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Building assessment for repair and maintenance by DEMATEL approach

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Research Paper

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The repair and maintenance activities are one of the basic concepts in buildings. The factors affecting repair and maintenance may significantly increase the life span of buildings, reduce costs, improve quality, increase productivity and consequently, fulfil the quantitative and qualitative goals of construction. Thus, determining the factors affecting this issue could be of great help in evaluating buildings. Proper selection of these factors is a multi-criteria decision-making problem involving definition of factors affecting the repair and maintenance of buildings, and their consideration as multiple criteria for the evaluation of buildings. In this paper, Delphi method and research literature are used to determine the factors affecting evaluation of buildings based on repair and maintenance. Also, the DANP (DEMATEL based on Network Analysis Process) hybrid approach is applied to calculate and evaluate all direct and indirect relationships between dimensions and components. The advantage of this approach lies in giving proper consideration to the relatively complex interdependencies of factors affecting performance. In this research work, an attempt is made to determine the basic characteristics of the repair and maintenance system in buildings, specify the correlation and relationship between the repair and maintenance criteria, and prioritize these criteria.

Key words:

repair and maintenance, multi-criteria decision making, network analysis process (ANP), decision making trial and evaluation laboratory (DEMATEL), hybrid approach

Prethodno priopćenje

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Primjena DEMATEL pristupa za ocjenu potrebe sanacija i održavanja zgrada

Radovi sanacija i održavanja smatraju se jednim od ključnih aktivnosti za funkcioniranje građevina. Faktori koji utječu na sanaciju i održavanje mogu uvelike povećati trajnost građevine, smanjiti troškove, poboljšati kvalitetu, povećati produktivnosti te posljedično znatno doprinijeti ispunjavanju kvantitativnih i kvalitativnih ciljeva građenja. Dakle, određivanje spomenutih faktora može u velikoj mjeri pomoći pri ocjenjivanju građevina. Pravilan odabir tih faktora bazira se na višekriterijskom donošenju odluka koje uključuje definiranje faktora značajnih za sanaciju i održavanja građevina te njihovu višekriterijsku analizu u svrhu ocjenjivanja građevina. U ovom se radu faktori koji utječu na ocjenjivanje građevina prema potrebama sanacije i održavanja određuju pomoću metode Delphi te na temelju odgovarajuće znanstvene literature. Hibridni pristup DANP (DEMATEL baziran na analitičkom mrežnom procesu) primjenjuje se za izračunavanje i ocjenjivanje svih izravnih i posrednih odnosa između dimenzija i komponenata. Prednost ovog pristupa leži u prikladnom razmatranju relativno složenih odnosa između faktora koji utječu na ponašanje građevina. U ovom se radu određuju osnovne karakteristike sustava za sanaciju i održavanje građevina, definiraju se korelacije i odnosi između kriterija sanacije i održavanja, te se zatim određuju prioriteti pojedinačnih kriterija.

Ključne riječi:
sanacija i održavanje, višekriterijsko donošenje odluka, analitički mrežni proces (ANP), laboratorij za donošenje i procjenu odluka (DEMATEL), hibridni pristup

1. Introduction

Repair and maintenance are two basic concepts that enable optimum performance of various components of the building while also reducing costs. The repair and maintenance refer to a set of activities used to maintain components, equipment, capital, and assets to prevent equipment failure and interruption in equipment operation [1]. An efficient maintenance management will be realized in the case of a long-term integration of information management and building management and short-term construction activities to minimize the building life cycle cost due to labour shortages in the labour market, and to make use of modern solutions [2].

Nowadays, much attention is being paid to strategies in the process of repair and maintenance of buildings, rather than to determination of necessary indicators for this important task. Therefore, new strategies have been proposed for the inspection and repair of structural elements and systems. By reviewing and studying the effective indicators relevant to repair and maintenance, it is possible to reduce the costs of repair and maintenance [3].

Since many indices are involved in the assessment of the repair and maintenance of buildings, and as buildings are a place where human beings spend considerable time, it is important to identify and rank these indices. Therefore, this research attempts to identify and prioritize the principal parameters of the repair and maintenance systems in buildings, and to determine the effectiveness as well as impact of the criteria on each other, and also to establish relationships between the criteria through a multi-criteria decision-making method.

This research is an attempt to determine and prioritize basic indicators of the repair and maintenance of buildings. First the relationships between the criteria and their influences are determined by DEMATEL method, and then the combined ANP and DEMATEL, called the DANP method, is used to determine the effective weight of the criteria, the influence of the criteria on each other, and the relationships between individual criteria. Then the theoretical concepts of the research and the methods used in the research are briefly introduced, and the research problem is discussed in practical terms. Finally, the conclusion is presented.

2. Literature review

2.1. Repair and maintenance

Building maintenance can be defined as a permanent activity that takes place during the service life of buildings. Generally, building maintenance puts the performance of the building and all of its sections at a certain level. An appropriate decision-making system is very important for logical management and maintenance of buildings [4]. Many experts believe that repair and maintenance developments have been greater than those made to any engineering systems. These developments include increasing physical capital, design, new repair and maintenance techniques, and changes in management. The repair and maintenance should also meet the new and changing demands of the today's civilized world [5]. The main objective of repair and maintenance in a system is to extend the life of equipment with the lowest cost and maximum efficiency, which is defined from the beginning of equipment installation and during the service period [6]. Understanding and selecting the factors that affect the repair and maintenance of buildings will enable effective performance of buildings and their components. The repair and maintenance involve a set of activities that lead to 100 % of maintenance of the equipment [7]. These expectations are due to an increasing awareness of stakeholders and building engineers regarding the effect of repair and maintenance on the environment and safety, product quality, and comfort, as well as to an increased pressure to achieve higher availability at lower costs. The evaluation of effective building maintenance indices allows analysis of the costs incurred under specific conditions, which can provide sufficient funding to maintain structural integrity of buildings and their systems, and to ensure proper quality of housing [8].

2.2. Evaluation criteria

To improve the quality of buildings, numerous guidelines and regulations have been developed to enable their proper design, construction, repair and maintenance. These guidelines/regulations can be used to evaluate the quality of buildings based on various indices. These indices are used to compare and rank repair and maintenance policies [9]. Opinions formulated by experts with regard to these criteria can be grouped into four main groups: cost, added value, safety, and performance [10]. The scope of this research is Iran, and the research is based on the Building Codes, Issues 2, 12 and 22 of the National Building Regulations, ISO, Housing health and safety rating system, US Housing Quality Standards (HHSRS), as well as on the existing articles and expert opinions on building repair and maintenance. Technical, social, economic, environmental and legal contexts are considered in this study using the Delphi method and eight parameters are considered as evaluation indices. The corresponding results are presented in Table 1.

2.3. Research background

In their paper, Moghadasi et al. [11] extracted and localized the performance assessment criteria of a maintenance management system using the physical asset management approach. After selection, the research results showed that, compared to other variables identified in the defence industry, the demolition process and standardization of equipment knowledge had a high influence and a low level of dependency. Using the DEMATEL multi-criteria decision-making methods and the fuzzy neural network process, Dabbagh et al. [12] detected, ranked, and determined the impact and interaction of factors affecting the productivity of organizational human resources of the Central Bank of East Azerbaijan Electricity Distribution Company. The results showed that the factor of job satisfaction had the highest impact, and that the organizational commitment had the lowest impact compared to other factors. Mishra et al. [13] addressed the issue of the time-based reliability modelling and preventive maintenance planning for residential buildings. Their purpose was to reduce the effect of storm damage using the gamma process to model random damage to building components. Ganji et al. [14] applied the decision-making trial and evaluation laboratory method (DEMATEL) and the analytical network process (ANP) to construct an Infrastructure Relationship Map (IRM) and to enable effective weighting of vehicle criteria. They also used an Evidential Reasoning (ER) algorithm to evaluate intercity buses for vehicle safety, and to deal with uncertainties regarding incomplete input data. The results showed that the braking system was the most important criterion affecting vehicle safety. Using a multi-criteria simulation and decision-making tool, Khodayari and Abdollahzadeh [15] examined an approach for the determination of appropriate maintenance policies and multi-product repairs in a food industry production unit. The main criteria in selecting the repair and maintenance policies were the profit, productivity, accessibility, environment, safety, and reliability. Using a computer simulation and multi-criteria decision-making, they selected the best policy for each production line separately. Nzukam et al. [16] argued that a large part of maintenance costs for non-residential buildings is related to air conditioning systems. They presented a method for multicomponent systems based on their remaining lifetime in order to improve maintenance plans. Abdollahzadeh et al. [17] studied the criteria and role of optimal maintenance strategies for bridges using the fuzzy AHP method. They determined optimum repair and maintenance strategies by choosing criteria and prioritizing them based on their need for repair and maintenance. Au-Yong et al. [18] conducted a study to determine characteristics of planned maintenance activities and emphasized the importance of proper planning and realisation of repair and maintenance work in order to improve its performance. Six planned maintenance characteristics were mainly used during the maintenance process to determine the maintenance and repair performance from planning to maintenance results. In this respect, five characteristics were significantly correlated to the maintenance cost variance, including skill and knowledge of work, level of spare parts and materials stock, quality of spare parts and materials, length of pre-determined maintenance interval, and amount of failure downtime, maintenance, and repair. Yau [19] examined relative importance of various decision-making criteria in the multi-year maintenance of residential buildings in Hong Kong and identified a set of decision criteria. Finally, the weight of these criteria was investigated using a fuzzy decision support system whose results showed that the cost of repair and maintenance of buildings affected the stakeholders' decision-making process. In their study entitled "Determining the best maintenance strategy", Zaim et al. [10] used two AHP and ANP techniques for the analysis of best-selling newspapers in Turkey according to four criteria, i.e., added value, cost, safety and feasibility, for three corrective, predictive, and periodic net strategies, and concluded that the predictive maintenance strategy is the most appropriate strategy for newspaper analysis. In the study entitled "Determining maintenance strategy", Foladgar et al. [20] examined maintenance strategies based on the cost, accessibility, risk and added value criteria using the fuzzy AHP and COPRAS techniques. The analysis showed that, according to the mentioned criteria, the programmed repair and maintenance is the best strategy.

According to the above-mentioned research activities and other studies presented by various authors, it can be stated that no studies, which use the weighting method and integrated ranking at the same time, have so far been conducted in the field of determining the building repair and maintenance indices. Besides, a method such as DEMATEL has not been used in this field due to its novelty. In the present study, a new integrated method is used to determine building repair and maintenance indices in order to eliminate the mentioned disadvantages.

According to the studies mentioned in previous sections, it can be concluded that the research has been done using separate or simultaneous multi-criteria decision-making techniques in order to determine repair and maintenance criteria and related strategies in various industries. However, this issue has been ignored in the field of construction industry. Therefore, the need to study the criteria, and to develop and apply appropriate models, is still felt in this area. Consequently, effective criteria for the repair and maintenance of buildings are identified in this study using the Delphi method, and the DANP technique is used to determine the relationship between repair and maintenance criteria, and to prioritize criteria in construction industry.

3. Research methods

Various theories were used to answer two basic questions for determining the key indices that affect repair and maintenance of buildings and their ranking, the aim being to specify the parameters that can effectively be used in the repair and maintenance of buildings. This research was conducted for this purpose and a survey was made using questionnaire tools to collect the data needed in the research. According to the decision-making methods and based on the necessity of using experts, 24 members of the Delphi panel, experts in various fields related to the construction industry and maintenance, highly familiar with construction industry issues and having scientific foundations, work experience, and appropriate expertise in this field, were selected in a targeted manner in the scope of this research to determine the parameters affecting the building repair and maintenance system. These experts were members of the University Faculty in the field of construction and had an appropriate repair and maintenance expertise. Thirteen initial criteria were identified in this research work, by firstly reviewing the literature and authoritative scientific articles, and then by consulting the experts. Finally, using the Delphi method and based on the experts' opinion, eight Indicators were extracted out of the thirteen criteria as the main indices affecting building repair and maintenance (cf. Table 1).

Table 1. Evaluation indices

Row	Criteria
1	Safety
2	Health
3	Comfort
4	Proper utilization
5	Energy saving
6	Environment
7	Economic saving
8	Citizenship rights

Building repair and maintenance criteria were selected based on the relevant concepts and thorough research data presented in the literature. The first criterion is safety; the word safety is used in the dictionary to denote security and health, and its scientific definition is the degree of freedom from any hazard that could potentially cause damage to staff, equipment and buildings, eliminate materials, or reduce efficiency in performing a predetermined task [21]. Another factor is health that can be defined as the ability of meeting the physical and mental needs of residents and preventing accidents [22]. Comfort is the feeling of satisfaction with the environment, temperature, colour, ventilation, sunlight, etc. [23]. Another criterion is proper utilization. In this study, proper utilization is a relative concept. Utilization in a building can be expressed as the quality and efficiency of equipment in providing services and in enabling maximum use of equipment, resources, and facilities [24]. Energy saving is a change in the pattern of energy consumption, enabling optimal use of energy resources while not being detrimental to economic well-being [25]. The following factor is the environment, i.e., the part of the Earth in which life exists. In this study, the environment of a residential building is the zone in which all components and people live, and where other natural, artificial, and social factors are related to each other and affect the process of life in the building [26]. In terms of economic savings, saving means finding innovative ways to make better use of limited resources, including time, cost, etc. [27]. Citizenship rights are the rights that are unconditionally recognized as the rights of all members of society. Citizens have the right to enjoy safe housing that is compliant with their needs. In this study, it refers to the rules and regulations that people in the building must follow to implement the repair and maintenance processes properly [28]. After collecting data to determine the total relationships (direct and indirect) between the dimensions and components, their prioritization was made by the experts using the DANP method and the pairwise comparison matrix. The purpose of the present study is to identify the key factors affecting the repair and maintenance of buildings, to determine the interdependencies between them, and, finally, to rank these factors.

The DEMATEL method maps the network relationships and interrelationships between the criteria. DEMATEL is a useful method for analysing the cause-and-effect relationships, where it can provide quantitative criteria and consider the related structural models. DEMATEL can effectively build the map of relationships' structure with clear interactions between sub-criteria of each criterion. It can also be used to create causal graphs that visualize the causal relationship of subsystems [29].

The following steps are used in traditional and classical methods applied to solve the DEMATEL and ANP hybrid model. Using the DEMATEL method, the total communication matrix is calculated, then the threshold value is taken, and the relationships between the criteria and the sub-criteria are extracted based on the threshold value and the total relation matrix. These relationships are then processed in the APN method, pairwise comparisons are performed once again, and the weight of the criteria and sub-criteria is calculated. However, in the other method, the threshold value is not taken from the total relation matrix and the initial supermatrix is formed with the same total effective numbers, and then it is weighted and powered by the infinite to calculate the final weight of the criteria and sub-criteria. This method is a combination of DEMATEL and ANP methods. Thus, this technique is used in conjunction with the ANP as the DANP technique where the results of the ANP are obtained by the total correlation matrix of T_c and T_D calculated by DEMATEL. So, DEMATEL is used in the DANP technique to construct the network structure model for each criterion and to improve the normalization process of the ANP [30].

In recent years, operational research techniques, such as the Multi-Criteria Decision-Making Tool (MCDM), which includes the Multi-Attribute Decision-Making (MADM) and the Multi-Objective Decision-Making (MODM), have been proposed to assist decision-makers in the evaluation of alternatives. The benefits of this approach include considering human preferences alongside computational considerations. The

Table 2. Scoring spectrum in the DEMATEL method

Ineffective	Very low effectiveness	Low effectiveness	High effectiveness	Very high effectiveness
0	1	2	3	4

following steps, based on Fontela and Gabus [31], are presented for the DEMATEL method.

Step 1: Forming the direct relationship matrix: In this step, the mutual impact of the criteria is examined. It is assumed that, in this study, there are H experts and n criteria. Each expert is asked to specify a level based on the matrix $D=[d^{ij}_c]$ which indicates the effects of i on the criterion j. These pairwise comparisons between the two criteria are expressed with d^{ij}_c. The scoring spectrum given in Table 2 is used to examine the effect of the criteria on each other.

$$D=\begin{bmatrix} d_c^{11}\cdots d_c^{1j}\cdots d_c^{1n} \\ \vdots \quad \vdots \quad \vdots \\ d_c^{i1}\cdots d_c^{ij}\cdots d_c^{in} \\ \vdots \quad \vdots \quad \vdots \\ d_c^{n1}\cdots d_c^{nj}\cdots d_c^{nn} \end{bmatrix} \tag{1}$$

Step 2: Calculating the normal direct relationship matrix: It is calculated using Eqn. (2):

$$N=VD;\ V=min\left\{\frac{1}{max_i\sum_{j=1}^{n}d_{ij},1/\,max_j\sum_{i=1}^{n}d_{ij}}\right\},\quad i,j\in\{1,2,\ldots,n\} \tag{2}$$

Step 3: Calculating the normal direct relationship matrix T_c**:** It is calculated using Eqn. (3); it is worth noting that I is the unit matrix.

$$T = N, N^2; N^3, \ldots, N^h = N(I-N)^{-1}, \text{ when } h\to\infty \tag{3}$$

$$\begin{array}{cc} & \begin{array}{ccccccc} D & & D & & D & \\ c_{11} \cdots c_{1m_1} & & c_{j1} \cdots c_{jm_j} & & c_{n1} \cdots c_{nm_n} \end{array} \\ \begin{array}{c} D\ c_{11} \vdots c_{i1} \\ c_{i2} \\ D \vdots c_{im_i} \\ c_{n1} \\ D \vdots c_{nm_n} \end{array} & \begin{bmatrix} T_c^{11} & \cdots & T_c^{1j} & \cdots & T_c^{1n} \\ \vdots & & \vdots & & \vdots \\ T_c^{i1} & \cdots & T_c^{ij} & \cdots & T_c^{in} \\ \vdots & & \vdots & & \vdots \\ T_c^{n1} & \cdots & T_c^{nj} & \cdots & T_c^{nn} \end{bmatrix} \end{array} \tag{4}$$

Step 4: Analysing results and plotting the causal graphs for the dimensions and criteria: This step sums the rows and columns of the total correlation matrix separately according to Eqn. (5). Here, the indices r_i and c_j represent the sum of the rows i and columns j, respectively.

$T = [t_{ij}]$, i,j ∈ {1, 2, 3, ..., n}

$$r=[r_i]_{n\times 1}=\left[\sum_{j=1}^{n}t_{ij}\right]_{n\times 1}\quad C=[c_j]_{1\times n}=\left[\sum_{i=1}^{n}t_{ij}\right]_{1\times n} \tag{5}$$

The index $r_i + c_j$ is obtained from the sum of the row i and column j indicating (i = j) the significance of the criterion i. Similarly, the index $r_i - c_j$ is the difference between the sum of row i and column j indicating the cause or effect of the criterion i. In general, if $r_i - c_j$ is positive (i=j), the criterion i is in the causal set of criteria; if $r_i - c_j$ is negative(i = j), the criterion i is in the effect set of criteria.

Step 5: Normalizing the total dimensions relationship matrix: T_D is obtained from the mean T^{ij}_c To normalize matrix T_D, the sum of each row is calculated, and each element is divided by the sum of its corresponding row elements.

$$T_D=\begin{bmatrix} t_{11}^{D_{11}} \cdots t_{1j}^{D_{1j}} \cdots t_{1m}^{D_{1m}} \\ \vdots \quad \vdots \quad \vdots \\ t_{i1}^{D_{i1}} \cdots t_{ij}^{D_{ij}} \cdots t_{im}^{D_{im}} \\ \vdots \quad \vdots \quad \vdots \\ t_{m1}^{D_{m1}} \cdots t_{mj}^{D_{mj}} \cdots t_{mm}^{D_{mm}} \end{bmatrix} \begin{array}{l} \to d_1\sum_{j=1}^{m}t_{1j}^{D_{1j}} \\ \to d_i\sum_{j=1}^{m}t_{ij}^{D_{ij}} \quad ,d_i\sum_{j=1}^{m}t_{ij}^{D_{ij}} \quad ,i=1,\ldots m \\ \to d_m\sum_{j=1}^{m}t_{mj}^{D_{mj}} \end{array} \tag{6}$$

$$T_D=\begin{bmatrix} \frac{t_{11}^{D_{11}}}{d_1} \cdots \frac{t_{1j}^{D_{1j}}}{d_1} \cdots \frac{t_{1m}^{D_{1m}}}{d_1} \\ \vdots \quad \vdots \quad \vdots \\ \frac{t_{i1}^{D_{i1}}}{d_i} \cdots \frac{t_{ij}^{D_{ij}}}{d_i} \cdots \frac{t_{im}^{D_{im}}}{d_i} \\ \vdots \quad \vdots \quad \vdots \\ \frac{t_{m1}^{D_{m1}}}{d_m} \cdots \frac{t_{mj}^{D_{mj}}}{d_m} \cdots \frac{t_{mm}^{D_{mm}}}{d_m} \end{bmatrix} = \begin{bmatrix} t_D^{\alpha_{11}} \cdots t_D^{\alpha_{1j}} \cdots t_D^{\alpha_{1n}} \\ \vdots \quad \vdots \quad \vdots \\ t_D^{\alpha_{i1}} \cdots t_D^{\alpha_{ij}} \cdots t_D^{\alpha_{in}} \\ \vdots \quad \vdots \quad \vdots \\ t_D^{\alpha_{n1}} \cdots t_D^{\alpha_{nj}} \cdots t_D^{\alpha_{nn}} \end{bmatrix} \tag{7}$$

Step 6: Normalizing the total criteria relationship matrix: The normalization of T_c is conducted by summing up the degree of the cause and effect of criteria and variables to achieve T^{α}_c as follows:

$$T_c^{\alpha}=\begin{array}{cc} & \begin{array}{ccccccc} D_1 & & D_j & & D_n & \\ c_{11} \cdots c_{1m_1} & & c_{j1} \cdots c_{jm_j} & & c_{n1} \cdots c_{nm_n} \end{array} \\ \begin{array}{c} D_1\ c_{11} \vdots c_{1m_1} \\ c_{i1} \\ D_i \vdots c_{im_i} \\ c_{n1} \\ D_n \vdots c_{nm_n} \end{array} & \begin{bmatrix} T_c^{\alpha 11} & \cdots & T_c^{\alpha 1j} & \cdots & T_c^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ T_c^{\alpha i1} & \cdots & T_c^{\alpha ij} & \cdots & T_c^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ T_c^{\alpha n1} & \cdots & T_c^{\alpha nj} & \cdots & T_c^{\alpha nn} \end{bmatrix} \end{array} \tag{8}$$

Step 7: Forming unweighted supermatrix (W): For this purpose, the transpose matrix of the normal total relationship T^{α}_D is calculated and the W matrix is obtained.

$$W = (T_c^{\alpha})^T = \begin{bmatrix} W^{11} & \cdots & W^{i1} & \cdots & W^{n1} \\ \vdots & & \vdots & & \vdots \\ W^{1j} & \cdots & W^{ij} & \cdots & W^{nj} \\ \vdots & & \vdots & & \vdots \\ W^{1n} & \cdots & W^{in} & \cdots & W^{11} \end{bmatrix} \quad (9)$$

Step 8: Forming weighted supermatrix: the transpose matrix of the normal total relationship T^{α}_{D} is multiplied by the unweighted supermatrix.

$$W^{\alpha} = T_D^{\alpha} W = \begin{bmatrix} t_D^{\alpha_{11}} \times W^{11} & \cdots & t_D^{\alpha_{1j}} \times W^{i1} & \cdots & t_D^{\alpha_{n1}} \times W^{n1} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha_{1j}} \times W^{1j} & \cdots & t_D^{\alpha_{ij}} \times W^{ij} & \cdots & t_D^{\alpha_{nj}} \times W^{nj} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha_{n1}} \times W^{1n} & \cdots & t_D^{\alpha_{in}} \times W^{in} & \cdots & t_D^{\alpha_{nn}} \times W^{nn} \end{bmatrix} \quad (10)$$

Step 9: Exponentiating the weighted matrix, followed by weighting and prioritization: the weighted supermatrix is powered by k to converge all elements of the supermatrix $(\lim_{k\to\infty}(W^{\alpha})^{k})$.

Then, the weights of the criteria and sub-criteria, also called dependency weights or DANP weights, are obtained from the limited supermatrix. Generally, despite the advantages, the DEMATEL method is not able to form a supermatrix, and, in contrast, ANP does have such ability. In the next step, the initial supermatrix is formed based on the outputs of DEMATEL and ANP, the supermatrix is calculated to a certain extent, and the weights of the factors are obtained. Finally, the causal factors and the priority of the factors over each other are obtained.

4. Results and discussion

The subject and its dimensions were defined in the initial part of this research. In this respect, the existing manuscripts were examined and the factors affecting their repair and maintenance were extracted. Based on the definition of the subject, the required specialties were determined, and the members of the Delphi panel were identified and selected. The composition and characteristics of the panel members are specified in Table 2. After determining the panel members, the Delphi method was implemented for three rounds. Questionnaires were distributed and collected electronically for each round. In the first round, a list of effective factors on the repair and maintenance that were extracted from successful research was provided to the members. Moreover, they were asked to submit their ideas about the factors that are absent from the list. In the second round, the set of factors that were proposed in the first round, along with the initial factors extracted from the literature, were provided to the panel members so that they can determine their importance. In the third round, the members' views on the factors, which were considered as moderate, high, and very high in the first and second rounds, were retrieved. The Delphi method was completed after the third round and the achievement of the desired consensus. In this study, the Kendall's coefficient of concordance was used to determine the degree of consensus among the panel members. The difference between Kendall coefficients in the two final rounds was 0.022. The Delphi method was applied to specify the key indices for maintenance-based evaluation of buildings. The Likert scale was used to determine the importance of the criteria. In each round, against each factor, the average of the answers of the panel members in the previous periods and the previous answers of each person were individually communicated to the respondents. In this study, the Kendall's coefficient of concordance was used to determine the consensus among panel members. Based on the results, the Kendall's coefficient of concordance and the Cronbach's alpha coefficient were (0.581) and (0.831) in the second round of questionnaire distribution. Based on the average experts' opinion, the indices with a low or very low effect in the previous round were eliminated and panel members were once again questioned on the order of importance of the indices. The corresponding results are listed in Table 3. The Kendall's coefficient of concordance of the members about the order of eight factors was (0.603), and the Cronbach's alpha coefficient was (0.707), showing no significant growth in two consecutive rounds, and indicating consensus among members. The face validity of the questionnaires was

Table 3. Composition and characteristics of panel members

Specialty	No	MSc degree	PhD degree
Electricity Eng.	1	-	1
Machinery Eng.	1	-	1
Traffic Eng.	2	1	1
Civil Eng.	10	4	6
Architecture Eng.	3	1	2
Environment Eng.	1	-	1
Repair and Maintenance Eng.	2	1	1
Mechanics Eng.	1	-	1
Urban Eng.	2	1	1
Surveyor Eng.	1	1	-

Table 4. Detailed description of the third-round results

Row	Criteria	Responses	Mean	SD	Min	Max	Rank of importance based on the mean
1	Safety	24	4.92	0.282	4	5	1
2	Health	24	4.08	0.282	4	5	2
3	Comfort	24	4.00	0.417	3	5	4
4	Proper utilization	24	4.04	0.359	3	5	3
5	Economic saving	24	3.17	0.381	3	4	7
6	Environment	24	4.08	0.408	3	5	2
7	Energy saving	24	3.75	0.608	3	5	5
8	Citizenship rights	24	3.71	0.464	3	4	6

Table 5. Direct relationship matrix

	C1	C2	C3	C4	C5	C6	C7	C8
C1	0.0000	2.3043	2.7826	2.6957	2.9565	2.0000	2.8261	2.3478
C2	1.2609	0.0000	2.0435	2.0870	2.3043	1.8696	1.9130	1.9130
C3	1.6957	1.8261	0.0000	1.9565	2.3478	2.0000	2.2174	2.1739
C4	1.5217	1.9130	1.4783	0.0000	2.0870	1.9565	2.2174	1.8696
C5	1.4348	1.5652	1.7391	1.5652	0.0000	1.8261	1.6957	1.8261
C6	1.5652	1.8696	2.3043	2.1739	2.6087	0.0000	2.2174	2.2174
C7	1.5652	1.8696	1.9130	1.8696	2.1304	1.8696	0.0000	1.8261
C8	1.4348	1.5652	2.0435	1.9565	2.3043	2.1304	2.1739	0.0000

Table 6. Weighted matrix

	C1	C2	C3	C4	C5	C6	C7	C8
C1	0.3293	0.5085	0.5655	0.5616	0.6408	0.5183	0.5946	0.5459
C2	0.3181	0.3013	0.4311	0.4331	0.4950	0.4144	0.4459	0.4254
C3	0.3538	0.4127	0.3498	0.4479	0.5208	0.4400	0.4817	0.4577
C4	0.3253	0.3925	0.4000	0.3231	0.4784	0.4122	0.4535	0.4172
C5	0.2985	0.3490	0.3821	0.3738	0.3397	0.3772	0.3983	0.3856
C6	0.3594	0.4282	0.4785	0.4723	0.5495	0.3542	0.4974	0.4745
C7	0.3278	0.3910	0.4203	0.4181	0.4811	0.4088	0.3439	0.4160
C8	0.3311	0.3876	0.4377	0.4334	0.5023	0.4321	0.4645	0.3352

also verified by professors and experts. Then, the content validity index (CVI=0.80) was calculated by CVR, thus approving the validity of the questions [32].

The importance of each criterion was determined by the experts based on the agreement on the indices proposed for the factors affecting the repair and maintenance of the building. In this regard, the purpose of choosing the most important index was determined. Hence, the criteria selected based on the Delphi method were attributed to the following eight criteria as follows: Safety (C1), Health (C2), Comfort (C3), Proper utilization (C4), Economic Saving (C5), Environment (C6), Energy saving (C7), and Citizenship rights (C8). After examining the decision structure, internal relations were also managed using the DEMATEL method. The geometric mean method was used in ANP and DEMATEL to aggregate the opinions. After aggregation of the opinions, appropriate results were obtained by the DEMATEL method (cf. Tables 4 and 5).

Reliability was calculated based on the following relationship (Eqn. 11). Indeed, this rate indicates that the experts' opinion has a good reliability with regard to DEMATEL. The value in this study was 0.04997, which is acceptable as it is lower than 0.05.

$$\textit{Incopability rate} = \frac{1}{n(n-1)}\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{\left|g_c^{ij\rho}-g_c^{ij(\rho-1)}\right|}{g_c^{ij\rho}}.100\% \quad (11)$$

The threshold value of the mean of all the numbers obtained from the direct and indirect relation matrix table was also considered. In this study, this value amounted to (0.4256). Accordingly, it is possible to neglect the partial relations (all relationships with the values smaller than the threshold value in the T matrix) and set them to zero, meaning that the relationship is not causal. After that, the network of reliable relations (relations whose values in T matrix are greater than the threshold value) was plotted. At this point, the causal graph was plotted, and the position of each factor was determined by a point with coordinates (D+R, D-R) in the system. Using Figure 1, one can identify the cause-and-effect factors as well as the extent to which factors influence each other.

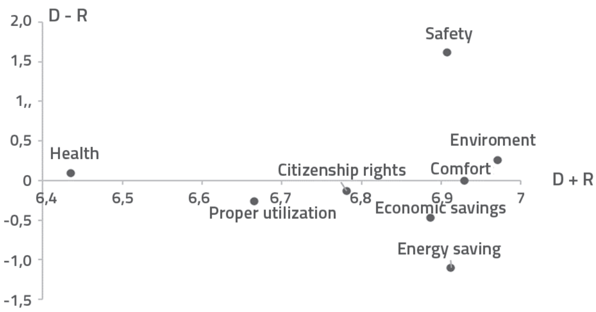

Figure 1. Diagram of the cause and effect

The horizontal axis (D+R) indicates the effect of the desired factor within the system. In other words, a higher D+R factor means that that the factor interacts more with other system factors; therefore, it is more important in the system. The vertical axis (D-R) displays the influence of each factor. In general, if D-R is positive, the variable is a cause variable, and if it is negative, it is an effect. The safety indicator has the highest value of D, and so it is the most influential factor. The economic saving criterion also has the highest R-value, and so it is the most effective factor. Besides, as the environment indicator has the highest value of D+R, it also has the highest relationship with other system factors. Moreover, because the D-R of safety, health and environment is positive, these variables are causal. The indicators of comfort, proper utilization, economic saving, energy saving, and citizenship, are considered to be effective indicators because their values are negative. The weighted matrix for the considered parameters is shown in Table 6.

The values of the weighted matrix, Table 6, were powered up to the final weight; normally the weighted supermatrix converges at 5 or 7 powers in DANP. In this study, it is converged by the power of 5 and the total weight of the criteria and their priority are determined. Finally, the results given in Figure 2 were ranked based on the obtained weights. According to Figure 2, the economic saving is more effective, so it has more weight while safety, which is more effective, will have less weight.

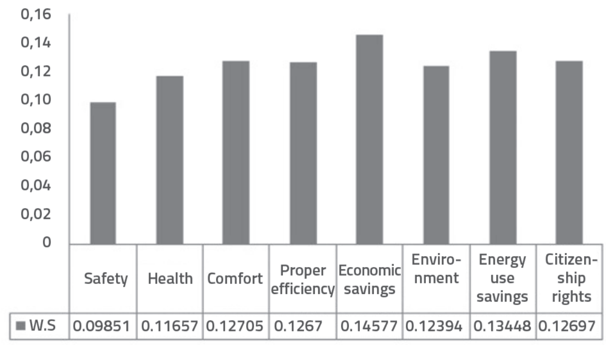

Figure 2. Ranking the indices

Since this research was conducted in construction industry, the repair and maintenance criteria differed from those defined in other industries. The following criteria were studied as the repair and maintenance criteria in other industries: Zaim et al. (2012) studied the added value, cost, safety and feasibility; Fooladgar et al. (2012) studied the cost, access, risk and added value, and Khodayari and Abdollahzadeh (2018) studied the criteria of profit, productivity, accessibility, environment, safety, and reliability. However, in addition to the safety, utilization, environment, and economic saving that are considered instead of cost and time, this study also introduces additional new criteria such as health, comfort, energy savings and citizenship rights with regard to the repair and maintenance of buildings.

5. Conclusions

The main purpose of this study was to identify the repair and maintenance characteristics of buildings so as to increase the efficiency of buildings as much as possible. One of the important problems facing managers is the lack of sufficient knowledge

Tablica 7. Ponderirana matrica

	C1	C2	C3	C4	C5	C6	C7	C8
C1	0.0772	0.0974	0.1021	0.1016	0.1028	0.0994	0.1022	0.0996
C2	0.1192	0.0923	0.1191	0.1226	0.1202	0.1185	0.1219	0.1166
C3	0.1326	0.1321	0.1010	0.1249	0.1316	0.1324	0.1311	0.1317
C4	0.1317	0.1327	0.1293	0.1009	0.1287	0.1307	0.1304	0.1304
C5	0.1503	0.1516	0.1503	0.1494	0.1170	0.1521	0.1500	0.1511
C6	0.1215	0.1269	0.1270	0.1287	0.1299	0.0980	0.1275	0.1300
C7	0.1394	0.1366	0.1391	0.1416	0.1371	0.1376	0.1072	0.1398
C8	0.1280	0.1303	0.1321	0.1303	0.1328	0.1313	0.1297	0.1008

about maintenance indicators in construction industry. The selection of appropriate repair and maintenance criteria for a building is a strategic decision-making issue based on which appropriate repair and maintenance policies can be determined in this area. In this study, a multi-criteria decision-making approach was applied to rank the key repair and maintenance indicators to assess buildings.

Since no studies have been conducted to determine the building repair and maintenance indices, a new integrated method called the DANP method was used to weigh and rank the indicators affecting the effective repair and maintenance of buildings.

The results obtained in this study through analysis of opinions formulated by experts show that the key indicators for assessing buildings based on repair and maintenance requirements are: safety, health, comfort, proper utilization, economic saving, energy savings, environment, and civil rights. These criteria differ from the corresponding criteria applied in other industries. In the current study, after identifying the maintenance criteria in construction industry using the DANP method, it was determined that the environment has the highest interaction with other components. Safety is the most effective factor, and economic saving is the most influenced factor. The health criterion has the lowest interaction. The comfort, health, citizenship rights, and energy saving criteria have not been considered in previous studies, and they can be used as new criteria for determining the repair and maintenance policies of buildings. Undoubtedly, the effective role of the identified repair and maintenance criteria will improve the quality and increase the useful life of buildings. This information may help decision makers to think about the maintenance priorities in the building sector from various points of views. By determining the priority of indicators and the relationship between the criteria, the sub-indicators of the buildings repair and maintenance system can be defined accurately, and so appropriate strategies can be adopted.

For further research, it is suggested to determine the sub-indicators of the repair and maintenance system as well as appropriate strategies in this field according to the mentioned criteria and sub-criteria using the TOPSIS, VIKOR and other multi-criteria decision-making techniques.

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