between Legal Awareness (LA) and Building Information Modelling (BIM). The results reveal a path loading of 0.447 in the original sample and 0.442 in the sample mean, indicating that LA positively affects BIM adoption. The significant T statistics (14.41) and p-value (0) indicate that hypothesis H3 is acceptable. For addressing legal issues, assuring compliance, and mitigating legal risks in construction projects, it is essential to have a solid comprehension of the legal facets of BIM usage [14,21].

The final hypothesis (H4) investigates the relationship between Risk Management (RM) and BIM. Path loadings of 0.209 in the original sample and 0.206 in the sample mean indicate a positive but relatively reduced influence of RM on BIM adoption. Although the T statistics (2,688) and p-value (0.007) support the acceptance of H4, the lower path loading (0.078) and more significant standard deviation (0.078) indicate that RM has a relatively less significant impact on BIM adoption.

The results highlight the practical significance of various variables in the context of the adoption of BIM in construction projects. Significant roles are played by contractual frameworks, dispute resolution mechanisms, legal awareness, and risk management in facilitating successful BIM implementation [1,3]. To enhance collaboration, mitigate disputes, ensure legal compliance, and effectively manage risks in BIM-enabled construction projects, stakeholders and decision-makers should prioritize these factors.

6.1. Managerial and empirical implications

Implications for Management: The findings of this study provide construction project managers and industry professionals with valuable insights. By grasping BIM adoption's legal and contractual implications, managers can mitigate risks, improve project efficiency, and ensure compliance with applicable regulations. They can create exhaustive contractual frameworks that address BIM-related issues and implement effective dispute resolution mechanisms. To maximize the benefits of BIM adoption, managers can also prioritize the development of legal awareness and encourage collaboration among project stakeholders.

This study contributes to the corpus of existing empirical research by empirically investigating BIM adoption's legal and contractual implications in construction projects. The results confirm the hypothesized associations between contractual frameworks, dispute resolution, legal awareness, risk management, and BIM adoption. This empirical evidence lays the groundwork for future research in BIM adoption and its implications. Future research can expand on these findings by investigating additional factors that influence BIM adoption and how BIM adoption affects the legal and contractual aspects of construction projects.

7. Conclusion

The present research looked at potential legal and contractual effects of building information modelling (BIM) in construction. This study analyzed the legal and contractual implications of BIM adoption in the construction industry. The key findings demonstrate that clearly defined contractual frameworks, efficient dispute resolution mechanisms, and robust legal knowledge have significant positive impacts on successful BIM implementation. Though risk management was considered an important factor, it had a comparatively minor influence. These results highlight the need for construction stakeholders to prioritize contractual protocols, dispute processes, and legal training to ensure effective BIM adoption. By proactively addressing these considerations, project teams can enhance collaboration, limit risks, and fully capitalize on BIM's benefits. In summary, this research emphasizes the importance of contractual, legal, dispute resolution, and risk management factors in optimizing BIM adoption outcomes. The insights equip industry practitioners to navigate BIM's complexities and serve as a valuable foundation for future scholarly work to continue advancing understanding of BIM implementation in construction.

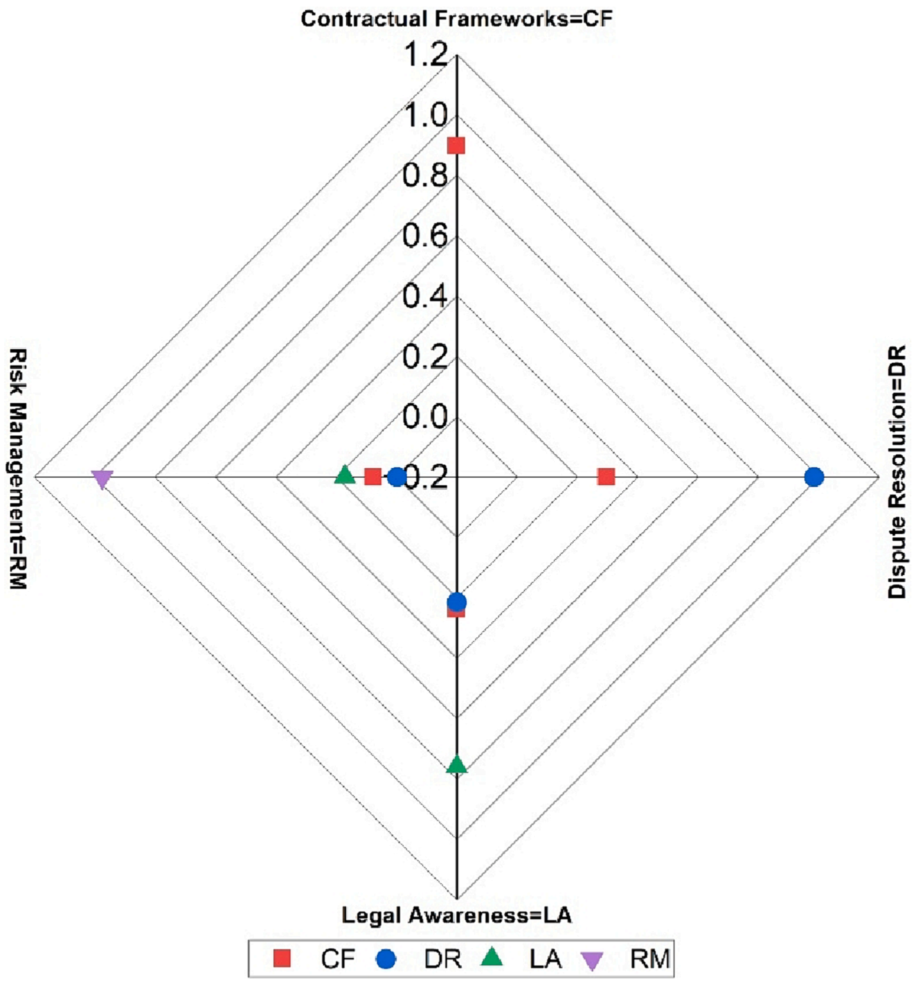

Fig. 6. Radar graph of the constructs indicating fornell and larcker correlations.

Table 9
Cross-loading criterion for discriminant validity.

Variables	Contractual Frameworks	Dispute Resolution	Legal Awareness	Risk Management
BIM-CF1	0.887	0.282	0.154	0.056
BIM-CF2	0.903	0.247	0.265	0.081
BIM-DR1	0.29	0.983	0.219	0.012
BIM-DR2	0.29	0.983	0.205	−0.014
BIM-LA1	0.24	0.319	0.802	0.123
BIM-LA2	0.095	0.02	0.759	0.142
BIM-LA3	0.176	0.084	0.713	0.132
BIM-RM1	0.101	0.009	0.208	0.981
BIM-RM2	0.041	−0.013	0.113	0.968

8. Limitations and future recommendations

This study's small sample size may limit its findings' generalizability. In addition, the focus on a specific geographic region or industry may encompass more than the complete scope of legal and contractual implications associated with BIM adoption

To surmount these limitations, future research should incorporate more immense and diverse samples to improve the generalizability of its findings. The legal and contractual ramifications of BIM adoption can be better comprehended through comparative analyses across diverse regions and industries. Longitudinal studies can provide insight into the long-term effects, while researchers, industry professionals, and policymakers can collaborate to develop standardized frameworks. In addition, investigating the impact of emergent technologies and investing in training programs can contribute to improving construction practices and the successful implementation of BIM in construction projects.

Table 10
Hypothesis testing of study by bootstrapping analysis.

Hypothesis	Relation	(O)	(M)	(STDEV)	T statistics	P values	Results
H1	CF −> BIM	0.466	0.461	0.031	15.133	0	Accepted
H2	DR −> BIM	0.436	0.431	0.044	9.933	0	Accepted
H3	LA −> BIM	0.447	0.442	0.031	14.41	0	Accepted
H4	RM −> BIM	0.209	0.206	0.078	2.688	0.007	Accepted

(O) = Original sample; (M) = Sample mean; (STDEV) = Standard deviation; CF = Contractual Frameworks; DR = Dispute Resolution; LA = Legal Awareness; RM = Risk Management.

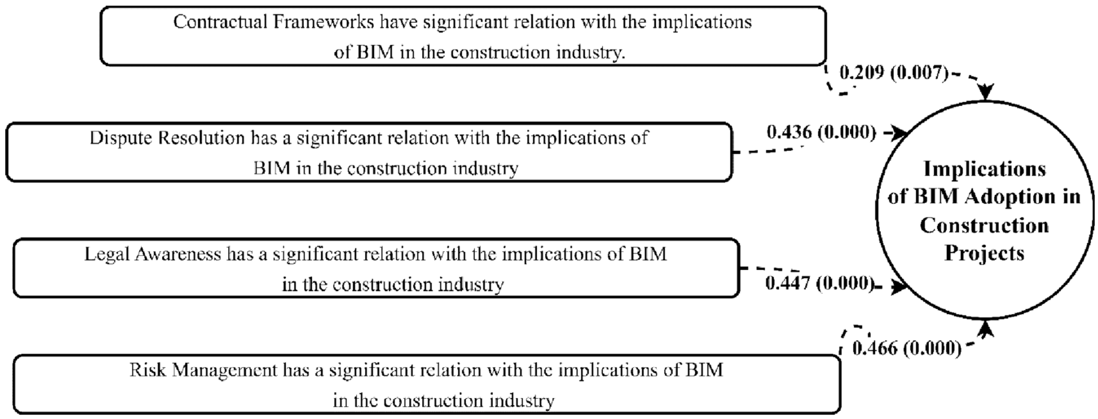

Fig. 7. Structural model indicating p-value and path loadings.

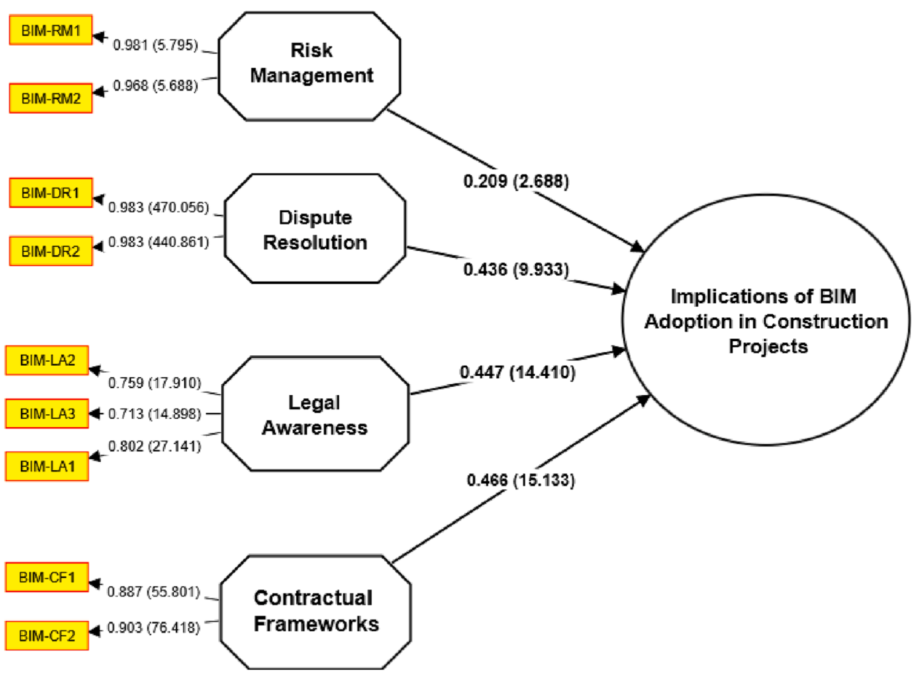

Fig. 8. Structural model indicating T value and path loadings.

Table 11
Predictive relevance results.

Predictive relevance analysis of model	SSO	SSE	Q^2 (=1- SSO/SSE)
Implications of BIM Adoption in Construction Projects	9056.000	7653.211	0.155

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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