A Combination of the Knapsack Algorithm and MIVES for Choosing Optimal Temporary Housing Site Locations: A Case Study in Tehran

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Abstract

In the aftermath of natural disasters, decision-makers often clash when tackling the challenge of choosing suitable temporary housing unit (THU) site locations. Site location considerably impacts temporary housing (TH) delivery time and the displaced population's (DP's) satisfaction. At the same time, selecting a suitable site is important to help increase the performance of the THUs in their subsequent life. To this end, this study aimed to design a new model for selecting site location based on sustainability concepts. The new model combines the integrated value model for sustainable assessment (MIVES) and the Knapsack algorithm to identify a subset of sustainable sites amongst the possible options based on the required area. The new model was applied to determine the best subset of sites for THUs for a seismic hazard along the Mosha fault in Tehran, Iran. The results show that weighting techniques can result in inappropriate weights for some indicators.

Keywords: Temporary housing; Disaster recovery; Site location; MCDM; MIVES; Knapsack algorithm

1. Introduction

Site selection is a process that involves many steps from planning to construction, including initial inventory, alternative analysis, assessment, detailed design, construction procedures and services [1]. This process becomes an even more complicated issue with important outcomes when decision-makers are forced to choose the site location of temporary housing units (THUs) in the wake of a natural disaster, in an emergency situation subject to external pressures. In addition to the emergency itself, the site selection problem is exacerbated by the need to move the displaced population (DP) from its previous properties, communities and activities [2]. One of the main reasons for TH delays is the need to find the safest areas for TH amongst the potential lands [3-5]. In this regard, TH site location can have a considerable impact on public expenditures, in addition to on the environment [6]. Determining a suitable location for the DP to live is also a common problem [7]. Furthermore, THU site selection can have an even larger negative economic impact if the THUs built for the DP are rejected due to an unsuitable site location, as occurred in Bam, Iran, and Pescomaggiore, Italy [8, 9].

In general, improper THU site location can lead to problems such as: (1) late delivery, (2) secondary hazards, (3) expenses, (4) the loss of previous communities, (5) effects on the host community and (6) environmental pollution [1, 6, 10]. However, decision-makers cannot avoid this approach, which has been used for many recovery programmes in recent decades, because of certain local limitations and THU benefits, including: (1) the lack of alternatives, (2) the huge demand, (3) the urgency of the situation, (4) climate conditions, (5) pressure from the DP, (6) DP reluctance, (7) fast delivery time, and (8) high quality [6, 11-13]. Although it seems to be an ordinary factor, site location considerably impacts recovery programme failure and the DP's satisfaction. It could moreover become an even more serious challenge due to the increase in urban population [14], especially in areas prone to natural disasters [15], informal settlements [5], changing natural disasters [16], insufficient research on disaster operations management [17-21], other area-specific limitations, such as land scarcity, and increasing global concern for environmental sustainability. In this regard, dealing with this issue with a representative number of stakeholders requires considering all aspects in order to select suitable sites to decrease negative impacts. At the same time, the provision of THUs cannot be avoided because of natural disasters, which recur, and local requirements. To find a suitable solution amongst the available sites, the most sustainable subset must be chosen based on the different factors. However, this can be a complicated process for decision-makers due to the intricacy of multifaceted site selection, the wide range of possible alternatives and the number and diversity of the stakeholders.

This paper aims to present a suitable avenue to find a sustainable solution for site selection. To this end, it provides a platform to help decision-makers identify the most sustainable alternatives amongst a wide range of possibilities. At the same time, the various experts and engineers must take part in the decision-making process for the site location selection. This paper aims to meet decision-makers' need to identify a set of sites whose total area is equal or close to the required area, which is calculated in terms of area per capita based on the size of the DP. However, in some cases, the total areas of a huge number of subsets, including all initially acceptable alternatives, may be equal or close to the area needed for the TH site. In such cases, a model is needed to identify the most appropriate subsets amongst them. This problem can be addressed in two stages: (1) determination of clusters with the required area, and (2) selection of the most suitable subset in terms of sustainability. This study combined the Knapsack algorithm and MIVES method to identify the best solutions in terms of sustainability.

The Knapsack algorithm is used to obtain a set of alternatives based on specific values and size [22]. It selects one or more sets consisting of those options with total sizes equal to or less than the required size and the highest total scores for the chosen value. In this research, the size was the total required area and the value was the sustainability index (SI), which was calculated using the integrated value model for sustainable assessment (MIVES). MIVES is a multi-criteria decision-making method (MCDM) that considers a value function based on utility theory. MIVES offers three key advantages compared to other MCDMs for TH management: (1) it is time-independent;(2) it can be applied to diverse areas with different local characteristics and requirements; and (3) it can be made to take all stakeholders' satisfaction levels and needs into account through simple adjustments to the requirements tree's items and their weights [23].

In recent years, MIVES has been used to assess sustainability and make decisions in the fields of (1) university faculty [24], (2) financial aspects of the Barcelona Metro system's Line 9 [25], (3) industrial buildings [26], (4) the Spanish Structural Concrete Code [27], (5) sewerage pipes [28], (6) school buildings [29], (7) developing the MIVES–EHEm–Mcarlo probabilistic method for large and complex buildings [30], (8) structural concrete columns [31], (9) wind-turbine supports [32] and (10) TH [10, 11].

The new model presented in this paper was applied to determine the best site location for TH in the case of a seismic hazard along the Mosha fault in Tehran (Iran), which can be expected to occur according to a report by the Japan International Cooperation Agency

(JICA) and the Centre for Earthquake and Environmental Studies of Tehran (CEST) [33]. This model was designed to choose a TH site location before this natural disaster can occur. However, it could also be used after a natural disaster, subject to a few modifications.

2. Methodology

This study consisted of two stages: (1) a *data-gathering stage*, to define site selection requirements and sustainability factors based on primary and secondary sources from previous recovery programmes; and (2) an *operation phase*, in which the solution was selected according to sustainability concepts, as shown in Fig. 1. This process was carried out using the MIVES-Knapsack algorithm. This algorithm, the flowchart of which is presented in Fig. A.1, incorporates for the first time in a MIVES model the Knapsack problem, which is explained in [22, 34].

Fig. 1. Proposed approach for sustainable site selection based on the coupled MIVES-Knapsack method

In the first stage, the problem was considered in general terms in order to define sustainability indicators based on previous research and recovery programmes. Possible alternatives were then determined according to specific local characteristics and requirements, based on current potentials and natural hazards. The problem data, including the necessary area, sustainability requirements, potential sites, and, thus, all possible or acceptable sites for the initial set of alternatives, were specified in this stage. In the next stage, subsets were selected provided they met two conditions: (1) the total area of the sites in each subset had to fall within the required range, and (2) the subset had to have the maximum SI. The model used MIVES as the sustainability assessment tool to determine the SI of each site alternative and, consequently, the SI of each chosen subset. Meanwhile, Knapsack was applied as the operational tool to identify optimised subsets based on the first and second conditions. Additionally, Knapsack was introduced in C++ software using dynamic programming to reduce operation time, achieving a computation time less than one second. The designed model was able to choose each subset according to equation (1). Indeed, in this site selection problem based on the Knapsack problem concept [22,34], the value that is being maximized is the sustainability index (*SI*). The weight is the area or total areas of site(s) ($\sum_1^i A_n$) and the weight capacity is constrained between the minimum and maximum required area (W_1 and W_2).

$$W_1 \leq \sum_1^i A_n \leq W_2 \quad (1)$$

$$\text{Maximise} \quad \frac{\sum_1^i SI_n * A_n}{\sum_1^i A_n}$$

A_n	:	Area of site *n*
W_1 , W_2	:	Minimum and maximum required area
i	:	Number of items (sites) in each subset
SI_n	:	Sustainability index of site *n*

MIVES method

In order to obtain the SI of each subset (group), the weighted mean of the SIs of its component sites was calculated. The SI for each site was obtained using MIVES, according to the following steps: (1) design of a requirements tree, (2) specification of minimum (X_{min}) and maximum (X_{max}) satisfaction values for each indicator, (3) determination of the tendency and shape of the value function, (4) weighting of indexes and (5) application of the MIVES formula. The SI was derived from equation (2), involving each indicator value (V_i) and its associated weight (λ_i).

$$V = \sum \lambda_i \, . V_i \, (x_i) \tag{2}$$

$V_i \, (x_i)$: The value function of each indicator, criterion or requirement

λ_i : The weight of the indicator, criterion or requirement considered.

Additionally, to achieve each indicator value equations (3) and (4) were applied. Equation (4), which takes into account the generation of sets of indicator values ($V_i \, (x_i)$) between zero and one, was used to obtain factor B for equation (3).

$$V_i = A + B. \left[1 - e^{-k_i \, . \left(\frac{|X_{ind} - X_{min}|}{C_i} \right)^{P_i}} \right] \tag{3}$$

A : The response value X_{min} (indicator abscissa), generally $A = 0$

X_{ind} : The indicator abscissa that generates the value V_i

P_i : A shape factor that determines whether the curve is concave or convex, linear or S-shaped

C_i : The factor that establishes the value of the abscissa for the inflexion point in curves with Pi > 1.

K_i : The factor that defines the response value to C_i

B : The factor preventing the function from leaving the range (0.00, 1.00); obtained with equation (4).

$$B = \left[1 - e^{k_i \, . \left(\frac{|X_{max} - X_{min}|}{C_i} \right)^{P_i}} \right]^{-1} \tag{4}$$

This study used two approaches to determine the indexes' weights: (1) evaluation of the weights by a group of multidisciplinary experts using the analytical hierarchy process (AHP) [35], and (2) Shannon entropy (SE), with and without regard to the weights assigned by the expert assessment. Furthermore, the function of each indicator could have four different shapes (concave, convex, linear or S-shaped), as shown in Fig. 2, in addition to decreasing or increasing tendency [36]. More detailed descriptions of the MIVES methodology have been reported elsewhere, such as [27, 36, 37].

Fig. 2. Value function shapes of MIVES indicators

3. Sustainability assessment model with MIVES

The site selection problem, requirements and, thus, indicators were derived according to [1, 10, 38-43]. However, the indexes were adjusted to reflect the chosen case study based on interviews with local experts. This process resulted in a requirements tree imposing the independence of both the indicators and the time, as shown in Fig. 3. Three different requirements (economic, social and environmental) were established in the first level of the tree.

The economic requirement (R_1) includes the total expenses for the TH site. The social requirement (R_2) was included to assess aspects related to the sites' user safety and flexibility. The environmental requirement (R_3) takes into account the environmental impact of the site selection throughout the entire life cycle of the TH. The tree's second hierarchical level consists of five criteria, and the third level includes nine indicators. Whilst the requirements and criteria are not quantifiable, the indicators are measurable.

Fig. 3. Requirements tree designed for the model

The first criterion, *capital investment* (C_1) encompasses two indicators: (I_1) *land price*, which considers the cost of the land (cost/m^2), and (I_2) *cost of site preparation*, which includes the costs of all activities required to prepare the site: mobilisation, levelling, utilities, and so on. Special attention should be paid to sites with existing utilities and facilities. In this regard, the factor δ represents the quality of the utilities and facilities in the aftermath of the natural disaster based on experts' predictions.

The second criterion, *user safety* (C_2), includes three indicators. (I_3) *access* reflects the site's accessibility, in terms of emergency services and the DP. As the immediacy of the DP's access is considerably lower than that of the emergency services' access, only the latter is considered. Additionally, the quality of the emergency services is treated as a sub-indicator of neighbourhood acceptance. (I_4) *population coverage* prevents decentralisation of the site alternative and rewards greater coverage based on DP distributions. This indicator can be assessed by means of equation (5), in which index *i* refers to site alternatives like in previous equations. (I_5) *distance from sources of danger* takes into account potential dangers, such as faults, rivers, hazardous materials plants, and warehouses, in order to prevent secondary hazards from happening by considering two factors: (1) distance from sources of danger and (2) quality or intensity of the dangers.

$$PC_i = \sum_1^m \left(\frac{D_{a_i \to R_m}}{P_{R_m}}\right) \qquad (5)$$

PC_i	:	Population coverage parameter for site alternative *i*
$D_{a_i \to R_m}$	:	Distance between the centre of gravity of site alternative *i* and the centre of gravity of region *m*
m	:	Number of assessed regions
P_{R_m}	:	Predicted DP in region *m*

Flexibility (C_3) comprises two indicators: (I_6) *property and land use zoning*, which assesses site alternatives in terms of ownership status and land use; and (I_7) *neighbourhood accessibility*, which includes six sub-indicators (density, green areas, schools, police, hospitals, and fire services of the required areas) that are used to assess the potential of a host area to accommodate the DP and the impacts such an accommodation would have on it.

The fourth criterion, *land use*(C_4), includes the indicator (I_8) *respect for the environment*, which takes into account the effects of site location in terms of changes to the ecosystem. The fifth criterion, *emissions* (C_5) includes the indicator (I_9) *CO_2 emissions*, expressed in terms of the equivalent CO_2 emissions Intergovernmental Panel on Climate Change (IPCC) (1996) associated with all activities required to prepare the site, including transport [44].

4. Case study (earthquake in Tehran)

Relevant data

This study considered four districts of Tehran, the capital of Iran, in the aftermath of a seismic event based on the Mosha fault scenario. The data were derived from a report prepared by the Japan International Cooperation Agency (JICA) [33] and the Centre for Earthquake and Environmental Studies of Tehran (CEST), as shown in Table 1. This report estimated the casualties and damage to buildings in the wake of probabilistic earthquakes based on four different scenarios: the Rey, Mosha and North Tehran fault models, and the floating model [41]. The present research sought to identify sustainable subsets of site alternatives with regard to the results for the Mosha fault model presented by the JICA and CEST based on the proposed approach.

Table 1. Relevant information of the four studied districts

According to the JICA and CEST study (2000), an earthquake with the expected intensity occurring during the day could lead to a DP of more than 610,000 people and almost 18,000 casualties. The estimated DP of the four districts exceeds 160,000 people. This implies that all the required sites should have sufficient capacity to accommodate one-third of the DP, whilst other types of TH could be used for the remaining two-thirds. Additionally, in order to increase the number of alternatives and potential subsets, to make the problem more difficult, it was assumed that some sites are located outside the city centre, close to entry roads, and that half of the DP would be settled there, whilst the other half would be settled in site alternatives located in the city centre. The total required area was nearly 50 hectares, calculated at 20 m^2per person. Although elsewhere the area required per person has been considered to be 30 and even 45 m^2 per person [51, 52], in this study, a required area of almost 20 m^2 per person was obtained, due to land scarcity in Tehran and the possibility of multi-storey THUs. It should be emphasized that the estimation of DP considered in this investigation has been defined based on the aforementioned JICA and CEST study (2000), which considers different scenarios, especially for Tehran. However, it is possible to apply other approaches to estimate DP, see [41, 53-55].

The possible site alternatives meeting the initial requirements were selected based on the defined sustainability requirements. Nineteen site alternatives (S_1-S_{19}) were identified in all, located in the four case study districts and one other nearby district, as shown in Fig. 4. The areas of the chosen sites ranged from 2.3 to 40.0 ha. All of these sites would need to be prepared before use, except S_{17} (a parking lot) and S_{19} (barracks).

Fig. 4. Tehran map (including the case study districts and site alternatives)

5. Analysis

In order to assess the SI of the subsets (with a total area close to the requisite 50 ha) is required to consider value functions. Indicators value functions and boundaries (X_{min} and

X_{max}) were established (Tables 2 and 3) based on data from the literature, international guidelines, Iranian principles, and knowledge generated at experts´ seminars. The resulting value functions had the following shapes: four decreased, including two convex functions (DCx) and two concave ones (DCv), and five increased, including two convex functions (ICx) and three S-shaped ones (IS). More detailed descriptions of the indicator value function assignment have been reported elsewhere, such as [26-27, 36, 37].

Table 2. Coefficients and parameters of each indicator

For some indicators (I_3, I_6, I_7, and I_8) point-assignment systems were applied. Additionally, it should be emphasised that the weights of the sub-indicators were considered to be the same for the *neighbourhood acceptability* indicator (I_7).

Table 3. Coefficients and parameters of each sub-indicator

Weight assignment

The weights were assigned using two approaches: (1) an expert assessment, abbreviated as AHP, as this approach used AHP based on the MIVES concept, and (2) Shannon entropy (SE). The weights (λ_i) (Table 4) were determined by holding meetings and seminars with professors from the Universitat Politècnica de Catalunya (UPC) andUniversitat Internacional de Catalunya (UIC) and experts from the Tehran Disaster Mitigation and Management Organisation. The coefficients of variation of each λ_i did not exceed 10%, excluding outliers, which were eliminated.

Additionally, to verify the adequacy of the model and minimise sources of error during the assignment of weights, the weights were previously estimated by SE using two approaches: (1) considering the indicator weights assigned by the experts (SE/AHP) and (2) not considering the weights proposed by the experts (SE/NW). In this regard, the computational framework is run three times with the same input data, except the weights assigned to indexes by the aforementioned three weighting techniques.

Table 4. Weights assigned to indexes based on expert assessments

Finally, it is possible to assess the SI of each site alternative with each index's value function (V_i) and weight (λ_i) and using equation (2) for each level of the requirements tree (Fig. 3). In this step, the proposed coupled MIVES-Knapsack algorithm must be applied to determine sustainable subsets, all of whose components have total areas close to 50 ha and maximise the SI (equation 1). It should be noted that solutions with total areas of up to 55 ha (10% more than the required 50 ha) were also considered acceptable with a view to finding more possible results for further analysis.

6. Results and discussion

The results obtained from applying the MIVES-Knapsack method and different weighting approaches are shown in Table 5. The three subsets presented in Table 5 were obtained with the three different weighting techniques (AHP, SE/AHP and SE/NW). The optimal alternatives resulting from the model confirm that a wide range of feasible sites was obtained. Consequently, the results should be rigorously analysed to achieve a more suitable subset. Indeed, when there are more alternatives in a subset, such as in the subset obtained with AHP, there is greater potential for higher satisfaction levels in terms of some social requirements compared to other methods, except for I_7, since AHP tends to assign a lower weight to I_7. Additionally, some sites are common to almost all the applied weighting techniques used to confirm the suitability of the alternatives, such as S_2, S_3, and S_4.The maximum SI was obtained for subset C (0.69, SE/NW), which had an SI 32.7% higher than that obtained for subset A (0.52, AHP) and 15% higher than that obtained for subset B (0.60, SE/AHP).

Table 5. Sustainable subsets obtained by the algorithm based on different weight assignments

These results were analysed following two different strategies: (1) consideration of the indicator values (V_i) derived using each weighting technique, and (2) adjustment of the requirement weights (sensitivity analysis). The indicator values (V_i) and SI values of the optimal subsets presented in Table 5 were reassessed using the other two weighting techniques (Table 6 and Fig. 5), e.g. the SI of subset A was also determined with the SE/AHP and SE/NW weighting techniques.

As the results presented in Tables 5 and 6 show, the resulting subsets were consistent with both the model and weighting criteria. For instance, the SI of subset A was 0.52, whilst the SIs of subsets B and C were 0.41 and 0.37, respectively, provided AHP was used, as shown in Fig. 5. The same trend was confirmed for the other subsets and weighting approaches.

Table 6. Consideration of the subsets obtained by other methods

The SIs of the optimal subsets show that subset C had the highest SI (0.69). The SIs of subsets B and A were ranked as the second and third ranges, respectively. Although the SIs of the subsets had been determined, it was necessary to consider each indicator's partial sustainability index ($I_{SI,i} = \lambda_{R,i} \cdot \lambda_{CR,i} \cdot \lambda_{I,i} \cdot V_i$). To this end, Fig. 6 shows the values of I_{SI} for each indicator and sub-indicator based on the three weighting techniques. In the legend of Fig. 6, the first term refers to the weighting technique used and the second term to the subset. AHP

(C) means that the AHP technique (45% Ec., 25% S., and 30%En.) was considered in relation to subset C.

Fig. 5. SI derived from applying the different weighting techniques for the selected subsets

Fig. 6 confirms that when the value functions of subsets were evaluated based on the AHP weights, the AHP values (A, B, and C) for the four indicators of subset A were higher than those of the other subsets, and the three indicators' values were almost the same for all the techniques (I_1, I_5, I_8, and I_9). Subset B had higher values for I_2, whilst the highest value for I_7 was obtained for subset C. These findings were true for all indicator values in the subsets when each of the three techniques was applied.

Fig. 6. Partial sustainability indexes of the indicators considering the criteria and requirement weights assigned by applying each of the three methods to the optimal subsets

Fig. 7 shows the indicator and sub-indicator values (V_i). In this case, it should be noted that no weights were applied. V_i can be understood as the satisfaction index associated with each indicator.

In terms of the *economic requirement*, the results presented in Fig. 7 show that subset A had the highest satisfaction level with regard to the land cost indicator (I_1) and the lowest one with regard to site preparation costs (I_2), since subset A included five more sites than subsets B and C. Subsets B and C were the result of combining site S_3 (the highest in land area and price) with sitesS_2 and S_4 (both with minimum land prices).

This analysis shows that application of the three weighting techniques resulted in two alternatives based on the economic requirement. On the one hand, SE/AHP (subset B) and

SE/NW (subset C) led to a combination of two unique sites with high land prices and the lowest site preparation cost; on the other, AHP (subset A) led to a subset composed of several sites with minimum land prices and higher site preparation costs.

With regard to the *social requirement*, the results presented in Fig. 7 show that the V_i values of indicators I_3 and I_4 were rather independent of the subset configuration and, consequently, of the weighting criteria. Moreover, subset A had the highest value for the indicators I_5 (43% higher than subset B and 150% higher than subset C) and I_6 (null satisfaction for subsets B and C).In contrast, subset A had lower satisfaction levels for I_7. Finally, subset A had the highest satisfaction level with regard to the environmental requirement indicators.

Fig. 7. Value functions of the indicators and sub-indicators without considering the weights assigned by applying each of the three methods to the optimal subsets

The analysis of the results presented in Fig. 7 led to the conclusion that each weighting technique, in addition to defining an optimal subset, also tends to favour a certain requirement. In other words, each selected subset has a more considerable impact on each requirement depending on the preferred technique. For instance, using SE/NW (subset C) results in the subsets with the highest satisfaction values for I_7, since this technique assigns greater weights to the sub-indicators that make up I_7, as shown in Fig. 8. In contrast, subset A has a higher value for I_1 because the AHP technique assigns high weights to the economic requirement and its associated indicators.

Weighting systems could considerably impact the results. Nevertheless, all the subsets obtained have maximum SIs compared to other feasible subsets. In this regard, it is highly recommended that the weights assigned to the indicators by the diverse techniques be assessed. Local experts should be involved in this process to confirm results and eliminate outliers.

As the SE/NW method does not consider stakeholders' concerns, it does not seem suited to the paramount issues of TH. It can thus be concluded that the results of the AHP and SE/AHP techniques are more reliable, as both techniques take expert assessments into consideration. However, in this study the weights determined by expert assessment needed to be modified slightly based on the results obtained, such as the ratio of the weights of I_1 and I_2. Nevertheless, in specific scenarios in which certain requirements are more important and different from the present research, the weights could be updated after following the same method. In general, the results confirm that subset A yielded the highest values for the environmental and economic requirements. According to the indicators' weights (Fig. 8), SE/AHP ranked second after the AHP technique in terms of the reliability of its results. The last option would be the SE/NW system, which gives greater priority to I_7. As SE/NW assigns high weights to I_7, no stakeholder preferences were considered.

Fig. 8. Weights assigned to the indicators and sub-indicators by the three methods

A sensitivity analysis of the AHP and SE/AHP methods considering the weighting distributions for twenty-eight requirements was performed. To this end, the experts established a range of weights from 10% to 80%. This range even included outliers. As shown in Fig. 9, the AHP and SE/AHP techniques led to different selection frequencies for each site. Specifically, four site alternatives (S_4, S_6, S_{17}, S_{19}) were selected more than the others by the AHP and SE/AHP techniques. Furthermore, subset A (S_2, S_4, S_5, S_6, S_{17}, S_{18}, and S_{19})

and B (S_3 and S_4) were selected by the AHP and SE/AHP techniques 23 and 13 times, respectively, out of the twenty-eight results for each technique.

Fig. 9. Frequency of each site (N_i) depending on the weighting technique

S_{17} and S_{19} have minimum site preparation costs due to their pre-disaster uses as a parking lot and barracks, respectively. Based on the minimum land prices of these two sites, S_{17} and S_{19}were expected to be selected as final alternatives. S_4 ranked after S_{17} and S_{19} in terms of minimum land price. S_4 and S_6 could be categorised in a group of sites with high I_2 values, with S_{17} and S_{19} at the top. S_4 and S_6 had higher I_5 values, whilst S_{17} was close to the mid-range sites in terms of this indicator's value. S_4 and S_6 had the second-highest values for I_8, after S_{17} and S_{19}. Additionally, S_4 and S_6 had the highest values for I_9; in this case, S_{17} fell within a group of sites with minimum values for I_9. In general, acceptable satisfaction indexes were obtained for these four sites for almost all indicators. Moreover, all four could generally be assigned to a group of site alternatives with the highest economic and environmental indicators based on the weights identified by the experts.

Based on the analysis of the partial satisfaction indexes (Fig. 6) and the site selection frequency (Fig. 9), it can be concluded that the proposed MIVES-Knapsack approach could be a robust decision-making model for dealing with the configuration of post-disaster housing sites.

Fig. 10 shows the SI trends based on the twenty-eight weighting scenarios. The results reveal that SIs increased as the weights assigned to the economic requirement decreased. This is due to the low satisfaction values of the economic indicators for all alternatives (see Fig. 7). However, it should be emphasised that the higher number of social indicators than of economic indicators (Y) was the reason for this upward trend in the SI. In this regard, it can be deduced from the results that SIs tend to decrease as the weight of the social requirement decreases, regardless of the weighting technique used. In contrast, the lowest SIs were obtained when the highest weight was assigned to the economic requirement. This shows that the SI is directly related to the social weights and inversely related to the economic weights.

It can likewise be observed that the SI trend was not very sensitive to variations in the environmental requirement weight. Finally, the results presented in Fig. 10 show that the SI values derived with both weighting techniques tended to converge as the weight assigned to the economic requirement was reduced. Furthermore, only for the weighting distribution 10% Ec., 10%S., and 80%En. would subset A (AHP) be more sustainable than subset B (SE/AHP).

Fig. 10. Sustainability indexes of the subsets chosen by AHP and SE/AHP based on twenty-eight weighting scenarios

Additionally, as shown in Table A.1, five high ranked alternative sets by AHP are assessed in order to implement a sensitivity analysis on the weights of indicators. Multidisciplinary experts assigned the weights to the indicators based on AHP during several seminars. The five sets are ranked based on highest sustainability indexes, the maximum one is the subset A (S_2, S_4, S_5, S_6, S_{17}, S_{18}, S_{19}), followed by other four subsets (A_2-A_5), respectively. Table A.1 presents sites of the five sets, indicators' and sub-indicators' satisfaction values, sustainability indexes of the five sets. According to Triantaphyllou and Sánchez (1997), sensitivity coefficients of indicators and sub-indicators are determined, as shown in Table A.2. More detailed descriptions of the sensitivity coefficient have been reported elsewhere, such as [69]. Finally, the results in Table A.2 confirm that the most sensitive indicator is I_1 and the least one is I_4.

7. Conclusions

This paper has proposed a new MCDM technique for selecting TH site location based on local requirements. The technique was built based on a synergistic coupling of the MIVES and Knapsack methods. The former makes it possible to assess the sustainability index of each site alternative, minimising the economic and environmental impacts and maximising social aspects with regard to stakeholder satisfaction. The latter allows the model to consider the SIs of the different potential subsets meeting the area requirement. The weights were assessed using different approaches: (1) expert seminars and AHP following the MIVES strategy, and (2) the Shannon entropy method. A sensitivity analysis of the results was also performed.

The proposed model was applied in a case study consisting of an earthquake scenario in Tehran. The results obtained are relevant for decision-makers in this specific case and, in general, confirm that the model is useful and flexible and that it represents the needs of stakeholders involved in DP recovery programmes. Therefore, the model can be said to have promising potential for future applications related to site selection in areas prone to natural disasters. Additionally, the following conclusions can be derived from this study:

- The AHP procedure yielded higher environmental indicator weights than the other two weighting approaches considered.
- In terms of economic aspects, there are two different strategies for selecting site alternatives based on this paper's results: choosing high numbers of small-area sites with low land prices, which increases site preparation costs, or choosing several large-area sites with higher land prices, resulting in lower site preparation costs.
- As expected and reported elsewhere, the analysis of the results confirmed that changes in the weight distribution considerably impacted the resulting subsets.

Therefore, in addition to the weight assignment methods, stakeholder concerns must be taken into account when dealing with TH management to avoid obtaining unrepresentative results. For this reason no further analysis limiting requirements was carried out in this research project.

- A higher sustainability index can be achieved if the chosen subset includes sites that have already been used for other purposes.

This paper covered a specific field of post-disaster TH management; however, there are still aspects of paramount importance to this topic that should be further explored, such as the impact of the number of indicators on the decision and, consequently, the value of the requirements. Indeed, the main limitation of this paper is the uncertainties related to input and output data, especially after natural disaster. Nevertheless, as it has been mentioned in the introduction section, the proposed model has been designed for applying before natural disaster. Additionally, it should be emphasized that the MIVES methodology used in this research project can be enhanced by using the Monte Carlo technique in order to include and deal with the uncertainty issues from a stochastic point of view [30].

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NOMENCLATURE

Smax	:	Maximum satisfaction
Smin	:	Minimum satisfaction
R_k	:	Requirement *k*
C_k	:	Criterion *k*
I_k	:	Indicator *k*
SBI_k	:	Sub-indicator *k*
V	:	Value
SI	:	Sustainability index
DCv	:	Decrease concavely
DCx	:	Decrease convexly
ICx	:	Increase convexly
IS	:	Increase S-shape
DS	:	Decrease S-shape
Xmax	:	Maximum value indicator
Xmin	:	Minimum value indicator
pts.	:	Points
Pop	:	Population
min.	:	Minute(s)
pers.	:	Person(s)
N Hosp.	:	Number of hospital(s)
N Sch.	:	Number of school(s)
N P.S.	:	Number of police station(s)
N F.S.	:	Number of fire station(s)
IRR	:	Iran Rial rates (Iranian currency)
Ec.	:	Economic
S.	:	Social
En.	:	Environmental
SE /AHP	:	Shannon's entropy with considering the weights assigned to the indicators
SE /NW	:	Shannon's entropy without considering the weights assigned to the indicators

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