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Barriers to BIM Implementation in the HVAC Industry: An Exploratory Study

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Abstract: In recent times, the rise of urbanization, industrialization, population growth, food security, and the COVID-19 pandemic have led to an increased demand for indoor spaces with efficient air conditioning systems. As a result, there is a growing interest in creating more complex HVAC systems to improve indoor spaces. Building information modeling (BIM) offers numerous benefits to the HVAC industry, such as clash detection, budget and time reductions, and increased efficiency. However, its implementation is currently hindered by various challenges. This research aims to identify the major barriers to BIM implementation in the HVAC industry in Turkey, using a questionnaire survey of 224 domain experts working in 42 different companies across various fields of the HVAC industry. The study utilized several statistical analyses to categorize and prioritize the most critical barriers, including reliability tests, exploratory factor analysis (EFA), confirmatory factor analysis (CFA), the Kaiser–Meyer–Olkin (KMO) test, Bartlett's test, and ranking of factors (IRI). The results indicate that the "Deficiencies of Infrastructure and Lack of Qualified Personnel (DIP)" factor group constituted the most significant barrier, followed by "Lack of Documentation and Specifications (LDS)", "Deficiencies of Case Studies and Project Drawings (DCP)", and "Lack of Motivation and Resistance to BIM (LMR)". Moreover, our research revealed that 60% of the participants' companies allocate less than 40% of their budgets to technological infrastructure, which hinders the adoption of BIM. To promote BIM in the HVAC sector, we recommend enhancing personnel capacity building, improving skills and knowledge about BIM, promoting guidelines, and providing free access to documentation for practitioners.

Keywords: BIM; HVAC; BIM implementation; BIM adoption

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1. Introduction

Building information modeling (BIM) is a cutting-edge technology that covers all activities involved in the construction process, from the initial planning stage to the demolition phase. BIM adoption has the potential to offer many benefits such as design visualization, rapid creation of alternative designs, reporting, and building performance predictions. BIM systems can also provide simulation, consistency, coordination and collaboration, clash detection and risk reduction, high levels of customization and flexibility, and improvements in cost, time, and quality. Furthermore, BIM ensures that all relevant information about the structure is collected in a centralized and easily accessible way [1]. Building information modeling (BIM) is a collaborative approach to store, share, exchange, and manage multidisciplinary information throughout the entire building project lifecycle, from planning and design to construction, operation, maintenance, and demolition. [2] When all project participants in the BIM system share information through common data, BIM ensures a systematic information flow. However, obstacles to its adoption also exist, which have slowed down its rate of implementation [3]. Many developing countries have adopted BIM systems, although this adoption is still limited, with BIM systems mainly implemented in large public projects [4,5]. On the other hand, the use of the BIM system is quite high in developed countries such as the United States, the United Kingdom, Germany, Finland, Norway, Australia, and Singapore.

In the early 2000s, with the emergence of design–build project delivery systems, the importance of BIM technology became more apparent. Computer-aided design (CAD) practitioners have also supported BIM, and this continues to be developed and integrated with various BIM software such as Autodesk, Bently, and Graphisoft [6]. Some BIM-based drawing illustrations are presented in Figure 1.

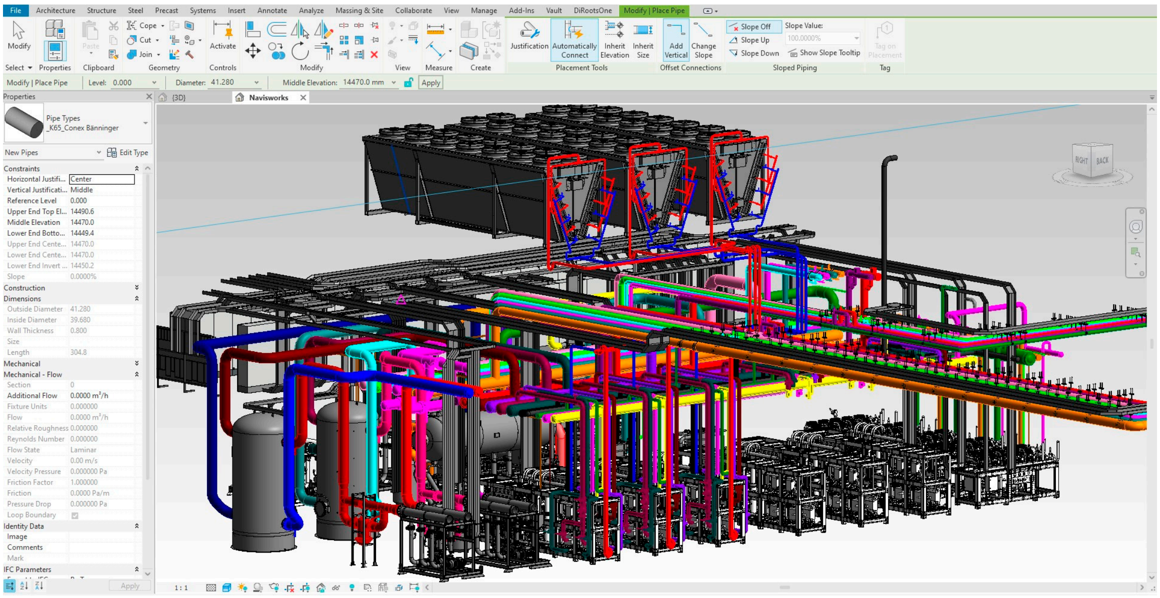

Figure 1. BIM-based drawing illustrations.

There is no consensus among BIM practitioners and theorists as to whether BIM is an evolution from CAD systems or a complete revolution in construction. BIM has two dimensions: information systems and philosophy. Therefore, BIM is more than just a construction tool—it represents a revolutionary philosophy. In Borkowski's study [7], the history of BIM was periodized according to three factors: idea, approach, and organizational culture. The numerous benefits of BIM have been demonstrated in a variety of applications, from its use in sustainability concepts [8] to its critical role in the public sector [9]. Augmented reality is also being explored in combination with BIM, as Al-Dhaimesh et al. [10] examined its benefits in the design process of the AEC industry. Other studies have shown the potential for BIM to benefit infrastructure time–cost analysis [11], minimize cost overruns in railway projects [12], transform traditional buildings into green buildings [13], and even aid in the design and manufacturing of prefabricated bridges [14]. While BIM has proven effective in solving problems across a wide range of projects, it is important to note that obstacles to its use can vary by country and project.

In Turkey, there has been an increase in the use of BIM systems in recent years, despite the lack of legal regulations, training, and experience [4]. The Turkish Ministry of Transport has mandated the use of BIM systems in some of the railway infrastructure projects since 2014, thereby raising awareness of BIM systems in the public and private sectors. However, BIM awareness in Turkey is still at an early level, and obstacles to its adoption have emerged, which have slowed down the pace of its implementation [15].

In today's world, the concentration of living and working areas in closed environments due to urbanization has led to various emerging issues, with ensuring air quality being one of the most critical concerns. HVAC systems have become an essential component of modern buildings, providing comfortable indoor environments while reducing carbon emissions and saving energy [16]. This is particularly important as buildings account for a significant portion of worldwide energy consumption and CO_2 emissions, and are the most extensive energy consumer and the second-largest CO_2 emitter after the industrial sector [17,18]. During the design phase of HVAC systems, the primary objectives are to achieve low carbon emissions, energy efficiency, comfort, and sustainability. A well-designed HVAC system not only determines resource consumption during the construction phase, but also has a direct impact on system performance during its operating phase. However, traditional engineering approaches to HVAC system design can be labor intensive, with design quality being reliant on the experience of the designer. This often leads to inconsistencies in achieving optimal designs in practical applications. The design process typically involves many repetitive and time-consuming tasks that are calculated manually, resulting in potential errors and reduced efficiency. Fortunately, the advancement of technology and developments in BIM-based software now enable automated and intelligent approaches to HVAC system engineering design, significantly improving the quality, efficiency, and precision of HVAC designs. This helps reduce the problem of low computational efficiency that occurs in traditional engineering design [19]. Simulation software for load and hydraulic simulation has been developed for HVAC system design, allowing for automatic calculations with higher accuracy than manual calculations. In traditional project design, stakeholders create their designs in two dimensions, resulting in independent drawings that often lead to clashes and errors in measurements. This is especially true if the problem of not being able to think in three dimensions arises. Drawing errors are usually noticed during the construction phase, leading to losses in time, cost, and quality. Creating a digital twin of the building with BIM-based programs significantly reduces these problems, and prevents clashes between structural design and HVAC systems. This considerably avoids weakening the building's bearing capacity. Additionally, BIM facilitates simultaneous building design processes, increasing communication efficiency between engineers, and serving as a common platform for engineers in various disciplines [20].

In recent years, there has been a significant increase in studies on the effective design of BIM-based HVAC systems. These studies have proposed various methods for the detailed environmental assessment of HVAC systems using BIM, BIM-based HVAC system design workflows, and approaches to integrate BIM with multiple building systems [21–24]. However, there are shortcomings in research that focus on both BIM barriers and the HVAC industry. Therefore, this study aims to contribute to the literature and capacity building by identifying barriers to the integration of BIM technology into the HVAC industry in Turkey, where industrial projects actively contribute to the economy. In addition, this research has a goal of proposing measures to overcome these identified barriers.

2. Literature Review

BIM technology, dating back to the 1970s, has been studied extensively by researchers in the construction industry for several years. There are a large number of studies that have addressed this ground-breaking technology, such as its benefits, barriers to implementation, and recommendations for better use of BIM.

BIM essentially involves relational databases that store information about building objects or collections of objects throughout their lifespan; the more information available, the better the decision-making process, as knowledge of the development is increased [7].

Some studies highlighted the benefits of BIM. Ngowtanasuwan and Hadikusumo [25] used a 'Causal Loop Diagram' to establish relationships between variables explaining BIM adoption behaviors in their study. They found that BIM awareness increases the workload of existing staff, which can reduce motivation and efficiency, particularly among project designers. Meanwhile, Bryde et al. [26] analyzed 35 documented cases where BIM was used in construction projects. Their study looked at the benefits of using BIM and investigated barriers to adoption, suggesting that BIM marketing and sales supported by cost/benefit analysis may help convince project managers of its benefits.

On the other hand, numerous studies have also revealed barriers to BIM adaptation. Recently, several studies have been conducted on the challenges of implementing BIM in various construction projects. These studies included topics such as barriers to BIM use in small construction projects (Waqar et al. [27]), interaction mechanisms of obstacles in implementing BIM in prefabricated construction (Xu et al. [28]), and determining obstacles to the use of 4D-BIM in offshore construction projects (El-Habashy et al. [29]). In addition, Waqar et al. [30] examined the obstacles in applying BIM for risk management of high-rise buildings. Kineber et al. [31] conducted a study on what the difficulties are in applying BIM for sustainable construction projects. Okwe et al. [32] examined the barriers to the integration of BIM and facility management applications in Nigeria. Chan [33] surveyed Hong Kong's architecture, engineering, and construction (AEC) sector to evaluate obstacles to BIM implementation and the benefits that could be achieved. The majority of participants agreed that BIM technologies increase employee workload. In Jordan, Matarneh and Hamed [34] found that a lack of BIM awareness, government support, and promotion opportunities were the main challenges to adoption. Saleh [35] conducted a survey study in the Libyan construction industry, identifying inadequate BIM education, a lack of promotion and awareness, and shortcomings in understanding BIM benefits as barriers to implementation. Alhumayn et al. [36] found that employees lack motivation for BIM applications, and do not attend training sessions or see the need to improve themselves in this field. Park and Kim [37] emphasized the lack of necessary project data as a major obstacle in BIM applications. Chan [38] pointed out the current lack of secure infrastructure and internet support for BIM projects. Latifi et al. [39] stated that the most important barrier to BIM implementation is the human factor. This means employers, owners, or project managers are not motivated to use BIM, and are not interested in going beyond the ordinary due to a lack of awareness of BIM benefits. Gerges et al. [40] also stated that Middle Eastern countries lack sufficient knowledge about BIM applications, its benefits, and do not have enough motivation in this direction. Chien et al. [41] argued that the biggest obstacles to the adoption and use of BIM technology are insufficient knowledge on how to proceed in standard contracts, insurance policies, dispute resolution mechanisms, and other similar legal situations. Eadie et al. [42] found that one of the challenges is uncertainty in legal and contractual regulations. They also explained that changes in obligations and responsibilities during the transition from construction to facility management create uncertainties, which slow down BIM adoption due to the lack of legal regulations. Harrison and Thurnell [43] saw the lack of any contractual framework in the use of BIM for quantity surveying as a major shortcoming. They emphasized that this significantly hinders the use of BIM, and that reforms need to be made to increase its use. Olatunjı [44] emphasized that electronic documents in BIM are vulnerable to viruses, data theft, and hacking. Therefore, he suggested that new legal regulations are needed to prevent the damage caused by these factors. Omar [45] argued that the construction industry is resistant to new generation technologies, and this is a major obstacle to the adoption of BIM technologies. He suggested that the use of BIM should be made mandatory by the state. Ganah and John [46] stated that all types of contractors in the construction industry are lagging behind in adopting new generation technologies. Sun [47] emphasized that one of the important factors limiting BIM applications in the construction industry is the lack of qualified personnel who are familiar with BIM and have experience in using BIM. He stated that the rate of adoption of BIM technologies remains low due to the lack of personnel with sufficient knowledge, and that a large number of professionals need to be trained to popularize the use of BIM. Yan and Damian [48], in their study, found that the excessive budget spent on education to increase the use of BIM technologies and train qualified personnel slows down the rate of BIM adoption. In their study, Memon et al. [49] identified the difficulties in ensuring interoperability in BIM applications as one of the most important challenges. They explained these difficulties as a lack of sufficient information about what the organizational chart could be like in BIM projects, and also the development of a single software tool to meet the requirements of different areas. Goedert and Meadati [50] stated that there is not enough time for BIM use and implementation, and that time pressure in projects is a limiting factor.

Some studies have addressed ways to better implement BIM to mitigate the identified barriers. Porwal and Hewage [51] proposed the idea of making the use of BIM a mandatory requirement in public projects to facilitate the adoption of BIM in Canada. They emphasized that awareness can be raised in other construction companies and more information about BIM can be obtained. In 2019, Elhendawi et al. [52] proposed a model requiring the use of BIM in public projects in Saudi Arabia to encourage its adoption in other companies. Bui et al. [53] suggested that developing countries need to improve their security and internet infrastructure to fully embrace BIM applications. Sebastian [54] recommended mandating secure infrastructure in BIM models through contract conditions to eliminate security problems. Liu et al. [55] found that large BIM file sizes make it challenging to move, store, or share project data, and that the internet infrastructure is not yet sufficient to support BIM. Volk [56] highlighted the lack of comprehensive regulations or specifications on BIM, and suggested a thorough reconsideration of national building regulations to increase its usage. McAuley et al. [57] stressed that innovative applications like digitalization and BIM will strengthen the construction industry, necessitating the establishment of adequate standards to promote its use.

In the last decade, there has been a growing interest in studies on the effective design of BIM-based HVAC systems. Kiamili et al. [21] focused on the detailed environmental assessment of HVAC systems using BIM, and proposed an integrated method to perform a complete life cycle assessment. Wang et al. [22] proposed a BIM-based HVAC system design workflow. Gao et al. [23] proposed an approach that can theoretically integrate BIM with multiple building systems, such as HVAC control systems, local weather stations, and building façade monitoring. Also, Mokhtar [24] presented an experiment using a BIM tool to explain the interrelationships between HVAC system components and architectural elements to architecture students.

Although several studies addressed BIM in different aspects, there is still room for investigating BIM and HVAC together. There is a growing demand for buildings with more complex HVAC systems, but BIM use is limited. Therefore, it is of great importance to investigate the barriers to BIM implementation in the HVAC industry.

3. Research Methodology

In this study, quantitative research methodology was adopted to identify the barriers that affect the use of BIM technology in the HVAC industry. In addition, the study aims to understand these barriers' impact levels. The steps within the scope of this research are presented in Figure 2.

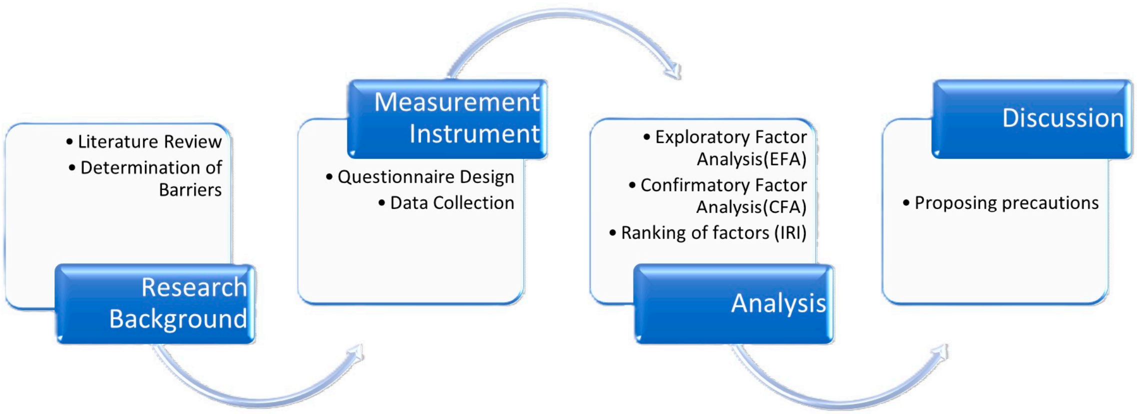

Figure 2. Flowchart of the study.

3.1. Determination of Barriers to BIM Implementation

First of all, the barriers that limit the use of BIM in different industries were examined with a comprehensive literature analysis. Later, common barriers mentioned in different studies were identified. The 16 selected barriers are shown in Table 1, and were accepted as independent variables for this research scale.

Table 1. Barriers to BIM implementation.

Barriers	References
The heavy workload of project designers	[25,33]
Lack of academic information and pilot studies, shortcomings in promotion	[26,34–36,51,58,59]
Lack of sufficient input data to create a BIM model	[37]
Lack of theoretical and practical practice of BIM tools	[52]
Lack of secure infrastructure in BIM models	[38,53,54]
Deficiencies in regulations, directives, and specifications about BIM	[34,56]
Lack of sufficient standards and guidelines about BIM	[57]
Insufficient internet infrastructure or open electronic data-sharing platforms	[38,53,55]
Lack of motivation on use of BIM by employers, owners, project managers	[26,34,36,39,40,59]
Lack of knowledge regarding legal issues attributed to BIM-based projects and contacts	[41–44,58]
Resistance to new generation technologies and changes	[45,46]
Lack of qualified staff	[34,47,57]
Necessity of extra budgeting for the use of BIM technologies and personnel training	[28,34,59]
Lack of information on BIM-based organizational scheme and project management	[40,49]
Time constraints	[50]
Insufficient cooperation and coordination among stakeholders on BIM use	[35,58]

3.2. Questionnaire Survey and Data Collection

A questionnaire survey was designed, based on the barriers identified in Section 3.1, as a tool to carry out the quantitative analysis of this study. The participants were selected from experts who work at design levels in HVAC projects and practitioners having valuable experience in relevant fields. According to data from the Turkish Statistical Institute [60] and The Union of Chambers and Commodity Exchanges of Turkey [61] approximately twenty thousand engineers and architects work in the Turkish HVAC industry. This number was accepted as the population for the study. The recommended sample size of a known population was considered according to Krejcie and Morgan [62], a frequently cited study in social sciences, and 224 participants working in 42 different companies were invited to contribute to the study. The questionnaires were distributed face-to-face to provide better results and ensure that the questions in the questionnaire form were well understood and answers were properly addressed. There were 160 valid questionnaire forms obtained, with a 71% response rate.

At the outset of the study, participants were queried about their demographic information, including age and years of experience in HVAC projects, which is shown in Figure 3. In addition, participants were asked to rate 16 identified barriers using a 5-point Likert scale based on their own project experiences. Additionally, they were asked about the percentage of their companies' budgets allocated to technological infrastructure, excluding direct production costs, such as research and development (R&D) and marketing. This information, which is presented in Table 2, was investigated to understand how much importance the HVAC firms give to technology. As BIM mainly depends on technological infrastructure, this information also provided crucial information regarding the degree to which BIM is valued in the HVAC industry.

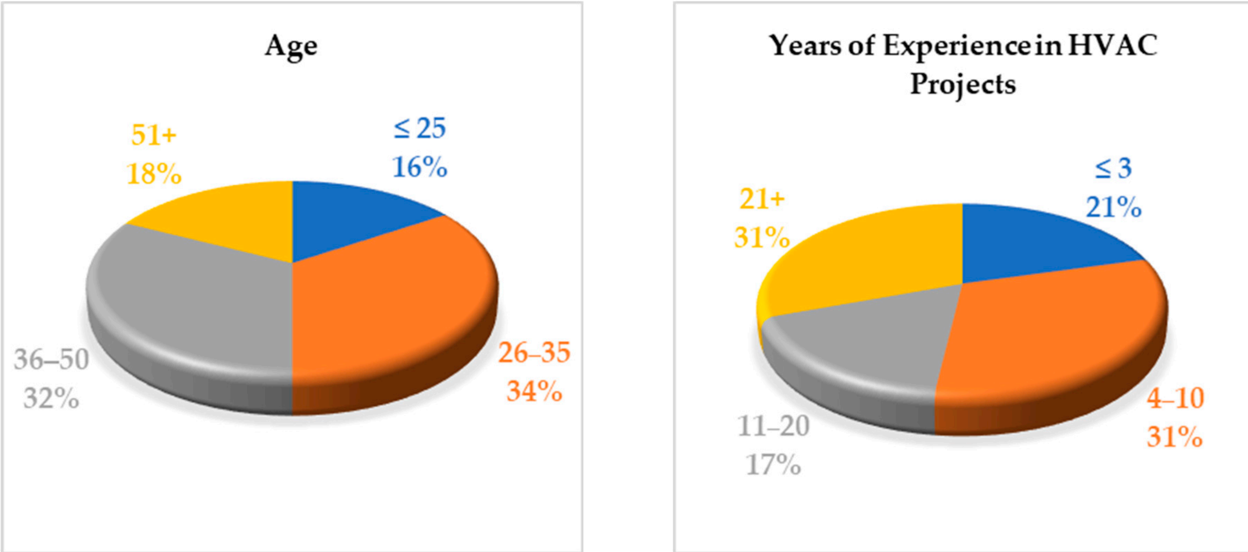

Figure 3. Demographic information about participants.

Table 2. Percentage of budget allocated for technological infrastructure.

Budget Allocated (%)	Frequency (f)	Percent (%)
0–20	44	27.5
20–40	52	32.5
40–60	36	22.5
60–80	21	13.1
80–100	7	4.4

3.3. Factor Structure and Data Analysis

It is crucial to ensure reliability and validity in surveys that utilize Likert-type scales before identifying the factor structure and beginning data analysis. In quantitative research, the Cronbach's alpha (Cα) value is widely used to evaluate reliability in social sciences [63–66]. The Cα value ranges from 0 to 1, and a value above 0.7 is considered sufficient for research purposes [67,68]. The methodological objectives of this study were to categorize the identified 16 barriers into certain groups and rank them based on their importance. To achieve these objectives, exploratory and confirmatory factor analyses (EFA, CFA), and index of relative importance index (IRI) calculations were adopted for this study. Factor analysis is a commonly used statistical technique to reduce larger variable sets to a fewer number of factor groups. There are two main methods used in factor analysis, namely exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). While EFA designs the structure of factor groups under which variables that do not have multiple relationships are be collected, CFA aims to verify the validity of this designed factor structure.

When conducting EFA, two measurement tools are commonly used to assess the suitability of the data set: the Kaiser–Meyer–Olkin (KMO) test and Bartlett's test of sphericity [69–71]. The KMO test evaluates the sample distribution's adequacy in relation to factor analysis, with a value of 0.7–0.8 typically considered satisfactory [72,73]. On the other hand, Bartlett's test assesses the correlation between the unit correlation matrix created based on the assumption that there should be no relationship between the variables and the correlation matrix created with the actual data [74,75]. If there is no similarity, it suggests that the variables are dependent on each other and can be grouped under the factor structure. Essentially, both tests measure the consistency of the data and variables used in initiating factor analysis.

During EFA, calculation methods were used to determine the appropriate variable categorization. Principal component analysis (PCA) is one of the key methods, which creates new variable sets by combining highly correlated variables [76–81]. This simplifies the multidimensional data set into a smaller number of variables. Meanwhile, eigenvalues were used to determine the number of factors and which variables belong to which factor group, indicating the variance that can be explained by artificial variable clusters [82,83]. Then, the rotation process is applied to identify variables with a strong relationship to the factors.

To assess the validity and consistency of the factor structure through EFA and CFA (confirmatory factor analysis), the accuracy of the factor structure was checked using set threshold values, such as χ^2/df, GFI, CFI, RMSEA, and NFI [84–86]. Each value was determined using AMOS vs. 18.0 software.

To determine the relative importance of each factor in the verified structure, the IRI (relative importance index) calculation was used [87,88]. IRI is a statistical measurement method that identifies the most important variables in a data set of independent variables. Each independent variable was calculated using Equation (1), as outlined by Zhao and C. [89]:

$$\text{IRI}(\%) = \frac{5(n_5) + 4(n_4) + 3(n_3) + 2(n_2) + (n_1)}{5(n_5 + n_4 + n_3 + n_2 + n_1)} \times 100 \tag{1}$$

The calculations in this study were performed using statistical software Statistical Package for the Social Sciences (SPSS) vs. 23.0.

4. Results

4.1. Analysis of Reliability and Validity

To ensure the reliability of the data set used in our study, we measured Cronbach's alpha (Cα), which was 0.821—indicating that the data set is suitable since it is greater than 0.7. We also calculated the Kaiser–Meyer–Olkin (KMO) and Bartlett's test of sphericity values to determine if the data set was appropriate for factor analysis. The KMO value, determined as 0.762, falls within the "good" range according to the literature. Additionally, the value obtained from the Bartlett test, 0.000 ($p < 0.05$), rejects the hypothesis that the variables are independent of each other, and confirms that the data set is convenient for creating factors.

4.2. Identifying Factors

For factor extraction in factor analysis, we chose the principal component analysis (PCA) method. Among the factors created, those with eigenvalues greater than 1 were preferred, since they explain the total variance the most. Figure 4 shows the total variance values explained according to the number of factors and the dots show the breakpoints for factor numbers.

We chose the frequently used varimax rotation method as the rotation process. As a result of these operations, we obtained a total of 4 factor clusters, and 13 of the 16 variables determined at the beginning were collected under these clusters. Three variables whose factor loadings were insufficient or could not establish a meaningful relationship with any factor cluster were excluded from the evaluation. Thus, the headings of the four factors were determined as follows: lack of documentation and specifications (F1), lack of motivation and resistance to BIM (F2), deficiencies of drawings and models (F3), deficiencies of infrastructure, and lack of qualified personnel (F4). The new factor headings and the factor loadings of the variables gathered under these factor groups are presented in Table 3.

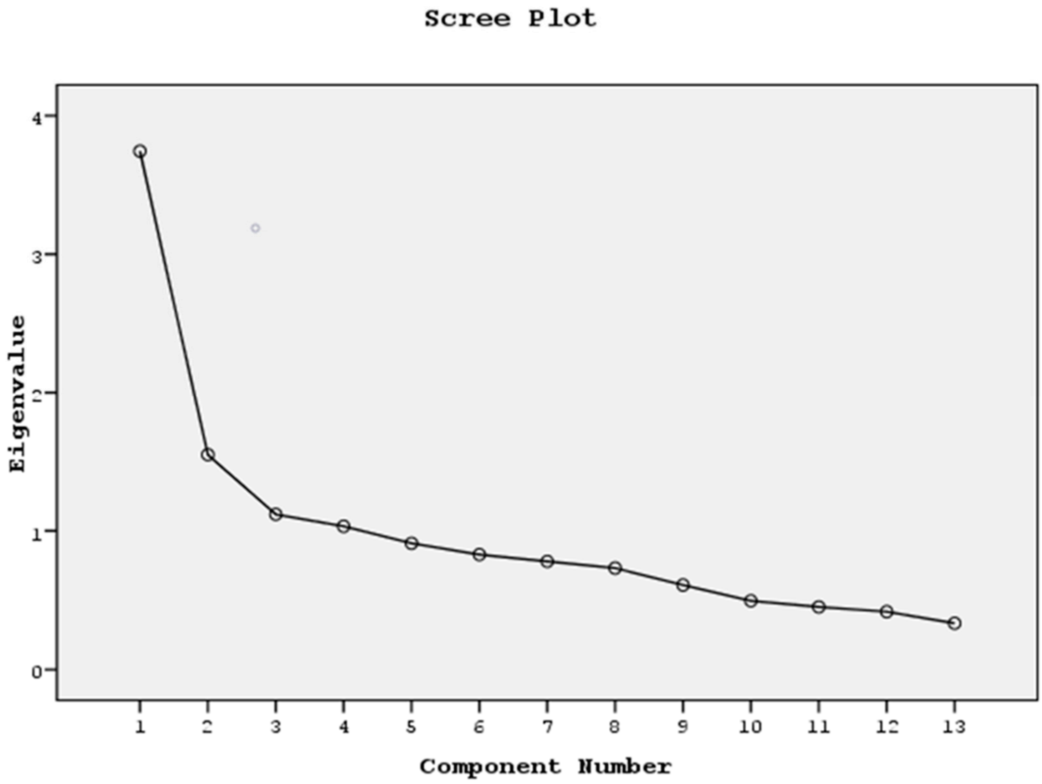

Figure 4. Scree plot for eigenvalue and factor numbers.

Table 3. Factor definitions and loadings.

	Factor	Items Code	Item Name	Factor Loadings	Eigen Values	% of Variance	Cronbach's Alpha (Cα)
Factor I	Lack of Documentation and Specifications (LDS)	LDS1	Lack of academic information and pilot studies, lack of promotion	0.689	3.761	28.94	0.807
		LDS2	Lack of sufficient input data to create a BIM model	0.722			
		LDS3	Deficiencies in regulations, directives, and specifications about BIM	0.688			
		LDS4	Lack of sufficient standards and guidelines about BIM	0.641			
Factor II	Lack of Motivation and Resistance to BIM (LMR)	LMR1	Lack of motivation on use of BIM by employers, owners, project managers	0.635	1.551	11.93	0.773
		LMR2	Resistance to new generation technologies and changes	0.744			
		LMR3	Insufficient cooperation and coordination among stakeholders on BIM use	0.617			
Factor III	Deficiencies in Case Studies and Project Drawings (DCP)	DCP1	Lack of theoretical and practical practice of BIM tools	0.777	1.145	8.81	0.785
		DCP2	Lack of information on BIM-based organizational scheme and project management	0.829			
Factor IV	Deficiencies in Infrastructure and Lack of Qualified Personnel (DIP)	DIP1	Lack of qualified staff	0.708	1.038	7.98	0.709
		DIP2	Necessity of extra budgeting for the use of BIM technologies and personnel training	0.797			

4.3. Confirmation of Factor and Model Analysis

CFA was conducted to measure and verify the quality of the factor model created in the previous section. It is necessary to compare the fit indices calculated with those recommended in the literature. The results and reference values are presented comparatively in Table 4, which shows that all of the calculated values met the criteria of recommended good fit values. This confirmed that the quality of the proposed factor model, which is shown in Figure 5, is at a sufficient level.

Table 4. Comparison of fit indices.

Fit Indices	Calculated Indices	Recommended Values
Chi-square/Degree of freedom (CMIN/DF)	1.121	<2.50
Root mean square residual (RMR)	0.053	<0.10
Goodness of fit index (GFI)	0.956	<1.00
Adjusted goodness of fit index (AGFI)	0.913	<1.00
Comparative fit index (CFI)	0.987	<1.00
Normed fit index (NFI)	0.897	<0.95
Relative fit index (RFI)	0.826	<0.90
Root mean square error of approximation (RMSEA)	0.028	<0.05

4.4. Ranking of Factor Groups

The identified factors and factor groups were ranked according to their importance through the IRI calculation. The average IRI values and the list of factors are presented in Table 5. The results show that the deficiencies in infrastructure and lack of qualified personnel (DIP) factor group has a significantly greater degree of importance than other factors. Then, the lack of documentation and specifications (LDS), deficiencies of case studies and project drawings (DCP), and lack of motivation and resistance to BIM (LMR) factor groups follow, as shown in Figure 6.

Table 5. IRI rankings.

	Factor	Items Code	Overall IRI(%)	Average IRI(%)	Rank of Factor
Factor I	Lack of Documentation and Specifications (LDS)	LDS1	68.62	69.96	2
		LDS2	70.50		
		LDS3	71.12		
		LDS4	69.62		
Factor II	Lack of Motivation and Resistance to BIM (LMR)	LMR1	67.50	66.83	4
		LMR2	66.75		
		LMR3	66.25		
Factor III	Deficiencies in Case Studies and Project Drawings (DCP)	DCP1	66.62	68.24	3
		DCP2	69.87		
Factor IV	Deficiencies in Infrastructure and Lack of Qualified Personnel (DIP)	DIP1	77.75	77.12	1

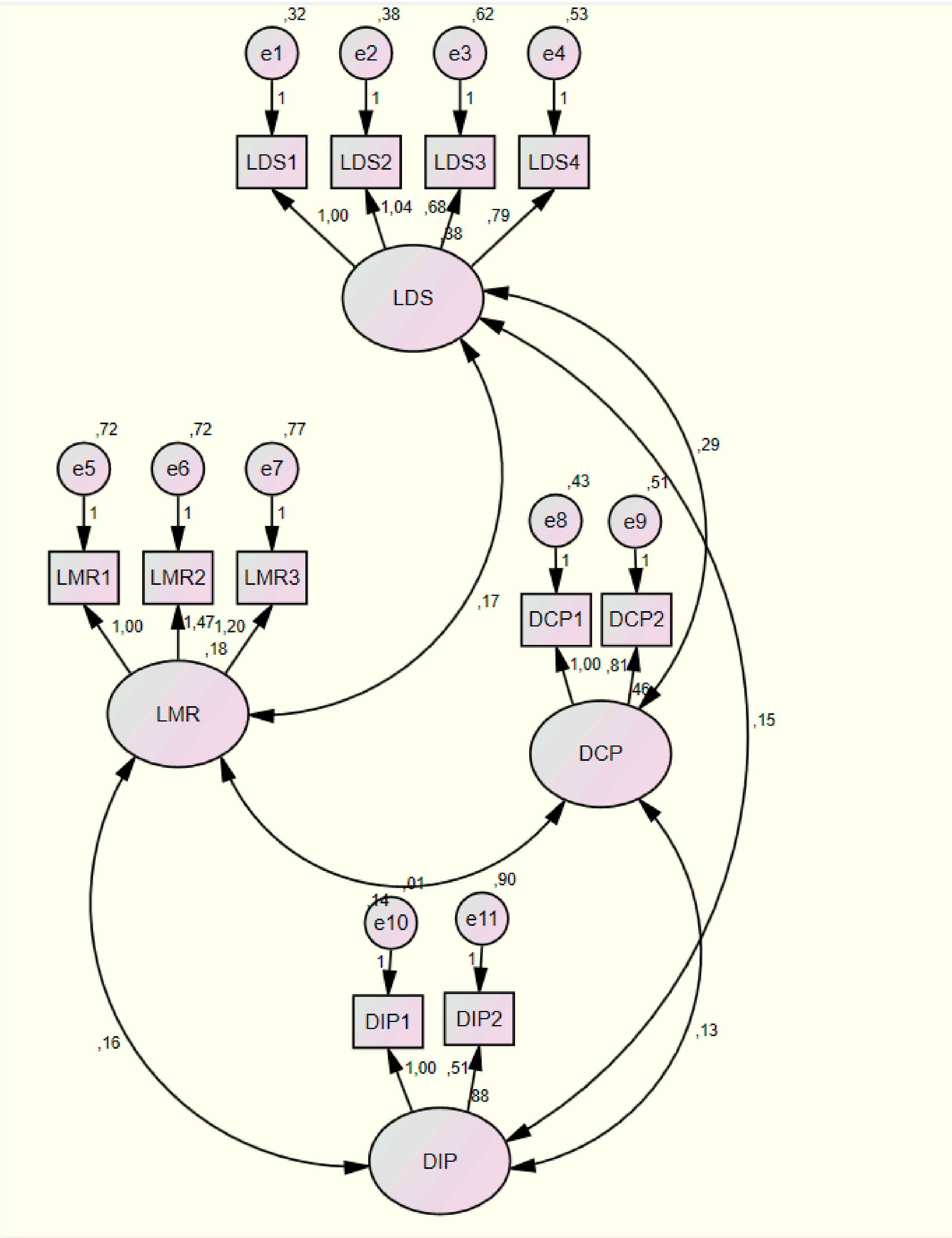

Figure 5. Factor structure of confirmatory factor analysis.

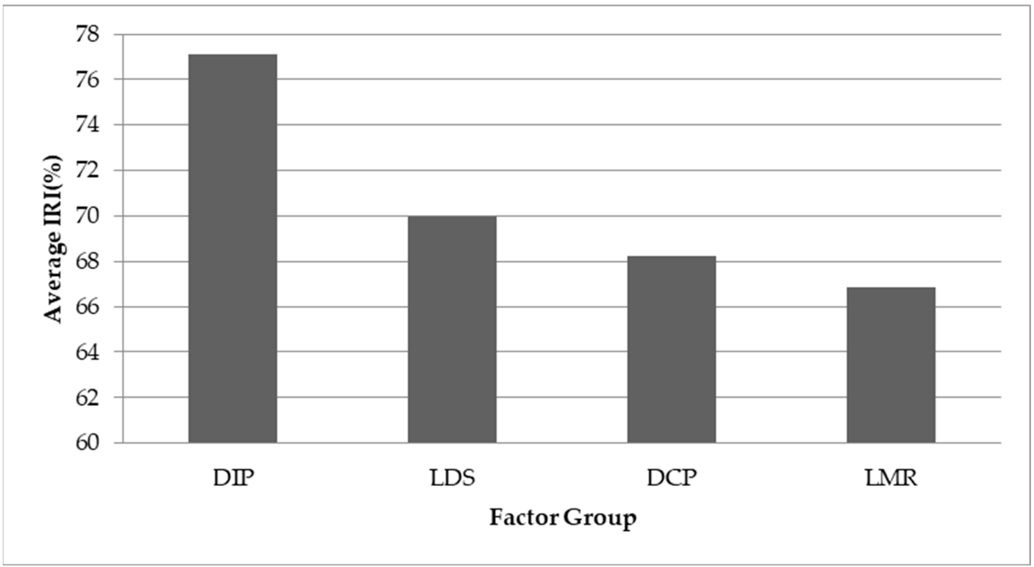

Figure 6. Average IRI vs. factor groups.

5. Discussion

In the last decade, various factors such as urbanization, industrialization, population growth, food security, and the COVİD-19 pandemic have led people to spend more time indoors. This has resulted in an increased demand for residential and office buildings with higher volumes and better air conditioning systems. As a result, there has been a growing interest in designing more complex HVAC systems. Building information modeling (BIM) has emerged as a powerful tool for overcoming the challenges of these complex project processes. However, the use of BIM in HVAC projects is not yet widespread due to several barriers. During the life cycle of HVAC systems, various malfunctions and problems may arise. Facility management plays a crucial role in solving HVAC-related issues, ensuring the satisfaction of building occupants, and safeguarding their health. However, modern HVAC systems are intricate, and determining the root cause of a problem can be challenging. HVAC technicians need to gather facility-specific information to identify the actual cause, as current practice lacks a systematic approach to determine what specific information to check. BIM can help record all maintenance information [90].

A large number of studies have shown that the primary obstacles to the adaptation of BIM in construction projects are a lack of motivation to use BIM by employers, owners, and project managers, and a lack of awareness of BIM. Nonetheless, this research has argued that a shortage of qualified technical staff is the most significant barrier to the adaptation of BIM in the HVAC industry. This may be sourced by the necessity to know about a large number of devices, equipment, auxiliary instruments, different fasteners, and complex installation details. This shortage of technical personnel leads to a lack of detailed and BIM-compatible as-built drawings and technical sheets for all devices, especially among small and medium-sized HVAC equipment manufacturers and application subcontractors. In addition, there is a problem with incresing the BIM capabilities of technical staff. Several studies have also highlighted lack of motivation and resistance to BIM [91–94]. BIM, which is a leading factor in increasing the production and efficiency [95], is more complex than traditional CAD software. As a result, the adoption of BIM technology is a complex issue and can not be always easily integrated [96,97]. Therefore, there is a need to provide BIM training in schools, especially in departments that train designers. Offering courses that support teamwork will also help students enter their professional lives with a BIM culture and enable them to work on projects together. This will provide project designers and practitioners with a suitable perspective on BIM systems at an early stage, and prevent the formation of negative attitudes towards BIM. Being aware of the benefits of BIM is crucial for constructing high-quality buildings. Research by Hauashdh et al. [98] showed that approximately 17% of total defects in buildings are caused by problems with HVAC systems, particularly system installation. Moreover, they argued that the use of BIM in project design can significantly reduce these defects. Furthermore, BIM contributes to sustainability. Alhamami et al. [99] pointed out that applying BIM can significantly reduce energy use, making it an ideal tool for sustainable building practices. Meanwhile, BIM technology has the potential to break down traditional barriers between industry stakeholders and facilitate the sharing of project information in a single model in collaborative environments [100]. However, stakeholders must first understand their role in the project team and transform their work processes to align with the requirements of BIM applications. This will necessitate changes to design processes, file organization, customer charges, and final results; hence, construction firms require adequate time to adapt to these changes [47,97].

The findings of this research indicate that 60% of participants' companies allocate less than 40% of their budgets to technological infrastructure. The limited number of companies with the necessary technological infrastructure and budget for BIM implementation also slows down its adoption in the HVAC industry, despite its benefits [101]. Aladağ [102] addressed digital transformation practices in the Turkish construction industry, and stated that companies generally tend to perform benefit–cost analyses when deciding on investments in digital technologies, and investment decisions are made based on the potential payback period of the investment. The low rate of Turkish HVAC firms' tendency to invest technological infrastructure can be attributed to longer payback periods and incorrect feasibility studies on the benefits and costs of digital transformation.

This research also discovered that a lack of documentation and specifications is a significant obstacle to BIM utilization in the HVAC industry. To address this issue, HVAC manufacturers and software developers should incorporate three-dimensional smart objects, detailed guidelines, and BIM software visuals into their product catalogs and websites, which should be freely accessible to everyone. This will not only facilitate the designing of HVAC systems via BIM, but also boost the sales of companies, as the integration of their products into projects will increase demand for their offerings. However, introducing guidelines and ensuring all stakeholders comply with the standards are not easy tasks. Therefore, guidelines should be prepared by involving diverse groups in the HVAC industry, and training should be organized for different roles, including contractors, clients, and subcontractors. BIM could become a trending issue, and this can lead to incorrect implementation, which may result in cost overruns and delays in HVAC projects. BIM implementation requires a significant amount of input data, which can be overwhelming for the average designer. This is particularly critical in HVAC project design, where accurate calculation of the building's thermal properties and correct data entry are crucial. All of the required information must be present and accurately entered for the thermal analysis to be precise. This is one of the reasons why the use of BIM is not widely welcomed. Shortcomings in documentation and specifications also make sustainable implemenatation difficult. Developing a reliable energy model for older residential buildings can be a challenging and time-consuming task, particularly as many of these buildings lack adequate documentation. However, with Europe's ambitious decarbonization targets requiring the renewal of this building stock, energy assessment has become a key priority. In line with this goal, BIM may play a crucial role. Converso et al. [103] showed the benefits of BIM in energy models. They carried out a study using Google Maps and various BIM-based programs to remodel three residential buildings with different climatic conditions and construction periods, resulting in the creation of a building energy model (BEM).

Shortcomings in case studies, technical drawings, and detailed product information are often responsible for problems that surface during construction, which result in delays, increased costs, and reduced quality. To mitigate these issues, it is recommended that small and medium-sized manufacturers become educated on the impacts of these losses and encouraged to train their personnel in this field. With a greater number of technical experts, it will be easier for them to create comprehensive BIM libraries for all HVAC products, streamlining the installation and completion of designs for implementing companies.

The findings of this study are crucial for future research on BIM and other technologies in the HVAC industry. Prospective research that expands the study by enlarging the sample and involving more countries may yield better results. This research only utilized a quantitative survey. More research, which may mix quantitative and qualitative surveys would yield more representative outputs. Despite these limitations, this study is important for highlighting potential barriers in the HVAC industry, particularly in developing countries. Since Turkey is one of the developing countries and Turkish contractors work in several countries, the findings of this study are valuable for identifying the most critical barriers in the HVAC industry in any country.

6. Conclusions

Widespread adoption of BIM technologies has proven important in overcoming challenges regarding resource scarcity, climate change, and environmental protection. In Turkey, BIM is primarily utilized in complex and large-scale designs such as high-performance buildings and airports. To maintain its position in the construction industry, Turkey should overcome the obstacles hindering the increased implementation of BIM by increasing knowledge and usage. This study aims to identify barriers to the widespread use of BIM technology in the HVAC sector in Turkey, and develop solutions to increase BIM applications in HVAC projects. The barriers limiting BIM usage in various sectors were identified through a comprehensive literature analysis, and a questionnaire study was conducted to provide quantitative analysis. A face-to-face survey was administered to 224 participants from 42 different companies comprising experts working in HVAC project design and practitioners with related experience, yielding 160 reliable responses. The results indicate that the "Deficiencies of Infrastructure and Lack of Qualified Personnel (DIP)" factor group constituted the most significant barrier, followed by "Lack of Documentation and Specifications (LDS)", "Deficiencies of Case Studies and Project Drawings (DCP)", and "Lack of Motivation and Resistance to BIM (LMR)". Moreover, our research revealed that 60% of the participants' companies allocate less than 40% of their budgets to technological infrastructure, which hinders the adoption of BIM. To accelerate the transition of the building industry to BIM technology, a feasible strategic roadmap should be developed. Investment costs for BIM applications can be prohibitively high for small and medium-sized enterprises. Developing subsidies and incentives for BIM use could be beneficial in this context. Additionally, incorporating BIM into AEC education curricula will contribute to BIM development in Turkey.

The use of BIM technology in the HVAC industry is increasing in popularity. While BIM is widely used for standard systems, it can prove challenging for specialized and industrial projects. Due to the complexity of HVAC systems, which involve multiple projects and tasks such as heating–cooling, ventilation, and electricity, BIM has become essential in the industry. This is particularly true for large facility installations where BIM can simplify the work of construction personnel and reduce the duration of construction items. Additionally, the accurate control of material purchases enabled by BIM can reduce installation and transportation costs. BIM can also identify and solve problems related to conflicting projects during the planning stage, minimizing errors during installation.

It is important to identify the primary obstacles to implementing BIM in the HVAC industry, and recommend solutions to make BIM applications more widely used in HVAC projects. Although BIM applications have great potential to benefit HVAC projects, its use is limited. Many of the barriers, which are commonly mentioned in the literature as hindering the use of BIM in other types of projects, also apply to HVAC projects. However, our research revealed that certain factors are more dominant in HVAC projects, such as inadequate infrastructure and a shortage of qualified personnel. Due to the unique characteristics of HVAC projects, which often involve many project-specific, specialized, and unprecedented items, it can be challenging to encourage designers and practitioners in the HVAC industry. Eliminating the lack of technical personnel will contribute to the solution of a significant part of the problem. Increasing the capability of BIM usage through education and training is the priority for overcoming this challenge. Universities should offer courses on modeling projects with BIM-based programs, and project stakeholders should receive training on teamwork with BIM. However, the cost of BIM training can be a concern for engineers and architects. To address this, chambers of engineers and architects can offer lower-fee courses, and companies can provide financial support for their employees. Ultimately, investing in BIM education and training can lead to higher productivity and better risk management outcomes. On the other hand, there are some limitations in BIM training due to its limited scope. BIM training often fails to address large-scale infrastructure projects and instead focuses mainly on buildings. To address this issue, it is essential to select training content and educators with a broader perspective. To overcome the shortage of technical personnel and increase the adoption of BIM-based programs in projects, public and private sector leaders must recognize the necessity and benefits of using BIM. Progress on these fronts can only be made if funding is available, which cannot be achieved through employee efforts alone. To ensure this, municipalities that carry out drawing inspections can encourage firms to submit BIM-based drawings by making discounts on the fees they will pay. Thus, public bodies can prevent time and cost losses by enabling efficient project delivery systems. This may considerably minimize errors and deficiencies in public projects.

Additionally, the lack of documentation and specifications are also crucial barriers to the adoption of BIM in HVAC projects. Insufficient documents and shortcomings in sample drawings and specifications may also hinder the implementation of BIM in HVAC projects. According to the findings of this study, identifying obstacles to BIM adaptation in HVAC projects and incorporating solution suggestions during the design process can greatly improve project outcomes in terms of meeting time, cost, and quality targets. As both HVAC and BIM technologies continue to advance, further research could explore additional factors for the proliferation of BIM systems.

While BIM primarily involves architectural and structural systems, it is crucial to consider other systems such as HVAC and electrical systems, which pose unique challenges and benefits. To further advance BIM, it is recommended to research the complexities of modeling HVAC and electrical systems together with BIM, and even modeling these two systems jointly with the carrier system.

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