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“Integrating Building Information Modeling With Data-Driven Strategies Considering Safety For Sustainable Construction: A Case Study Of Tehran”

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Abstract

This study investigates the application of sustainable development models in the construction industry, aimed at reducing environmental, economic, and social impacts. It particularly emphasizes energy efficiency, process optimization, accurate scheduling, cost reduction, and enhanced safety in construction projects. The study focuses on Tehran, Iran, where the potential for employing Building Information Modeling (BIM) to support sustainable construction is considerable. A mixed-methods approach was adopted, combining qualitative and quantitative strategies. In the qualitative phase, semi-structured interviews were conducted with experts, professors, and practitioners involved in construction projects under the supervision of Tehran’s District 3 Municipality. The interview data were analyzed using grounded theory coding procedures (open, axial, and selective coding) and categorized into 55 concepts and 14 core categories, leading to the development of a conceptual model. In the quantitative phase, the proposed model was tested through survey data and structural equation modeling. The findings indicate that optimal building design, integration of contract models, conservation of natural resources, professional training, organizational factors, and information technology significantly influence the infrastructural, managerial, and macro-level outcomes of sustainable construction in Iran.

Keywords Building Information Modeling. Sustainable Development. Safety efficiency. Construction Industry. Foundation Data Theorizing.

Introduction

The demand for sustainable construction has increased significantly in the 21st century, driven by the urgent need to address environmental degradation, resource depletion, and the growing challenges of urbanization [1]. Sustainable construction aims to minimize the negative environmental, economic, and social impacts of the building industry while ensuring efficiency, safety, and long-term resilience [2]. Achieving these goals requires innovative approaches supported by advancements in science and technology, particularly in clean production processes and performance management [3].

Building Information Modeling (BIM) has emerged as a transformative tool that redefines how buildings are designed, constructed, and managed. It enables multidimensional coordination by integrating 3D design, analysis, and scheduling [4]. BIM contributes to sustainability by promoting energy efficiency, process optimization, accurate project scheduling, cost reduction, and improved safety in construction [5]. As BIM provides precise information on design and resource requirements, it enhances contractors' planning and ensures the timely availability of human resources, equipment, and materials [6]. Consequently, project costs are reduced, and collaboration among stakeholders is improved. Furthermore, when combined with mobile and digital technologies, BIM supports material tracking, installation management, and automated positioning, thereby increasing productivity across project phases [7,8].

BIM also allows stakeholders—including architects, engineers, builders, and clients—to share and manage digital data throughout the building life cycle. This capability facilitates the evaluation of performance indicators and the integration of sustainability and green construction concepts at all stages of a project [9]. For BIM to be effective, however, it must incorporate a wide range of components and specifications, such as technical drawings, regulatory standards, manufacturer data, logistics, and environmental conditions. When properly managed, BIM reduces information loss between the design, construction, and operation phases, ensuring a more coherent and efficient project delivery [10,11].

Recent research further highlights the potential of BIM to accelerate the realization of buildings and cities that meet sustainability criteria. Specifically, BIM supports energy-demand simulation and life cycle assessment, offering effective strategies for reducing emissions associated with materials and construction methods [12–14]. These advantages position BIM as a key enabler of sustainable development in the construction industry.

Theoretical Literature and Research Background

Sustainability, in its broadest sense, refers to the capacity of a community, ecosystem, or system to function indefinitely without exhausting the resources on which it depends [15]. A sustainable system must be resilient, adaptable, and responsive to continuous environmental change, ensuring both internal stability and external balance [16,17]. In the construction industry, technological advancements have gradually transformed traditional practices. Earlier reliance on hand-drawn designs, which were often time-consuming and error-prone, has been replaced by digital modeling tools that allow faster and more accurate planning [18]. Nevertheless, these tools were still limited by issues of data inconsistency and lack of intelligence, leading to the emergence of Building Information Modeling (BIM) as a more effective solution [19,20].

The concept of sustainable development also represents a paradigm shift in understanding the relationship between humans and the environment. Unlike past approaches that separated environmental, social, and economic considerations, modern sustainability emphasizes integration and balance among these dimensions [21]. In this context, BIM plays a critical role by enabling the creation of comprehensive databases for buildings and their components, thereby supporting informed decision-making across all project stages [22].

BIM has become increasingly indispensable due to its many advantages, such as:

1. reducing construction costs by up to 20%;
2. shortening project execution times by up to 35%;
3. minimizing errors and design changes.

By enhancing coordination among project stakeholders, BIM promotes efficiency and safety throughout the building lifecycle [20,23]. Despite these benefits, its implementation also raises new challenges, particularly in legal and contractual frameworks. Traditional contracts often fail to clearly define the roles and responsibilities of stakeholders in a BIM-enabled environment, creating ambiguities regarding accountability and intellectual property rights [24–26]. The integration of BIM may blur responsibility boundaries, especially when design errors occur, necessitating updated legal frameworks aligned with international standards such as ISO 19650-1 [27,28]. One effective solution is the adoption of integrated project delivery (IPD) contracts, which distribute both risks and rewards among project participants [29].

Globally, construction is a major economic sector, accounting for approximately 10% of GDP and employing nearly 7% of the workforce. In countries like Germany, for instance, the construction industry contributes nearly half of an annual €230 billion market and employs over one million people. However, a significant share of current construction activity is dedicated to renovation and maintenance, reflecting growing needs for energy efficiency and environmental adaptation. Studies indicate that nearly 80% of existing buildings consume more than twice the energy required by new constructions, underscoring the urgency of adopting energy management systems, insulation technologies, and renewable energy solutions such as photovoltaics.

Several studies have examined the intersection of BIM and sustainability. Haruna et al. [30] applied a multi-criteria decision-making approach to integrate BIM with sustainability goals, highlighting design optimization and material reduction as key drivers of energy and carbon savings. Olawumi and Chan [12] investigated critical success factors for BIM adoption in sustainable construction projects, identifying democratization and data-driven intervention technologies as essential enablers. Similarly, Zhang et al. [31] explored the limitations of BIM in sustainable building projects, identifying barriers such as limited public participation, technological constraints, and program management challenges.

Methodology of Research

This study employed a mixed-methods design that combined qualitative and quantitative approaches. The qualitative component was based on grounded theory, while the quantitative component utilized structural equation modeling (SEM) following the framework of Glaser and Strauss [32]. Grounded theory was selected to inductively develop a theoretical model through systematic data analysis, and SEM was applied to validate the proposed model.

Qualitative Methodology

The qualitative phase relied on semi-structured interviews with experts, academics, and professionals experienced in BIM and sustainable development. Participants were recruited through purposive and snowball sampling to ensure the inclusion of individuals with relevant expertise. Interviews continued until theoretical saturation was achieved, ensuring that no new concepts emerged. The collected data were analyzed using open, axial, and selective coding consistent with grounded theory procedures, leading to the identification of concepts and categories that informed the conceptual model [33].

Quantitative Methodology

In the quantitative phase, Partial Least Squares Structural Equation Modeling (PLS-SEM) was applied to test the conceptual model derived from the qualitative findings. The target population included civil engineers and project managers involved in construction projects under Tehran

Municipality, District 3 (estimated at over 100,000 individuals). Using Krejcie and Morgan's (1970) table, a sample of 384 respondents was determined, which provides sufficient reliability at a 5% margin of error and a 95% confidence level. Data were collected through a researcher-developed questionnaire consisting of 55 items. The questionnaire items were derived from the coding results of the qualitative analysis, ensuring alignment between both phases of the study. Reliability and validity of the instrument were confirmed prior to data collection.

Summary

In summary, the mixed-methods design allowed for both the inductive development and the empirical testing of a conceptual model for sustainable construction based on BIM. The qualitative phase ensured a theory-driven foundation, while the quantitative phase provided robust validation of the model through statistical analysis.

Importantly, this methodological integration directly aligns with the objectives of the research. The use of grounded theory facilitated the discovery of key concepts and relationships within the context of sustainable construction in Tehran, while the application of PLS-SEM enabled the rigorous testing of these relationships across a broader population of engineers and managers. This dual approach ensures that the proposed model is not only theoretically sound but also empirically validated, thereby contributing to both academic knowledge and practical application in the construction industry.

Research Findings

Analysis Process

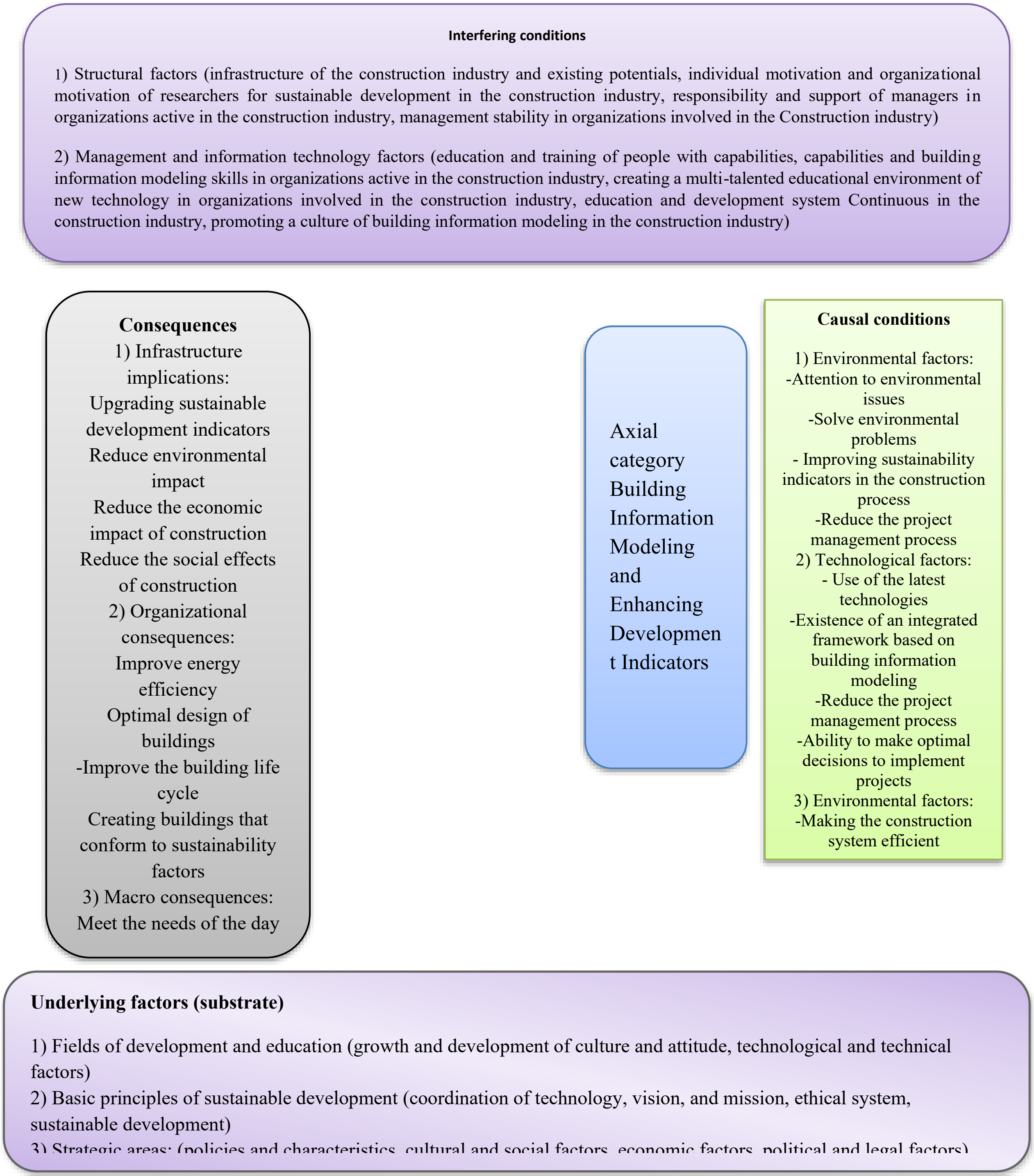
The qualitative data obtained from interviews were analyzed using the three-step coding procedure of Strauss and Corbin (1998), namely open, axial, and selective coding. Initially, a detailed description of the research context, events, and participants was prepared. During open coding, the data were systematically examined, labeled, and categorized into distinct concepts. This stage ensured that the raw data were conceptualized into a broad set of ideas.

In the axial coding stage, relationships between categories and subcategories were identified, highlighting their characteristics and dimensions. This process allowed for the development of core themes relevant to the research objectives. Selective coding was then employed to integrate these categories into a coherent theoretical framework. Through constant comparison and the use of analytical questioning, the emerging relationships were refined into a conceptual model of sustainable development in the construction industry based on BIM.

Following the qualitative phase, a questionnaire was developed to test the proposed model. The questionnaire contained 55 items derived from the identified indicators, components, and categories. A five-point Likert scale was used for measurement. The validity and reliability of the instrument were confirmed by experts, and Cronbach's alpha exceeded the acceptable threshold of 0.70, indicating high reliability. The questionnaire was distributed among the study population, and the collected data were analyzed using confirmatory factor analysis and structural equation modeling (SEM) through SmartPLS 3.0 software.

Summary

The findings from the qualitative analysis provided a comprehensive framework of concepts and categories that reflect the dynamics of sustainable construction based on BIM. The subsequent quantitative analysis validated this framework, confirming the robustness and reliability of the proposed model. Together, these results demonstrate that the methodological integration of grounded theory and SEM is effective in both theory-building and empirical testing, directly



Interfering conditions

1) Structural factors (infrastructure of the construction industry and existing potentials, individual motivation and organizational motivation of researchers for sustainable development in the construction industry, responsibility and support of managers in organizations active in the construction industry, management stability in organizations involved in the Construction industry)

2) Management and information technology factors (education and training of people with capabilities, capabilities and building information modeling skills in organizations active in the construction industry, creating a multi-talented educational environment of new technology in organizations involved in the construction industry, education and development system Continuous in the construction industry, promoting a culture of building information modeling in the construction industry)

Consequences
1) Infrastructure implications:
Upgrading sustainable development indicators
Reduce environmental impact
Reduce the economic impact of construction
Reduce the social effects of construction
2) Organizational consequences:
Improve energy efficiency
Optimal design of buildings
-Improve the building life cycle
Creating buildings that conform to sustainability factors
3) Macro consequences:
Meet the needs of the day

Axial category Building Information Modeling and Enhancing Development Indicators

Causal conditions

1) Environmental factors:
-Attention to environmental issues
-Solve environmental problems
- Improving sustainability indicators in the construction process
-Reduce the project management process
2) Technological factors:
- Use of the latest technologies
-Existence of an integrated framework based on building information modeling
-Reduce the project management process
-Ability to make optimal decisions to implement projects
3) Environmental factors:
-Making the construction system efficient

Underlying factors (substrate)

1) Fields of development and education (growth and development of culture and attitude, technological and technical factors)
2) Basic principles of sustainable development (coordination of technology, vision, and mission, ethical system, sustainable development)
3) Strategic areas: (policies and characteristics, cultural and social factors, economic factors, political and legal factors)

supporting the research objective of developing a sustainable construction model for the Iranian context.

Figure 4-1. Integrated model of Building Information Modeling (BIM) and Grounded Theory for enhancisustainable development indicators in the construction industry

For the quantitative portion of the study, a questionnaire with 55 questions was designed, and 384 people were surveyed. We entered the information from these questionnaires into SPSS software and analyzed the results with smartPLS software. Thus, the structural equation modeling of the research design and the relationships between the variables were investigated and tested. In Figure 2 and Figure 3, the structural model of the research is reported in two modes: standard coefficients and significance coefficients.

In Figure 2, the relationship between the hypotheses was evaluated for significance and the size of the path coefficients. The coefficients indicate that the standard coefficients for all numerical hypotheses greater than zero are obtained and confirmed. Also, since the t-coefficients for all hypotheses are higher than ±1.96, their significance is confirmed at the confidence level of 0.95.

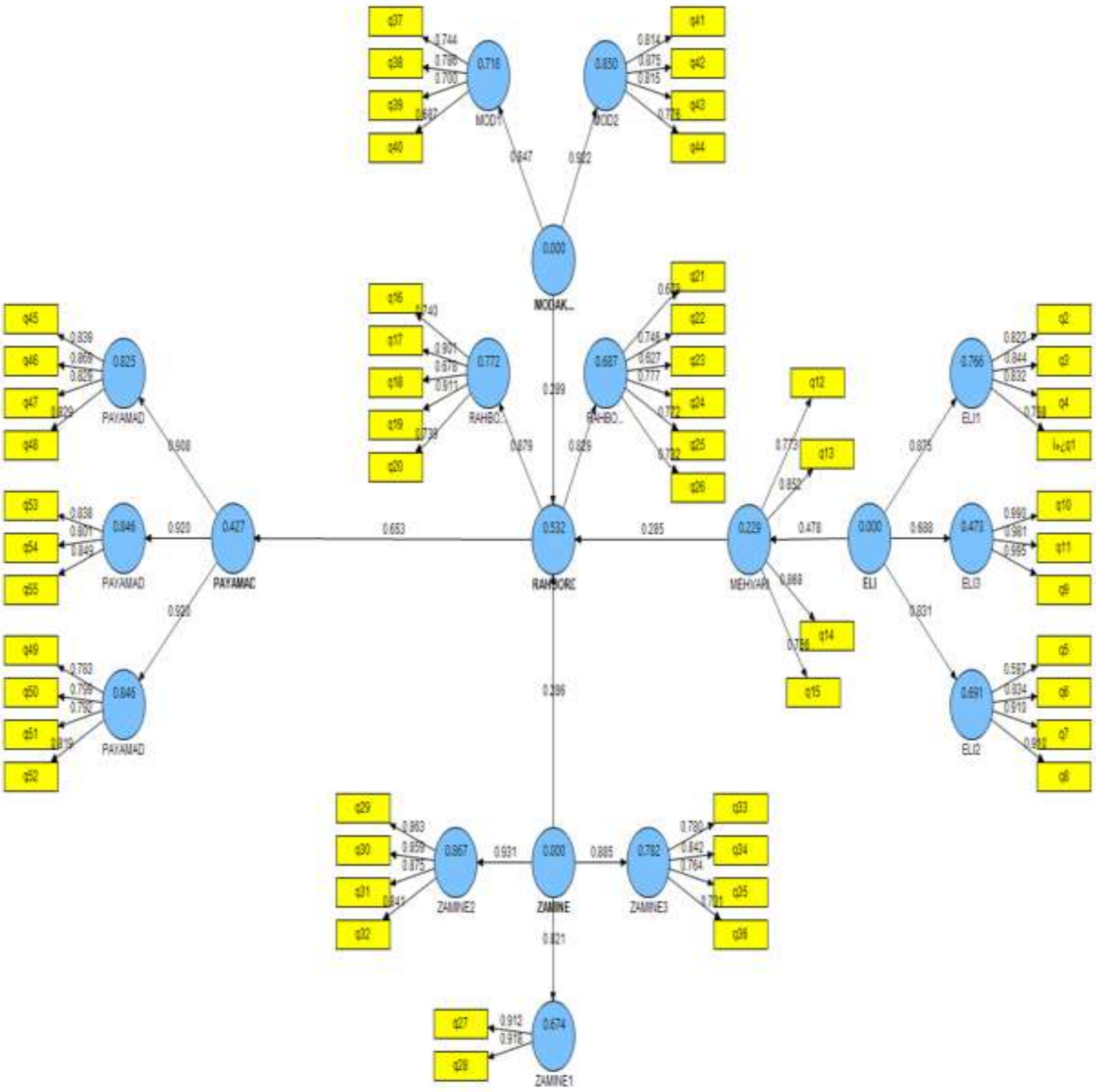


Fig.2 Structural model in the form of standard coefficients

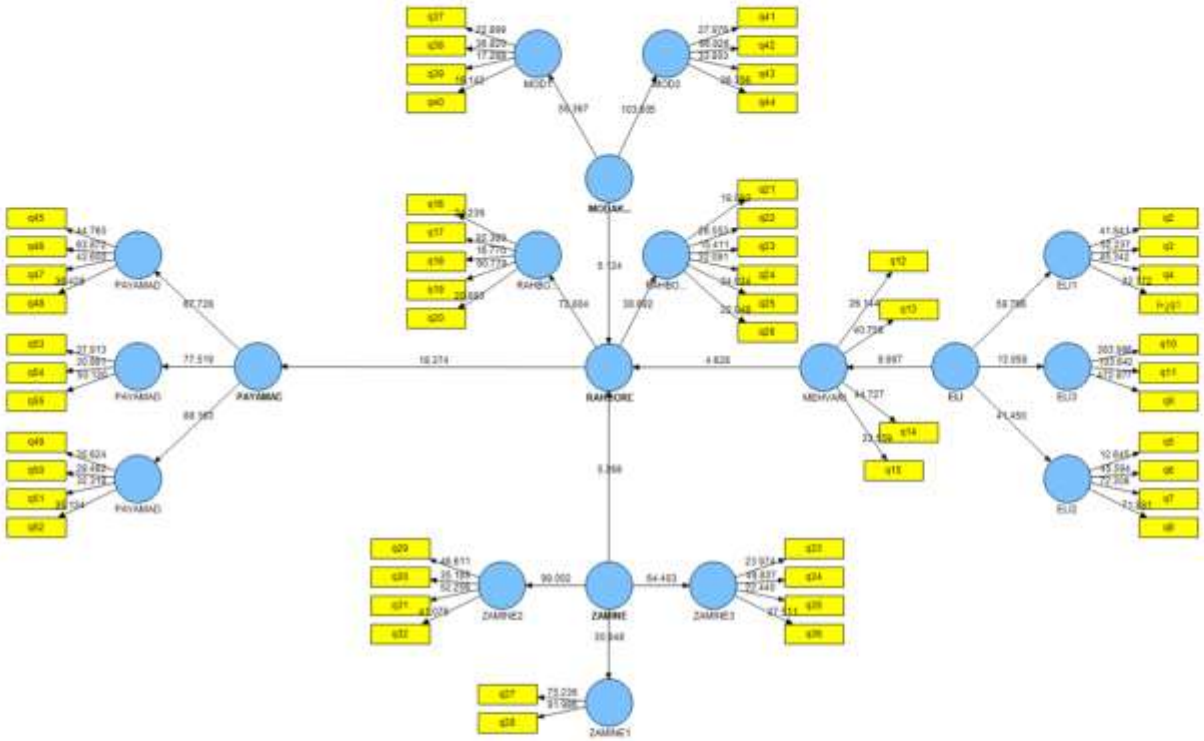


Fig.3 Structural model in the case of significant coefficients

Validity and reliability of the quantitative research section (questionnaire)
The validity of the questionnaire was evaluated through a face validity analysis and diagnostic validity analysis using the extracted mean-variance index as a measure of fact. This coefficient shows what percentage of the variance of the structure under study has been affected by its variables. Researchers have set the value of 0.5 and above as appropriate for this index. People outside the statistical sample completed a total of 30 questionnaires. In addition, 30 questionnaires were completed by people outside the statistical model to determine the reliability. (Table 1) values indicate that the research tool can collect information. In order to evaluate the reliability of the survey, 30 questionnaires were filled out by people outside the statistical sample. In addition, people outside the statistical model filled out 30 questionnaires to assess the reliability. (Table 1) values indicate that the research tool can collect information.

Table 1 Model reliability and validity test

Variable	Indicators	Composite reliability	Cronbach's alpha	AVE
Causal conditions	Environmental factors	0/893	0/839	0/675
	Technological factors	0/891	0/830	0/677
	Environmental factors	0/992	0/988	0/978
Axial category	building information modeling and	0/888	0/831	0/666

	promoting sustainable development indicators			
Strategic factors	Optimal building design and integration of contract models	0/897	0/854	0/639
	Sustainable development and conservation of natural resources	0/868	0/817	0/524
Hospitalization factors	Development and training factors	0/912	0/806	0/838
	Basic principles of sustainable development	0/915	0/882	0/739
	Strategic areas	0/861	0/785	0/609
interfering factors	Structural factors	0/820	0/710	0/533
	Management and IT factors	0/892	0/838	0/674
Results and Consequences	Infrastructure implications	0/907	0/862	0/708
	Organizational Consequences	0/876	0/811	0/638
	Macro consequences	0/869	0/774	0/688

Testing research hypotheses

The research hypotheses are as follows:

- The identified causal conditions give rise to a central phenomenon (designing and explaining the sustainable development model of the construction industry based on building information modeling).
- The effect of causal conditions on the central phenomenon is considerable.
- The effects of phenomena-driven strategies are considerable.
- The effect of contextual conditions on strategies is significant.
- The effect of intervention factors on strategies is significant.
- The impact of strategies on outcomes is considerable.

According to the characteristics of the research structural equation model in (Table 2), all hypotheses are confirmed, and these effects are substantial. For example, the impact of causal conditions on the central phenomenon is established, and this effect is significant.

Table 2 Indicators for measuring research hypotheses

independent variable	The dependent variable	Standard coefficient	Significance factor	The result of the hypothesis
Causal conditions	Axial phenomenon	0.478	9.997	proving a theory
Axial phenomenon	Strategies	0.285	4.528	proving a theory
Underlying conditions	Strategies	0.286	5.268	proving a theory
Interfering conditions	Strategies	0.289	5.124	proving a theory
Strategies	consequences	0.653	18.374	proving a theory

Research discussion

As previously mentioned, in the present study, the qualitative strategy of foundation data processing theory has been applied to improve the indicators of sustainable development of the construction industry. An integrated model and approach have been developed to link the building information modeling model and foundation data theory. The research steps were followed step by step based on the data theorizing method of the foundation. Finally, 55 concepts and 14 categories were identified based on the research literature and interviews. The components of data theory form the basis of the research. The main category identified in this study is building information modeling and promoting sustainable development indicators that the other types find troubling. Classes are also presented in the visual model in five groups: context (3 categories), interventionist conditions (2 varieties), causal conditions (3 categories), strategies (2 categories), and consequences (3 categories).

Moreover, the study localizes the studies on sustainable development indicators in the construction industry. It was to analyze and describe in-depth each piece of the extraction code. An integral part of an overall research model (a model of building information modeling and data theory used to improve sustainable development indicators in the construction industry). The subject presents a combined building information modeling and data foundation theory model to promote sustainable development indicators in the construction industry. As part of this study, a survey method survey, including categories, concepts, and final codes, is conducted. Determine the status of each of these final codes extracted from the proposed final model.

As a result of inferential statistics, each dimension of the final organizational model is approved (presence) or rejected (absence). It should be noted that the results of inferential statistics also include two parts: first (the first part) the results of the confirmatory factor analysis of the questionnaire structures (respectively, confirmatory factor analysis of causal variables, confirmatory factor analysis of axial category variable, confirmatory factor analysis Strategies variable, confirmatory factor analysis of the outcome variable, confirmatory factor analysis of the intervening condition variable, confirmatory factor analysis is the context variable And then (Part II) the final model (a combined model of building information modeling and data theory of the foundation to improve the indicators of sustainable development of the construction industry) and all the structural relationships in the research model are tested for quantitative analysis accuracy and reliability. They are the results of qualitative analysis.

A study has shown that powerful technologies such as building information modeling can achieve an index of sustainable construction and accelerate and facilitate it. Several gaps and challenges of studies in this field, such as the lack of a comprehensive model that includes sustainability indicators, can be a suitable research platform for future studies. Due to the significant improvement of building performance in economic, environmental, and social dimensions, which are indicators of sustainable development, this revolutionary technology is recommended to employers and construction managers in Iran, a developing country.

The suggestions that may be useful to managers include the following:

1. The optimistic attitude of experts toward model building information and its decisive role in the future success of the builder
2. The willingness of company management to invest in technology and building information modeling
3. It provides a suitable platform and conditions for implementing building information modeling to promote the sustainable development of the construction industry.
4. Considered and allocated the necessary financial budget to realize and implement the building information modeling program in the construction industry.
5. They examined how the latest technologies and international standards are being developed and how they can be applied to the construction industry to promote sustainability.
6. The development of extensive national infrastructure is necessary to facilitate building information modeling in the construction industry.
7. Providing training platforms for building information modeling and facilitating learning for professionals in the construction industry.

Conclusions

The results of the measurement model provide strong evidence for the validity and reliability of the proposed framework. The factor loadings related to environmental factors were greater than 0.5, with significance coefficients above 1.96. In addition, Cronbach's alpha (0.839) and composite reliability (0.893) exceeded the threshold of 0.70, while the AVE (0.675) surpassed 0.50, confirming environmental factors as components of the causal conditions. Similarly, the items related to Building Information Modeling (BIM) and the promotion of sustainable development indicators demonstrated acceptable statistical values (factor loadings > 0.5, significance > 1.96, Cronbach's alpha = 0.831, CR = 0.888, AVE = 0.666), thereby validating this construct as a core category.

The constructs associated with optimal building design and the integration of contractual models also showed high reliability and validity (factor loadings > 0.5, significance > 1.96, Cronbach's alpha = 0.8854, CR = 0.897, AVE = 0.639), confirming their role as strategic factors. Furthermore, the fundamental principles of sustainable development were supported by robust statistical indicators (factor loadings > 0.5, significance > 1.96, Cronbach's alpha = 0.8882, CR = 0.919, AVE = 0.739), classifying them as underlying factors. Finally, sustainable development and the conservation of natural resources achieved acceptable thresholds (factor loadings > 0.5, significance > 1.96, Cronbach's alpha = 0.817, CR = 0.868, AVE = 0.524), validating their role as strategic factors.

In conclusion, all examined dimensions—including environmental factors, BIM and sustainability indicators, optimal building design and contractual integration, fundamental principles of sustainable development, and natural resource conservation—met the psychometric requirements of reliability and validity. These findings not only demonstrate the robustness of the conceptual framework but also emphasize its practical significance. The integration of BIM with sustainability principles emerges as a scientifically validated and reliable pathway to improve construction efficiency, reduce environmental impacts, and advance sustainable development in the construction industry.

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