

Evaluating the function of prefabrication in high-rise buildings

Evaluación de la función de la prefabricación en edificios de gran altura

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Abstract

Prefabrication in a high-rise building can reduce construction waste. In this research, high-rise construction companies in Iran were studied, and the advantages and disadvantages of prefabrication were identified; then the development strategies of this industry were reviewed. For this purpose, the questionnaires were used to select the proper sub-systems for prefabrication. Delphi Snowball method was applied according to experts' opinion, and these questionnaires were identified and adopted. Then the effect of prefabrication on non-structural components was examined on the extent of waste reduction. Consequently, the investigation results of waste production on a high-rise building revealed that prefabrication can reduce the cost of waste to 97.54%, and the total cost of the project would be reduced by 5.06%.

Keywords: Construction Waste, Prefabrication, High-rise Building, Waste Cost

Resumen

La prefabricación en un edificio de gran altura puede reducir los desechos de la construcción. En esta investigación, se estudiaron las empresas constructoras de gran altura en Irán y se identificaron las ventajas y desventajas de la prefabricación; luego se revisaron las estrategias de desarrollo de esta industria. Para ello se utilizaron cuestionarios para seleccionar los subsistemas adecuados para prefabricación. A partir de la opinión de los expertos se aplicó el método Delphi Snowball para identificar y adoptar los cuestionarios adecuados. Luego, se examinó el efecto de la prefabricación en componentes no estructurales en la reducción de desechos. En consecuencia, los resultados de la investigación de la producción de desechos en un edificio de gran altura revelaron que la prefabricación puede reducir el costo de los desechos al 97.54% y el costo total del proyecto se reduciría en un 5.06%.

Palabras clave: Desechos de construcción, Prefabricación, Edificios de gran altura, Costo de desechos

1. Introduction

Sustainable development refers to the proper use of natural resources and environmental principles, and it can prevent problems such as degradation of natural resources and ecosystems, reduce in justice and environmental pollution, and enhance the quality of life. In construction, a reasonable use of energy and reducing the production of construction waste are considered to be the characteristics of eco-efficiency. Natural resource scarcity is no longer merely a remote possibility and governments increasingly seek information about the global distribution of resource use and related environmental pressures (Teixidó-Figueras et al., 2016).

One of the largest consumers of non-renewable resources is buildings, and many natural materials are being constructed around the world. At the same time, large quantities of waste from the construction or demolition of old buildings are being produced. While demand for construction increased, waste generation has become a major threat to the environment. Therefore, building management is necessary to reducing the production and recycling of construction waste. Extensive research has been conducted on various construction projects in this regard.

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Most construction waste is abandoned in nature, and only 10% to 30% of them are managed in the world and buried in the right way (Agamuthu, 2018). Construction activities account for approximately 20% to 30% of all wastes buried in Australia (Craven and Eilenberg, 1994), this is 29% In the United States (Rogoff and Williams, 1994), and in the UK this is 50% (Ferguson et al., 1995). Definitely, by identifying the causes of building waste production, it is possible to determine the control strategies (Lu et al., 2018). In Hong Kong, a plan to encourage the production of paper from wood waste was presented to reduce construction waste and to protect the environment (Vivian et al., 2007). A case study in Brazil indicated that while a proper design is done, wood waste can be reduced by up to 89% (Parisi et al., 2018). Yashai Lee et al. proposed a model for estimating the construction waste, and it provided a theoretical analysis of the construction process and the failure structure of the project as well as the process of waste production in a project for developing this model (Li et al., 2016). Note that the terms of the contract with the contractor as a key criterion and isolation of construction waste at the site, reuse of usable waste, and management of transportation to reduce construction waste are effective (Ajayi et al., 2017b). Recycling waste can also reduce costs and improve environmental conditions (Ibrahim, 2016). The standardization of the amount of waste produced, use of modern construction methods, adopting the action required for the flexibility of architectural spaces, and the use of Building Information Management (BIM) methods for design are the appropriate solutions for minimizing construction waste (Ajayi et al., 2017a); moreover, the commitment of suppliers to low waste measures such as packaging of materials, preventing excessive ordering of materials, and attention to the design and management of waste management are also effective in minimizing waste (Ajayi et al., 2017c).

Individual norms of the contractor agents also play a role in reducing construction waste (Li et al., 2018), and it was found that with modern construction design and methods, the construction waste will be reduced by investigating and using structural equations, (Ajayi and Oyedele, 2018).

Research shows that landfill is the most expensive approach while recycling is the most sustainable waste management mode (Di Maria et al., 2018); (Wu et al., 2016); (Zaharieva et al., 2003); (Rosado et al., 2019).

Number of floors and construction floor areas are critical factors highly related to waste (Furtado et al., 2020); (Domingo and Batty, 2021). A study in Thailand suggested that building waste in high-rise buildings will have adverse environmental impacts (Thongkamsuk et al., 2017); therefore, controlling and reducing the consumption of raw materials, and sorting waste and recycling them will reduce waste production (Ding et al., 2016); (Martos et al., 2018); (Ansari and Ehrampoush, 2018); (Lockrey et al., 2016). As a solution, one can crack concrete, glass, tile, bricks waste and produce recycled bricks, blocks, and mosaics after aggregation with alkali, cement, and water activators (Robayo-Salazar et al., 2017). Furthermore, nanoparticles rich in metals are harmful to the environment, so it is better to take advantage of certain techniques in the disposal of waste containing nanoparticles rich in metals such as tiles and plaster concrete (Oliveira et al., 2019).

In some studies, prefabrication was used as a solution for reducing construction wastes in the design and construction phases while it contributes to stability in the construction cycle (Jaillon and Poon, 2014). Prefabrication is regarded as a cleaner production and sustainable construction approach with less negative impacts on the environment (Teng and Pan, 2019). With respect to the lifecycle assessment results, the prefabrication industry is not only environment-friendly but also energy efficiency (Zhu et al., 2018). In the last hundred years, buildings had to be quickly built to come into operation following the earthquakes that could cause extensive destruction (Downing, 2002).

Prefabrication is a salient method for cost-effective and coefficient construction, and it has been defined as the prefabrication or construction without water consumption at the construction site. In addition, modular building is a major subcategory of prefabrication and has been defined as the construction of a part of the building at the factory site and its assembly at the construction site. Different options are available in prefabrication, e.g. plaster board is used for the ceilings and walls; Autoclaved Aerated Concrete (AAC) blocks are used for interior and exterior partition walls; and ceramics with mechanical connections are used for facades. Iran is one of the countries that are prone to various types of natural disasters such as earthquakes, flood, storm, and drought because of its position. The incidence of different types of natural disasters not only hinders sustainable development in Iran but also imposes irreversible lethal and financial damage to this country (Afrakhteh, 2007).

Construction waste minimization is a key sustainability goal in green building rating systems although these rating systems traverse countries' boundaries, but no research has yet compared construction waste minimization performance in such systems across countries (Chi et al., 2020). One of the ways of sustainable development in construction is to minimize produced wastes, and this issue is more important in high-rise buildings. There are several ways to minimize construction waste, and one of them is applying prefabrication, especially in non-structural parts of high-rise buildings. If one can reduce the amount of construction waste, this will improve the environmental conditions and reduce costs. Prefabrication, despite many advantages, has not yet made good progress due to the high cost of constructing such buildings. The cost and advantages of a building were analyzed in a case study; then it was found that to achieve the economic advantages of prefabrication, the government; therefore, should create appropriate



markets and supports builders with financial support and focus on prefabrication and reform of laws (Mahpour, 2018); (Hong et al., 2018).

Prefabrication is an innovative construction method designed to minimize the construction activities on-site and transfer many activities to the factory to ensure about the development of a product with higher quality, safety, and a shorter project delivery time (Chauhan et al., 2019). The major difference between a prefabricated system and a conventional building system is that a large part of the building components is produced outside the construction site in the prefabricated system (Arif and Egbu, 2010); (Neill and Organ, 2016), and prefabrication is also safer and more environment-friendly compared to conventional construction, so This technology suits different types of construction projects (Steinhardt et al., 2019). Prefabrication is a highly beneficial approach with numerous advantages such as the short project delivery time, higher quality, higher control over the construction activities, workers' safety and improvement, environment-friendliness, and lower project costs (Lu, 2009). The construction industry can support prefabrication technology in many ways to improving productivity and performance (Tam et al., 2007), and there are numerous suggestions for improving productivity and the industry performs with the aid of the advantages of prefabrication technology over the conventional construction system (Bell, 2009). Various researchers defined productivity as the measurement of availability of resources for the attainment of a predetermined goal (Durdyev and Ismail, 2019); (Ghasemi Poor Sabet and Chong, 2019); (Ranasinghe et al., 2011). In addition, cost and time are known as the factors influencing the training of human forces in the prefabrication industry (Arashpour et al., 2018);(Wang et al., 2018), and economic advantage is one of the major reasons mentioned by the stakeholders involved in the construction process, so it is expected to considerably increase the delivery of prefabricated buildings. Besides, financial support can promote prefabrication technology, optimize the integration of prefabricated buildings, and improve market maturity in comparison with the traditional construction system (Hong et al., 2018). Although many studies have reported the advantages of prefabrication such as its simplicity, speed, and cost-effectiveness, but one of the reasons for the reduction in the market share in the construction industry is the limited diversity of the design of prefabricated buildings in the current condition (Kasperzyk et al., 2017).

The descriptive statistics tests of data were processed in Iran and the results showed that 53,445 ton of waste are annually generated in the city of Yazd, and the amount of cement and concrete, bricks, tile and ceramic (TC), ferrous metals, non-ferrous metals, glass, plastic, and wood are approximately 38%, 20%, 14%, 11%, 6%, 5%, 3%, and 3%, respectively. Regarding to the high volume of waste generated and a remarkable part of the recyclable waste, urban planners should pay attention to the implementation of waste reduction and recycling programs (Ansari and Ehrampoush, 2018).

As the main gap identified in the studied literature, the previous researches have mainly examined the benefits of prefabrication while its disadvantages, which could be an obstacle to future development, have not been assessed. Also, the impact of prefabrication on various components has not yet been studied; therefore, the study aimed at checking the waste indicators and related costs.

In this research, the feasibility for construction of components of buildings is analyzed, and the advantages and disadvantages of prefabrication and the possibility of its development are investigated. Then the amount and cost of building waste are compared with those of two methods of prefabrication and traditional method in a case study.

2. Material and Methods

In this research, the questionnaires were used at two phases. In the first step, the advantages, disadvantages, and the functional programs for the development of dry systems were checked, and in the second step, the proper subsystems for prefabrication were selected. Then by using Delphi Snowball method and according to experts' opinion, the questionnaires were identified and adopted. To prepare the two questionnaires, 10 experts with high professional backgrounds and degrees were employed, and the Likert range was used to prioritize the options.

From 4500 mass producers as the statistical population of the first questionnaire, 351 mass producers were sampled according to the Morgan table. The questionnaires were distributed by simple random method, and they were collected by the researchers. The questionnaires were distributed among the samples of the statistical population, and 228 questionnaires(65%)were answered (21 questionnaires were incomplete and 207 were completed). The prepared questionnaires include the advantages of prefabrication with 8 questions, the disadvantages of prefabrication with 10 questions, and prefabrication development applications with 7 questions; besides, experts were asked to determine which methods were chosen between the traditional, partially-prefabricated, prefabricated and modular to implement different components of a high-rise building. Finally, the waste cost was estimated in a case study of a high-rise building according to the information obtained. In this study, after studying the relevant sources, content validation method was used to determine the validity of the questionnaire; then the initial plan of the questionnaire was prepared, reviewed, and revised by several professors and experts; afterward the desired comments were applied, and the final questionnaire was compiled. Cronbach's alpha method was used to



evaluate the reliability of the questionnaire. This method is used to calculate the internal coordination of the measurement tool that measures different characteristics. To calculate Cronbach's alpha coefficient, the variance of the scores of each subset of the questionnaire and the total variance was calculated. The closer the percentage is to 100%, the more reliable the questionnaire is; moreover, the amount of Cronbach's alpha obtained should be above 0.7 to ensure the reliability of the questionnaire so the Cronbach's alpha that was calculated for each research variable can be seen in (Table 1) and (Table 2). The results show that the all variables are acceptable.

Table 1. Evaluation of Validity for Questionnaire

| Questionnaire -1 | Sample Volume | NO. of Item | Cronbach's Alpha | Result |
|--|---------------|-------------|------------------|------------|
| Advantages of prefabrication | 207 | 8 | 0.795 | Acceptable |
| Disadvantages of prefabrication | 207 | 10 | 0.914 | Acceptable |
| Functional programs for the development of prefabrication for high-rise projects | 207 | 7 | 0.785 | Acceptable |

Table 2. Evaluation of Validity for Questionnaire

| Questionnaire -2 | Sample Volume | NO. of Item | Cronbach's Alpha | Result |
|---|---------------|-------------|------------------|------------|
| Facilities and drainage services and urban services | 207 | 8 | 0.908 | Acceptable |
| Building skeleton | 207 | 6 | 0.723 | Acceptable |
| Exterior Building Operations | 207 | 2 | 0.957 | Acceptable |
| Interior Building Operations | 207 | 5 | 0.836 | Acceptable |

3.Data Analysis

Before analyzing the questionnaires, the experts were questioned about the impact and value of the respondents on their professional experience records, educational level, and drying experience, and the impact factors were determined according to 10 experts' opinion. Experts valued the opinion of experts with a professional background of less than 5 years, 5-10 years, 10- 15 years, 15-20 years, and a significant number of people with over 20 years, and their impact factors were 1, 1.1, 1.2, 1.3, and 1.4, respectively; furthermore, for the degree of education, the impact factors of 0.8, 1, 1.2, and 1.4 were proposed for associate diploma, bachelor's, master's, and doctoral degrees, respectively. The respondents with high prefabrication experience were known 50% greater than the subjects without prefabrication experience.

Among participants, 50 have associate diploma, 76 have a bachelor's degree, 56 have master's degrees, and 25 had doctorate degree, and all of these people were active in the field of construction and familiar with prefabrication; moreover, some of these people were contractors and had high executive experience in this field (106 people). A number of respondents also were designers in the field of construction, and they were not directly involved in prefabrication but had sufficient and necessary knowledge (101 people). In the following, the results, which have



been extracted based on the questionnaire, are presented on the advantages, disadvantages, and solutions of prefabrication development.

3.1. Prefabrication Advantages

The advantages of using prefabrication in the building industry were arranged according to the Likert Table pattern in the form of questions with five answers provided for the respondents. In (Table 3), the value of the opinions of the respondents was averaged, and the answer to each question was compared with the total average; furthermore, in the column of average value, the value was recorded, and the ranking was determined based on the average value in the last column.

Table 3. Prioritization of the advantages of using prefabrication

| Advantages of prefabrication | very low | Low | moderate | high | Very high | Average value | ranking |
|--|-----------------|------------|-----------------|-------------|------------------|----------------------|----------------|
| <i>Better dry solid objects have been incorporated in the design, and have better architectural form (better architectural design)</i> | 16 | 46 | 80 | 54 | 11 | 0.81 | 8 |
| <i>Better monitoring and improving the quality of work in prefabrication</i> | 0 | 20 | 72 | 93 | 22 | 1.00 | 4 |
| <i>Reduced cost of construction with prefabrication</i> | 11 | 30 | 59 | 82 | 25 | 0.95 | 6 |
| <i>Shortened construction time with prefabrication</i> | 0 | 7 | 43 | 96 | 61 | 1.15 | 1 |
| <i>Improved environmental performance and minimizing construction waste with prefabrication</i> | 1 | 10 | 47 | 126 | 23 | 1.07 | 3 |
| <i>Increased ease and efficiency in building construction in the use of repetitive modular parts in prefabrication</i> | 3 | 7 | 50 | 117 | 30 | 1.08 | 2 |
| <i>Increased beauty and harmony due to the presence of repetitive parts in the facade of the building in prefabrication</i> | 6 | 22 | 89 | 80 | 10 | 0.92 | 7 |
| <i>Better coherence and resistance of dry structures to earthquake forces</i> | 4 | 18 | 74 | 92 | 19 | 0.98 | 5 |

For ranking, any advantage with a higher average value number is ranked first up to the eighth in the final column, respectively. (Table 3) indicate that, with regard to the advantages of prefabrication, the experts ranked the shortened construction time with the average value of 1.15 as the top priority, followed by the increased ease and efficiency of the construction using modular repetitive parts with an average value of 1.08. Then improved environmental performance and minimizing construction waste with average value of 1.07, and better monitoring and improving the quality of work with an average value of 1 were ranked forth and fifth, respectively. Definitely, despite its many advantages, prefabrication has some disadvantages, which will be discussed further.

3.2. Disadvantages of prefabrication

According to (Table 4), the disadvantages of prefabrication were identified and prioritized. The participants responded to the importance of each item in this table, and the respondents' opinion values were summed up and averaged, meaning that with the answer to each question further compared to the average. The ranking of each disadvantage of prefabrication is presented in the last column, where the importance of each of the disadvantages was determined according to the experts.



Table 4. Prioritization of the disadvantages of prefabrication

| Disadvantages of prefabrication | Very low | Low | moderate | high | Very high | Average value | Ranking |
|--|-----------------|------------|-----------------|-------------|------------------|----------------------|----------------|
| <i>Inadequate design flexibility due to the presence of modular dry parts</i> | 8 | 21 | 82 | 76 | 20 | 1.02 | 5 |
| <i>Higher initial investment</i> | 2 | 13 | 89 | 82 | 21 | 1.07 | 2 |
| <i>Lack of research information due to the newness of technology</i> | 8 | 36 | 58 | 78 | 27 | 1.03 | 4 |
| <i>being time-consuming in the early design of prefabrication</i> | 7 | 43 | 98 | 52 | 7 | 0.90 | 9 |
| <i>Not having a proper construction method for prefabrication</i> | 9 | 54 | 70 | 58 | 16 | 0.92 | 8 |
| <i>Not having a suitable location for the primary storage of materials at the installation site</i> | 10 | 50 | 86 | 54 | 7 | 0.88 | 10 |
| <i>Inability and lack of expertise to resolve failures in different parts (lack of a program for resolving failures)</i> | 6 | 42 | 64 | 73 | 22 | 1 | 6 |
| <i>The lack of variety and beauty of the interior space due to the repetition of repetitive modules</i> | 12 | 16 | 92 | 72 | 15 | 0.99 | 7 |
| <i>Lack of demand for prefabrication</i> | 2 | 13 | 97 | 77 | 18 | 1.05 | 3 |
| <i>Lack of local contractor experience</i> | 3 | 21 | 66 | 82 | 35 | 1.1 | 1 |

According to (Table 4), the lack of experience of local contractors; higher initial investment; lack of demand for prefabrication; lack of research information due to the novelty of this technology, and the lack of proper flexibility in design due to the presence of modular dry parts with ratings of 1.1, 1.07, 1.05, 1.03, and 1.02, respectively, were the most important disadvantages of prefabrication from the experts' perspective.

Considering the fact that prefabrication is one of the ways of eco-efficiency in construction, and the production of waste resulting from construction will be minimized with this technology; furthermore, functional programs for the development of prefabrication can support the sustainability of construction.

3.3. Functional programs for the development of prefabrication

According to the experts, important cases in the development of prefabrication in a high-rise buildings were determined by Delphi Snowball method; then the participants responded to each question according to (Table 5).

Table 5. Functional programs for the development of prefabrication in high-rise buildings

| Functional programs for the development of prefabrication for high-rise buildings | Very low | Low | moderate | high | Very high | Average value | Ranking |
|--|-----------------|------------|-----------------|-------------|------------------|----------------------|----------------|
| <i>Providing native guidelines for the design and implementation of prefabrication</i> | 16 | 29 | 77 | 57 | 28 | 0.96 | 5 |
| <i>The requirement to use dry parts for governmental buildings</i> | 21 | 27 | 83 | 65 | 11 | 0.91 | 6 |
| <i>The construction of model buildings with dry parts by the government</i> | 19 | 50 | 52 | 69 | 17 | 0.90 | 7 |
| <i>Making incentive decisions to expand prefabrication</i> | 13 | 16 | 61 | 82 | 35 | 1.06 | 2 |
| <i>Training and holding specialized courses in the design and execution of dry parts</i> | 11 | 33 | 57 | 68 | 38 | 1.02 | 4 |
| <i>Acquiring knowledge and localization of dry piece devices</i> | 9 | 19 | 56 | 86 | 37 | 1.08 | 1 |
| <i>Developing culture for the preservation of the environment in educational centers and governmental agencies to use prefabrication</i> | 7 | 36 | 52 | 75 | 37 | 1.04 | 3 |



In the ranking of future functional programs for prefabrication in high-rise buildings, the average number, which shown in (Table 5) for each program, represents the importance of each program in the development of prefabrication. The most important program according to the experts' opinion for the development of prefabrication in high-rise buildings was acquiring the knowledge of localization of the dry parts with an average value of 1.08, followed by making incentive decisions to expand the prefabrication with an average value of 1.06; then developing culture for protecting the environment in educational centers and governmental agencies using prefabrication with an average value of 1.04, and training and holding specialized courses in the design and implementation of dry parts with an average value of 1.02" accordingly.

In adopting prefabrication, it is of particular importance to choose the appropriate dry system, which deals with the environmental problems stably to be implemented. This point is discussed further.

3.4. Selection of proper dry systems

Based on review of the feasibility study on various projects regarding the use of dry part production technologies, in recent years, designers and executives have shown a greater willingness to use industrial construction. In traditional ways of construction of buildings, the impact of human factors has been considerable while it has reduced the quality of the implementation of buildings. Industrial building techniques and the use of prefabrication lead to increased quality requirements; indeed, due to the mass production of parts in industrial methods, the efficiency of building production has increased, so the final product has a higher quality.

Expert opinions on the adoption of a dry method in the components of high-rise buildings are as follows; Prefabrication minimizes the construction activities on-site and transfer many activities to the factory to ensure higher quality and safety as well as a shorter project delivery time; in fact, the major difference between a prefabricated system and a traditional building system would be a large part of the building components produced outside of the construction site in the prefabricated system. In the Modular system, the building is installed as prefabricated volumetric parts.

In these questionnaires, each of the different components of the building includes traditional, partially-prefabricated, prefabricated, and modular methods were investigated, and the respondents commented on the selection of implementation method of various components in high-rise buildings can be seen in (Table 6).

Table 6. Determination of the implementation method of various components of high-rise buildings

| Main components of the building | Subcomponents and sub-elements | weight of traditional method | weight of partially-prefabricated method | weight of prefabricated method | weight of modular method |
|---|---|------------------------------|--|--------------------------------|--------------------------|
| Foundation | Foundation | <u>59.5</u> | 31.3 | 8.7 | 0.5 |
| Facilities and drainage services and urban services | Implementation of the installation manholes | 20.8 | <u>47.9</u> | 29.9 | 1.4 |
| | Engine room buildings | 24.1 | <u>40</u> | 33 | 2.8 |
| | Deploying installation and engine room facilities | 24.5 | <u>42.1</u> | 31.3 | 2 |
| | Implementation of water and sewage lines | 17 | 37 | <u>44.5</u> | 1.4 |
| | Installation ducts | 8.5 | 42.3 | <u>47.3</u> | 1.8 |
| | Power distribution (cabling from the counter) | 12.7 | <u>43.5</u> | 41.9 | 1.8 |
| | Cooling and heating channels | 9.7 | <u>49</u> | 39 | 2.2 |
| Building skeleton | Escalators and elevators | 19.2 | <u>53.9</u> | 23.5 | 2.3 |
| | columns | <u>37.7</u> | 28.8 | 31.8 | 2.7 |
| | Beams | <u>39.8</u> | 28.3 | 30 | 2.7 |
| | Separator walls | 16.2 | 38.7 | <u>39.1</u> | 5.9 |
| | The walls of the periphery of the elevator pit | 19 | 37.5 | <u>40</u> | 3.7 |
| | stairs | <u>44.4</u> | 21.7 | 32.4 | 1.5 |
| Exterior Building Operations | Ceilings | 25 | <u>32.5</u> | 30.5 | 3.6 |
| | Building facades | 20 | <u>39.8</u> | 37.3 | 2.7 |
| | Roof of the building | 18.4 | <u>46.7</u> | 33 | 1.8 |
| Interior Building Operations | Internal separator walls | 9.4 | <u>44.9</u> | 39 | 6.5 |
| | Plastering | 24.1 | <u>35.7</u> | <u>36.3</u> | 0.5 |
| | Tiling | 23.8 | <u>40</u> | 33.8 | 2.2 |
| | the kitchen | 13.7 | <u>51.2</u> | 32.4 | 2.7 |
| | Bathroom and services | 21.3 | <u>42</u> | 34 | 2.7 |



The selection of the method for implementing the work in various components and sub-elements was asked from experts in the form of a questionnaire, and each expert chose one of the four methods for each sub-element. Then the number of respondents to each method in a particular element was divided by the total number of respondents, and the weight value of each method was obtained for different components. According to experts showed in (Table 6), the facade of the building, the execution of interior partition walls, tiling, masonry, flooring and plastering as prefabricated and partially prefabricated is the most appropriate method of execution. In the following, the cost of waste reduction in the prefabricated method compared to the traditional method is examined. (Figure 1) reveals the relationship between each method for a specific component.

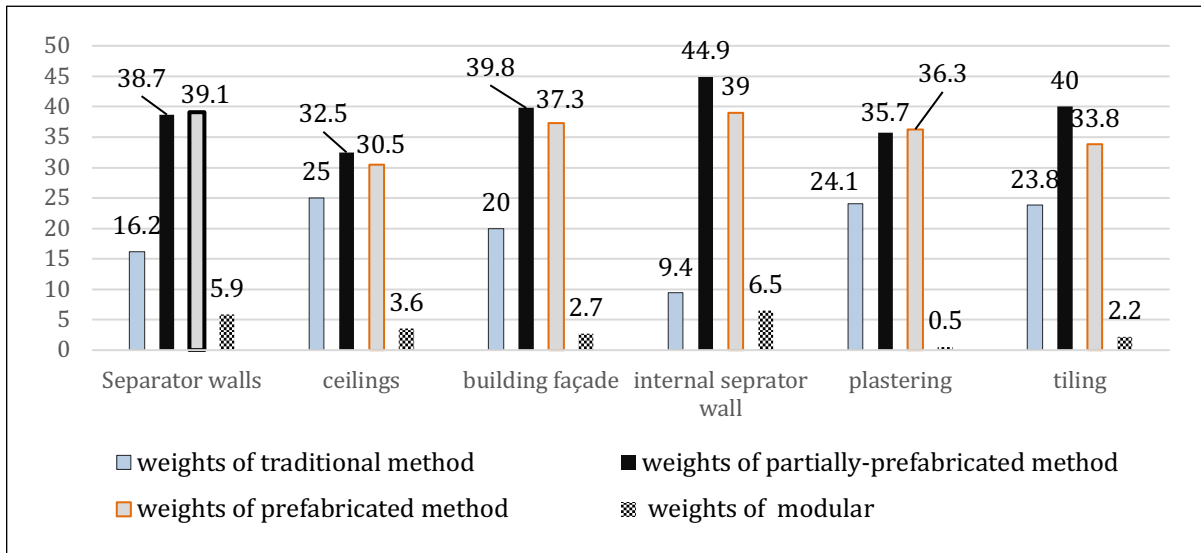


Figure 1. Comparison of the weights of prefabricated, Partially-prefabricated, traditional, and modular methods

Experts believe that the foundation and skeletons in the traditional form are much appropriate in Iran for high-rise buildings, and the use of modular systems was not welcomed by experts. They showed a great deal of interest for using prefabrication for building installation systems, and the Partially-prefabricated exterior of the building was recommended along with the use of internal walls and plastering in dry and Partially-prefabricated conditions; in addition, experts believed that tiling in the kitchen and bathroom should be done in Partially-prefabricated manner. Based on the results of (Figure 1) as a case study, the cost estimation of waste in a high-rise building has been investigated further.

3.5. Estimating the cost of waste in a high-rise building

This section investigates the effect of prefabrication on high-rise buildings waste. For this purpose, in a case study, the cost of preparation of materials and the implementation of various components of a concrete structure (Twin Tower of Yazd) was specifically estimated. First, the volume and cost for various components such as concrete, fittings, non-structural parts, installation pipes, internal and external walls, plastering, flooring, tiling, and stoning were estimated; then given the exact recording of construction waste information in each section of the project, the cost of waste in various components that can be reduced by prefabrication were determined according to (Table 6). In a building, which has an area of 36000 m² of infrastructure and has been implemented in 22 stories in a traditional way, about 2800 tons of wastes are produced (based on the manufacturer's documentation), and (Table 7) provides the various components of the building, the amount and volume of materials consumed, the unit price of consumables, the average level of waste in the traditional and dry state, the percentage reduction in construction waste in the dry state, and the total amount of waste in dry and traditional states for various components; in addition, the waste costs in the traditional and dry states as well as the waste cost reduction in the case of prefabrication and the waste cost reduction in dry state were determined.



Table 7. The comparison of waste in a high-rise building in two construction modes of traditional and prefabrication

| A | B (m ³) | C (Rial) | D | | E % | F | G (m ³) | H (Rial) | I (Rial) | J (Rial) | K % | L % | M % |
|---------------------------------------|------------------------|-------------|---------------------|---------------------|--------|-------|------------------------|--------------|-------------|---------------|--------|--------|--------|
| | | | D ₁ % | D ₂ % | | | | | | | | | |
| Faceting | 1292.5 | 1,500,000 | 28 | 1 | 93 | 361.9 | 12.92 | 542,852,000 | 19,380,000 | 523,470,000 | 4.4 | 11.8 | 96.42 |
| Internal and external blades | 8800 | 450,000 | 8 | 0.1 | 93 | 704 | 8.8 | 316,800,000 | 3,960,000 | 312,840,000 | 5.8 | 0.46 | 98.75 |
| Plastering | 1284 | 825,000 | 25 | 0.2 | 97 | 321 | 2.56 | 264,825,000 | 2,112,000 | 262,713,000 | 9.8 | 2.43 | 99.2 |
| Flooring | 1250 | 3,500,000 | 7 | 0.1 | 91 | 87.5 | 1.25 | 306,250,000 | 4,375,000 | 30,1875,000 | 11.2 | 0.77 | 98.57 |
| Tiling and stoning | 475 | 8,800,000 | 5 | 0.25 | 86 | 23.75 | 1.18 | 209,000,000 | 10,384,000 | 198,616,000 | 4.7 | 0.22 | 95.03 |
| Total | | | | | | | | 1639,725,000 | 40,211,000 | 1,599,514,000 | 5.06 | | |

A Building components

B Amounts and volumes

C Unit cost

D Average level of waste

D₁ Traditional Construction

D₂ Prefabrication

E The amount of waste reduction in drying [$E = (D_1 - D_2) / D_1$]

F Total amount of traditional waste [$F = B \times D_1$]

G Total amount of dry waste [$G = B \times D_2$]

H The cost of traditional waste - [$H = F \times C$]

I The cost of dry waste - [$I = G \times C$]

J The reduce costs of dry waste - [$J = H - I$]

K Weight(WBS)

L Percentage reduction of project cost in detail = [$\frac{J}{B \times C} \times K$]

M Ecoefficiency in the use of prefabrication = [$\frac{F-G}{F} \times 100$]

(Table 7) compares the cost of waste in two cases. According to (Equation 1), using prefabricated construction, cost of waste can be reduced to 97.54%.

$$\frac{1599514000}{1639725000} * 100 = \%97.54 \quad (1)$$

Based on the calculations in (Table 7), the following result is considered with prefabrication: While the total cost of the project is reduced by 5.06%, the most effective component was plastering (2.43%), and the lowest one was tiling and stoning (0.22%) (Figure 2).



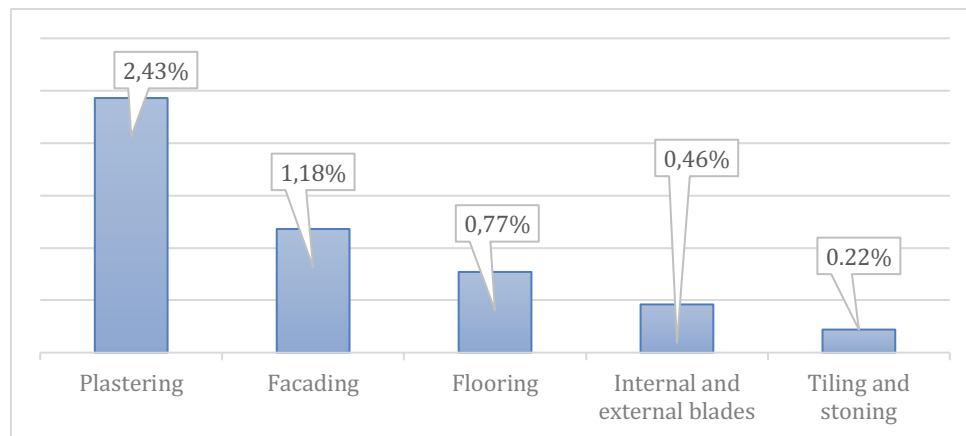


Figure 2. Cost reduction in the use of prefabrication in various non-structural components

The highest environmental efficiency in the use of prefabrication is related to plastering with 99.2%, and the lowest efficiency in using prefabricated buildings with 95.03% is related to tiling and stoning (Figure 3).

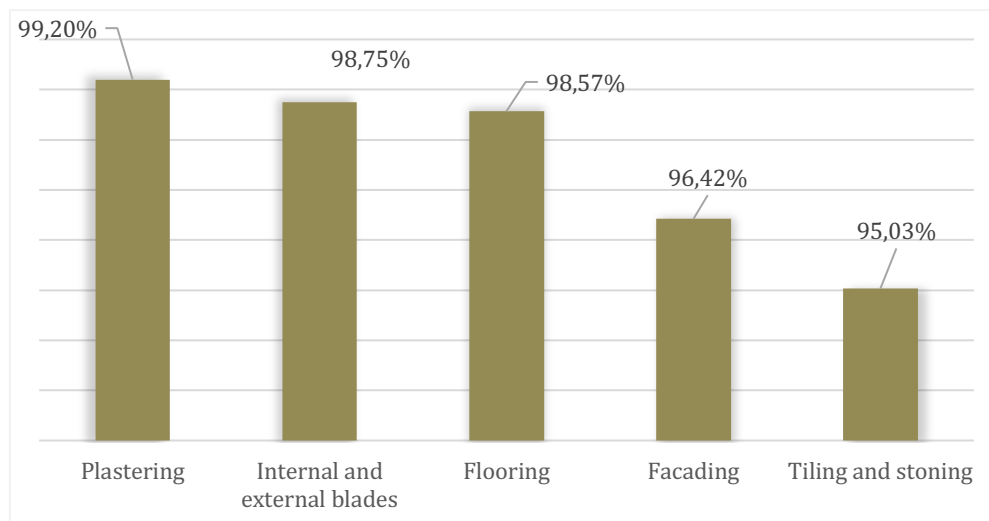


Figure 3. Ecoefficiency in the use of prefabrication in various non-structural components in the study

In the studies, the foundation and the skeleton as well as ceiling are considered as traditional form while the non-structural components are regarded as the dry state. The results of (Table 7) indicate that if the skeletons and ceilings are traditionally executed according to experts (Table 6) and the rest are implemented in prefabrication states, the cost of waste would be reduced by 97.54%.

In prefabrication, the plaster board for walls and ceilings, AAC blocks for interior and exterior partition walls, and ceramics with mechanical connections for building facades are used. In the prefabrication, estimation of materials is more accurate than traditional construction, and quality of construction is better and change of maps is a little; hence, the amount of construction waste is few. In the current study, the total cost of the project was reduced by 5.06%, and environmental efficiency in the background for the reduction of construction waste production was determined to be 99.2%.

4. Conclusion

Reduction or conversion of construction waste in the construction industry is an important issue. In this regard, prefabrication is one of the ways to reduce construction waste, and there is still a problem in the construction of building in a dry method, yet the adoption of prefabrication can reduce both the waste and construction costs. In this research, the advantages, disadvantages of prefabrication, and its development strategies were determined. For this,

waste costs in both traditional and prefabrication was determined by adopting prefabrication in non-structural components of high-rise buildings, so the waste cost would be reduced to 97.54%, and it can probably prevent problems such as degradation of natural resources and ecosystems; reduce environmental pollution; and enhance the quality of life. In construction, a reasonable using of energy and reducing the production of construction waste are considered to be the characteristics of eco-efficiency; therefore, the total cost of the project was reduced by 5.06%, and environmental efficiency for the reduction of construction waste production was determined to be 99.2%.

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