Computers and Concrete, *Vol. 22, No. 3 (2018) 327-336*
DOI: https://doi.org/10.12989/cac.2018.22.3.327

Selecting optimized concrete structure by Analytic Hierarchy Process (AHP)

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(Received May 12, 2017, Revised August 2, 2018, Accepted September 4, 2018)

Abstract. Increase in population and its daily increasing in our today society results in an increase in housing demand while traditional methods are not applicable. The project preparation and realization processes, based on theoretical and empirical studies, a creation of goods, services, and technologies, are the most important human activities. Selection of effective technological systems in construction is a complex multi-criteria decision-making task. Many decision-makers refuse innovations once faced with similar difficulties. Therefore, using modern materials and methods in this industry is necessary. Modern methods increase quality and construction speed in addition to decrease energy consumption and costs. One of the problems in the way of any project is selecting construction system compatible with the project needs and characteristics. In the present research, different concrete structures such as common reinforced concrete (RC) structure, prefabricated, Insulating Concrete Formwork (ICF), 3D Panel and Tunnel Concrete Formwork (TCF) for buildings with limited floors in Iran are studied and compared from the viewpoint of different criteria like cost, time, applicability and technical characteristics with industrialization approach. Therefore, some questionnaires filled out by construction industry experts in order to compare criteria and sub-criteria in addition to evaluation of optimized structural systems. Then, results of the questionnaires ranked by Analytic Hierarchy Process (AHP) and the most effective alternative selected. The AHP results show that 3D Panel system 36.5%, ICF 21.7%, TCF 19.03%, prefabricated system 13.3% and common RC system 9.3% are the most and the least efficient systems respectively.

Keywords: concrete structure; common reinforced concrete; prefabricated system; tunnel concrete formwork; 3D panel; insulating concrete formwork; AHP; multi-criteria decision-making

1. Introduction

The project preparation and realization processes, based on theoretical and empirical studies, a creation of goods, services, and technologies, are the most important human activities. Today, a project preparation and realization processes, based on theoretical and empirical studies, a creation of goods, services, and technologies it has become a common practice. Construction is a sector that accepts innovations slowly (Zavadskas *et al.* 2013b). Selection of effective technological systems in construction is a complex multi-criteria task. Many decision-makers refuse innovations once faced with similar difficulties. The article presents an original approach towards a development of multi-criteria assessment and ranking technique for alternatives to technology in construction. The problem was solved using different well-known Multi Criteria Decision Making (MCDM) methods ELECTRE IV and MULTIMOORA. Three hybrid methods SWARA-TOPSIS, SWARA-ELECTRE III, SWARA-VIKOR were used to solve the same problem. The growth in construction works is creating a demand for suitable materials, retrofitting techniques and research (Zagorskas *et al.* 2014). This process will lead to the sequence of environmental and economic losses. Alternative solutions can be successfully evaluated applying MCDM methods. There are a lot of methods available for supporting complex decisions in construction. The problem of measuring according to some criteria is known as multi-attribute decision-making (Zavadskas *et al.* 2009). A number of authors purpose their decision-making methods and models. However, there is lack of methods and models of evaluating the efficiency of refurbishment and/or renovation of the building. The company's survival in competing for construction market depends on the successful implementation of projects. Another, equally important, is a high efficiency of project implementation being the characteristics of a company's competitiveness in the market (Zavadskas *et al.* 2014). It has been long recognized that as competition augments and technological differentiation becomes more difficult, design specifically what is referred to as industrial design offers an efficacious way to position and differentiate products (Hashemkhani Zolfani *et al.* 2013). Multi-criteria decision-making approach is very useful in many problems such as project selection, supplier selection, risk assessment, contractor evaluation, etc. Many studies have been made on MCDM methods and applications. Keshavarz Ghorabaee *et al*. (2015) introduced the evaluation method based on distance from average solution (EDAS) for multi-criteria

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ISSN: 1598-8198 (Print), 1598-818X (Online)

inventory classification problems. MCDM methods in construction can be used on the national, organization and project levels. However, most assessment methods are seeking to find how to make the most economic construction decisions, and most of all these decisions are intended only for economic objectives (Sivilevicius *et al*. 2008).

Peldschus *et al.* (2010) proposed and applied two-person zero-sum game theory methods for sustainable assessment of alternatives in construction. The effectiveness of the construction companies usually performs several construction projects at the same time. Projects differ by complexity, duration, budget, a variety of works, and a number of implementers. Also, vary the results of the projects: some of them have been implemented successfully, other terminated with losses or accidents.

Saparauskas *et al*. (2011) assessed and prioritized the relative importance of various criteria based on Saaty's AHP that includes and measures all tangible and intangible, quantitatively measurable and qualitative criteria, and calibrates each into a numerical scale. To calculate the best-performed project the multiplicative exponential weighting (MEW) was applied (Yoon and Hwang 1995). Zavadskas *et al.* (2013a) employed a couple of MCDM methods: WASPAS (Weighted Aggregated Sum Product Assessment) and MULTIMOORA (Multiple Objective Optimization on the basis of Ratio Analysis Plus Full Multiplicative Form) for multiple criteria assessment of alternative building designs. A continuous increase in electricity and heat prices for citizens necessitates new alternative solutions regarding the rational application of existing resources, in order to minimize electric energy production costs (Turskis *et al.* 2012). The results gained applying integrating AHP and ARAS-F methods. Analytic Network Process (ANP) is also a MCDM method that is able to model the whole process of quality function deployment (QFD) and derive the final priorities of alternatives, with the quantification process of QFD being regarded as decision problem (Mohammadi *et al*. 2014).

The Analytical Hierarchy Process (AHP) is a decision-making method developed by Saaty (1980). It is observed that AHP is the most popular multi-criteria decision-making technique followed by outranking technique TOPSIS (Aouadni *et al*. 2017, Zavadskas *et al.* 2016). Rozanne and Saaty (1987) studied about what is AHP and how it is used. They introduced AHP as a measurement method by ratio of scales. Moreover, they presented discussions about ideas and thoughts related to this process and its branches. Saaty (1988) wrote a book about what is the AHP is. Saaty (1990) conducted a research about how to make decision by AHP. They introduced the AHP as a multi-variable decision-making method based on factors organized by AHP in addition to briefly express principles and philosophy of this theory in a way that general background information, type of applied measurement and its characteristics and applications represented. Ishizaka and Labib (2009) discussed the benefits and limitations of AHP using software package Expert Choice through a practical example. In this valuable paper, they discussed problem modelling, pairwise comparisons, judgement scales, derivation methods, consistency indices, synthesis of the weights and sensitivity analysis. Lin *et al*. (2008) proposed an adaptive AHP approach (A3) that used a soft computing scheme, Genetic Algorithms, to recover the real number weightings of the various criteria in AHP and provided a function for automatically improving the consistency ratio of pairwise comparisons.

Many researchers studied about application of AHP in different branches of science. For instance, Zahedi (1986) studied about AHP and its applications. Triantaphyllou *et al*. (1995) studied the application of AHP in engineering decision-makings. Since final decision in many applications of industrial engineering is based on evaluation of many choices with different criteria, it is hard to make decision for such problems. The AHP is a very effective method to solve multi-criteria decision-making problems.

Moreover, some of practical and causational problems using AHP in industrial engineering are studied in the present research. Vaidya and Kumar (2006) conducted a review about application of AHP. They reviewed previous studies and expressed that AHP is a multi-variable decision-making method, which is applicable in almost all problems need decision-making. In Vaidya and Kumar (2006) research, articles categorized based on their specifications and field. The references also categorized based on logical zone and year in order to follow-up growth path of AHP applications. In addition, the references information compiled in form of table and chart briefly to help readers for quick and content-related extraction of information. One of advantage of AHP is its ability to measure quantity and quality indicators by using mental expertise, preferences, and objective information (Balali *et al*. 2014). AHP is a reliable method for calculating the weight of each criterion since it is based on decision makers' points of view rather than decision matrices. AHP also allows performing sensitivity analysis over criteria and sub-criteria (Balali *et al*. 2014).

Considering increasing growth of population and their daily increasing needs for building recently, using modern materials and methods in construction for increasing construction speed, lightweight construction, increase useful life, reinforcement of building against earthquakes and optimization of energy consumption seem necessary more than before. Using modern structural systems solves problems such as much costs, long construction time, low quality of constructed buildings, and investors' lack of ROI (return on investment). There are several methods over the world for construction of concrete structures with limited floors (max: 2 stories).

Nowadays, using AHP for decision-making about issues related to buildings considered by researchers more than before (Vichair *et al*. 2015, Erkayman and Ozkal 2016, Farokhzade *et al*. 2015, Wong and Li 2008). Das *et al*. (2010) analyzed multi-variable decision-making in buildings maintenance capability through AHP. Shi *et al*. (2009) tried to improve the AHP for applying in fire risk of public buildings. Juhua *et al*. (2011) studied the application of AHP in construction of buildings in combination to human culture. Dan *et al*. (2014) studied regarding the application of a fuzzy inference system and AHP based

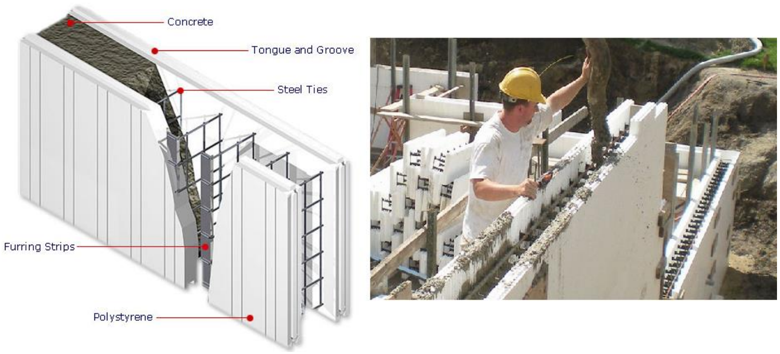

Fig. 1 The RC structure with ICF

online evaluation framework to the Donghai Bridge Health Monitoring System. Lin *et al*. (2015) studied about decision-making framework of AHP for selecting a strategy of procurement in building maintenance. They presented their researches about selecting procurement method in maintenance management of public universities buildings in Malaysia through multiple criteria of decision-making especially AHP. Kuzman *et al*. (2014) compared different types of construction of public buildings through AHP. Jin (2014) conducted a research about risk assessment in construction stage of engineering projects in building construction based on AHP. Balali *et al*. (2014) compared decision-making methods of AHP and PROMETHEE family for selecting building system structure.

The purpose of this research is to find out that which one of modern construction systems such as prefabricated, insulating concrete formwork (ICF), 3D panel and tunnel concrete formwork (TCF) systems is the most optimized for limited floors buildings in comparison to common RC building from the viewpoint of constructional-technical, environmental, technical knowledge and constructional force criteria. In addition, technical and economic considerations are considered in this research for decrease in cost and increase in construction quality. At the end, according to the results of questionnaires filled out by building industry experts, analysis by AHP and the mentioned criteria, the optimized structural system is introduced.

2. Research method

In the present research, the comparison between four modern technologies of building construction and the common RC structure done through questionnaires filled out by building industry experts considering specified scales, studied. Each one of these criteria and sub-criteria in this questionnaire was weighed by AHP. Regarding effective weights of each criteria and sub-criteria and evaluation results for each scale, final score of each system and its rank determined. The AHP is of most applicable methods in MCDM problems. Experts base the AHP on pairwise comparisons between alternatives and criteria for each level of identified hierarchy and analysis of such results leads to determination of criteria weights and ranks in addition to prioritization of alternatives (Saaty 1980).

Some advantages of this method are pairwise comparison, respondent's more contemplation, possibility of group decision-making, considering qualitative and quantitative criteria and simple and powerful theory. The AHP is one of the Group Decision Support System (GDSS) and increases individuals' participation in decision-making and its mutual effects. Using experts' opinions and thoughts reduces decision-making errors and improves final decision. To do so, pairwise comparisons done by experts in form of questionnaires and then their individual judgments converted into group judgment (for pairwise comparison) by means of geometric averaging (Qodsi Pour 2013).

3. Modern technologies of building construction

3.1 The RC structure with Insulating Concrete Formwork (ICF).

The ICF composed of permanent formworks used for concreting and RC walls construction and then considered as a part of the wall after concreting. In industrial countries, such product is used for constructing of small residential units. Most formworks in this system made of expanded polystyrene but rarely made of plastics or other materials. Other types of formworks are such as polystyrene composite, polyurethane cement or foam which are used much less than polystyrene (Fig. 1). This system invented during 1950s by Lastedil company in Europe (Swiss or Germany) (Mohammad Kari and Khalili Jahromi 2008).

3.2 Tunnel Concrete Formwork (TCF).

The TCF structure is one of industrial methods of building construction in which wall and ceiling constructed together in integrated formworks (Fig. 2). These formworks are nearly in the same size of the existing spaces. There is no need to change them into smaller sizes to formwork or removing them and the sizes will exit from the space as an integrated form. In TCF system, the RC walls and ceilings reinforced, casted and concreted simultaneously. This method increases speed and quality of construction in addition to improve structural efficiency and seismic behavior of the structure due to integrated joints significantly (Ma'soumi and Mohammad Kari 2008).

Construction through TCF method goes back to more

Fig. 2 An RC structure constructed by TCF

than 40 years ago. This method which considered as an industrial construction type RC building, mostly applied in mass construction and high-rise buildings. Like other industrial methods of building construction, the TCF method includes four advantages: time and cost reduction in addition to increase in quality and workers' safety (Salamiyan and Qale'h Noei 2013). In TCF method, walls used as bearing elements of the building. Considering the point that all external and internal walls constructed simultaneously and joint to the floor and ceiling appropriately, combination of such walls and the common RC slabs of floor creates a kind of unite set with high integrity and coherence against lateral forces of wind and earthquake (Golabchi and Mazaheriyan 2010).

3.3 An RC structure constructed by lightweight prefabricated 3D panel

The prefabricated sandwich panel system registered by Victor Wiseman (1967) in California, US for the first time and then in 1980s applied vastly in building construction industry as sandwich panels through the method of shotcrete at the site. Production of 3D panel structures in Iran began in 1991 practically and in large scale. Italy and Austria were the first two countries presenting this system and then production and construction of such system expanded in many countries such as China, Turkey, Brazil, Argentina, Columbia and Iran. This system is a spatial truss structure composed of a reinforcing mesh and galvanized or stainless-steel rods welded at an angle to the welded reinforcing mesh, the core of polystyrene foam and two layers of concrete, supported by shotcrete. The main elements in this system are wall and ceiling panels and there is not any linear bearing part or a column (Amin Zadeh and Mohseni Mahani 2013). The panels consist of two steel, welded meshes with an insulation core inside welded by some truss structures that two layers of concrete on both sides supported by shotcrete after installation (Fig. 3), (Aqa Khani and *et al*. 2014).

Fig. 3 An RC structure constructed by lightweight prefabricated 3D Panel

3.4 Prefabricated RC structure

All structural parts and some of nonstructural parts of building made of prefabricated RC segments in factory joined by dry or wet joints (Fig. 4). The concept of construction by prefabricated RC segments means designing, concreting, curing, reinforcement and final finishing done in factory and then the panels brought to the site and join them through special methods (Smith and Testa 2004). Application of prefabricated panels in building industry is increasing quickly in a way they are applied under the general title of prefabricated RC panels. Structural prefabricated structural segments divided into two general groups: common RC segments and pre-stressed RC segments which are divided into two pre-tensioned and post-tensioned groups. Some of prefabricated segments are ceiling, slab columns, beams, girders, joists, filler walls, conveyor piles and stairs (Ayatollahi 2009).

Fig. 4 A prefabricated RC structure

3.5 Common RC structure

A common RC structure (beam+column+shear wall) is a structure built by concrete or commonly reinforced concrete (cement, aggregate and steel in form of simple or indented bar), (Fig. 5). If RC used in columns, ceiling joists and foundation of a building, it is called a common RC structure (Peydayesh and Labaf Zadeh 2013).

Fig. 5 A common RC structure

4. AHP method

Application of AHP method needs the following four steps (Saaty 1990):

4.1 Modeling

In this step, the problem and goal of decision-making changed into a hierarchy of decision elements related with each other. Decision elements consist of decision-making indices and decision alternatives. The AHP needs to break down a problem of multiple indices into a hierarchy of levels. Upper level shows the main goal of decision-making process. The second level shows main and basic indices which may break down into subordinate indices in next level. The last level presents decision-making alternatives.

4.2 Pairwise comparison matrix

Mental judgments of decision-makers used in comparison of criteria based on goal or comparing alternatives based on criteria in a way if element *i* compared with element *j*, decision-maker will say one of the following modes for the importance of *i* in proportion to *j* (see table 1). Note that if alternative B preferred to A, numerical value of this preference for B is $\frac{1}{n}$; where n is the very preferential value in the pairwise comparisons table.

4.3 Calculations of relative weights

Determination of decision elements weights is carried out through a set of numerical calculations. The next stage of analytical hierarchical process is to carry out required calculations for determining the priority of each decision element using information of pairwise comparisons matrices. Primary and general figure of pairwise comparisons matrices is presented in Eq. (1).

$$\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

4.4 Calculation of consistency rate

Table 1 Values of preferences for pairwise comparison

Preferential value	Comparing *i* in proportion to *j*	Description
9	Perfectly important	Alternative A absolutely important than B and not comparable with *j*
7	Very important	Alternative A preferred very much than B
5	More important	Alternative A is important than B
3	Relatively important	Alternative A is a little important than B
1	Equally important	Alternative A and B are equally important or do not have any preference to each other
2,4,6,8		Middle values between preference values e.g. 8 shows an importance more than 7 an less than 9 for *i*

Consistent matrix is defined as follows:

Consider n criteria including C_1, C_2, …, C_n, in which their pairwise matrix is as Eq. (2) and a_{ij} is indicative of C_i preference on C_j. If Eq. (3) is true in the matrix, then matrix A is consistent.

$$A = [a_{ij}] \quad i,j = 1,2,\ldots,\mathrm{n} \tag{2}$$

$$[a_{ik}] \times [a_{kj}] = [a_{ij}] \quad i,j,k = 1,2,\ldots,\mathrm{n} \tag{3}$$

In every consistent matrix, special value is equal to the matrix length. If there are n number of criteria under the names of C_1, C_2, …., C_n and their weight is W_1, W_2, …, W_n respectively, then pairwise matrix for these elements is according to Eq. (4)

$$A = \begin{array}{c} \begin{array}{ccc} C_1 & \ldots & C_n \end{array} \\ \begin{bmatrix} \frac{W_1}{W_1} & \cdots & \frac{W_1}{W_n} \\ \vdots & \ddots & \vdots \\ \frac{W_n}{W_1} & \cdots & \frac{W_n}{W_n} \end{bmatrix} \end{array} \begin{array}{c} C_1 \\ \ldots \\ C_n \end{array} \tag{4}$$

Theorem 1: If λ_1, λ_2,…, λ_n are special values of pairwise comparison matrix A, then total amount of their values is equal to n (Eq. (5)).

$$\sum_{\mathrm{i}=1}^{\mathrm{n}} \lambda_{\mathrm{i}} = \mathrm{n} \tag{5}$$

Theorem 2: The biggest special value ($\lambda_{\max}$) is always greater than or equal to n (some of are negative).

$$\lambda_{\max} \geq \mathrm{n} \tag{6}$$

Theorem 3: If the matrix elements get away from consistency mode, then its special value will get a little away from its consistency mode.

On the other hand, Eq. (7) is true according to the definition for every square matrix A

$$A \times W = \lambda.\mathrm{W} \tag{7}$$

If matrix A is consistent, then a special value is equal to n (the biggest special value is equal to zero), therefore Eq. (8) is true

$$AW = \mathrm{nW} \tag{8}$$

If the pairwise comparison matrix A is inconsistent (theorem 3), the Eq. (9) is true

$$A \times W = \lambda_{max}.\mathrm{W} \tag{9}$$

Since $\lambda_{\max}$ is always greater than or equal to n and if the matrix gets a little away from consistency mode, $\lambda_{\max}$ will get a little away from n. Therefore, difference between $\lambda_{\max}$ and n ($\lambda_{\max} - n$) can be an appropriate criterion for measuring the matrix consistency. Undoubtedly, the $\lambda_{\max} - n$ criterion depends on the matrix length (n) and such dependency can be removed by defining the criteria in form of Eq. (10) which is called consistency index (CI).

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{\mathrm{n}-1} \tag{10}$$

The CI value for the matrixes with random numbers calculated and called it Random Index matrix (RI) that their values are equal to *n*-dimension matrixes according to Table 2:

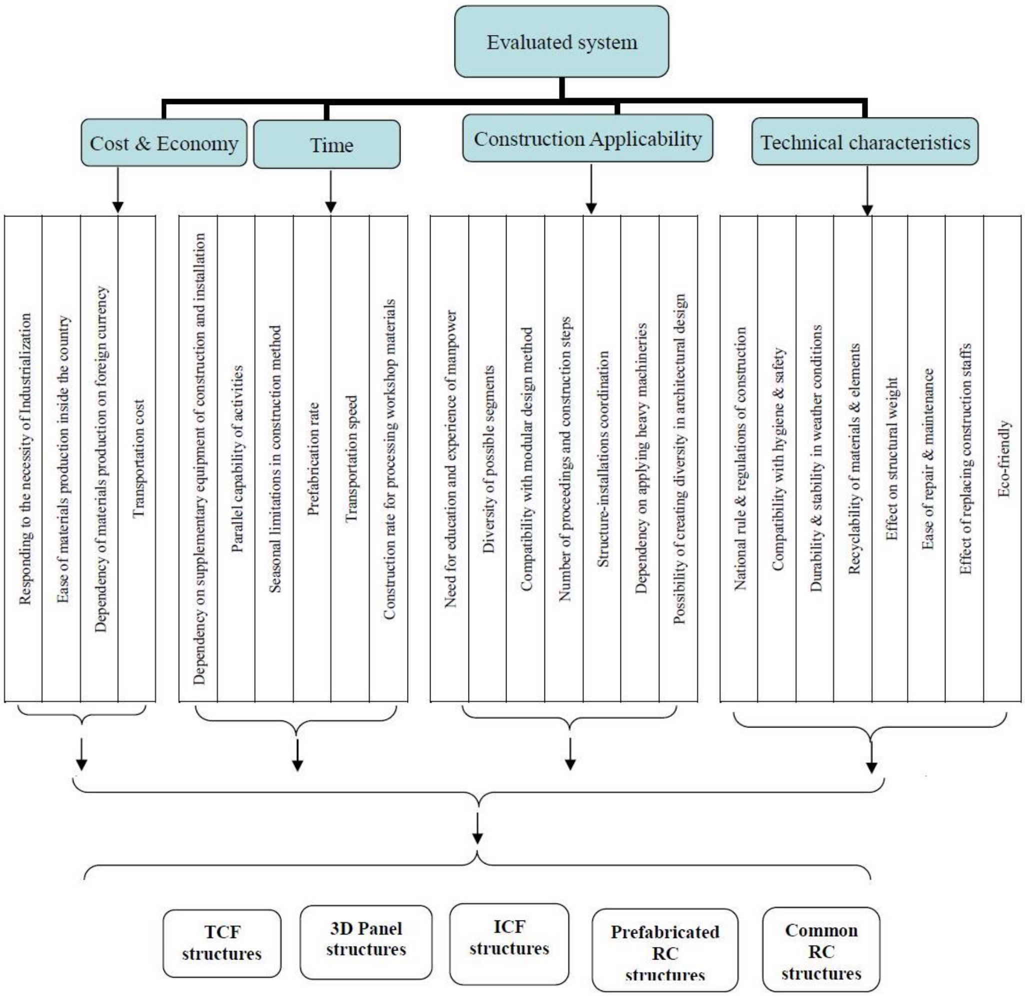

Fig. 6 Hierarchy of decision-making of the evaluated system

Table 2 Random consistency indices adopted from Saaty (1988)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RI	0.0	0.0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57

Dividing CI of any matrix by RI of the same dimension is an appropriate criterion for judgment about consistency, which is called consistency rate (CR). If this value is less than or equal to 0.1, system consistency accepted otherwise judgments have to be reviewed. The CR obtained from Eq. (11)

$$\mathrm{CR} = \frac{CI}{RI} \tag{11}$$

4.5 Evaluation criteria

The final criteria, which are obtained to select concrete structure system through studying criteria in previous researches and asking building industry experts, are shown in Fig. 6 that is consisting of four main criteria and their sub-criteria. Then, criteria comparison and weight value of each one done through pairwise comparisons by the experts and geometrical average of the opinions with the assumption of equal decision-making power of respondents shown in Tables 4 to 8. To do so, the Expert Choice

Table 4 Group pairwise matrix of main criteria of selecting optimized concrete system

Index A \ Index B	Cost	Time	Applicability	Technical characteristic
Cost	1	2	3	2
Time	0.5	1	2	2
Applicability	0.33	0.5	1	$\frac{1}{2}$
Technical characteristic	0.5	0.5	2	1

software is used to model and rank decision-making problems through AHP.

The average of technical value of each criteria and sub-criteria are shown in above tables. In next part, final evaluation and ranking of construction systems of concrete structure is done through evaluation of each system for criteria and by technical value of criteria.

5. Results and discussion

5.1 Evaluation of construction systems of concrete structure

Table 5 Group pairwise matrix of cost sub-criteria of selecting optimized concrete system

Index B / Index A	Industrialization necessity	Ease of materials production inside the country	Dependency of materials production on foreign currency	Transportation cost
Industrialization necessity	1	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{5}$
Ease of materials production inside the country	3	1	4	$\frac{1}{3}$
Dependency of materials production on foreign currency	2	0.25	1	$\frac{1}{5}$
Transportation cost	5	3	5	1

Table 6 Group pairwise matrix of time sub-criteria of selecting optimized concrete system

Index B / Index A	Equipment &facilities for construction & installation	Parallel capability of building activities	Material processing & workshop materials	Seasonal limitation in construction method	Prefabrication rate	Transportation speed
Equipment & facilities for construction installation &	1	5	$\frac{1}{3}$	$\frac{1}{5}$	$\frac{1}{3}$	$\frac{1}{2}$
Parallel capability of building activities	0.2	1	3	3	$\frac{1}{2}$	3
Material processing & workshop materials	3	0.33	1	3	$\frac{1}{4}$	2
Seasonal limitation in construction method	5	0.33	0.33	1	$\frac{1}{3}$	1
Prefabrication rate	3	2	4	3	1	2
Transportation speed	2	0.33	0.5	1	0.5	1

Table 7 Group pairwise matrix of applicability sub-criteria of selecting optimized concrete system

Index B / Index A	Need for education & experience of manpower	Segments variety (replicability of a segment by another one if not exist)	Compatibility with modular design method	No. of proceedings & construction steps	Structure-installations coordination	Dependency on application of machineries (light/heavy)	Possibility of creating diversity in architecture design
Need for education & experience of manpower	1	2	3	$\frac{1}{2}$	3	3	5
Segments variety (replicability of a segment by another one if not exist)3	0.5	1	3	3	2	3	5
Compatibility4 with modular 3design m3ethod	0.33	0.33	1	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	3
No. of proceedings & construction steps	2	0.33	3	1	2	3	4
Structure-installations coordination	0.33	0.5	2	0.5	1	3	3
Dependency on application of machineries (light/heavy)	0.33	0.33	3	0.33	0.33	1	3
Possibility of creating diversity in architecture design	0.2	0.2	0.33	0.25	0.33	0.33	1

Table 8 Group pairwise matrix of technical characteristics sub-criteria of selecting optimized concrete system

Index B Index A	National rule & regulations of construction	Compatibility with hygiene & safety	Durability & stability in weather conditions	Recyclability of materials & elements	Repair & maintenance	Role of construction staffs	Structural weight	Eco-friendly
National rule & regulations of construction	1	4	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{3}$	3	$\frac{1}{4}$	3
Compatibility with hygiene & safety	0.25	1	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	3	$\frac{1}{5}$	3
Durability & stability in weather conditions	3	4	1	3	3	4	$\frac{1}{3}$	4
Recyclability of materials & elements	4	4	0.33	1	3	3	$\frac{1}{3}$	4
Repair & maintenance	3	4	0.33	0.33	1	4	$\frac{1}{4}$	4
Role of construction staffs	0.33	0.33	0.25	0.33	0.25	1	$\frac{1}{5}$	3
Structural weight	4	5	3	3	4	5	1	6
Eco-friendly	0.33	0.33	0.25	0.25	0.25	0.33	0.17	1

Table 9 Relative weights of all criteria and sub-criteria

Main Criterion	Sub-Criterion	Weights: Sub-Criterion	Weights: Main Criterion
Cost & Economy	Industrialization necessity	0.08	0.408
	Ease of materials production inside the country	0.267	
	Dependency of materials production on foreign currency	0.106	
	Transportation cost	0.547	
Time	Dependency on supplementary equipment of construction and installation	0.15	0.273
	Parallel capability of building activities	0.18	
	Construction rate for processing workshop materials	0.159	
	Seasonal limitations in construction method	0.14	
	Prefabrication rate	0.275	
	Transportation speed	0.096	
Construction Applicability	Need for education and experience of manpower	0.239	0.126
	Diversity of possible segments	0.244	
	Compatibility with modular design method	0.064	
	Number of proceedings and construction steps	0.21	
	Structure-installations coordination	0.121	
	Dependency on applying heavy machineries	0.086	
	Possibility of creating diversity in architectural design	0.036	
Technical characteristics	National rule & regulations of construction	0.08	0.192
	Compatibility with hygiene & safety	0.052	
	Durability & stability in weather conditions	0.207	
	Recyclability of materials & elements	0.161	
	Ease of repair & maintenance	0.116	
	Effect of replacing construction staffs	0.041	
	Effect on structural weight	0.315	
	Eco-friendly	0.029	

Based on the results obtained from analyses, the cost criterion (0.408) has the highest priority and applicability (0.126) has the lowest priority among criteria. The relative weights of other criteria, all sub-criteria and their prioritization are listed in Table 9.

According to Fig. 7 and comparisons, the RC structure

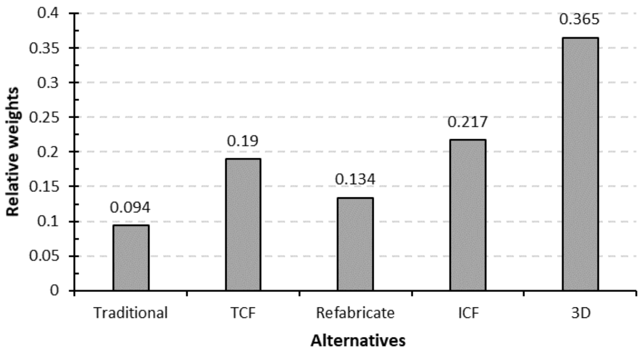

Fig. 7 Relative weights of alternatives in proportion to the goal

Table 10 Parameters in calculating CR in pairwise comparison matrix

CR (%)	CI	RI	λ_{max}
9.692	0.087	0.900	4.262

constructed by lightweight prefabricated 3D Panel system (36.5%) selected as the best system and the common RC structure system (9.3%) selected as the worst system. Relative weight of other systems and their prioritization is shown in the same figure.

5.2 Studying the system consistency

The consistency rate of results for pairwise comparison matrix of the criteria for selecting concrete structure, which is calculated by Expert Choice software, was 3%. The calculated values for parameters CI, CR, RI and $\lambda_{\max}$ for the selected alternatives are summarized in Table 10. As the results of this table indicate the value of parameter CR is less than or equal to acceptable value of consistency rate (10%) in AHP and thus accepted.

6. Conclusions

Increase in population and its daily increasing in our today society results in increase in housing demand while traditional methods are not applicable. One of the problems in the way of any project is selecting construction system compatible with the project needs and characteristics. In the present research, different common traditional and modern systems for concrete structures are studied and different criteria like cost, time, applicability and technical characteristics with industrialization approach compared. To do so, some questionnaires filled out by construction industry experts in order to compare criteria and sub-criteria and then, different structural systems ranked by AHP and the most optimized choice selected.

Finally considering the importance of main criteria (cost 0.408, time 0.273, technical characteristics 0.192 and construction applicability 0.126) and other sub-criteria that were compared for five concrete structural systems (3D Panel, ICF, TCF, prefabricated and common RC), the results of software analysis show that the 3D Panel system 36.5%, ICF 21.7%, TCF 19.03%, prefabricated 13.3%, and common RC system 9.3% are the most and the least efficient systems respectively.

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