Examining the Adoption of Prefabricated Construction Methods for Building Housing in Egypt

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Abstract: **Prefabricated construction methods have become a key strategy to achieve sustainable development in building housing around the world. However, these methods are still used in a narrow context in building Egyptian housing. This research aims to examine the adoption of prefabricated construction methods for building Egyptian housing. To achieve the aim of the research, 28 performance criteria under economic, social, environmental, and technical categories were used to evaluate the performance of prefabricated and traditional on-site frame construction methods in building Egyptian housing. Multi-criteria decision-making techniques (MCDM): the Technique for Order of Preference by Similarity to Ideal Solution technique (TOPSIS) and the Importance Performance analysis technique (IPA) were used to contextualize the final findings. The results revealed that prefabrication can achieve a good level of performance in building Egyptian housing with some recommendations. Most causes that weaken the performance of prefabrication in Egypt are back to the strategic criteria including; the lack of construction practitioners' knowledge, standardization availability, and customer perception. This research provides a notion about the prefabrication performance in building Egyptian housing by using the multi-criteria decision-making analysis.**

Keywords— **Egyptian housing construction sector; prefabricated construction methods; traditional on-site frame construction methods; IPA and TOPSIS methods.**

1. INTRODUCTION

Egyptian housing construction sector is one of the main pillars to develop the economy [8]. Thus any development for this sector can contribute to the country's prosperity [18]. Egyptian vision 2030 for development emphasized the necessity to improve the housing construction sector guided by sustainability principles [8, 14]. Affordability, the speed of implementation, and the time frame are the key requirements for improving this sector due to the backlog in affordable housing units which was calculated by 7 million units over the period (2007-2022). Egyptian housing construction generally depends on the structural traditional concrete cast-in-situ and masonry systems for a long time and till now. On-site traditional construction methods refer to the most executed systems and most accepted. Construction operations of these systems are largely based on the laborers' on-site activities and all construction elements are executed on-site [33].

Agrama et al. [2] and El-hakim [10] showed that the on-site reinforced concrete column and beam system (i.e., frame-skeletal system) is the most common traditional construction method in building Egyptian housing. Din [7] stated that traditional on-site construction methods provide many advantages such as; high compressive strength, a good amount of tensile stress, fire and weather resistance, durability and requires less skilled laborers for the erection of the structure. Designers and construction practitioners prefer the useful qualities offered by this construction method because of years of experience [24]. However, on-site traditional construction methods are denounced because of tough-working conditions, low productivity, and high risks [17].

According to a study conducted in Egypt, approximately 18% of occupational injuries were recorded in the construction industry [11]. On-site traditional construction methods are considered also a big consumer of raw materials and energy, and the main source of solid waste and gas emissions [3]. Everything in our life is subject to change to suit the era in which we live as well as the construction method must keep up to date to meet the current needs of the community [19]. Lately, the prefabricated construction technique has attracted the construction professionals' attention as a promising eco-friendly innovation. It aims to improve the construction life cycle starting from the extraction of raw material until the disposal of the construction [5]. Prefabricated construction is a method in which planning, design, and fabrication of building components were implemented at a location away from their final installation [26].

This technique has been used as a strategy to minimize construction waste [20] depending on the use of fewer materials in a more developed manner [29]. The prefabricated method can achieve a better level of sustainability due to increasing energy efficiency, waste reduction, and low carbon emission. It also increases the possibilities of recycling and reusing building components and materials, improving energy and water consumption efficiency, reducing air pollution, diminishing noise during the construction process [16]. Moreover, prefabrication provides a better quality product, improves health and safety conditions, in addition to, shorten the time of project delivery because construction elements can be fabricated and erected at high speed [27].

Despite all advantages of prefabrication, Mostafa et al. [22] stated that prefabrication was found in Egyptian buildings but in a limited context specialized in building precast concrete elements. Schafer et al. [25] indicated to collaboration has been established between the National Housing and Building Research center (HBRC) and the

United States to use light steel frame system in residential buildings. Achturk Company guide [1], a leading Egyptian company in glass fiber reinforced concrete system, introduced a report based on the National HBRC to evaluate the glass fiber reinforced system in building housing. However, there is no clear vision about the performance of using prefabrication in building Egyptian housing. This research aims to examine the decision to adopt prefabricated construction methods as the sustainable choice in building Egyptian housing. To make an effective decision, prefabricated construction methods should be evaluated versus the common traditional on-site frame construction methods based on the comprehensive performance criteria of selecting Egyptian housing construction method. Thus, the multi-decision-making process can play an essential role in this research issue.

2. METHODOLOGY

To achieve the aim of this research, a structured systematic steps were developed followed the multi-criteria decision-making (MCDM) approach as shown in Figure 1. The MCDM is a useful technique used to make a successful decision by comparing different alternatives according to specific criteria by decision-makers. Consequently, alternatives can be explored in greater depth. The distinguishing attribute of the MCDM approach is the conflicts and interactions between criteria that can help to understand the problem and provide a suitable solution [12].

A. Data Collection from field study

The field study stage aimed to collect data from Egyptian housing construction practitioners about the performance of using prefabricated construction methods and the traditional on-site frame construction methods for building Egyptian housing. Two successive questionnaires were conducted through this stage based on a deep review of previous studies. The SPSS program was used to analyze the collected data to put them in a simple form.

B. Questionnaires targeted population

Both questionnaires targeted the same sample of Egyptian housing builders from engineers, designers, architects, contractors, researchers, academicians, etc. who are experienced and familiar with both traditional and prefabricated construction methods. Both questionnaires were electronic, designed by Google electronic form, and sent to 385 persons via email and by WhatsApp mobile application with a cover letter to illustrate their purpose. The rate of response on both questionnaires was very slow. More than 4 reminders were sent to respondents. Some questionnaires were printed and delivered by hand. However, only 90 responses of the same respondents of each questionnaire were valid for analysis, and the other responses were refused because of some reasons like; giving the same degree to all the criteria, conflicting answers to personal information questions, and the participant didn't complete both questionnaires. The responses percentage was considered acceptable as the number of workers in the prefabricated construction sector in Egypt is very limited. The demographic data of the respondents is shown in Table 1 and Figure 2.

B.1 The first questionnaire: Defining decision criteria

This questionnaire was used to define and evaluate the criteria by which the Egyptian housing construction practitioners select the appropriate construction methods for building housing. The five-Likert scale for importance was used to evaluate the criteria where; 1=very low importance, 2=low importance, 3= fairly important, 4=important, and 5=very important. Through this questionnaire, twenty-eight performance criteria were defined under 4 categories (i.e., economic, social, environmental, and technical) as shown in Table 2.

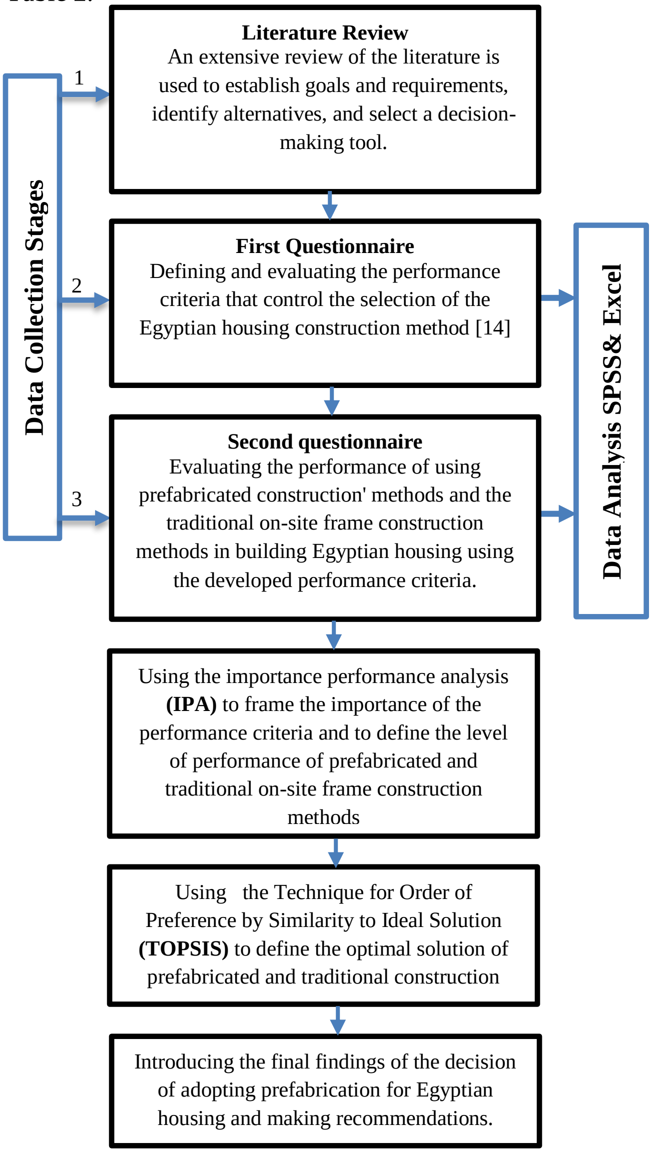

Figure 1. Research methodology

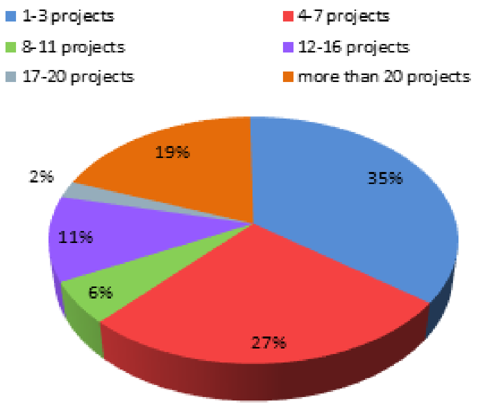

Figure 2. Number of projects in which participants used prefabricated construction methods

The analysis of the questionnaire found all the 28 developed criteria have belonged to above-medium levels ‘‘fairly important’’ of importance. This indicates the increasing interest of construction practitioners in achieving holistic performance in housing construction. This questionnaire, by using SPSS program, was analysed and discussed in more detail in the first part of this research [14].

B.2 The second questionnaire: Performance of prefabricated & traditional construction methods

This questionnaire was the second step in data collection. The five-Likert scale of performance was used to evaluate the performance of using prefabricated construction methods and the traditional on-site frame construction methods for building Egyptian housing according to the previously defined criteria from the first questionnaire where; 1= very poor performance, 2= poor performance, 3= fair performance and 4= good performance, 5= excellent performance. This questionnaire was divided into three parts;

a. The first part was about participants' general information. This part was analyzed and discussed as shown in Table 1.
b. The second part was about evaluating the performance of prefabricated construction methods as shown in Table 2.
c. The third part was about evaluating traditional on-site frame construction methods as shown in Table 2.

The Cronbach's Alpha values were used to measure the internal consistency for the responses of both questionnaire partitions (prefabrication and traditional). Cronbach's alpha values that are in the range of .7 to 1 are acceptable. The more increase of Cronbach's Alpha value to be more than .7 and closer to 1 the more increasing in internal consistency of the questionnaire's responses [28]. The Internal Consistency analysis of this questionnaire was performed 5 times based on the criteria categories, where four times were performed for the categories of the criteria (i.e., economic, social, environmental, and technical) and the fifth one was performed for all the categories together. All Cronbach's Alpha values were found more than 0.7 so the internal consistency of the responses is acceptable.

C. Importance performance analysis

The Importance performance analysis (IPA) is a useful management graphical tool used to evaluate the quality of the products [21]. It was introduced to develop marketing strategies by analyzing the customers' satisfaction towards a specific organization’s products or services .Therefore, IPA was used in many fields to evaluate services such as; tourism, government, banking, education, healthcare...etc. services. The IPA graphic matrix as shown in Figure 3 consists of two axes: the y-axis represents the importance of a set of attributes to customers and the x-axis represents the company's performance to provide specific products or services according to the same attributes [23].

These two axes inter to create 4 quadrants. The four quadrants are determined based on the intersection of the centre points of the IPA axes [23, 32].

I. Quadrant I (Keep Up the Good Work) contains the attributes that are at high levels of importance and performance. These attributes refer to the key strengths and opportunities for achieving the competitive advantage of the product.
II. Quadrant II (Concentrate Here) contains the attributes that are at high levels of importance and low levels of performance. This means that the attributes play an important role however the products provide a fairly level of performance. Therefore these attributes can be considered the key weaknesses that are in urgent need of improvement.
III. Quadrant III (Low Priority) contains the attributes that are at low levels of importance and performance. This means that the attributes set in these quadrants don't need any improvements because they play a low role in importance and performance so, they don't have a priority for implementation.
IV. Quadrant IV (Possible Overkill) contains the attributes with low levels of importance and high levels of performance. In this case, the organization shouldn't waste the time improving these attributes, supporting them with resources, or investing in them [23, 32]. The IPA analysis was developed by many researchers in various styles but this research has introduced only the traditional/ classical IPA to explain the final results.

Table 1. Demographic data of the survey participants

Variable Level of Education	Frequency	Percent
Bachelor	42	46.67%
Diploma	5	5.56%
MBA	3	3.33%
MSc	11	12.22%
PhD	29	32.22%
Sum	90	100%
Years of experience	**Frequency**	**Percent**
7-10 years	28	31.11%
11-15 years	15	16.67%
16-20 years	10	11.11%
21-25 years	9	10%
more than 25 years	28	31.11%
Sum	90	100%
Specialization	**Frequency**	**Percent**
Civil	79	87.8%

Architecture	11	12.2%
Sum	90	100%

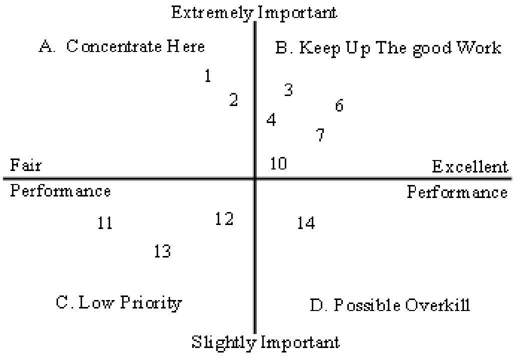

Figure 3. The original IPA matrix [13]

Table 2. The importance of the decision criteria & performance of prefabricated and traditional construction methods.

Characteristics of decision criteria				Prefabrication's scores of performance	Traditional 's scores of performance
	Criteria	Decision criteria's scores of importance	overall ranking of decision criteria		
Economic criteria	1. Construction cost (CC).	4.32	2	3.53	3.30
	2. Construction duration (CD).	3.71	21	4.33	3.00
	3. Maintenance cost (MC).	4.00	11	3.66	3.20
	4. Disposal cost (DC).	3.19	28	3.99	2.69
	5. Affordability (A).	4.20	7	3.31	3.24
	6. Resource availability (RA).	4.33	1	3.73	4.08
	7. Speed of return on investment (IR).	3.89	15	3.66	3.23
	8. Structure future value (FV).	3.98	13	3.7	3.81
Social criteria	9. Previous experience of Practitioners and knowledge availability (EK).	4.22	5	3.01	4.39
	10. Influence on job market (JM)	3.60	24	3.64	4.27
	11. Customer acceptance and perception (CP).	4.06	9	3.37	3.88
	12. Health &safety of workers (HS).	4.20	6	4.13	2.86
Environmental criteria	13. Efficiency of Energy consumption (EEC).	3.84	16	3.84	2.84
	14. Efficiency of Water consumption (EWC).	3.82	17	4	2.66
	15. Efficiency of Materials consumption (EMC).	4.00	12	4.03	2.98
	16. Use Eco-friendly materials (EFM).	3.5	26	3.86	2.44
	17. Waste reduction (WR).	3.58	25	3.87	2.37
	18. Pollution generation reduction (PGR).	3.42	27	3.78	2.50
	19. Efficiency of acoustic insulation (AI).	3.68	23	3.46	3.03
	20. Efficiency of construction thermal conductivity (ETC).	3.7	22	3.36	3.07
Technical criteria	21. Standardization availability (S).	4.17	8	3.09	4.17
	22. Loading capacity (LC).	4.30	3	3.63	4.19
	23. Life spans (LS).	4.02	10	3.94	4.03
	24. Construction quality control (QC).	3.92	14	4.22	3.44
	25. Constructability (C).	4.24	4	4.18	3.46
	26. Flexibility to modify (F).	3.79	19	2.9	3.42
	27. Building's aesthetic options (BAO).	3.78	20	3.64	3.89
	28. Transportation constrains (TC).	3.80	18	3.71	3.82

C.1 IPA of using prefabricated and traditional construction methods for building Egyptian housing

The classical IPA method was used in this research to frame the importance of the performance criteria that control the Egyptian housing construction methods. Then the performance levels of prefabricated and traditional on-site frame construction methods in building housing in Egypt are clarified according to the importance of these criteria. The IPA also used to defining the strengths and weaknesses of using prefabricated construction methods in building Egyptian housing.

The IPA charts of Prefabricated and traditional on-site frame construction methods were represented as shown in Figure 4 and Figure 5 through the following steps;

- The values of the y-axis in both charts represent the importance scores of the decision criteria.
- The values of the x-axis represent the performance scores of the traditional on-site frame as shown in Figure 4 and represent the performance scores of prefabricated construction methods as shown in Figure 5.
- To plot the four quadrants of both IPA charts, the coordinates' centers were determined based on the data center using the average of the values from Table 2. The average of the importance scores for the decision criteria was calculated as 3.9. The average of the performance scores for both prefabricated and traditional on-site frame construction methods together was calculated as 3.53.

C.2 Results of IPA to frame the level of importance for criteria and level of performance for construction methods

1. The IPA charts in Figure 4 and Figure 5 show that only 14 criteria from the 28 defined criteria have importance more than 3.9 and concentrated in the quadrant I " keep up the good work with high performance and importance " and the quadrant II "concentrate here with low performance and high importance". These criteria according to the IPA are the most important criteria and the controller criteria when selecting the construction methods for building Egyptian housing which are; resource availability (RA), construction cost (CC), load capacity (LC), constructability(C), previous experience of practitioners & knowledge availability (EK), affordability(A), health &safety of workers (HS), standardization (S), customer acceptance and perception (CP), life spans (LS), maintenance cost(MC), and efficiency of material consumption (EMC), structure future value (FV) and construction quality control (QC).
2. The other remaining 14 criteria are less than 3.9 and concentrated in the quadrant III "low priority" with low performance and low importance and the quadrant IV "possible over kill'' with high performance and low importance. These criteria are less important in decision making when selecting construction methods for building housing in Egypt. Most of these criteria were the environmental criteria. These criteria are considered additional advantages or disadvantages in any construction method but not strengths or weaknesses for adopting these methods in building Egyptian housing. Table 3 summarizes IPA results.
3. The IPA of prefabricated construction methods as shown in Figure 5 and in Table 3 found that prefabricated construction methods can achieve good levels of performance in only 9 criteria from the most important 14 criteria which are marked in the first quadrant "keep up the good work".

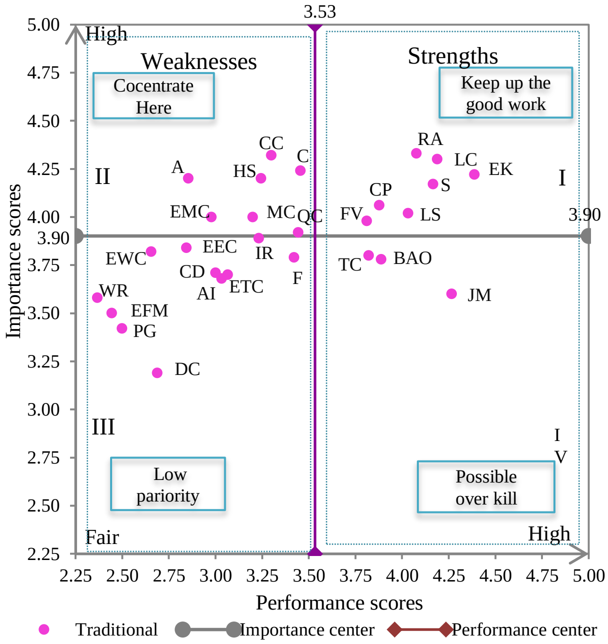

Figure 4. The IPA of traditional construction methods

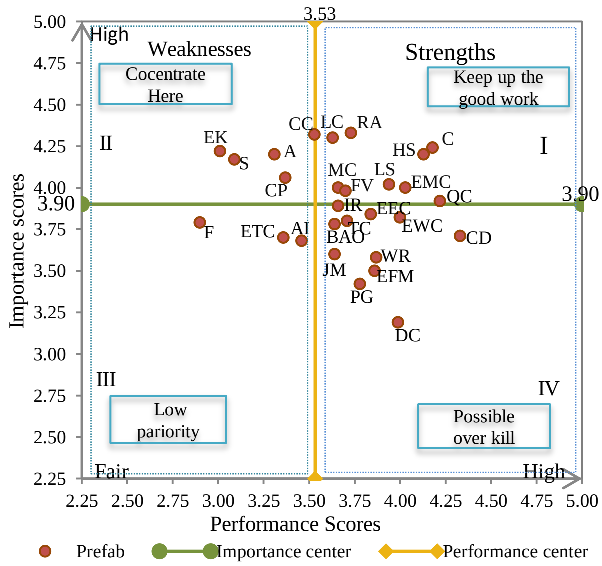

Figure 5. The IPA of prefabricated construction methods

These 9 performance criteria are considered strengths of using prefabricated construction methods in building Egyptian housing which are; resource availability (RA), loading capacity (LC), constructability (C), health &safety of workers (HS), life spans (LS), maintenance cost (MC), structure future value (FV), construction quality control (QC)**.** The rest 5 criteria from the most important 14 criteria fell in the second quadrant "concentrate here" with a low level of performance. Thus these five criteria are considered the weaknesses that hinder using prefabricated construction methods for building Egyptian housing which are; construction cost (CC), affordability (A), previous experience of practitioners and knowledge availability (EK), customer acceptance and perception (CP), and standardization availability (S).

4. While The IPA chart of traditional on-site frame construction methods as shown in **Figure 5** found that traditional on-site frame construction methods can achieve good levels of performance in only 7 criteria from the most important 14 criteria which are marked in the first quadrant "keep up the good work". These seven criteria are considered strengths of traditional construction methods as shown in **Table 3.** The other 7 criteria of the most important 14 criteria fell in the second quadrant "concentrate here" with a low level of performance so they considered weaknesses of traditional construction methods which are; construction cost (CC), affordability (A), maintenance cost (MC), health &safety of workers (HS), the efficiency of materials consumption (EMC), construction quality control (QC), and constructability(C).
5. For the other less important 14 criteria in decision making whose importance is less than 3.9; The IPA charts of Figure 4 and Figure 5 show that traditional on-site frame construction methods can achieve only 3 advantages of these criteria while prefabricated construction methods can achieve 11 advantages from these criteria. Table 3 summarizes the results of the IPA according to the importance of decision criteria.

Table 3. IPA conclusion

Decision Criteria Ranking by its importance	Prefabrication implication of IPA			Traditional implication of IPA			Conclusion
	Performance	IPA quadrant	Strengths-weaknesses	Performance	IPA quadrant	Strengths-weaknesses	
*Resource availability (RA)	3.73	I	Strength	4.08	I	Strength	Head to head-competition but traditional gives better performance
*Construction cost (CC).	3.53	II	Weakness	3.3	II	Weakness	weaknesses in both construction methods
*Loading capacity (LC)	3.63	I	Strength	4.19	I	Strength	Head to head-competition but traditional gives better performance
*Constructability (C)	4.18	I	Strength	3.46	II	Weakness	(Competitive-advantage) opportunity to adopt prefabrication
*Previous experience of Practitioners and knowledge availability (EK)	3.01	II	Weakness	4.39	I	Strength	Threat to adopt prefabrication
*Affordability (A)	3.31	II	Weakness	3.24	II	Weakness	weaknesses in both construction methods
*Health &safety of workers (HS)	4.13	I	Strength	2.86	II	Weakness	(Competitive-advantage) opportunity to adopt prefabrication
*Standardization availability (S)	3.09	II	Weakness	4.17	I	Strength	Threat to adopt prefabrication
*Customer acceptance and perception (CP)	3.37	II	Weakness	3.88	I	Strength	Threat to adopt prefabrication
*Life spans (LS)	3.94	I	Strength	4.03	I	Strength	Head to head-competition
*Maintenance cost (MC)	3.66	I	Strength	3.2	II	Weakness	(Competitive-advantage) opportunity to adopt prefabrication
*Efficiency of Materials consumption (EMC)	4.03	I	Strength	2.98	II	Weakness	(Competitive-advantage) opportunity to adopt prefabrication
*Structure future value (FV)	3.7	I	Strength	3.81	I	Strength	Head to head-competition
*Construction quality control (QC)	4.22	I	Strength	3.44	II	Weakness	(Competitive-advantage) opportunity to adopt prefabrication
Speed of return on investment (IR)	3.66	IV	Advantage	3.23	III	Disadvantage	advantage to adopt prefabrication
Efficiency of Energy consumption (EEC)	3.84	IV	Advantage	2.84	III	Disadvantage	advantage to adopt prefabrication
Efficiency of Water consumption (EWC)	4	IV	Advantage	2.66	III	Disadvantage	advantage to adopt prefabrication
Transportation constrains (TC)	3.71	IV	Advantage	3.82	IV	Advantage	Head to head-competition
Flexibility to modify (F)	2.9	III	Disadvantage	3.42	III	Disadvantage	Dis advantage to adopt prefabrication
Building's aesthetic options (BAO)	3.64	IV	Advantage	3.89	IV	Advantage	Head to head-competition
Construction duration (CD)	4.33	IV	Advantage	3	III	Disadvantage	advantage to adopt prefabrication

Efficiency of construction thermal conductivity (ETC)	3.36	III	Disadvantage	3.07	III	Disadvantage	Disadvantage in both construction methods
Efficiency of acoustic insulation (AI)	3.46	III	Disadvantage	3.03	III	Disadvantage	Disadvantages in both construction methods
Influence on job market (JM)	3.64	IV	Advantage	4.27	IV	Advantage	Head to head-competition but traditional gives better performance
Waste reduction (WR)	3.87	IV	Advantage	2.37	III	Disadvantage	advantage to adopt prefabrication
Use Eco-friendly materials (EFM)	3.86	IV	Advantage	2.44	III	Disadvantage	advantage to adopt prefabrication
Pollution generation reduction (PGR)	3.78	IV	Advantage	2.5	III	Disadvantage	advantage to adopt prefabrication
Disposal cost (DC)	3.99	IV	Advantage	2.69	III	Disadvantage	advantage to adopt prefabrication

* The most important criteria

Table 4. Decision Evaluation Matrix $(x_{ij})_{m*n}$ with m=2 alternatives (prefabrication & traditional) and n=14 most important criteria.

	Decision Criteria	n (criteria)= 14	m (alternatives)=2	
		Importance Weight Of Decision Criteria (WJ)	Performance weight of Prefabrication (X_{1j})	Performance Weight of Traditional (X_{2j})
Economic criteria				
1	*Construction cost (CC)	4.32	3.53	3.30
2	*Maintenance cost (MC)	4.00	3.66	3.20
3	*Affordability (A)	4.20	3.31	3.24
4	*Resource availability (RA)	4.33	3.73	4.08
5	*Structure future value (FV)	3.98	3.70	3.81
Social criteria				
6	*Previous experience of Practitioners and knowledge availability (EK)	4.22	3.01	4.39
7	*Customer acceptance and perception (CP)	4.06	3.37	3.88
8	*Health &safety of workers (HS)	4.20	4.13	2.86
Environmental criteria				
9	*Efficiency of Materials consumption (EMC)	4.00	4.03	2.98
Technical criteria				
10	*Standardization availability (S)	4.17	3.09	4.17
11	*Loading capacity (LC)	4.30	3.63	4.19
12	*Life spans (LS)	4.02	3.94	4.03
13	*Construction quality control (QC)	3.92	4.22	3.44
14	*Constructability (C)	4.24	4.18	3.46

***The most important criteria**

6. The IPA of prefabricated in Figure 5 also stated that despite the good performance of the prefabricated construction methods in the resource availability (RA) criterion, RA is close to the quadrant of concentrated here. Thus, this criterion requires further improvement and focus due to its pivotal importance in adopting any construction method.

D. TOPSIS method

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) can be defined as a simple effective tool used for multi-criteria decision analysis issues to rank alternatives by determining the weights for the criteria, normalizing scores for them then calculating the geometric distance between each alternative and the ideal solution. The TOPSIS method is based on the rule that the selected alternative should have the shortest distance from the positive-ideal solution, and the longest distance from the negative ideal solution [4, 31]. This method was used widely in various fields because of the possibility of determining the best and worst alternative in a simple and fast mathematical process [15]. The procedures of TOPSIS method can be described and illustrated as the following.

D.1 Determination the best performance alternative using TOPSIS technique

Based on the previous analysis of the collected data, the TOPSIS method for multi criteria decision making was used to define the better performance between both the prefabricated (Prefab.) and traditional on-site frame (Trad.) construction methods for building Egyptian housing according to all the 14 defined criteria firstly, secondly according to the most important 28 criteria through the following steps as shown in Tables 4 to 9 by using Microsoft Excel.

<u>The first step</u> in this method is creating the decision evaluation matrix as shown in Figure 6 and applied in Table 4 where; V represents a set of alternatives V = {Vi | i = 1, 2,

. . ., m}, C represents a set of criteria C = {Cj | j = 1, 2, . . .,n}, X is the decision matrix and xij represents the value of jth criterion to ith alternative, X = {xij | i = 1, 2, . . ., m; j = 1, 2, . . ., n}, W is the set of the weight of n criteria, w= {wj | j = 1, 2, . . ., n} [4, 6, 31].

Step 2 is establishing the normalized decision matrix as shown in **Table 5** by calculating the vector normalization [4, 6, 31].

$$\overline{xij} = \frac{xij}{\sqrt{\sum_{i=1}^{m} X_{ij}^{2}}} \text{ (i = 1, 2,.., m; j = 1, 2,..., n) … Eq. (1)}$$

Step 3 is calculating the weighted normalized decision matrix V_{ij} [4, 6, 31] as shown in **Table 6**.

$$V_{ij} = \overline{xij} * w_j, \text{ (i= 1, 2,... , m; j=1,2,…,n) … Eq. (2)}$$

$$w_j = Wj / \textstyle\sum_{j=1}^{n} W_J, \text{ (j= 1,… , n); } \textstyle\sum_{j=1}^{n} w_j = 1 \text{ … Eq. (3)}$$

Wj is the importance weight of the criteria

$$\begin{array}{c|cccccc|} & w1 & w2 & \dots & wj & \dots & wn \\ & C1 & c2 & \dots & cj & \dots & cn \\ \hline V1 & x11 & x12 & \dots & x1j & \dots & x1n \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ Vi & xi1 & xi2 & \dots & xij & \dots & xin \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ Vim & xm1 & xm2 & \dots & xmj & \dots & xmn \end{array}$$

Figure 6. The TOPSIS decision Matrix

Table 5: Normalized Decision Matrix ($\overline{xij}$)

Criteria		(Prefab) X_{1j}^{2}	(Trad.) X_{2j}^{2}	$\sqrt{\sum_{i=1}^{2=} X_{ij}^{2}}$ (Prefab & Trad.)	(Prefab) $\overline{X_{1j}} = \frac{x_{1j}}{\sqrt{\sum_{i=1}^{2=} X_{ij}^{2}}}$	(Trad.) $\overline{X_{2j}} = \frac{x_{2j}}{\sqrt{\sum_{i=1}^{2=} X_{ij}^{2}}}$
1	(CC)	12.461	10.890	4.832	0.7305	0.56951
2	(MC)	13.396	10.240	4.862	0.75283	0.55885
3	(A)	10.956	10.526	4.633	0.71414	0.73787
4	(RA)	13.396	10.454	4.884	0.74944	0.71749
5	(FV)	13.690	14.525	5.312	0.69657	0.82468
6	(EK)	9.060	19.262	5.322	0.56559	0.75479
7	(CP)	11.357	15.037	5.138	0.65596	0.56872
8	(HS)	17.0569	8.154	5.021	0.82254	0.59427
9	(EMC)	16.241	8.867	5.0108	0.80426	0.80323
10	(S)	9.548	17.361	5.187	0.59567	0.75572
11	(LC)	13.177	17.547	5.5429	0.65489	0.71534
12	(LS)	15.524	16.268	5.638	0.69878	0.63233
13	(QC)	17.808	11.864	5.447	0.7747	0.63716
14	(C)	17.472	11.941	5.4234	0.77073	0.75479

Table 6. Defining the Best (v_{ij+}) and the Worst (v_{ij-}) Ideal Solutions

Decision Criteria		$wj = \frac{WJ}{\sum_{J=1}^{n=14} W_J}$	Prefab $V_{1j} = \overline{X_{1j}} * w_j$	Trad. $V_{2j} = \overline{X_{2j}} * w_j$	v_{ij+} Max of ($V_{1j}prefab$ & V_{2j} $trad$)	v_{ij-} Min of ($V_{1j}prefab$ & V_{2j} $trad$)
1	(CC)	0.074534	0.05445	0.05089	0.05445	0.05089
2	(MC)	0.069013	0.05196	0.04542	0.05196	0.04543
3	(A)	0.07246	0.05175	0.05073	0.05175	0.05073
4	(RA)	0.07471	0.05042	0.05512	0.05512	0.05042
5	(FV)	0.06867	0.04783	0.04927	0.04927	0.04783
6	(EK)	0.07281	0.04118	0.06005	0.06005	0.04118
7	(CP)	0.07005	0.04595	0.05287	0.05287	0.04595
8	(HS)	0.07246	0.05960	0.04121	0.05960	0.04121
9	(EMC)	0.06901	0.055511	0.04101	0.05551	0.04101
10	(S)	0.07195	0.04286	0.05779	0.05779	0.04286
11	(LC)	0.07419	0.04857	0.05607	0.05607	0.048586
12	(LS)	0.06936	0.04847	0.04961	0.04961	0.04847
13	(QC)	0.06763	0.05239	0.04277	0.05239	0.04277
14	(C)	0.073154	0.05638	0.04661	0.05638	0.04661

Step 4 is to define the positive (best) and the negative (worst) ideal solutions using the weighted normalized decision evaluation matrix for every attribute/criterion [4, 6, 31]. Wang and Elhag [30] showed that the beneficial criteria in TOPSIS maximize the benefit in the case of the positive ideal solution and the cost is minimized, in contrast to the case of the negative ideal solution, cost criteria are maximized and beneficial criteria are minimized.

$$\text{Worst} = v_{ij-} = \begin{Bmatrix} \langle max(vij \mid i = 1,2,\dots,m) \mid j \in J_-\rangle \\ \langle \min(vij \mid i = 1,2,\dots,m) \mid j \in J_+\rangle \end{Bmatrix},$$

(j = 1, …, n) … Eq. (4)

v_{ij-} = min of vij for the beneficial criteria and max of vij for criteria- related cost (criteria that maximize the cost).

$$\text{Best} = v_{ij+} = \begin{Bmatrix} \langle min(vij \mid i = 1,2,\dots,m) \mid j \in J_-\rangle, \\ \langle max(vij \mid i = 1,2,\dots,m) \mid j \in J_+\rangle \end{Bmatrix},$$

(j = 1, …, n) … Eq. (5)

v_{ij+}= max of vij for the beneficial criteria and min of vij for criteria-related cost (criteria that minimize the cost).

In this research all the criteria were assumed beneficial because they measure the performance efficiency through the proposed criteria. So, the best solution for every criteria (v_{ij+})= max of vij from both alternatives (Prefab. & Trad.).

The worst solution for every criteria (v_{ij-})= min of vij from both alternatives (Prefab. & Trad.) as shown in Table 6.

Step 5 is calculating the distance of the alternatives from the best and the worst ideal solution where; SI^+ is the distance from the best solution and SI^- is the distance from the worst solution [4, 6, 31]. Table 7 contains calculating the distance of prefabricated and traditional from the worst solution SI_i^- and the best solution SI_i^+.

$$SI_i^+ = \sqrt{\sum_{J=1}^{n}(vij - vij^+)^2}, \quad (i = 1, 2, \dots, m;\ j = 1, 2, \dots, n)$$

Eq. (6)

$$SI_i^- = \sqrt{\sum_{J=1}^{n}(vij - vij^-)^2}, \quad (i = 1, 2, \dots, m;\ j = 1, 2, \dots, n)$$

Eq. (7)

Table 7. Determining of SI_i^+, SI_i^-

Decision Criteria		Prefab	Trad.	prefab	Trad.
		$(V_{1j}prefab - vij^+)^2$	$(V_{2J}\,trad - vij^+)^2$	$(V_{1j}prefab - vij^-)^2$	$(V_{2J}\,trad - vij^-)^2$
1	(CC)	0.0	0.0000126	0.0000126	0.0
2	(MC)	0.0	0.0000426	0.0000426	0.0
3	(A)	0.0	0.0000011	0.0000011	0.0
4	(RA)	0.0000221	0.0	0.0	0.0000221
5	(FV)	0.0000022	0.0	0.0	0.0000022
6	(EK)	0.0003559	0.0	0.0	0.0003559
7	(CP)	0.0000479	0.0	0.0	0.0000479
8	(HS)	0.0	0.000338292	0.000338292	0.0
9	(EMC)	0.0	0.000210022	0.000210022	0.0
10	(S)	0.0002229	0.0	0.0	0.0002229
11	(LC)	0.0000559	0.0	0.0	0.0000559
12	(LS)	0.0000013	0.0	0.0	0.0000013
13	(QC)	0.0	0.0000927	0.0000927	0.0
14	(C)	0.0	0.0000955	0.0000955	0.0
Sum		**0.0007082**	**0.0007928**	**0.0007928**	**0.0007082**
$SI_i = \sqrt{sum}$		SI_i^+		SI_i^-	
		SI_1^+ **prefab**	SI_2^+ $Trad$	SI_1^- **prefab**	SI_2^- $Trad$
		$\sqrt{\sum_{J=1}^{14}(V_{1j}prefab - vij^+)^2}$	$\sqrt{\sum_{J=1}^{14}(V_{2j}\,trad - vij^+)^2}$	$\sqrt{\sum_{J=1}^{14}(V_{1j}prefab - vij^-)^2}$	$\sqrt{\sum_{J=1}^{14}(V_{2J}\,trad - vij^-)^2}$
		0.0266	**0.0283**	**0.0283**	**0.0266**

Step 6 is determining the best ideal solution (PIS_i) by the similarity to the worst condition (closeness coefficients from the ideal solution) [4, 6, 31].

$$PIS_i = \frac{SI_i^-}{SI_i^- + SI_i^+}, \quad 0 \le PIS \le 1, \quad i = 1,2,\dots,m \ \dots \text{Eq. (8)}$$

PIS =1 if the alternative has the ideal condition and PIS =0 if the alternative has the worst condition.

Finally, ranking alternatives in descending order according to the closeness coefficients where the best alternative has the biggest PIS (the longest distance from the worst ideal solution) as shown in Table 8 and defining the best alternative (PIS) from both construction methods (prefabrication and traditional by the similarity to the worst condition (closeness coefficients from the ideal solution).

The TOPSIS technique showed that the PIS "similarity with the ideal solution" values of the most important 14 criteria are slightly higher in prefabricated construction methods than in traditional on-site frame construction methods. This means that prefabricated construction methods are slightly better in performance than traditional on-site frame construction methods. To confirm this result, the same steps of TOPSIS technique was implemented according to the 28 performance criteria and the final result of PIS values were introduced as shown in Table 9.

The PIS "Similarity with the ideal solution" values were found equal to 0.653612 for the performance of the prefabricated construction methods and equal to 0.346388 for the traditional construction method. This means that the prefabricated construction methods can introduce a better performance than the traditional on-site frame construction methods in building Egyptian housing according to all the 28 defined decision criteria. Because the most important 14 criteria lack the environmental ones that have more performance score for prefabricated than traditional. Hence the authors wanted to measure the decision sensitivity if the specimen's awareness of the importance of environmental criteria increases. The result of the TOPSIS method showed that prefabricated can perform better than traditional on-site frame construction methods according to all the 28 decision criteria and according to the most important 14 criteria but the difference is not significant in this case.

Table 8. PIS values and ranking the alternatives according to the most important 14 performance criteria

	$PIS_{Prefab.} = \frac{SI_{1pref.}^{-}}{SI_{1\,pref.}^{-} + SI_{1\,pref.}^{+}}$	$PIS_{Trad.} = \frac{SI_{2\,Trad.}^{-}}{SI_{2\,Trad.}^{-} + SI_{2\,Trad.}^{+}}$
***PIS*$_i$**	**0.5141**	**0.4859**
Rank	**1 (Prefab.)**	**2 (Trad.)**

Table 9. PIS values and ranking the alternatives according to all the 28 performance criteria

Result of TOPSIS	**Prefabricated construction methods**	**Traditional construction methods**
***PIS*$_i$**	**0.653611715**	**0.346388285**
Rank	**1**	**2**

3. DISCUSSION

Through this research 28 performance criteria were picked to evaluate the Egyptian housing construction methods. These criteria have varying scores of importance. However, according to the IPA method, only 14 of these criteria were categorized as the most important criteria that control the selection of the Egyptian housing construction methods. These important criteria belonged to economic, social and technical categories and only one criterion belonged to the environmental category as summarized in Tables 3 & 4. Although the environmental criteria have gained the attention of Egyptian building practitioners, the results of the IPA showed that they are still not fundamentally influential in adopting the construction method. The evaluation of prefabricated construction methods and traditional on-site frame construction methods was conducted based on the top important 14 criteria and all the 28 defined criteria. The TOPSIS method showed the superior performance of prefabricated construction methods more than the traditional on-site frame construction methods according to the 28 performance criteria. This is what was confirmed by the IPA method during measuring the level of performance. The IPA of Figures 4 & 5 showed that using prefabricated construction methods in building Egyptian housing can achieve a good level of performance in 20 criteria out of the defined 28 decision criteria which are approximately equal to 70% of the total number of the criteria, while the traditional on-site frame construction methods can give a good level of performance in 10 criteria out of the defined 28 decision criteria. The superior number of the performance criteria of prefabricated construction methods was mostly back to environmental criteria which are considered added advantages, not strengths in the embracing of construction methods for Egyptian housing. On the other hand, the results of the TOPSIS and IPA that were based on the most influential fourteen performance criteria in selecting Egyptian housing construction methods stated that prefabricated construction methods is slightly better in performance than traditional on-site frames in building Egyptian housing which indicated the convergent level of performance in both construction techniques. The IPA method also revealed that prefabricated construction methods only met nine criteria and traditional on-site frame construction methods only met seven of the most important 14 criteria. This means that both prefabricated construction methods and traditional on-site frame construction methods didn't meet all of the most influential 14 criteria for the selection of Egyptian housing construction methods. Although the good level of performance that prefabricated construction methods can introduce, there are weaknesses in these methods in Egypt hinder their adoption. These weaknesses are mostly back to the low level of knowledge about these systems and the customer acceptance and perception as shown in Table 3.

4. CONCLUSION

Prefabricated construction methods have caught the attention of housing builders around the world due to their sustainable performance. In Egypt, the housing construction sector is basically depends on traditional on-site frame construction methods. While the use of prefabricated construction methods in building Egyptian housing is very limited. This research used the TOPSIS and IPA decision-making methods to study the performance of prefabricated construction methods versus the performance of traditional on-site construction methods in building Egyptian housing based on the concept of comprehensive performance for 28 criteria divided into four categories (i.e., economic, social, environmental, and technical). The results showed superior performance of prefabricated construction methods over traditional on-site construction methods in building Egyptian housing. This better performance of prefabricated construction methods is significantly due to the constructability, health &safety of workers, quality control and environmental efficiency. Although the prefabricated construction methods are superior in performance, the results found that construction cost and affordability criteria are weaknesses for prefabricated construction methods as in traditional on-site frame construction methods. The main threats that hinder the adoption of prefabricated construction methods for Egyptian housing construction are due to the lack of knowledge of the building practitioners, the lack of customers' adaptation of these systems, and the lack of standardization. Improving the general awareness of prefabricated construction methods is considered a decisive factor in the successful adoption of these methods in Egypt. Introducing the prefabricated construction methods as a competitor to traditional on-site frame construction methods can help the development of the Egyptian housing construction sector due to its efficient performance.

A. Recommendations

The adoption of prefabricated construction methods for building housing in Egypt still needs deep socio-engineering research in order to be compatible with the Egyptian environment. The attitude of people tends to modify their houses frequently. That is the main reason to socio-reject prefabricated methods. Hence, prefabricated methods are not suitable for all categories of people. If these systems are adopted, they must be promoted by the Egyptian government which is considered the main controller in succeeding these methods. The Egyptian government also should commit to providing standardizations and training to improve the awareness of engineers and contractors of these methods. To adopt these methods, it must be used for administration buildings or for new residential areas and maintenance centers must be constructed in these areas to be ready for any changes. Hence, limited prefabricated methods will be suitable and may need to be modified.

Funding: This research has not received any type of funding.

Conflicts of Interest: The author declares that there is no conflict of interest.

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