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Evaluating the Impact of Building Information Modeling (BIM) on Mass House Building Projects

Hadi Sarvari [1,*], Daniel W. M. Chan [2], Mansooreh Rakhshanifar [3], Nerija Banaitiene [4] and Audrius Banaitis [4]

1 Department of Civil Engineering, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan 81595-39998, Iran
2 Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China; daniel.w.m.chan@polyu.edu.hk
3 Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor, Skudai 81310, Malaysia; rmansooreh2@live.utm.my
4 Department of Construction Management and Real Estate, Vilnius Gediminas Technical University, Sauletekio al. 11, 10223 Vilnius, Lithuania; nerija.banaitiene@vgtu.lt (N.B.); audrius.banaitis@vgtu.lt (A.B.)
* Correspondence: h.sarvari@khuisf.ac.ir; Tel.: +98-901-727-7879

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Abstract: This paper aims to identify and investigate the factors affecting the goals of mass-housing building projects due to the use of building information modeling (BIM). A descriptive-survey method was used to collect necessary data. Fifty respondents from the target sectors and experts in the field of modeling building information participated in self-selection survey. The tools of collecting data included three questionnaires regarding three phases of construction work: pre-construction, during construction and post-construction, which were developed based on the three indices of cost, time and quality. The face, content and construct validity of the questionnaires were confirmed after several rounds of testing. The reliability coefficient of the pre-construction, during the construction and post-construction questionnaires were 0.923, 0.917 and 0.876, respectively. The results show that the F-statistic is significant for the difference between the three groups (pre-construction, during construction and post-construction) at the 0.01 level. The results confirmed that BIM has a great influence on a project in terms of meeting time, cost and quality objectives through the whole life cycle of a construction project: during pre-construction, construction, and post-construction stages.

Keywords: building information modeling; mass house building project; quality; cost; time

1. Introduction

Housing is one of the most basic human needs. Humans have always been struggling with housing problems, and have always tried to do it in a suitable and sensible way. Huge destruction after world wars resulted in a massive and urgent need for new housing in Europe. Indeed, housing has always been one of most important priorities in government for the creation of sustainable employment and social-economic stability. Different approaches were used in an attempt to solve the housing issues. One of the methods—construction of mass housing—was used to address housing shortages in the post-war period [1]. Today, in most developing countries, access to adequate, safe and affordable housing is more essential than ever, especially among low-income groups [2,3]. Housing problems include physical problems (overcrowding in facility and structural deficiencies) and affordability problems [4,5]. Mass housing development could be a desirable model for developing countries in order to tackle emerging challenges in the provision of adequate housing [6–10]. Mass housing is a model of construction that has high-economic, -technical and -managerial feasibility [11–13]. Mass housing is based on the standardization of parts, components, systems and modules, and on the systematization of processes [14]. This concept has the potential for solving certain economic and social problems as well as technical challenges. Prefabricated building elements are created off-site in a controlled manufacturing environment and follow specified standards, wherefore the sub-assemblies of the structure can be built to a consistently high, uniform quality. At the same time; however, prefabrication and off-site construction requires more coordination and planning during the design phase, forcing the construction professionals to make earlier decisions, and have better communication and collaboration to avoid costly design changes [15,16]. In addition to the construction benefits and financial savings, prefabrication helps improve sustainability in construction and provides environmental benefits [17].

The housing market and housing construction in various economies have served as an engine of growth [7]. The use of new technologies in mass housing brings the potential for efficiency in project delivery in terms of time, cost and quality; in addition, safety, sustainability, energy efficiency and environmental goals are realized. Building information modeling offers the potential to achieve these goals [18]. According to the National Institute of Building Sciences [19], building information modeling (BIM) is "a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition".

The activities of the construction industry have great significance in relation to the achievement of the national socio-economic development goals of providing shelter, infrastructure and employment [20–23]. Bon [24] notes that construction activity has a global dimension, with activity spilling over from advanced economies, with high levels of capital, to emerging and developing market contexts. While the construction sector is a key driver of the overall economy, it faces numerous challenges relating to competitiveness, labor shortage, resource efficiency and productivity. BIM is an innovative technology influencing productivity, as well as enhancing design, construction and project management [25,26]. Adoption of BIM assures construction quality, safety and environmental friendliness [27,28]. Therefore, it has been widely noted that BIM's capabilities are enhancing operations and facility management [29], as well as the integration the life cycle assessment (LCA), help to reduce resource consumption and environmental impact [30].

Building information modeling facilitates collaboration throughout the entire life cycle of the project. BIM improves communication and information management due to more efficient exchange and updates of project data. Project participants need to collaborate using BIM-based processes and procedures. However, collaboration utilizing a BIM system needs efforts from all members from the initial stages. The collaboration of different stakeholders within the project is based on principles that include trust, transparency, efficient communication, open information sharing, risk-taking, equal reward, value-based decision making and the use of all technological and support capabilities. Finally, BIM offers the potential to produce a high-quality and performing construction project, faster and cheaper, along with reducing errors and the waste of time and cost.

The decision about BIM use is more a commercial and operational aspect [31]. Protecting or improving the competitive position in the labor market, and aligning and strengthening business activities, are among the reasons why business executives generally decide to use BIM system. To succeed using the BIM system, the necessary arrangements corresponding to compatibility and community culture in the framework of a transformation strategy should be considered. Although the potential benefits of BIM are quite evident, there are some barriers and challenges to the implementation of BIM in construction to overcome. Despite BIM having considerable potential for enhancing sustainability and effectiveness in all stages of a construction project, BIM application in construction requires additional investment in new technologies and training, and the development of new ways of collaboration [32]. In addition, BIM implementation changes the values towards collaboration, cooperation and client/end-user engagement [33,34]. BIM use has a great potential to improve the design and construction of project. However, BIM is not yet the universal standard in the construction industry; thus it is possible that construction partners are not utilizing BIM software and; therefore, will not be able to use BIM models [35]. Implementing new technologies, such as BIM, is costly in terms of training and changing work processes, as well as investment into software and hardware [36]. BIM implementation is not as advanced in most developing countries, perhaps because it requires additional investments, training and support efforts of all project partners.

Governments across Europe and around the world are recognizing the value of BIM as a strategic enabler for cost, quality and policy goals [37]. BIM is becoming the standard amongst countries such as the United Kingdom [38–40], the United States [39] and Scandinavian countries such as Norway, Denmark and Finland [41]. However, BIM technology is not used so much in Iran; what is visible is the scattered and non-integrated use of modeling software. This study seeks to fill the existing research gap in the field by investigating the factors that influence the goals of mass housing projects using BIM. Though BIM plays a very important role in managing the cost and time of construction projects, and reducing rework, usage of this technology in mass production can make the housing industry professionals more interested in implementing BIM. Moreover, since construction project success is measured in terms of time, cost and quality, the use of BIM may affect the success of construction projects. Thus, taking into account the added value of BIM, Iranian construction professionals should pay attention to this issue swiftly and with greater awareness, as, using BIM, they can improve the quality of design, construction and operation, can save time and money, can reduce energy consumption, and can even improve workplace safety. Given the content listed above, the purpose of this study is to investigate and analyze the factors affecting the goals (cost, time and quality) of mass housing projects due to the use of BIM, and to answer the question: How does building information modeling affect the achievement of mass housing project goals?

2. Research Method

This research is descriptive in nature and applied in terms of the goal. In this study, which aimed to investigate the factors affecting the goals of mass housing construction using BIM, the accessible population comprised the experts from the government and executive bodies, consultants and contractors from the private and semi-government sectors in Iran, which related with construction projects. In addition, the experience and expertise in the area of building information modeling (BIM) were required. The research strategy is based on the insignificance of the representation of the statistical population number by indirect sampling and self-selectivity methods. Therefore, 50 experts were selected as the statistical sample, which is independent from the original sample and can be analyzed statistically.

The questionnaire was designed and developed within the framework specified by the researcher in two sections: general questions and specialized questions. The general questionnaires attempted to collect general and demographic information about the respondents, including questions about the gender, age, education, experience of the respondent and job title. In addition, the questions regarding the use of BIM in construction projects were discussed:

Have you ever used BIM in your projects?

What percentage of projects have you used BIM so far?

The main questions of the questionnaire include three sections: pre-construction, during construction and post construction questionnaire. Three questionnaires were prepared with 33 pre-construction items, with 23 during construction items, and with 14 post-construction items in terms of cost, time and quality indices. The questionnaire used in this study was designed reviewing the literature and interviewing the experts in the field. In this questionnaire, the subject can select grades 1 to 5 based on the Likert scale depending on the type of question. Table 1 represents the distribution of questions in all of the questionnaires according to indicators.

Content validity, face validity and validity of the questionnaire structure were confirmed using Kaiser-Meyer-Olkin (KMO) and Bartlett's test. The respondents to the validity test were selected based on their level of knowledge and experience in BIM applications in projects (with different sizes) among construction experts and academics, and were asked to validate data regarding time, cost and quality in three questionnaires. KMO is an indicator of sampling adequacy ranging from zero to one. If the index value is close to one, the data are suitable for factor analysis. KMO for all questionnaires and indicators are acceptable as shown in Table 1.

Table 1. Distribution of questions in the questionnaire and the Kaiser-Meyer-Olkin test results.

Questionnaire	Indicators	Number of Questions	KMO
Pre-construction	Time	10	0.781
	Cost	5	0.643
	Quality	18	0.740
During construction	Time	8	0.686
	Cost	3	0.753
	Quality	12	0.796
Post-construction	Time	2	0.500
	Cost	2	0.500
	Quality	10	0.738

The Bartlett's test examines when the correlation matrix is known mathematically and; therefore, is inappropriate to identify the structure (loading model). If the significance level in the Bartlett's test is less than 5%, factor analysis is appropriate to identify the structure because it is assumed to be known. The correlation matrix is rejected. The factor loadings in the entire questionnaire were all above (0.3). The stability coefficient of questionnaire in pre-construction (0.923) and indicators of cost in pre-construction (0.722), time in pre-construction (0.839), quality in pre-construction (0.844); the stability coefficient of the questionnaire during construction (0.917) and indicators of cost during construction (0.769), time during construction (0.778), quality during construction (0.885); and the stability coefficient of the questionnaire in post-construction (0.876) and indicators of cost in post-construction (0.744), time in post-construction (0.818) and quality in post-construction (0.833) were estimated.

Different statistical tests are used to analyze the data. In order to provide a good interpretation of the data, descriptive analyses were conducted to investigate the statistical population under study. The purpose of this analysis was to evaluate the demographic spectrum of the sample under study. In order to obtain a complete view of the subjects in a descriptive view, data were analyzed by SPSS software (version 25) using descriptive statistics, such as frequency, percentage, mean and standard deviation and inferential statistics using the Kolmogorov–Smirnov test. The use of repeated measures covariance analysis was examined. Multivariate analysis of covariance (MANCOVA) and repeated measurements were performed using SPSS software. The factors influencing the objectives of the mass housing projects due to the use of BIM are presented in Table A1 (see Appendix A). These factors were identified through a comprehensive literature review and discussions with subject-matter experts.

3. Survey Findings

In this part of the study, the research data collected through questionnaires are analyzed and discussed. At the beginning of the discussion, descriptive analysis of demographic data included: Gender, age, education, work experience, job title, BIM use in the project, percentage of BIM use in the project, limitations of not using BIM in the project and preference for using BIM in the project. The sample members of the statistical population are presented in Table 2. The rest of this section covers the examination of the research questions.

Table 2. Respondent data.

Basic Information	Question	Frequency	Percentage
Education	Diploma	1	2%
	Bachelor degree	20	40%
	Master degree	22	44%
	PhD	7	14%
Work experience	Below 10	15	30%
	10 to 20	30	60%
	Over 20	5	10%
Job title	Project drafter	10	20%
	Senior project consultant	2	4%
	Project manager	7	14%
	Contractor/client	11	22%
	Lecturer	6	12%
	Others	14	28%
Experience in BIM * implementation	Yes	20	40%
	No	30	60%
Share of BIM use in projects	Below 20%	36	72%
	20% to 35%	4	8%
	35% to 50%	5	10%
	Over 50%	5	10%

* Building Information Modeling (BIM)

To examine the research question, multivariate analysis of covariance (MANCOVA) and repeated measurements were used. In order to use covariance analysis and repeated measures as parametric methods, the underlying assumptions must be met. These causal assumptions are necessary for the conclusion and interpretation of the results. For multivariate analysis of covariance (MANCOVA), five assumptions (first four are needed for repeated measures) were tested:

1. Having a minimum distance of measurement scale;
2. Independence of observation;
3. Normal distribution of data;
4. Homogeneity of variance–covariance matrix of subject groups;
5. Homogeneity of regression slope (for covariance analysis).

Having a minimum distance of measurement scale—Regarding the measurement method used in this study and not considering the absolute zero, it can be said that the variables were measured on interval scale and the first assumption is established.

Independence of observation—Because the questionnaires (pre-construction, during construction and post-construction) used in the research were distributed separately, and respondents were not aware of each other's answers. We can say that the participants in the research did not influence each other's perceptions, and all observations were done independently. Therefore, the second assumption is established.

Normal distribution of data—To test the assumption about the normal distribution of data, a single-sample Kolmogorov–Smirnov test was used for the variables of the subject groups (pre-construction, during construction and post-construction).

As shown in Table 3, single-sample Kolmogorov–Smirnov test statistics were not significant in all three groups (pre-construction, during construction and post-construction) at the level of 0.05. Therefore, it can be concluded that the distribution of data is normal at all stages.

Table 3. The Kolmogorov–Smirnov test results.

Research Variables	Test Statistic	Significance Level	Error Value	Confirmation of Assumption	Normal Distribution
Pre-construction	0.586	0.822	0.05	H_0*	Yes
During construction	0.793	0.556	0.05	H_0	Yes
Post-construction	0.934	0.348	0.05	H_0	Yes

* H_0: The data distribution is normal

Homogeneity of variance–covariance matrix of subject groups—According to Table 4, the result of the Box's M test at the level of 0.05 was not significant, and the fourth assumption is verified. Therefore, we can say that there is no significant difference between covariance matrices of the three groups (pre-construction, during construction and post-construction), and it is established assuming homogeneity of the within-group covariance matrices.

Table 4. The Box's M test results.

Test Statistic	*F* Statistic	Degree of Freedom 1	Degree of Freedom 2	Significance Level
10.257	1.653	6	69,583.698	0.128

Homogeneity of regression slope—As can be seen in Table 5, for comparing of the performance of cost, time and quality indicators in pre-construction, during construction and post-construction groups, the probability of accepting zero assumption is greater than 0.05 (sig = 0.14). Therefore, the assumption of homogeneity of regression slopes was confirmed.

Table 5. The test results of the effect between the subjects (the dependent variable in pre-construction, during construction and post-construction).

Sources Change	Sum of Squares	Degree of Freedom	Average of Squares	*F* Statistic	Significance
Groups	0.81	2	0.81	4.89	0.03
Groups' indicators	0.37	4	0.37	2.27	0.14
Error	4.31	294	0.16		

Research Question Test

Research question—What is the effect of building information modeling on the achievement of mass housing project objectives?

An analysis of covariance (MANCOVA) and repeated measurements were used to answer the research question. Before examining the research question, we need to consider the effect of independent variable that causes a change in dependent variables. If this effect is significant, it is possible to examine the effectiveness of cost, time and quality indicators in each of the dependent variables in pre-construction, during construction and post-construction group.

According to Table 6, the rate of *F* statistics is related to the Pillai's trace, Wilks' lambda and Hotelling's trace tests, and the largest root growth is significant at 0.01 levels ($p \leq 0.000$, $F = 97.834$). The effect size obtained by each of the four tests is given in the last column of Table 4. To calculate the effect size, the coefficient of eta squared (η^2) was used. The effect size index $\eta^2 = 0.573$ indicates that 57% of the variance will be explained after the tests of the dependent variables by the difference between the groups resulting from BIM. The effect of total interventions made by cost, time and quality indicators on the dependent variable (pre-construction, during construction and post-construction) was significant. Therefore, we can conclude that a 99% probability of the interventions completed (taking into account the initial differences in the three groups of subjects) cause a significant difference in the dependent variables (pre-construction, during construction and post-construction), and these interventions are effective. Since the differences are significant in the multivariable analysis, so, in the following, we can review the differences of indicators in each of the dependent variables separately.

Table 6. Multivariate analysis of variance tests to compare the post-tests of three groups (pre- construction, during construction and post-construction).

Test	Value	*F* Statistic	Degree of Freedom of Hypothesis	Degree of Freedom of Error	Significance Level	Squared of Share of η
Pillai's trace	0.573	97.834	2	146	0.000	0.573
Wilks' lambda	0.427	97.834	2	146	0.000	0.573
Hotelling's trace	1.34	97.834	2	146	0.000	0.573
Largest root growth	1.34	97.834	2	146	0.000	0.573

To test the research, one-variable covariance analysis (ANCOVA) and repeated measures were used. The results of these two statistical methods are reported in Tables 7–10. The homogeneity hypothesis of post-test variances was reviewed in three groups (pre-construction, during construction and post-construction) by Levene's test, because, it is necessary to establish it before performing a single-variable covariance analysis. In this test, the difference between the variances of the three groups was checked.

Table 7. The Levene's test results.

Variable	*F* Statistic	Degree of Freedom 1	Degree of Freedom 2	Significance Level
Pre-construction	1.312	2	147	0.272
During construction	1.722	2	147	0.182
Post-construction	0.846	2	147	0.431

Table 8. Results of the test of effects between subjects.

Index	Sum of Squares	Degree of Freedom	Average of Squares	*F* Statistic	Significance Level	Squared of Share of η
Cost, time and quality	14.2522	2	71.126	10.2470	0.000	0.577

Table 9. The Mauchly's sphericity test results.

Variable	Mauchly's Statistic	Approx. value of *Chi*-Square	Degree of Freedom	Significance Level	Epsilon		
					Greenhouse–Geisser	Huynh–Feldt	Lower–Bound
Pre, during and post-construction	0.576	80.615	2	0.000	0.702	0.716	0.500

Table 10. Results of the test of within-subjects' effects.

Variable	Sum of Squares	Degree of Freedom	Average of Squares	*F* Statistic	Significance Level
Pre, during and post-construction	47.417	2	23.709	100.247	0.000

According to Table 7, the *F* statistic in the various stages of construction (pre-construction, during construction and post-construction) is not significant at the 0.05 level, so the zero assumption is accepted. It means that variance is not significant in the three groups (pre-construction, during construction and post-construction) with each other and is identical. Table 6 shows the results of covariance analysis of cost, time and quality indicators.

According to the results obtained (Table 8), *F* statistic is significant in relation to differences of cost, time and quality indicators in the three groups (pre-construction, during construction and post-construction) at the 0.05 level ($p < 0.000$, $F = 100.247$), so the null hypothesis considering the initial differences between the indicators was rejected. We could conclude that building information modeling leads to changes in cost, time and quality in the three stages (pre-construction, during construction and post-construction). The eta-squared (η^2) share, as the effect size, was obtained at a rate of 0.577, based on that, BIM explains 58% of variance in cost, time and quality indicators.

Additionally, to determine the effectiveness of BIM in the subject group (pre-construction, during construction and post-construction), repeated measurements were used. In this section, the process of changes in cost, time and quality during the stages of pre-construction, during construction and post-construction was investigated and tested, which were reported in the results in Tables 7 and 8. Before interpreting the results of repeated measurements, it is necessary to determine the assumption of the data sphericity. The assumption of sphericity was tested with Mauchly's sphericity test, and the results are reported in Table 9.

As it was seen, the Mauchly's statistic was reported for the variable pre-construction, during construction and post-construction, equal to 0.576; therefore, the null hypothesis is accepted. This means that the variances of values with the difference between the three groups (pre-construction, during construction and post-construction) have no significant difference and are homogeneous; so, the sphericity assumption is established and it is not necessary to use one of the three Epsilon indicators (Table 9). The results of the within-subjects analysis in pre-construction, during construction and post-construction are reported in Table 10.

According to Table 10, the *F* statistic is significant, this indicates the difference among the three groups at 0.01 level ($p \leq 0.000$, $F = 100.247$), then the null hypothesis is rejected. We can conclude that there is a significant difference between the values of pre-construction, during construction and post-construction (0.99); this difference is due to interventions of cost, time and quality indicators. Therefore, BIM has been effective at each stage (pre-construction, during construction and post-construction) on cost, time and quality indicators. Figure 1 illustrates the trend of changes of the cost, time and quality indicators in the stages of pre-construction, during construction and post-construction. Figures 2–4 show that the variable of cost and time in the pre-construction stage, compared to two other steps, tends to be high, this amount tends to decrease in the during construction and post-construction stages, gradually, while the quality variable in the pre-construction and construction stages is roughly equal to or greater than the median value; it tends to be high in the post-construction stage. It is quite evident that the use of BIM in the pre-construction stage will lead to a reduction in cost and time and increase the quality in the pre-construction and during construction stages.

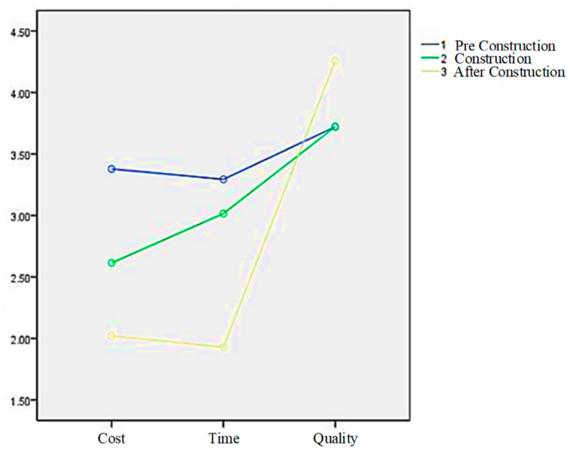

Figure 1. Comparison of trends in indicators (cost, time, quality) in stages (pre-construction, construction, post-construction).

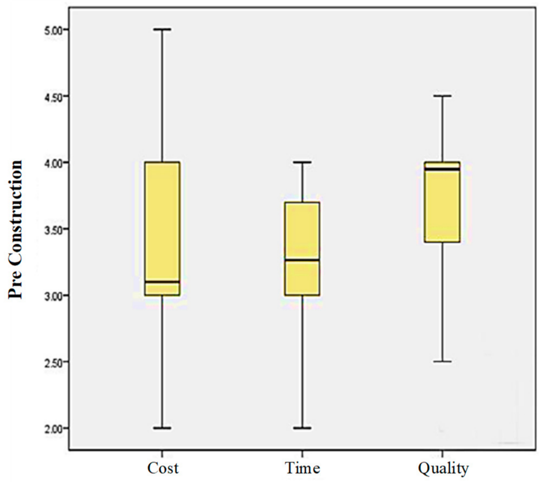

Figure 2. Comparison of changes in indicators (cost, time, quality) in the pre-construction stage.

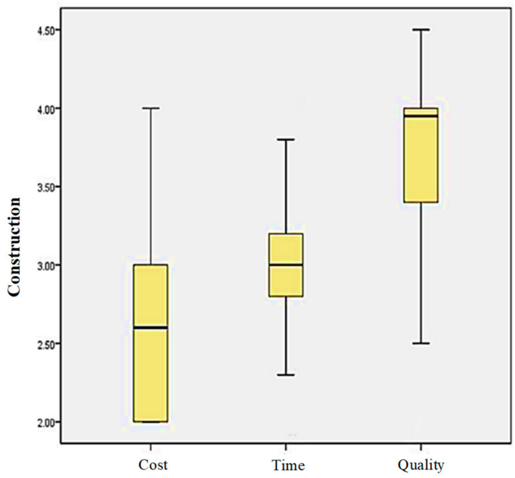

Figure 3. Comparison of changes in indicators (cost, time, quality) in the during construction stage.

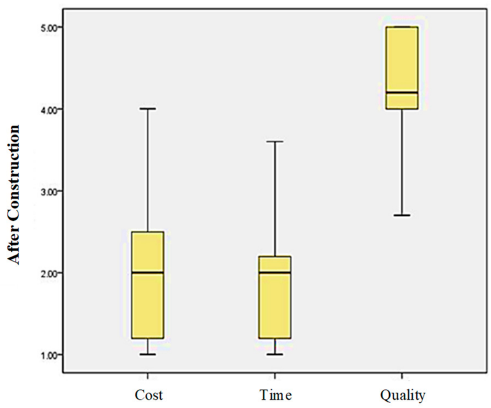

Figure 4. Comparison of changes in indicators (cost, time, quality) in the post-construction stage.

4. Discussions and Conclusions

Today, with the advances in technology, the use of computers to improve the design and documentation process, and to enhance the collaboration between architects and engineers from other disciplines, has increased dramatically. In this context, building information modeling (BIM) is a new concept for developing countries like Iran. BIM is a 3D model-based approach that gives construction project participants the tools to more efficiently plan, design, construct and manage buildings. This model is a collaborative and reliable database for making the right decisions throughout the lifecycle of the building. BIM technology, as a powerful tool in the hands of managers, contributes to project success. Over the past decade, due to the growth of the community and widespread need for housing, the necessity for use of new building systems and materials to enhance the quality of construction, in order to increase the speed of construction, the useful life span of buildings and earthquake resistance, has been raised. In this regard, the promotion to the scientific and specialist level for the country's engineering community and familiarity with new systems, materials and new technologies, such as BIM, is inevitable. Considering the fact that mass housing caused fundamental changes in the construction method, it can be pointed out that mass housing represents a pattern of production, whose goal is to provide a variety of custom products with better expense, quality and delivery performance. BIM constitutes a review of design and the optimization of building. Moreover, sharing of the model provides a complete understanding of the layout by the owner/end-user and compliance with all his needs. BIM is becoming an essential tool for the integration of models and the discovery of spatial conflict resolutions among different disciplines. This technology is used for simulation of building energy consumption and the manufacturing process, examining safety issues in construction, monitoring the construction process and delivery, and for facilities management. In addition, 3D laser scanning could be explored to create accurate as-built models and capture real-world information of buildings. It can be expressed as a lever for better mass housing, as well as guidance for manufacturers to increase effectiveness and quality, reduce time and cost, and more accurately estimate these indices, especially in pre-construction, during construction and post-construction in mass production of housing. Considering the mentioned cases, this research question is explained. With regard to the above, the following suggestions are expressed:

- The strengthening of links between mass housing programs, land use policies and investment that are supportive of employment and activities.
- Provision of adequate housing is inevitably connected with the meeting of individual and social needs, both within and outside the residential unit. Therefore, urban planning and design to provide these needs should be seriously considered in accordance with different levels of space. Furthermore, housing planning must inevitably take into account different issues, like, infrastructure needs, establishment of social and public services centers, designing an outsourced and inland urban transport system with the economic and social characteristics of the inhabitants, and access and geographical alignment to production and activity centers.
- An economy to enhance the quality of construction and providing the field for using day technology in the mass production of housing and buildings provides the opportunity for success in construction.
- Support mass production and the provision of housing by the private sector by way of modern technology, like BIM, and observe the optimal construction pattern.
- By using the correct management actions, educate and develop a culture of using BIM technology. This can help to achieve the benefits, like increased utilization of human resources, better management of capital costs, energy consumption and resources, identifying and removing activities with no added value.
- The use of prefabricated systems and industrial production, in spite of raising the initial cost, leads to an increase in the quality of construction. Since construction quality is one of the most important criteria for evaluating the performance of construction projects, the use of BIM technology can greatly reduce the additional costs for impairment.
- Taking into account the added value of BIM, Iranian construction professionals should pay attention to this issue more quickly and with greater awareness. By using BIM, they can improve the quality of design, construction and operation, save time and money, reduce energy consumption and even improve workplace safety. The Iran construction sector remains a major focus of this survey, but all the stakeholders from the construction sector and society in developing and emerging countries alike can also benefit from the findings.

To realize the effectiveness of mass housing in urban housing, removing barriers and management constraints is one of the most important factors. Accurate and active management not only helps in the planning and implementation of mass housing, but it is also essential for problems review, document management, executive operations and finance operation and maintenance at different stages of a construction project.

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Appendix A

Table A1. Factors affecting the objectives of mass housing projects due to BIM deployment.

Row	Stage	Indicator	Subset	Reference
1	Pre-Construction	Cost	Construction cost estimation throughout design development	[42]
2			Reduce workshops during pre-construction	[43,44]
3			Decrease design mistakes and inaccuracies	[45,46]
4			Cost estimates can be generated at the feasibility stage	[15]
5			Preliminary cost estimation by extracting quantities from the model	[27,47]
6			More accurate cost estimation and monitoring	[48]
7			Reduce project cost and material waste	[48,49]
8			More accurate estimates of project cost at conceptual design stage	[15,50]
9			Balancing of budgeted and actual project cost	[51]
10			Providing reliable and accurate quantities	[52,53]
11		Time	Rapid and precise design display	[54]
12			Generate two-dimensional plans, sections and views	[55,56]
13			Rapid response to design changes	[57]
14			Shortening the project time by parametric modeling	[52,55]
15			Reduce risks related to schedule	[58]
16		Quality	Improve the coordination between project participants through the integrated project management system	[18]
17			Reduce errors in project design	[59,60]
18			Reduce redesign and rework	[61,62]
19			Provide estimates more quickly and accurately	[55]
20			Investigate and easier control with project goals	[52]
21			Improve the efficiency of the plan in terms of energy and sustainability	[52]
22			Discover design errors before construction	[55]
23			Overall coordination of design and construction	[18,63]
24			Get valuable feedback from project stakeholders using visual simulations	[52]
25			Simulate the type of operation and its related items	[52]
26			Improve design matching with required criteria using analytical tools	[52]
27			Avoiding disagreement and claims by creating building information model, and confirming by all of them	[64]
28			Intelligent communication can be made between different design elements	[64]
29			Rotating of the building model and investigation the changes in its energy consumption	[64]
30			Ensure the document management and design information	[65]
31			Improve quality and operation of building	[18]
32			Integration of the material and supply information	[66]
33			Lighting simulation and analysis	[67]

Table A1. *Cont.*

Row	Stage	Indicator	Subset	Reference
34	During Construction	Cost	Reduce energy consumption by energy analysis in model	[68]
35			Helps to avoid additional costs and financial corruption (that may take place in project)	[18,52]
36			Reduce risk of human factor	[68,69]
37			Reduce the amount of materials being "needed"	[18,70]
38			Reduce accidents and safety problems	[71,72]
39			Reduce cost of construction project	[73]
40			Cost estimates for alternative designs are easily provided	[15]
41			Cost of design changes can be estimated easily	[15]
42		Time	Shortening the project time by multi-party collaboration during pre-construction and construction	[55]
43			Draft schedule generation in pre-sale stage	[74]
44			Quick response to unpredictable conditions	[52]
45		Quality	Better implementation of construction techniques	[18]
46			More details of the planning process are given and easily updated	[52]
47			Project design changes are reflected in a schedule	[55]
48			Reduce conflicts and claims among project participants	[52]
49			Production of buildings with greater potential for operation and maintenance	[52]
50			Accurate data and information for design, procurement and construction	[18]
51			Coordination of project by creating a complete integration between design, construction and facilities	[52]
52			Design changes are constantly reflected in all plans	[15]
53			Project parties can understand and review design more easily	[15]
54			Intelligent information management allows data to be saved in a BIM model.	[15]
55			Increase the quality of the building	[52]
56			Improve the coordination between design and construction with construction operation simulations	[18]
57	Post-Construction	Cost	Cost monitoring is done quickly to ensure that all things are considered	[52]
58			Reducing costs of maintenance stage and occurrence of accidents such as earthquakes and floods	[75]
59		Time	Reduce the demand of change due to defects or mistakes in early design	[52]
60			Reduce rework and repairs	[60,76]
61		Quality	In the post-construction stage it can be a measure of efficiency, quality and monetary spending by owner	[52]
62			Deliver better project by owner/end-user	[52]
63			Increase efficiency at the time of operation according to the simulation using the model	[52]
64			Proper transfer of information to owner/end-user	[52]
65			Explore the data throughout the project life cycle	[18]
66			Reduce the process of setting up and transferring facilities to owner/end-user	[18]
67			Reduce cost of poor quality	[27,55]
68			Improved management and better operation of the project and facilities	[55]
69			Data integration into facilities management systems	[52]
70			Access to project records and database throughout the life cycle of a building	[75,77–79]

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