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Decision Making Support Model for Choosing Construction Method: A Case Study of Egypt

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***Abstract* -** Egypt as developing nation, has adopted construction industry as an engine of development to support the country's current challenging economic circumstances and local inflation, along with global inflation and resource depletion. Consequently, it necessary to continuously search for innovation construction methods which minimize cost, wastes and time, while maximizing quality. Therefore, the aim of this research is to create a decision-making model that will assist stakeholder to choose the best construction method for residential projects in Egypt during the feasibility study or early study stage. Three construction techniques, conventional, prefabricated on-site and prefabricated off-site served as the foundation of measuring and developing process. A mixed research method were utilized for this research. First, a questionnaire was developed based on construction method' constructability. Second, the data were gathered and analyzed by Analytical Hierarchy Process (AHP) to determine the weights of criteria, sub criteria and alternatives. This process was done in order to improve and develop the decision-making model for selecting the construction method in residential Egyptian projects. Then, the validation procedure revealed that the created model could assist the project' stakeholder in choosing the most appropriate construction method. Furthermore, a parametric study were carried out for most common residential construction project' cases in Egypt. The findings demonstrated that prefabricated off-sit is the appropriate for projects with built up area greater than 100,000 m^2. Whereas, the conventional approach is appropriate for social-fast track projects with built up area up to 100,000 m^2. Also, the study showed that the prefabricated off-site is suitable to luxury-fast track residential projects with built up areas greater than 10,000 m^2.

***Keywords*:** Construction method, Conventional method, prefabricated method, Decision making, AHP.

1. Introduction

The world struggles mightily to build new homes quickly enough to close the so-called "housing gap," which exists between rising population and available housing supply [1, 2]. The housing gap, according to the Association for Consultancy and Engineering (ACE), is the difference between the supply and pace of population growth in homes [3]. Moreover, due to the drawbacks of the traditional technique, which is still widely used in the majority of the world's countries, as well as the global resource scarcity and inflation that is currently occurring, it is exceedingly challenging to supply housing [4-7]. Hence, that issue cannot be resolved by conventional building methods since they are time-consuming and fraught with issues including cost overruns, poor quality, low productivity, and excessive waste, issues with safety and health, and environmental issues [8]. In order to close this gap, the world requires innovative techniques like modern methods of construction (MMC), which allow for large-scale house production at a lower cost and time investment. To accomplish its primary objective of providing new homes quickly, at a low cost, in a timely manner, with excellent quality, and an easy way to construct, MMC intends to shift construction activities from the site (on-site), where it is known to use a conventional method, to a factory (off-site), in a controlled environment. Improvements in productivity, health and safety, quality, building life cycle, environmental effect, and building performance are just a few of the numerous other advantages [9-26].

It is important to urge developing nations to use the MMC to address their local housing gap issues. Egypt is one of the developing nations that is the subject of this research, particularly in light of the significant efforts being made by the government to eradicate the slums, which call for the construction of additional new buildings in a short amount of time. Shahpari, M. et al. developed a multi-criteria decision-making model to assess the productivity of residential buildings; the model ranked three construction methods according to high productivity [27]. Reda M., et al., developed a model ranked three construction method, which are conventional method, prefabricated on-site and prefabricated off-site based on sustainability [28]. Furthermore, previous studies developed models to just rank rather than select between different construction methods. Thus, the goal of this research was to create a decision-making model for choosing the best construction technique for residential buildings in Egypt, one of the emerging nations. The model is intended to assist stakeholders in construction projects in making informed decisions during the early stages of the project, such as the feasibility study or scheme stage. These decision will determine the most appropriate construction method to use, which in turn will determine the design and procurement approach to pursue. In order to create the decision-making support model for the selection of construction methods for Egyptian residential construction projects, data for the research was gathered from Egypt's construction specialists.

2. Research methodology

The analytical hierarchy process (AHP), a multi-criteria decision-making technique created by Saaty in the 1970s [29], was employed with a mixed research method for this research [30]. It is a very popular and effective technique that has been used in many fields, including social science, engineering, politics, and economics, to facilitate decision-making regardless of the activity's complexity. By prioritizing the options to reach the goal [28], AHP helps decision makers make the best and most optimal decision possible for a given problem. As a result, it makes decision making easier for a given situation.

3. Data collection.

A variety of methods, including internet research, literature reviews, interviews, observation, and questionnaires, are used to gather specific data. Additionally, data collection techniques are divided into two categories based on the degree of acceptance of the feedback. The first category is the liner data collection method, which refers to data that is transferred from participants to the recipient in a single way without feedback because there is no interaction between the researcher and the data provider, such as when a questionnaire is sent by mail. On the other hand, the two-way data collection method ensures that the researcher understood the meaning of the data from the perspective of the data provider rather than from the data receiver by allowing interaction between the data provider and data receiver and allowing feedback through questionnaires in semi-structured interviews [31]. Experts in Egypt's construction field provided the data for this research, which aims to establish a decision-making model for selecting construction methods while taking constructability into account.

The necessary data was gathered from Egyptian building specialists using a questionnaire and face to face interviews. Using the Delphi approach, Likert scale, Alpha coefficient, and SPSS, the factors influencing the choice of construction methods in Egypt were identified and quantified [32, in press]. Furthermore, the questionnaire was designed to gather evaluation criteria and sub-criteria for the three possibilities of construction methods: conventional, prefabricated off-site, and prefabricated on-site. The questionnaire was created in sections to accomplish this goal. The first section examined the relative importance of the nine criteria for constructability of construction methods in actual Egyptian sites. The experts were asked to rate the criteria on a Likert scale from 1 to 9**.** Section two was created to assess how the primary criterion and sub-criteria related to each other. The experts were requested to use the analytical hierarchy process (AHP) scale to rate the relative importance of each sub-criteria with relation to the main criterion on a scale of 1 to 9. The third section was created to assess how elements and alternatives relate to one another. The experts were asked to use a Likert scale to rate the relative relevance of each possibility among the sub-criteria on a scale of 1 to 9.

4. Data analysis

The analysis of all the data gathered in the section above is covered in this section. As will be covered in section 4.1, the gathered data was utilized to calculate the importance weight of the criterion, sub-criteria, and alternatives utilizing the analytical hierarchy process (AHP). As will be covered in section 4.2, the final weights will be taken into consideration when creating the model that will assist in decision-making when selecting a construction approach. As will be explained in section 5, the final two processes involve validating and verifying the constructed model against actual construction sites in Egypt.

4.1. Analytical Hierarchy Process

The outputs of the analytical hierarchy method are covered in this section. In contrast, the pairwise matrices for nine criteria, eight sub-criteria, and three alternatives were presented to the experts in order for them to make a judgment regarding the significance level for each level component of the hierarchy tree, as illustrated in Figure 1. The fourteen construction experts were included in a face-to-face interview to make this determination.

Goal	**CONSTRUCTION METHOD SELECTION**								
Criteria	COST			TIME			QUALITY		
	BUA<= 10,000	10,000< BUA <= 100,000	BUA > 100,000	On time	Fast track	Limit less	Social	Average	Luxury
Sub-criteria	Construction cost	Construction cost	Construction cost	Construction cost	Construction cost	Construction cost	Construction cost	Construction cost	Construction cost
	Transport cost	Transport cost	Transport cost	Transport cost	Transport cost	Transport cost	Transport cost	Transport cost	Transport cost
	Equipment cost	Equipment cost	Equipment cost	Equipment cost	Equipment cost	Equipment cost	Equipment cost	Equipment cost	Equipment cost
	Construction time	Construction time	Construction time	Construction time	Construction time	Construction time	Construction time	Construction time	Construction time
	Transport time	Transport time	Transport time	Transport time	Transport time	Transport time	Transport time	Transport time	Transport time
	Equipment time	Equipment time	Equipment time	Equipment time	Equipment time	Equipment time	Equipment time	Equipment time	Equipment time
	Tolerance	Tolerance	Tolerance	Tolerance	Tolerance	Tolerance	Tolerance	Tolerance	Tolerance
	Rework	Rework	Rework	Rework	Rework	Rework	Rework	Rework	Rework
Alternatives	Conventional method (A)			Prefabricated on-site (B)			Prefabricated off-site (C)		

Fig. 1: Hierarchy levels for criteria, sub-criteria and alternatives.

4.2. AHP global weights

The global weight of each alternative is determined by the analytical hierarchy process (AHP) analysis, which also determines the local weight of each hierarchy levels, starting at the top and working down to the last level. Furthermore, the local weight for criteria (local 1) were calculated with consideration to research' goal, then, the local weight for sub-criteria (local 2) were calculated with consideration to main criteria, and local weight for alternatives (local 3) were calculated with consideration to sub-criteria. Additionally, the local weights of the criteria and sub-criteria which calculated from first and second levels are multiplied to get the global importance weight, which is then multiplied by the local weight of each alternative which calculated in the bottom level to determine the global priority weight for alternatives. Therefore, all local and global weights were integrated into an Excel-based computerized model to aid stakeholders in choosing the best construction method in relation to the project's desired preferences, which include cost, time, and quality in terms of project constructability. The next section will cover developing a model for construction technique selection, as well as verification and validation.

5. Developing CMS model

In light of the findings of the Analytical Hierarchy Process, it is recommended to create a computerized model for selecting the best building methods in order to speed up decision-making during the early phases of a project while taking end user requirements into account. The decision model was created with Microsoft 365 Excel, a Windows 10 Pro system setup, an Intel Core i5-4570 running at 3.2 GHz, 8GB of RAM, and an NVIDIA Quadro P620 graphics coprocessor. Additionally, the outcomes of the construction method selection model were achieved by the Graphical User Interface (GUI) depicted in Figure 2 which was constructed using the system configuration previously discussed.

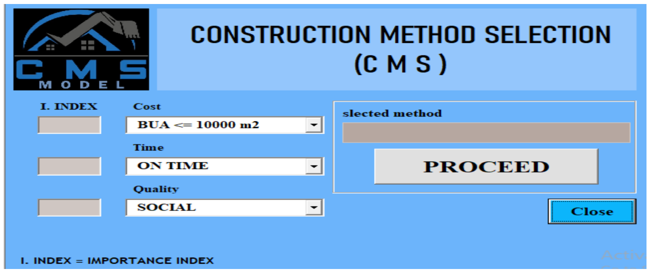

Fig. 2: Construction method selection model GUI.

5.1. CMS model verification and validation

The Construction Method Selection Model (CMSM) was created as was covered in the section above. In addition, the model functions properly and generates results for each set of data that is entered. To accomplish this goal, five trials will be run through the model, and the results will be compared with the results of manual calculations, with the assumption of user preferences and project information in each trial. This will allow us to determine whether the results obtained from the model are accurate or not. Furthermore, when comparing the model result with the results of the manual calculation, it gets the same weights, therefore, the selected construction method matches the model result in each trial, indicating that the model is functioning correctly and yielding trustworthy results. Thus, the verification process was successful.

The validation process involved three case studies based on three completed real residential construction projects in Egypt. The construction method selection model was used to determine the best approach for each project and compare the outcomes with actual circumstances. The results were also given to the project's experts for their input. Additionally, the comparative results demonstrated how well the building method selection model generated the suitable approach.

Case study # no. 1:

A portion of the 300-acre prototype compound at North Coast, Marsa Matrouh, Egypt, is the subject of the first case study. The proposed home is a two-story villa. The owner's representative and the project manager provided the following information on the construction project: The project has a built-up size of 441,000 m² and one villa built up area 307 m², while, project time frame is on time completion, a luxury finishing level, and owner preferences of 20% cost, 20% time, and 60% quality. In addition, the project manager was asked during an interview to identify the construction technique—conventional method—that was utilized to build the project based on experience. These data will be used as inputs in CMSM to determine the optimal construction method for this project. Furthermore, Figure 3 and Figure 4 display the CMSM results in case of constructing one villa with BUA 307 m2 as a separate and repeated project, while, the other case is the result for constructing the project as one unit with BUA 441,000 m².

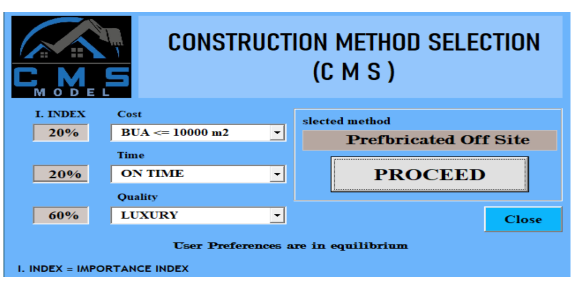

Fig. 3: CMSM result for one villa.

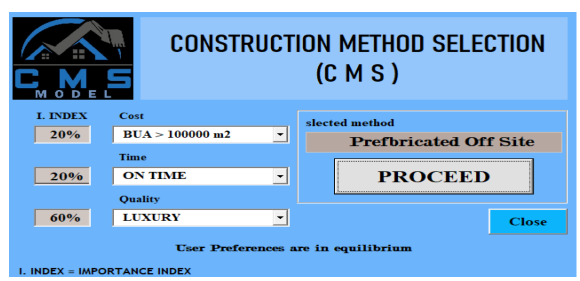

Fig. 4: CMSM result for the project.

Prefabricated off-site construction method is the CMSM's recommended approach for that project in the first case study, as illustrated in figure 3, 4. Furthermore, in order to validate the model, a group of six specialists, including the project manager, were tasked with determining the most suitable building approach for the project. These experts possess over 15 years of expertise in the construction field. The prefabricated off-site method was unanimously agreed upon by the experts as the most appropriate way to be used for this project, particularly the villa in the case study, which is one of the compound's repeating prototype buildings. Additionally, all the six experts agreed that, based on their experience, the optimum method of construction to be used in this case study is the prefabricated off-sit technique which same technique selected by the proposed model.

Case study # no. 2:

The second case study is situated in Alexandria, Egypt's Smouha. The project is a residential structure with ten regular stories, a ground level, and three story basements. The following information about the construction project was obtained from the project manager and owner's representative: 34,299 square meters make up the project's built-up area. The owner's preferences are cost 65%, time 10%, and quality 25%. The project is to be completed on schedule. In addition, the project manager was asked during an interview to identify the construction technique—conventional method—that was utilized to build the project based on experience. These data will be used as inputs in CMSM to determine the optimal construction method for this project. The CMSM results are displayed in Figure 5.

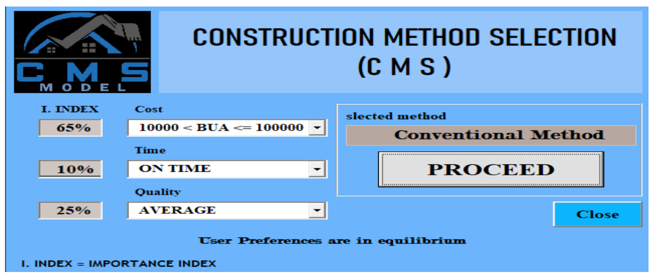

Fig. 5: CMSM result for case study 2.

Figure 5 illustrates the conventional technique as the CMSM's output result for the project's suitable construction method in the second case study. Furthermore, in order to validate the model, a group of six specialists, including the project manager, were entrusted with identifying the most suitable building approach for the project. These experts possess over 15 years of expertise in the construction field. Regarding the usual approach that was employed to build the project, all the six experts agreed that, based on their experience, the optimum method of construction to be used in this case study is the conventional technique which same technique selected by the proposed model.

Case study # no. 3:

The third case study is situated in Alexandria, Egypt's Maamoura. The project is a residential structure with ten regular stories, a ground level, and two basements. The following information about the construction project was obtained from the project manager and owner's representative: Project built-up area is 31,905 square meters, project duration is infinite, project completion level is opulent, and owner preferences are as follows: 50% for cost, 5% for time, and 45% for quality. In addition, the project manager was asked during an interview to identify the construction technique-conventional method-that was utilized to build the project based on experience. These data will be used as inputs in CMSM to determine the optimal construction method for this project. The CMSM results are displayed in Figure 6.

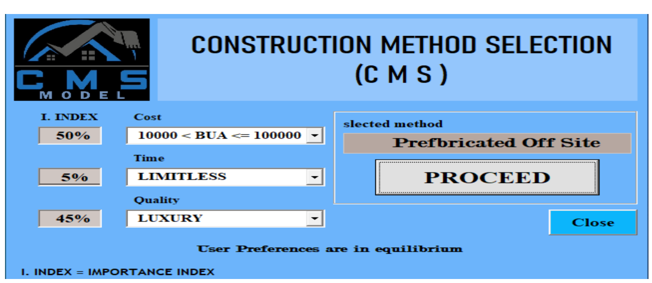

Fig. 6:. CMSM result for case study 3.

Figure 6 illustrates the CMSM's output result on the suitable building approach for the third case study project, which is prefabricated off site. In addition, in order to validate the model, a team of seven experts-including the project manager-were entrusted with determining the best building approach to employ for the project, taking into account their combined experience of over 15 years in the field of construction. For this case study, two experts advised against using anything other than the conventional approach for building. While, five experts advised using prefabricated off-site construction. Additionally, the CMSM output result was presented to the seven specialists in order to validate the chosen approach, and five of them concurred on the chosen construction method that was selected by construction.

6. Parametric study.

The decision-making support model for selecting the best construction method was integrated into a parametric study for various cases, which represent the most common residential construction cases in Egypt's current housing revolution. Additionally, the findings demonstrated that prefabricated off-site is suitable for projects larger than 100,000 m^2 and that the conventional method is appropriate for social-fast track projects with built-up areas up to 100,000 m^2 as shown in figure (7).

The private sector tends to focus on fast-track and luxury residential buildings, which usually described with crowded project locations with high traffic and population densities. These projects locations present challenging conditions for the construction process, manoeuvrability, and equipment availability levels during the project execution phase. Hence, in case of importance index for cost, time and quality are equal, the prefabricated off-site construction is thought to be the best option for luxury fast-track residential projects with built-up areas more than 10,000 m^2, while, conventional technique is the best option for same projects with built-up area less than 10,000 m^2 as shown in figure (8).

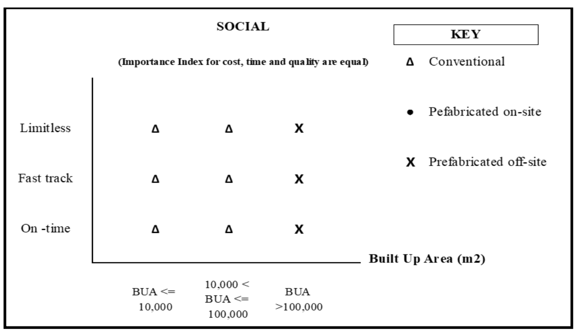

Fig. 7: Social and equal I. Index.

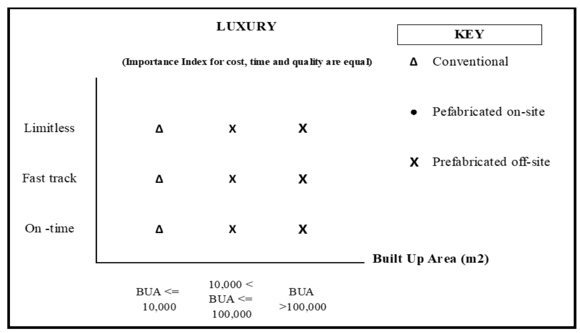

Fig. 8: Luxury and equal I. index.

7. Conclusion:

Despite the fact that choosing a construction method is a crucial choice made early in a project's life cycle, Egypt's construction sector is still lagging behind in creating computerized models that aid in decision-making when choosing the best construction method for a given project. This was because the techniques that were already in use did not provide a model that could meet the needs of the end user. In order to choose the most feasible approach that works for the entire project, this deficit prompted the development of a new computerized model for construction technique selection based on project parameters and user preferences in terms of cost, time, and quality. Thus, the goal of this research was accomplished by creating an automated model for selecting construction methods for residential projects. This model can help make decisions during the early stages of a project, close a research gap, and ensure project success by recommending the best construction method to meet the project's constructability. Three actual case studies from Egypt were used to validate the model, demonstrating its efficacy in determining the best construction technique.

However, the model for the construction techniques selection were created using certain selection criteria, such as built-up area, project timeline, and project completion level for residential buildings in Egypt. But adding more details to the model, including project location, site layout, and surrounding environment, might make it more functional. Furthermore, the model for selecting construction methods is able to produce the suitable construction method for Egyptian residential buildings. On the other hand, it is thought that the CMSM will extend in the future to incorporate more elements from the construction industry, such as commercial and administrative buildings and industrial projects.

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