PROVIDE A MODEL TO SELECT AN OPTIMUM MASS HOUSING METHOD

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Abstract: Identifying criteria affecting mass housing and comparing different construction systems with these criteria in order to determine optimal construction method based on a powerful decision making technique can considerably help to optimize mass housing, creating more incentives for private contractors and Acquiring the ultimate success in mass building projects. In this paper, 15 effective criteria on industrialized mass-housing were identified through interviews and questionnaires. Then alternatives of mass housing were detected and a model, which determines the best building method considering criteria, was developed through ANP technique and Super Decision software. The reason for using ANP is to organize decision-making process with respect to a scenario affected by multiple independent factors. Contractors, consultants, owners and those who are concerned with the issues of industrial building are considered beneficiaries of this study.

1 INTRODUCTION

Conventional on-site construction methods have long been criticized for low productivity, poor quality and safety records, long construction time, and large quantities of waste in the industry (Sawicka and Zak 2014, Gettinger et al 2013).

Leading to high quality and cost-effectiveness, industrialized building methods expedite the procedure of construction (Mydin et al., 2014). Several benefits of applying industrial mass-housing technology in construction are shortened construction time, lower overall construction cost, improved quality, enhanced durability, better architectural appearance, enhanced occupational health and safety, material conservation, less construction site waste, less environmental emissions, and reduction of energy and water consumption. These advantages provide opportunities for industrialization to better serve sustainable building projects. [Chen et al, 2009]

Therefore, one of the most important decision makings is to choose right building system which has direct impact on the cost and time of project, design and operation issues, and quality of deliverable houses. Selection of the building systems must be done based on different criteria such as financial, technical, social, speed and ease of implementation. This is of a great deal of importance, especially in mass-housing projects, and once selected correctly can lead to project completion in the planned cost and time as well as promotion of the desired quality (Gharouni Jafari et al 2014). This shows that using an effective scientific and practical model and selection of the proper method with respect to the effective criteria in industrialized building is necessary. This paper tries to examine and evaluate new building systems, determine quantitative effective criteria and finally select the most appropriate building system by the means of Multi-Criteria Decision Making (MCDM).

2 LITERATURE REVIEW

In order to industrialization, one of the most important decisions is to select correct building system. Therefore, applying an appropriate decision making method is of special importance to choose the best building method.

Nowadays, considering human needs, traditional building methods have been gradually pretermitted due to some reasons such as high construction cost and time, low construction productivity and therefore most countries have made industrialized construction. The industrialization is construction in which a large number of typical residential units by machinery and equipment with large cut are made. The most popular industrialized building methods in Iran which have unique features include Insulated Concrete Forms (ICF), Light Steel Frame (LSF), Reinforced Concrete Structures with Continuous Frame, Steel Bolt and Nut, and Tunnel Formwork.

Decision makers prefer the methods which are not very complicated in terms of mathematical and the way of considering point of views in decision making process is simply visible (Balali et al. 2014, Noorzai 2010) and Analytical Network Process (ANP) is an appropriate technique in this regard. In this paper, ANP technique, which is more full-fledged method than Analytical hierarchy process (AHP), was applied to select the most appropriate building system.

ANP is a general case of AHP in which priorities (weights) are established through pairwise comparisons and experts' judgments like the AHP method. The network analysis process first converts the problem into a hierarchical structure the components of which act also as the decision components are not independent from each other. In the ANP method, a complicated relation is considered between the decision elements by replacing a hierarchical structure of AHP with a network structure (Zebardast, 2010).

In ANP, clusters are not orderly arranged and are rather spread in different directions. Moreover, the ANP network has the ability to create both an internal dependence (elements of a group which are dependent to each other) and an external dependence (feedback from lower levels to upper levels) (Horenbeek and Pintelon 2013).

Furthermore, in the ANP network the elements inside the cluster might be correlated with one or all element(s) of the other clusters (being affected by them or being effective on them). These external relations are shown with arrows. The elements inside a cluster may also be correlated with themselves (internal dependence) which is indicated using an arc (Golabchi and Noorzai 2013).

This feature of the ANP makes possible considering mutual dependencies between the elements and thus presents an exact approach toward the complicated problems of fabrication management. Effect of the elements on the other elements is considered in a super matrix (Zebardast 2010).

3 RESEARCH BACKGROUND

Idrus and Newman (2002) conducted a survey within the UK construction industry to investigate the construction related factors influencing the choice of concrete floor systems: in situ, precast and hybrid construction. Ultimately, 12 factors were identified as being directly related to the construction process. For prefabrication, Pasquire et al. (2005) recommended six factors of measurement when comparing prefabrication and traditional construction: cost, time, quality, health and safety, sustainability and site issues. A total of 97 detailed items and considerations for the six factors were included in the research. Lam et al. (2007) ranked construction systems using AHP method in view of the Constructability criterion in Hong Kong.

Chen et al. (2010) adopted to determine the most important criteria of stable fabrication using a questionnaire and interview method. They finally found the criteria in three categories of financial, social and environmental, and then they could get to the final list of the criteria and their ranking via experts' viewpoints and factor analysis. The results of this research revealed that using prefabrication techniques in comparison with the conventional construction techniques can provide major advantages in terms of cost, time, quality and etc.

Jahan et al (2011) used seven decision methods of Ordinary-TOPSIS, Block-TOPSIS, VIKOR, ELECTRE, Comprehensive VIKOR, AHP-Comprehensive VIKOR, and AHP-TOPSIS in selection of suitable materials for a statically loaded thermal conductor. Application of various MCDM methods leads to different results and rankings of materials. They proposed an Aggregation Technique in which different results produced by various methods used as input and its output is new and final ranking of materials.

Mela et al. (2012) exerted several methods of decision making in building design to study the efficiency and their results. Six methods are compared including: weighted sum, produced sum, VIKOR, TOPSIS, PROMETHE II and a procedure based on PEG-theorem. In this paper, the best MCDM method was not determined but the performance of each method was explained.

Zavadskas et al (2013) ranked four facade's alternatives for public or commercial building, with a set of 12 quantitative and qualitative criteria. WSM (Weighted Sum Model), WPM (Weighted Product Model), and WASPAS technique that combines the two previous techniques were applied to problem and propinquity of results were compared with reputed MOORA (Multiple Objective Optimization on the basis of Ratio Analysis) method. Different decision methods eventuate to different rankings of alternatives.

4 RESEARCH METHOD

4.1 Criteria Determination

Theoretical references, previous studies throughout the world, as well as case studies, and interviews were all used in this contribution to identify the most important opportunities and challenges for industrialization.

Implementation of Theoretical Studies: Different scientific references such as reports of researches currently under run in mass housing projects, scientific papers and conference articles, relevant research works were explored at this step. As a result of this literature review, 14 measures were identified

Studying Available Worldwide Experiences: This step was divided into two phases: principles and general terms of the international rules were studied first along with important characteristics and key points of mass-housing. Then, the status of mass-housing was examined in some candidate countries, such as the United States, the United Kingdom, Australia, and Malaysia, during the second phase, with their dominant measures being determined and introduced. In this stage, effective measures were identified, and at last, 26 measures with more effectiveness were extracted.

Case Studies: These projects related to current research. In this stage, mass-housing projects in Parand site, Mehr housing in Khoramabad and Firouzkouh which are among the largest mass-housing projects in Iran were studied. Thereby, 20 measures were derived consequently.

Interviewing and Studying Current situation of Mass-Housing in Iran: Another objective of this research is to present the identified factors in a structured form. A set of interviews was done in order to ensure validity of the identified factors and provide them in a structured form, which led to identification of 22 measures.

Having accomplished the aforementioned four steps, 82 measures were identified which were reduced to total number of 70 after deleting the repetitions. They were used to prepare the questionnaire number 1.

4.2 Questionnaire

Questionnaire (1): This questionnaire was included 70 criteria. In the questionnaire, the participants were asked to score for importance of each of the criteria with numbers from 1 to 9 (Saaty's 9 scales). Output of the Questionnaire (1) was determination of the 15 most significant criteria.

In Questionnaire (2) which is also known as ANP questionnaire, 15 main criteria were defined and compared with each other in terms of different aspects. For this purpose, Questionnaire (2) contained 19 tables, in which a table was first related to the pair-wise comparison of the criteria with respect to the research objective. The three next tables were related to the pair-wise comparison of the criteria in each of the options and finally 15 tables were evaluated for the pair-wise comparison of the criteria based on the criteria (i.e. internal comparison). Relative importance of the elements was assessed based on Saaty's 9 scales, in which the criteria (variables) were compared dually first: if the importance degree of two criteria is found to be equal, number 1 is selected, and if one criterion is of greater importance as compared to the other one, the preferred criterion is specified and one of the numbers from 1 to 9 is marked for definition of the preference of the selected criterion which are listed below:

- C1 Reduction of Total Construction Time
- C2 Reduction of Construction Cost
- C3 Increasing Safety
- C4 Ensuring Quality of Construction
- C5 Possibility to Design Various Architectural Plans
- C6 Ability and Potency of Contractors and Consultants
- C7 Possibility of Comprehensive Planning and Scheduling the Activities
- C8 Iterative Process which results by High Mechanization and High Production Ability
- C9 Reduction of Problems in Implementation of Finishing Operations and Installation
- C10 Lightweight Structure and High Ratio of Strength to Weight
- C11 Fast and Easy Access to Materials in Different Situations
- C12 Reduction of Energy Consumption in the Life Cycle of the Project
- C13 Compatibility with Environment
- C14 Existence of Building Regulations about the method
- C15 Existence of Popularity and Request between Customers

The options considered in this research were:

- A1 Insulated Concrete Forms (ICF)
- A2 Light Steel Frame (LSF)
- A3 Reinforced Concrete Structures with Continuous Frame
- A4 Steel Bolt and Nut
- A5 Tunnel Formwork

4.3 Main Population and Sample Size Estimation

Common attributes of experts are at least a bachelor's degree in engineering and more than seven years' experience in owner part or first or second grade consultants and contractors companies in mass-housing projects. In this study in order to estimate the number of main population, Levy and Lemeshow (2008) sampling model was hired. Main population was 200 and sample size were estimated 30, but in order to ensure, 40 questionnaires were distributed and analyzed.

4.4 Data Analysis through ANP

The AHP process, thanks to its simple and comprehensive nature it has, has attracted much interest among various managers and users of scientific society. However, this method has some disadvantages (deficiencies) which are solved to some extent in a much generalized form of it that is ANP (Saaty 2003). An interested reader is referred to the studies of Saaty (Saaty and Ozdemir 2005).

One may put forward different reasons why to believe ANP as a proper method for selection of the best building system in mass-housing projects. First of all, ANP is a firm strategic model of decision making which is used in many applications (Horenbeek and Pintelon 2013). Another reason to adopt the ANP method is provision of the possibility to incorporate qualitative criteria like quality along with the quantitative criteria in the decision making matrix. Another reason is application of the matrixes of pair-wise comparison in order to get the criteria weights in respect to each other and generally in the comparison process of different decision elements. The pair-wise comparison has a better accuracy in comparison with the simple additive weighing (SAW) or direct data entry, since it leads to much better and deeper involvement of the decision maker with the problem. Meanwhile, performing of further comparisons makes the inaccurate data rather less effective and thus improves accuracy of the ANP method (and thus more reliable results). many decision making problems cannot be structured since the involve interaction and dependence of overhead elements on lower elements (Saaty and Vargas 2006). ANP is the first mathematical theory which is able to systematically consider all kinds of dependences and feedbacks (Saaty 2003).

4.4.1 Methodology of Analytic Network Process

The network analysis process can be summarized in 4 steps as below (Zebardast 2010):

- Development of model and converting the problem to a network structure;
- Development of pair-wise comparison matrix and definition of priority vectors;
- Development of super matrix and converting it to a limit super matrix and
- Selection of the best option.

4.4.2 Development of Model and Converting the Problem to a Network Structure

The ANP model provided in this paper contains one goal cluster, 15 criteria to detect priority of different building systems in mass-housing project and five building systems as the options. Different relations considered in the ANP model include the relation between goal and criteria (pair-wise comparison of the criteria based on selection of the best building system), the relation between goal and options cluster, the mutual relation between option cluster and criteria with each other. The internal relation of different criteria with each other is neglected due to avoiding excessive complexity and the multiplicity of questionnaires. These relations are illustrated in Figure 1.

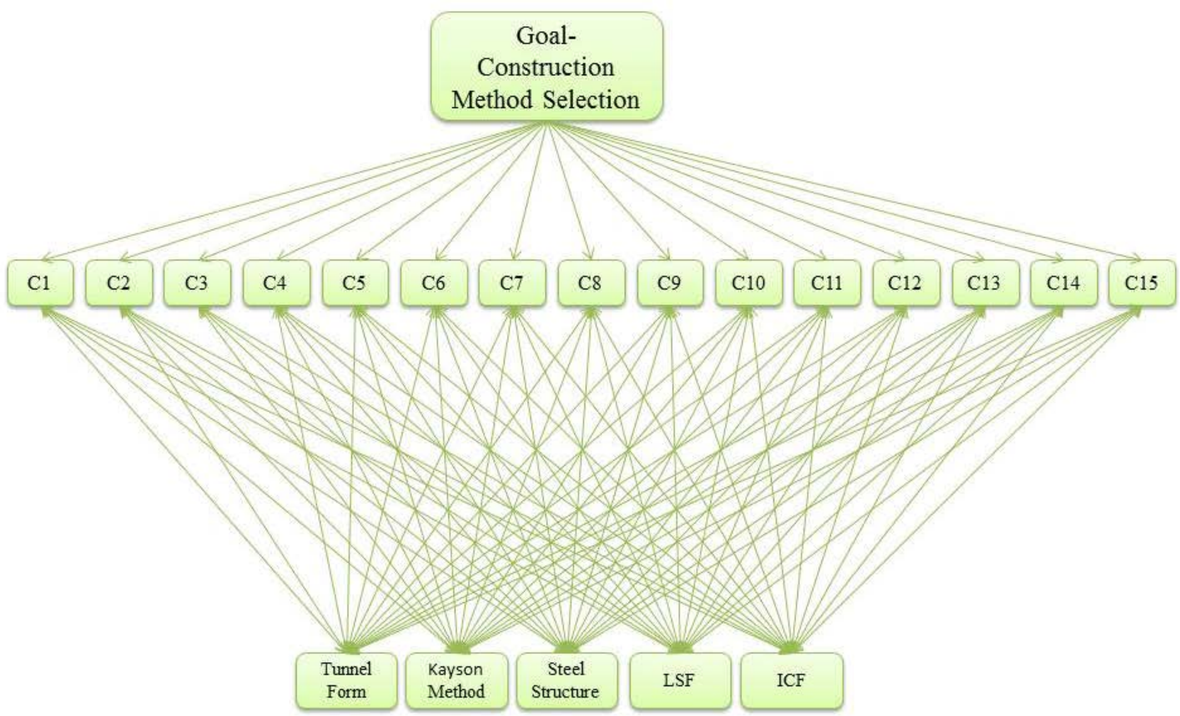


Figure 1: Network Structure of Construction Method Selection Problem

4.4.3 Development of Pair-Wise Comparison Matrix and Definition of Priority Vectors

Extraction of the priorities of different component required performing a series of pair-wise comparisons by the decision maker. The decision elements in each of the clusters are compared dually based on their importance in respect with control criteria. In addition, the mutual dependences between elements of a cluster must be compared dually with internal relations of the criteria being compared at last. Relative importance of the elements is evaluated based on Saaty's 9 scales where number 1 represents indifference between two components and 9 indicates dominance of a component on another.

A pair-wise comparison matrix must be developed for every relation which is defined in the network between the clusters or elements. Considering Figure 1, there are 6 pair-wise comparison matrixes in this model including one goal-based comparison matrix of the criteria, and five comparison matrixes of the criteria based on each of the options. Number of the pair-wise comparisons conducted by a decision maker for a n×n matrix is equal to n×(n-1)/2, where "n" denotes number of the elements, since all elements on the main diagonal are equal to unit.

The results of these comparisons can be seen in limit super matrix. As discussed before, in the ANP model used in this study, a group decision making is followed. Therefore, each questionnaire is filled by a group of experts, geometric mean of the figures filled by them being used as the input data for the software.

4.4.4 Development of Super Matrix and converting it to a Limit Super Matrix

Vectors of internal priorities were entered into related columns of a matrix in order to find general priorities in a system of mutual effects. Thus, a super matrix was obtained, each part of which indicates relation between two clusters in a system. This is called the initial super matrix. An unweighted super matrix is obtained by replacing the internal priority (importance coefficient) of the elements and clusters in the initial super matrix. A weighted super matrix will be calculated in the next step via multiplying the values of unweighted super matrix in the cluster matrix. Thereafter, this super matrix is changed to random state in terms of its columns by normalization of the weighted super matrix (Saaty and Vargas 2006). In the third and last step, the limit super matrix is calculated by exponentiation of all elements of the weighted super matrix until reaching convergence (via repetition), so all elements of the super matrix will become the same. The resulting super matrix from this research is provided in table 1.

Table 1- Limit super matrix

name	G	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	A1	A2	A3	A4	A5
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C1	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
C2	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
C3	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
C4	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
C5	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
C6	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
C7	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
C8	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
C9	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
C10	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
C11	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C12	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C13	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C14	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C15	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
A1	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08

name	G	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	A1	A2	A3	A4	A5
A2	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
A3	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
A4	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
A5	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

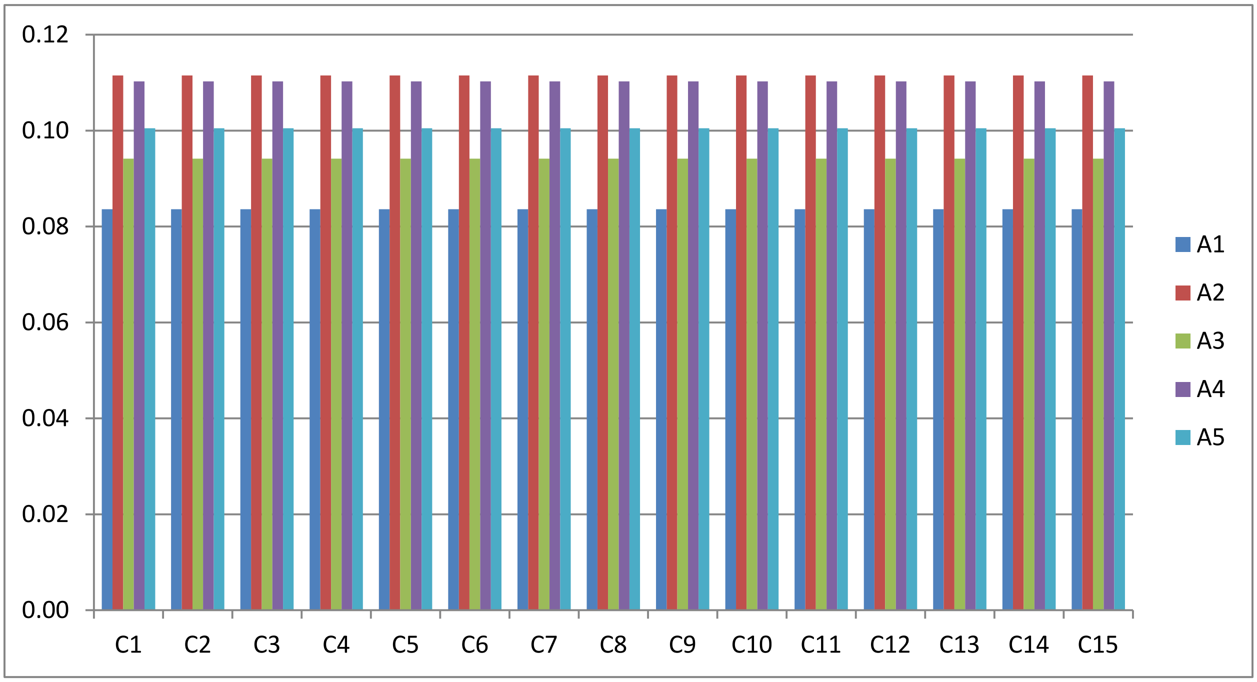


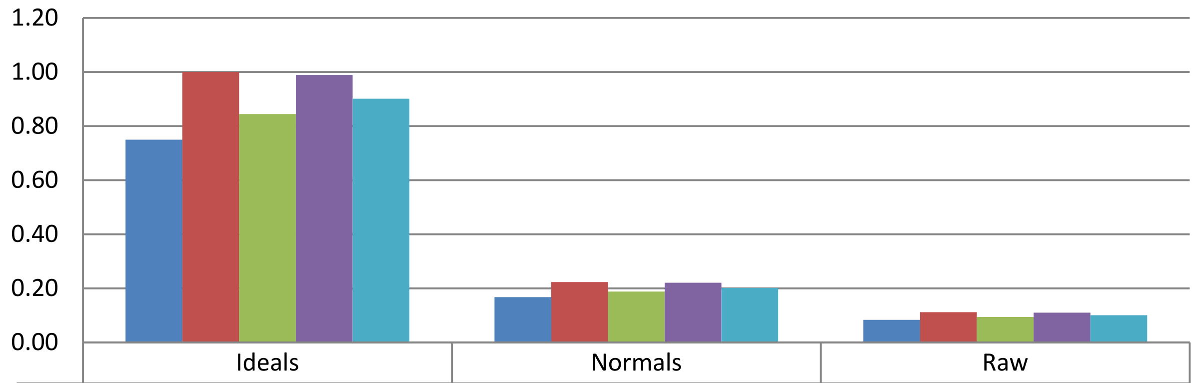
Figure 2: Comparison of the Score of Each Criterion in Each of the Five Types of Building Methods Regarding Last Five Rows of Limit Super Matrix

The resultant Limit super matrix is shown in Table 1, which includes the vector of final priorities. Exponentiation of the super matrix is done to intermix all relations between the clusters and elements in the network structure. Thereby, all effects of the internal dependences will be embedded in the vector of final priorities.

Based on the five last rows of the limit matrix (i.e. converged outputs of the program), it can be said that the final product of the model are these elements which are seen in the final output of the model itself at “Raw” column. When these figures are divided to total value of them, “Normals” column is obtained and if they are divided once more to the greatest of them, “Ideals” column is obtained. These results can also be seen in Figure 3.

4.4.5 The Priority of the Criteria and Options

In table 2 which lists outputs of “Super Matrix” software, one may find priority of the criteria. It can be inferred that the values of “Limiting” column are in fact the values of the first column of the limit matrix that is score of each criterion taking into account the objective. In “Normalized by Cluster” column the evaluation is done considering row sum of each criterion and in the row sum, importance of a criterion is assessed with respect to the other criteria and options in addition to the importance it has towards the objective. On the other hand, output of the program just examines importance of the criterion considering the objective.



	Ideals	Normals	Raw
A1	0.75	0.17	0.08
A2	1.00	0.22	0.11
A3	0.84	0.19	0.09
A4	0.99	0.22	0.11
A5	0.90	0.20	0.10

Figure 3: The Final Prioritization of Options

Table 2: priority of the Criteria Based on Final Output of Model

Name	Normalized By Cluster	Limiting
G	0.000	0.000
C1	0.197	0.099
C2	0.162	0.081
C3	0.117	0.058
C4	0.141	0.070
C5	0.068	0.034
C6	0.057	0.028
C7	0.054	0.027
C8	0.044	0.022
C9	0.038	0.019
C10	0.032	0.016
C11	0.024	0.012
C12	0.018	0.009
C13	0.016	0.008
C14	0.017	0.008
C15	0.016	0.008
A1	0.167	0.084
A2	0.223	0.112
A3	0.188	0.094
A4	0.220	0.110
A5	0.201	0.100

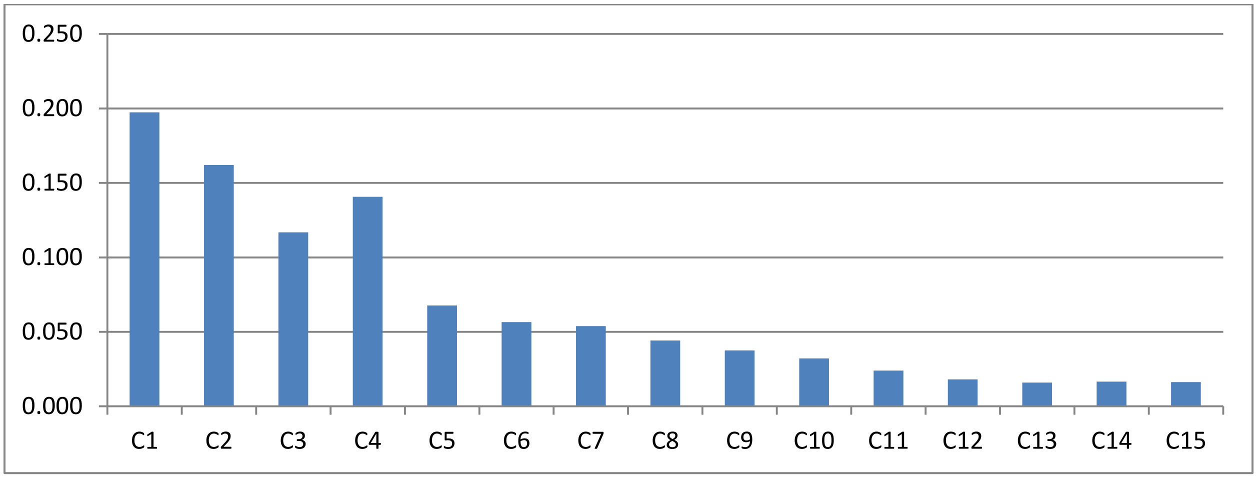


Figure 4: Priority of the Criteria Based on Normalized by Cluster in Final Output of Model

If the super matrix formed at the third step has considered the whole "Network", which means that the choices are also considered in the super matrix, then the general priority of the choices can be derived from the columns, which is associated with the choices. The choice with the greatest general priority will be introduced as the best choice.

5 CONCLUSION

The results of this paper shows:

A- The most important effective criteria on the building method selection in the mass-housing projects in Iran in order of importance are as follows:

- Reduction of Total Construction Time (C1 = 0.197)
- Reduction of Construction Cost (C2 = 0.162)
- Ensuring Quality of Construction (C4 = 0.141)
- Increasing Safety (C3 = 0.117)
- Possibility to Design Various Architectural Plans (C5 = 0.068)
- Ability and Potency of Contractors and Consultants (C6 = 0.057)
- Possibility of Comprehensive Planning and Scheduling the Activities (C7 = 0.054)
- Iterative Process which results by High Mechanization and High Production Ability (C8 = 0.044)
- Reduction of Problems in Implementation of Finishing Operations and Installation (C9 = 0.038)
- Lightweight Structure and High Ratio of Strength to Weight (C10 = 0.032)
- Fast and Easy Access to Materials in Different Situations (C11 = 0.024)
- Reduction of Energy Consumption in the Life Cycle of the Project (C12 = 0.018)
- Existence of Building Regulations about the method (C14 = 0.017)
- Existence of Popularity and Request between Customers (C15 = 0.016)
- Compatibility with Environment (C13 = 0.016)

B- The alternatives of building methods for mass-housing projects in Iran in order of importance are as follows:

- Light Steel Frame (LSF) (A2 = 0.223)
- Steel Bolt and Nut (A4 = 0.220)
- Tunnel Formwork (A5 = 0.201)
- Reinforced Concrete Structures with Continuous Frame (A3 = 0.188)
- Insulated Concrete Forms (ICF) (A1 = 0.167)

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