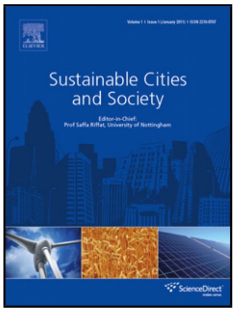

Title: Multi-Criteria Decision-Making Method for Assessing the Sustainability of Post-Disaster Temporary Housing Units Technologies: A Case Study in Bam, 2003

Author: S. M. Amin Hosseini Albert de la Fuente Oriol Pons

PII: S2210-6707(15)30038-X
DOI: http://dx.doi.org/doi:10.1016/j.scs.2015.09.012
Reference: SCS 331

To appear in:

Received date: 2-7-2015
Revised date: 20-9-2015
Accepted date: 21-9-2015

Please cite this article as: Hosseini, S. M. A., de la Fuente, A., and Pons, O.,**Multi-Criteria Decision-Making Method for Assessing the Sustainability of Post-Disaster Temporary Housing Units Technologies: A Case Study in Bam, 2003**, *Sustainable Cities and Society* (2015), http://dx.doi.org/10.1016/j.scs.2015.09.012

Research Highlights

A new sustainability assessment model specifically configured to analyze THUs

This considers the most relevant indicators, based on quick and easy localization

Study case on temporary housing units for post-earthquake disaster in Bam

The local alternative, concrete masonry unit, is the most sustainable one

Multi-Criteria Decision-Making Method for Assessing the Sustainability of Post-Disaster Temporary Housing Units Technologies: A Case Study in Bam, 2003

S. M. Amin Hosseini[a], Albert de la Fuente[a], Oriol Pons[b]

a Department of Construction Engineering, Universitat Politècnica de Catalunya (UPC), Jordi Girona 1-3, 08034, Barcelona, Spain.

b Department of Architectonic Structures I, Universitat Politècnica de Catalunya (UPC), Jordi Girona 1-3, 08034, Barcelona, Spain.

E-mail address of corresponding author: seyed.mohammad.amin.hosseini@estudiant.upc.edu

Abstract

Temporary housing units (THUs) have been used for displaced population (DP) in the aftermath of natural disasters to serve as an alternative residence while the permanent housing process is completed. A THU is often provided as a prefabricated system, which has been criticized due to the economic, environmental, and social aspects of THUs. However, this model has been widely used in previous recovery programs. Additionally, it should be highlighted that the lack of potential of certain areas persuades decision-makers to implement the THUs.° This paper presents a new model for choosing optimized THUs

---

THU	Temporary housing unit	3D	3D sandwich panels	DCv	Decrease concavely
TH	Temporary housing	S_{max}	Maximum satisfaction	DCx	Decrease convexly
DP	Displaced population	S_{min}	Minimum satisfaction	ICx	Increase convexly
HFIR	Housing Foundation of Islamic Republic of Iran	I	Sustainability index	IS	Increase S-shape
AAC	Autoclaved aerated concrete blocks	V_{R_k}	Requirement value	IRR	Iranian Rial (Iranian currency)
CMU	Concrete masonry units	V_{C_k}	Criterion value	pts.	Points
PR	Pressed reeds	V_{I_k}	Indicator value		

based on the sustainability concept. This model supports decision-makers in selecting a more adequate type of THU, to reduce the negative impact of temporary housing (TH) when there is no other possibility.

The Integrated Value Model for Sustainable Assessment (MIVES), a Multi-Criteria Decision Making (MCDM) model that includes the value function concept, is used to evaluate the sustainability value of each THU alternative.

THU technologies that had been suggested for the Bam earthquake recovery program by a semi-public organization have been analysed by this method to achieve two aims: (1) to determine the most sustainable technology to use and (2) to test the designed model.

Keywords: Post-disaster temporary housing, Sustainability, Bam earthquake, MIVES, MCDM, AHP

Introduction

According to Global Estimates 2014, Twenty-two million people worldwide lost their homes to natural disasters in 2013. Additionally, in 2050, the population of areas highly prone to natural disasters is expected to be double that of 2009 for the same area (Lall & Deichmann, 2009). Furthermore the urban population will reach 66% of the world population by 2050 (UN, 2014). Meanwhile, UN-habitat (2014) reported that in developing countries, one third of the urban population lives in slums that are highly vulnerable in terms of temporary housing (TH) provision (Johnson, Lizarralde, & Davidson, 2006).

DP need somewhere to live in secure and sanitary conditions, and to return to normal life as before the disaster while their permanent houses are reconstructed; this is called TH (Collins, Corsellis, & Vitale, 2010; Davis, 1978; United Nations Disaster Relief Organization (UNDRO), 1982). TH has generally been criticized due to the lack of sensibility towards an integrated view of sustainability, especially regarding the THUs.

THUs which need to be constructed after natural disasters are often categorized as a camp (United Nations High Commissioner for Refugees (UNHCR), 1999), grouped in planned camps (Corsellis & Vitale, 2005), organized in a top-down approach (Johnson, 2007a). According to Félix et al. (2013), THUs consist of (1) ready-made units and (2) supply kits. Although a THU is often conceived as a precast system (Johnson, 2009), on-site masonry construction was used in previous TH programs.

The problems of the THU as a commonly used type of TH can be: (1) delays, (2) lack of fit with the culture of the DP, (3) the need for large public expenditures, (4) consumption of resources and investment assigned to permanent buildings, (5) permanent building reconstruction delays, (6) discordant durability of used materials and usage time, (7) site development process requirements, (8) site pollution, (9) infrastructure needs, (10) inflexibility, and (11) top-down approaches (Arslan, 2007; Arslan & Cosgun, 2008; Barakat, 2003; Chandler, 2007; El-Anwar, El-Rayes, & Elnashai, 2009a; Hadafi & Fallahi, 2010; Johnson, Lizarralde, & Davidson, 2006; Johnson, 2007a).

In this sense, most significant research studies and guidelines acknowledge that THUs have discordant characteristics and have focused on solving the aforementioned issues. However, according to El-Anwar, El-Rayes, & Elnashai (2009a) and Yi & Yang (2014), there are few studies that have considered THU optimization and sustainable construction such as: Johnson, 2007a; El-Anwar, El-Rayes, & Elnashai, 2009a, b, c; El-Anwar, 2010,2013; Chen, 2012; Karatas & El-Rayes, 2014. Meanwhile, the use of THUs has been widespread in previous TH, as shown in Table 1.

Despite the weakness of the THU, the use of this TH model illustrates why decision-makers have chosen this model for DP. The factors in THU choice can be: (1) immediacy, (2) high demand, (3) DP pressure on the government, (4) lack of other options, and (5) avoiding the mass exodus of DP (Hadafi & Fallahi, 2010; Quarantelli, 1995). Therefore, for the aforementioned reasons, sometimes there are no suitable TH alternatives (e.g., apartment rental) besides THUs. Although this type of building, with its short life span, has generally been criticized in terms of sustainability, it is possible to determine a more adequate alternative within this category.

The objective of this paper is to present a model for selecting the optimized THU by considering local characteristics and sustainability for regions using exclusively THUs, either because it is the only choice or because THUs are part of the region’s TH program. The model is capable of identifying the optimized THU based on the satisfaction function of the involved stakeholders.

To that end, the Integrated Value Model for Sustainable Assessment (MIVES) from the Spain has been used in this paper. The MIVES model, which is a multi-criteria decision-making method which incorporates the concept of a value function (Alarcon et al., 2011), assesses the main sustainability requirements of different alternatives which answer the same housing requirements. MIVES can also be calibrated to a certain time period and applied for different areas with varied local living standards and characteristics by adapting the indicators and weights defined in the requirements tree. MIVES has been used to evaluate sustainability and to make decisions in the fields of (1) university professors (Viñolas et al., 2009), (2) infrastructure (Ormazabal, Viñolas, & Aguado, 2008), (3) industrial buildings (Aguado et al., 2012; del Caño, 2012; Fuente et al., 2015; Lombera & Rojo, 2010; Pons & Aguado, 2012; Pons & Fuente, 2013), and (4) TH.

As a case study, four technologies suggested for THUs after the Bam earthquake are assessed. This paper aims to reconsider these technologies to determine suitable options and to evaluate the sustainability of each technology. This study also assesses the THUs for a total usage period of 50 years: 5 years of temporary use and the rest as permanent use in the same location. This assumption has been made based on THUs of Bam, especially those which have been erected in private properties.

Methodology

The decision-making process proposed in this paper was organized in three choice phases: (1) initial, (2) middle, and (3) final choice, as shown in Fig. 1. In the *initial choice phase*, decision-makers consider the local potential based on TH features. In the *middle choice phase*, a requirements tree comprises criteria and indicators. The tree is designed with three varying levels (economic, environmental, and social) based on local characteristics (geographic and stakeholder requirements). In the *final choice phase*, a suitable decision-making model is used to determine sustainable THUs. Finally, the weights of the indexes have been determined by a group of experts using the Analytical Hierarchy Process (AHP) (Saaty, 1990).

Certain indexes, such as material availability, plan, storey, and second life of THUs can have considerable effects on the design tree and weights. Meanwhile, in this paper, only the second and third phases of the method have been applied in the case study to determine a suitable alternative, as shown in Fig. 1. Eight technologies had already been suggested by decision-makers as initial alternatives after the Bam earthquake, based on local potential.

Technologies Suggested for Constructing THUs in Bam

An earthquake that was estimated at Mw=6.6 by the USGS (United States Geological Survey) (Kuwata, Takada, & Bastami, 2005) occurred on September 26th, 2003, in Bam, which is located in southeastern Iran, approximately 1000 km southeast of Tehran (Anafpour, 2008). The population of Bam was approximately 100,000 before the disaster (Ahmadizadeh & Shakib, 2004). In the aftermath of the earthquake, 80% of buildings were completely destroyed (Havaii & Hosseini, 2004), approximately 30% of Bam´s population was killed (Kuwata, Takada, & Bastami, 2005), and approximately 75,000 people were left homeless (Khazai, M.EERI, & Hausler, 2005).

In general, the Bam THU provision was based on two approaches: (1) THU provision in public camps and (2) THU provision on private properties. A total of 35,905 THUs were built: 26,900 units on private properties and 9,005 in 23 camps (Ghafory-Ashtiany & Hosseini, 2008; Rafieian & Asgary, 2013). THUs that were provided at camp sites had considerable problems. Khatam (2006) states the TH cost reached $60 million, while 10-20 percent of THUs have never been occupied.

In April 2004, most of the DP received THUs with an area of 18–20 m^2 (Fallahi, 2007; Havaii & Hosseini, 2004) that were built using different technologies by several contractors about seven months after the earthquake. The Foundation of Islamic Republic of Iran

(HFIR) and the Minstry of Defence were selected for the responsibility of THU provision by the Iranian government. These organizations constructed THUs directly or by hiring contractors (Khazai, M.EERI, & Hausler, 2005).

Therefore, the HFIR delegated responsibility of THU design and construction to one of its subsets, called the Bonyadbeton Iran Co., and the experts at this organization designed eight alternatives based on four wall technologies and two roofing technologies, as shown in Table 2. Additionally, the designed THUs were considered in eighteen, twenty, and thirty-six square meter types with different plans and light steel structures. The eighteen and twenty m^2 plans are shown in Fig. 2.

The wall technologies were: (1) *autoclaved aerated concrete blocks* (AAC Block), which is called “Siporex” in Iran; (2) cement block which is a concrete masonary unit (CMU); (3) *pressed reeds panel*, which is a prefabricated panel consisting of pressed reeds and joined by galvanized wire and framed by wooden or metal components, called “Cantex panel” in Iran. The two sides of a Cantex panel can be covered with different plasters, such as concrete and gypsum plaster (What Is Cantex?, 2013); and (4) *3D sandwich panel*, which is a prefabricated lightweight structural panel consisting of a polystyrene core sandwiched between two welded steel wires meshes (Rezaifar et al., 2008), as shown in Fig. 3. Each side of the 3D panel is covered in sprayed concrete. Furtheremore, two materials were suggested for roofing: (1) *sandwich panel* roofing, which includes galvanized iron sheets on theoutside, polyurethane in the core, and foil cover for the inside, for a roof thickness two centimeters; and (2) *Corrugated galvanized iron* with four centimeters of polystyrene.

Elements of the Sustainability Assessment Method Proposed for THUs

Requirements tree

The THU indexes have been defined based on Sustainability and Performance Assessment and Benchmarking of Buildings (Häkkinen, T. et al., 2012) and collected TH data, including TH characteristics and TH stakeholders’ needs. The TH data have been collected through primary and secondary sources in previous TH programs, such as Iran, Turkey, USA, Japan, and especially the Bam recovery process in 2003. The general indexes involved in TH are organized into three main groups in Table 3, based on a global model according to (Anderson & UNHCR, 1994; Berardi, 2013; Davis & Lambert, 2002; Johnson, 2009; Karatas & El-Rayes, 2014; Krank, Wallbaum, & Gret-Regamey, 2010; McConnan, 1998; UNHCR, 1999; UNISDR, 2010).

Therefore, as different locations have different standards and requirements (Davis, 1978; Johnson, 2007a), the indicators and weights can be different based on the local characteristics. Thus, based on the local characteristics and seminars results, the specific indicators for this case study have been collected from the general indexes of Table 3 and organized into three main requirements, as shown in Fig. 4.

The *economic requiremen*t (R_1) assesses the investment demanded of each proposed TH model over its entire life cycle. The *social requirement* (R_2) takes into account the impact of each TH alternative on DP as users of temporary houses and third parties who are involved. The *environmental requirement* (R_3) assesses the environmental effects of TH alternatives on the entire life cycle.

Economic indicators

I_1. The *building cost* indicator evaluates the construction cost of the building, including mobilization, site preparation, material, transportation, and installation for each unit.

I_2. The *maintenance cost* indicator considers the alternatives when these are used in the same location with the same function (THUs for the next natural disaster) or other function (permanent housing, low-income housing, etc.) based on this paper scenario and technology possibilities. The service lifespans of TH materials have been assigned based on The Whitestone facility maintenance and repair cost reference 2012–2013 (Lufkin, et al., 2012).

Social indicators

I_3. The *construction time* indicator assesses the alternatives in terms of normal time for the housing provision process, from the very raw materials up to delivery of the house.

I_4. The *risk resistance* indicator evaluates the strength of the alternatives against a natural or man-made disaster, such as a fire, earthquake, typhoon, tsunami, etc. Thus, this indicator has been assessed using two sub-indicators: S_1. *natural disaster risk* is evaluated by an assigned point system. As the steel structure of the case study alternatives was designed based on Iranian National Building Regulations, the steel frame generally has a low percentage of critical damping in an earthquake response (Dowrick, 2009), and the ductility of the structure has not been considered. Therefore, the ductility of partition materials is assessed to determine the value of this sub-indicator. S_2. *Fire resistance* assesses the durability of the exterior wall material subject to fire, based on comparing minimum international fire resistance times as shown in Table 4.

I_5. The *comfort indicator* considers the rate of comfortable conditions in terms of indoor quality for THU users based on international code, as shown in Table 4. This indicator has two sub-indicators: S_3. *Acoustics range* considers the rate of air-borne soundproofing of each alternative by sound transmission class (STC). STC is calculated based on ASTM E413 and ISO/R717 (Long, 2005). However, Long (2005) mentions the minmum STC rating of dwelling walls is 50 dB. In this paper, the minimum STC rating has been set at 45 dB based on other standards, as shown in Table 4, and the high quality rating has been set at 65 dB according to Long. S_4. *thermal resistance* assesses the amount of heat and mass transfer from exterior walls (Feng, 2004), which must resist passing the heat into and out of the building (Allen & Iano, 2013). This sub-indicator controls the thermal comfort of alternatives, which is one of the main reasons to use spaces sheltered from the weather (Häkkinen, T. et al., 2012).

I_6. The *compatibility* indicator evaluates the adaptability of THU characteristics to the local culture. This indicator includes three sub-indicators: S_5. *cultural acceptance*, which considers whether technologies are consistent with DP culture, indigenous material, and pre-disaster local housing, and can be a reason for THU rejection (Marcillia & Ohno, 2012; UNDRO, 1982). Therefore, the alternatives are evaluated based on similarity of the technologies to common pre-disaster local housing by an assigned point system. S_6. *skilled labour* index considers the adaptability of technologies with local labour proficiency. THU technologies that are provided by highly skilled labour require training, professional equipment, etc. Consequently, these technologies cause some problems, such as: (a) insufficient THU quality, (b) minimum DP participation, (c) low level of maintenance, (d) unemployed local labour, (e) migration of non-local labour to affected areas and vice versa, (f) construction delays, and (g) an increase in required expenditures (Abulnour, 2014; Kennedy et Al., 2008; Ophiyandri et al., 2013; Sadiqi, Coffey, & Trigunarsyah, 2012; Transitional Shelter guidelines, 2012). Therefore, a technology that requires a minimum skill level is the more sufficient technology (Wallbaum, Ostermeyer, Salzer, & Escamilla, 2012). S_7. *Flexibility* evaluates the modifiability of each technology by users during the construction process and usage phase. THUs are usually provided based on a top-down approach, with minimum stakeholder participation as a weakness of the process (Davidson, Lizarralde, & Johnson, 2008). Therefore, TH projects can be failures because of THU abandonment (Davidson et al., 2007) or lack of resident responsibility during the maintenance phase (Arslan & Unlu, 2006). In other to objectively measure I_6 and its sub-indicators, point systems have been used.

Environmental indicators

Buildings cause resource consumption and gas emissions during their lifespans, including the construction, usage, and demolitions phases (Dakwale, Ralegaonkar, & Mandavgane, 2011; Miller, Doh, Panuwatwanich, & Oers, 2015; Nkwetta & Haghighat, 2014; Pons & Wadel, 2011). Thus, four indicators should be designed to assess the TH impact on the environment based on Life-Cycle Assessment (LCA), as stated in ISO 14040. The life-cycle assessment of the building industry can be arranged in four phases: (1) manufacturing (building material production, transportation); (2) construction (activities, transportation, and water consumption); (3) use (water and energy consumption, such as electricity or gas);

and (4) demolition (Bribia, Uso, & Scarpellini, 2009; Mosteiro-Romero, et al., 2014; Pacheco-Torres et al., 2014).

I_7. The *energy consumption* indicator evaluates the amount of energy consumed based on LCA in three of the four phases: manufacturing, construction, and demolition. Inventory of Carbon & Energy (ICE) (Hammond & Jones, 2011) has been used to evaluate energy consumption.

Energy consumed to provide comfortable conditions during the operations phase has not been evaluated in the energy consumption indicator. The thermal resistance sub-indicator embraces both comfortable conditions and energy consumption. Based on the MIVES concept, indicators should be independent from each other and considered once; thus, this indicator has not been assessed again. Additionally, as alternatives conditions were almost same during the operation phase in terms of other environmental indicators, these indicators have not considered for this phase.

I_8. The *water consumption* indicator assesses the amount of water usage in the three mentioned phases. The amount of water consumption has been determined based on Wuppertal institute for climate, environment and energy (2011).

I_9. The *waste material* indicators evaluate the amount of waste material remaining from the manufacturing, construction, and demolition phases. This paper considers the waste material range of each technology during the construction phase.

I_{10}. The *CO_2 emissions* indicator measures the amount of CO_2 emissions for each alternative in the three aforementioned phases, according to a Life-Cycle Assessment (LCA). To evaluate CO_2 emissions, Inventory of Carbon & Energy (ICE) (Hammond & Jones, 2011) has been used because this database raises the possibility of considering used materials individually.

5. Analysis

This paper aims to reassess the four alternatives shown in Fig. 3 to determine the most sustainable alternative and to evaluate the sustainablity of technologies using a newly designed sustainability model based on MIVES, with a simplified Life-Cycle Assessment (LCA), local standards, and local needs, by considering all indexes and the entire life cycle of THUs. In this paper, four alternatives with corrogated galvanized iron roofing (AAC-C, CMU-C, PR-C, and 3D-C) have been assessed. The two roof materials and costs are almost equal.

To evaluate the sustainability values of different technologies in this case study based on defined indexes, one square meter of these building designs is considered. The common materials have not considered by this model. The same construction materials for all alternatives excluding service, kitchen, electrical, and mechanical materials are summarized in Table 5. Furthermore, the technologies' materials and their characteristics are individually organized in Table 6 and as assembled in Table 7.

In this stage, the parameters necessary for evaluating each indicator are assigned. According to Alarcon et al. (2011), in the next step, the tendency of the value function (increase or decrease) is determined, and then the points that produce minimum and maximum satisfaction (S_{min} and S_{max}) are assigned. Finally, the shape of the value function (concave, convex, linear, S-shaped) and the mathematical expression of the value function are determined.

According to Alarcon et al. (2011), when satisfaction increases rapidly or decreases slightly, a *concave-shaped* function is the most suitable. The *convex* function is used when the satisfaction tendency is contrary to the concave curve case. If satisfaction increases/decreases steadily, a *linear* function is presented. An *S-shaped* function is used when the satisfaction tendency contains a combination of concave and convex functions, as shown in Fig. 5.

The parameters, tendency and shape of the value function for each indicator are determined from international guidelines, scientific literature, Iranian National Building Regulations, and the background of experts, including professors and HFIR engineers and experts that participated in the seminars, as shown in Table 8. In the next step, the value function is obtained based upon the general exponential in MIVES Eq. (1).

$$V_i = 1 - e^{\left(-k_i \cdot \left(\frac{\left|X_{ind} - X_{min}\right|}{C_i}\right)^{P_i}\right)} \qquad (1)$$

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

X_{ind} : The considered indicator abscissa which generates a value V_i

P_i : A shape factor that determines if the curve is concave or convex; or is linear or shaped as a ‘‘S’’

C_i : Factor that establishes, in curves with Pi > 1, abscissa's value for the inflexion point.

K_i : Factor that defines the response value to C_i

B : The factor that prevents the function from getting out of the range (0.00, 1.00), is obtained by Eq. (2).

The sets of indicator values ($V_i(x_i)$) that are between 0 and 1, according to the satisfaction range, is generated by Eq. (1). [1]

$$B = 1 - e^{\left(k_i \cdot \left(\left|\frac{X_{max} - X_{min}}{C_i}\right|\right)^{P_i}\right)} \Big]^{-1} \quad (2)$$

The indicators tendencies have been determined based on seminars results and cases study data, for instance to evaluate the sustainability value of the building cost indicator (I_1), X_{min} = 600,000 IRR /m^2; this price had been suggested by the HFIR and accepted by the local government as a base price for each square meter of THUs. X_{max} = 1,350,000 IRR/m^2 based on the cost of other THU types (Khazai, M.EERI, & Hausler, 2005). Additionally, satisfaction decreases rapidly when the building cost increases, a decreasing, convex (DCx) curve is assigned for the tendency of this indicator value function, as shown in Fig. 6.

Regarding the shape of the value functions assigned to the indicators, six decrease in a convex manner (DCx) and four increase, of which two are S-shape (IS) and two increase in a convex manner (ICx). Furthermore, the X_{min} and X_{max} of each indicator are defined, as shown in table 8.

Additionally, some indicators comprise sub-indicators, such as I_4, I_5, and I_6. The defined process for indicators is applied to sub-indicators as well, so the demanded parameters and shape of the value function are assigned to each of the sub-indicators as shown in Table 9. The sub-indicator functions also have the following shapes: seven increase, of which four are S-shape (IS) and three increase in a convex manner (ICx).

After the assessment of the sustainability value of the indicators for each alternative technology, the formula that is presented in Eq. (3) should be applied to each tree level. In this equation, the indicator value ($V_i(x_i)$) has previously been determined and the weights (λ_i) are assigned to determine the sustainability value of each branch. For the multi-criteria case, the additive formula corresponding to Eq. (3) is applied to determine the sustainability value of each technology.

$$V = \sum \lambda_i \cdot V_i(x_i) \quad (3)$$

$V_{i\square}(x_i)$: The value function of each indicator and each criterion

$\lambda_{i\square}$: The weight of considered indicator or criterion.

Therefore, based on previous studies and the knowledge of the professors and HFIR experts involved in the seminars, the weights for requirements, criteria, and indicators were assigned using the Analytical Hierarchy Process (AHP), as shown in Table 10. Finally, Eq. (3) is applied for each level of the tree when the value function of each index $[(V]_{x_k})$ and its weight (λ_k) had been determined.

6. Results and Discussion

The results from this evaluation are a sustainability index (I), requirements values (V_{Rk}), criteria values (V_{Ck}), and indicators values (V_{Ik}) for each alternative shown in Table 11. This sustainability index (I) quantifies the four technologies from more to less sustainable: CMU, PR, AAC and 3D, with indexes of 0.53, 0.53, 0.50 and 0.36, respectively. The results show that the case study alternatives mostly fell in the middle of the sustainability index range. As permanent housing standards have been used to evaluate indicator values, especially in terms of social aspects, the range of the obtained sustainability indexes is not large. However, if the quality of THUs is equal to permanent housing, it is very difficult to motivate DP to move to their new permanent housing. Thus, the difference between temporary and permanent usage should be considered.

The specific sustainability indexes and requirement values of the four technologies are shown in Fig. 7. This consideration shows that each technology has strengths and weaknesses, while the CMU and PR technologies obtained higher sustainability index values. In general, the AAC and CMU technologies achieved the highest social requirement value (0.39); meanwhile, the AAC and PR technologies obtained the highest economic requirement (0.76) and environmental requirement (0.79), respectively.

In terms of the economic requirement, the AAC technology has obtained the highest value among the alternatives, as the construction cost of this technology was the lowest according to the HFIR at that time, as shown in Fig. 7. The economic values of THUs are closely related to the economic power of the affected area.

In terms of social requirements, ACC, CMU, and 3D technologies are almost the same, while the PR technology obtained the lowest social requirement value. The model results show that the alternatives must be enhanced for long-term use in terms of social aspects; however, these alternatives are generally acceptable for use in emergencies as a THU, except for PR. Because of the low fire resistance rating of PR technology, this technology must be enhanced with a longer fire resistance time to be reconsidered.

The AAC and CMU technologies have minimum construction time indicator values, and these technologies obtained maximum customization criterion values, especially for CMU. These two technologies also have maximum fire rating.

3D has a maximum construction time indicator and natural disaster resistance sub-indicator. Moreover, this technology is acceptable in terms of fire rating, thermal resistance, and STC rating; however, this technology obtains a low social requirement satisfaction value compared to AAC and CMU. Because 3D technology was unfamiliar for the DP of Bam, this technology was refused and could not achieve a high social value. Meanwhile, AAC and CMU have high compatibility indicator values, and PR has a lower value.

In terms of environmental requirements, the values of the four technologies are, from greatest to least, PR, CMU, 3D and AAC; with indexes 0.79, 0.49, 0.46 and 0.19, respectively. PR has the highest environmental requirement value; this technology obtained the highest values of any alternative in all indicators related to the environment, as shown in Fig. 8. In this case, PR has the highest energy consumption value, and AAC has the lowest. The energy consumption values of CMU and 3D technologies are located between those of PR and AAC, from high to low, respectively.

CMU consumes more water than other technologies, although the amount of water consumed is negligible compared to the operation phase; thus, a low weight of 18% has been assigned for the *water consumption* indicator.

CMU and AAC have lower values for waste material than the other technologies because CMU and AAC are masonry technologies. According to Table 11, the waste material values of the alternatives are lower than the middle value range, 0.50. Furthermore, CO_2 emissions values for the four technologies are ranked, from most to least, PR, 3D, CMU, and AAC, with indexes of 0.9, 0.52, 0.51 and 0.11, respectively.

In the end, the most sustainable technology(s) has been determined using economic, social, and environment requirement weights of 45%, 25%, and 30%, respectively, as determined by experts. Consequently, CMU and PR technologies obtained the highest sustainability index and AAC comes after the first two technologies. Beyond a determination of the sustainability indexes of alternatives, this study has presented a model that has the ability to specify strengths and weaknesses of alternatives. Meanwhile, this decision-making model is capable of considering alternatives in various scenarios using different requirement weights to obviate deficiencies and increase the acceptability range of THUs.

Therefore, each technology has been considered with different requirement weights to obtain suitable alternatives in diverse conditions and situations, with the suitable requirement weights assigned by experts. Sixteen different scenarios have been considered to determine sustainability index trends of the four technologies when the requirement ratios would be different, as shown in Fig. 9. The highlighted point on the horizontal axis (economic 45%, social 25%, and environmental 30%) shows the sustainability indexes of technologies based on suitable weights chosen by experts. If the environmental weight increases compared to the social weight, such as the first point on the horizontal axis in Fig. 9 (economic 47%, social 18%, and environmental 35%), PR becomes a more sustainable technology. If the social requirement weight increases, CMU and AAC will be suitable alternatives, although the social and environmental requirement weights can qualify either CMU or ACC as a final result. Therefore, if the quality life of DP were the first priority for decision-makers, these two technologies could be suitable alternatives. However, CMU obtains a high sustainability value in this condition, several times more than that of ACC and the other technologies.

The sustainability indexes for 3D technology did not change drastically when considering different requirement weights. As this technology was more expensive, unfamiliar to DP, and consumed high energy compared to CMU and PR, 3D cannot obtain a high sustainability index. Additionally, the trend of the 3D sustainability index will approach other technology points if the economic requirement weight decreases drastically.

In the end, it should be mentioned that, according to the results of this study, CMU obtained the highest sustainability index. However, this technology has been an unsuitable alternative for THUs at first glance because of its weaknesses, such as construction delivery time. To choose a suitable THU, all factors, including essential and lower-priority factors, must be considered.

7. Conclusions

This research paper presented a new sustainability assessment model that has been specifically configured to analyse THU alternatives. This model enables decision-makers to determine more sustainable THUs after the initial choice phase is complete and acceptable or available alternatives have been chosen. This model is based on the MIVES methodology, which has proven to be a suitable strategy for conducting multi-criteria decision processes for an integral sustainability analysis of each alternative. This methodology can be used for different locations with diverse characteristics without being limited by the present conjuncture. Therefore, this model is an ideal tool for choosing

THUs, because it embraces the essential aspects of THU provision, such as quick and easy localization, the ability to address THU issues consisting of various criteria with different priorities, and using a value function system that is a suitable approach to the particularities of THU indicators.

For the application example, a total of four different THUs from the Bam earthquake in 2003 have been assessed to test the designed model and analyse the THUs used. In this sense, CMU and PR have the highest sustainability indexes, though CMU has a greater impact on the environment than does PR. Nevertheless, CMU technology has been chosen as the more sustainable of the technologies, because this technology obtained higher sustainability indexes with regard to different requirement weights, as shown in Fig. 9. Additionally, the local alternative can be an appropriate solution based on the results of this study; however, decision-makers can improve the sustainability index of this alternative by recognizing low indicator values and modifying them.

However, this model has only been applied to determine qualities of the four THU alternatives used in Bam. This model can be used to determine the most sustainable alternative for any type of post-disaster TH. To this end, some indicators and weights should be adjusted to the new location’s characteristics and requirements. Furthermore, this paper provides this customizable model as a specific approach to dealing with TH for future research.

Acknowledgements

The authors want to acknowledge the kindly support offered by both the professors Antonio Aguado and Sergio Cavalaro from the Construction Engineering Department of the Universitat Politècnica de Catalunya. In addition, the authors would like to thank group of engineers and experts from the Housing Foundation of Islamic Republic of Iran (HFIR), especially Majid Keshavarz Mehr and Mohammad Alizamani, the reconstruction experts of the HFIR, who supported this paper for collecting and improving data.

References

Abulnour, A. H. (2014). The post-disaster temporary dwelling: Fundamentals of provision, design and construction. *HBRC Journal, 10*(1), 10–24. doi:10.1016/j.hbrcj.2013.06.001

Aguado, A., Caño, A. d., Cruz, M. P., Gómez, D., & Josa, A. (2012). Sustainability Assessment of Concrete Structures within the Spanish Structural Concrete Code. *CONSTRUCTION ENGINEERING AND MANAGEMENT, 138*(2), 268–276. doi:10.1061/(ASCE)CO.1943-7862.0000419

Ahmadizadeh, M., & Shakib, H. (2004). On the December 26, 2003, southeastern Iran earthquake in Bam region. *Engineering Structures, 26*(8), 1055–1070. doi:10.1016/j.engstruct.2004.03.006

Alarcon, B., Aguado, A., Manga, R., & Josa, A. (2011). A Value Function for Assessing Sustainability: Application to Industrial Buildings. *Sustainability, 3*(1), 35-50. doi:10.3390/su3010035

Allen, E., & Iano, J. (2013). *Fundamentals of building construction: materials and methods.* John Wiley & Sons.

Anafpour, A. R. (2008). Bam earthquake, Iran: Lessons on the seismic behaviour of building structures. *14th World Conference on Earthquake Engineering.* Beijing, China.

Anderson, M. B., & Office of the United Nations High Commissioner for Refugees. (1994). *People-Oriented Planning at Work: Using POP to Improve UNHCR Programming.* UNHCR.

Arslan, H. (2007). Re-design, re-use and recycle of temporary houses. *Building and Environment, 42*, 400–406. doi:10.1016/j.buildenv.2005.07.032

Arslan, H., & Cosgun, N. (2008). Reuse and recycle potentials of the temporary houses after occupancy:Example of Duzce, Turkey. *Building and Environment, 43,* 702–709. doi:10.1016/j.buildenv.2007.01.051

Arslan, H., & Unlu, A. (2006). The evaluation of community participation in housing reconstruction projects after Düzce earthquake. *In Proceeding. International Conference and Student Competition on Post-disaster Reconstruction" Meeting stakeholder interests"*, (pp. 17-19). Florence. Italy.

Barakat, S. (2003). Housing reconstruction after conflict and disaster. *Humanitarian Policy Group, Network Papers, 43,* 1-40.

Berardi, U. (2013). Clarifying the new interpretations of the concept of sustainable building. *Sustainable Cities and Society, 8*, 72–78. doi:10.1016/j.scs.2013.01.008

Bribia, I. Z., Uso, A. A., & Scarpellini, S. (2009). Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. *Building and Environment, 44*(12), 2510–2520. doi:10.1016/j.buildenv.2009.05.001

Building Regulations. (2010). *Approved Document E - Resistance to the passage of sound.*

Cavanaugh, W. J., & Wilkes, J. A. (1999). *Architectural Acoustics: Principles and Practice.* John Wiley & Sons.

Chandler, P. J. (2007). *Environmental factors influencing the sitting of temporary housing.* Master thesis, Louisiana State University.

Charleson, A. (2008). *Seismic design for architects: outwitting the quake.* Taylor & Francis.

Chen, L. (2012). *A Web-based System for Optimizing Post Disaster Temporary Housing Allocation.* Master Thesis, University of Washington.

Collins, S., Corsellis, T., & Vitale, A. (2010). *Transitional shelter: understanding shelter from the emergency through reconstruction and beyond.* ALNAP.

Corsellis, T., & Vitale, A. (2005). *transitional settlement displaced populations.* Oxfam.

Corsellis, T., & Vitale, A. (2008). *Transitional settlement and reconstruction after natural disaster*. Geneva: United Nations (UN).

Cuadrado, J., Zubizarreta, M., Pelaz, B., & Marcos, I. (2015). Methodology to assess the environmental sustainability of timber structures. *Construction and Building Materials*, *86*, 149-158. doi:10.1016/j.conbuildmat.2015.03.109

Dakwale, V. A., Ralegaonkar, R. V., & Mandavgane, S. (2011). Improving environmental performance of building through increased energy efficiency: A review. *Sustainable Cities and Society, 1*, 211– 218. doi:10.1016/j.scs.2011.07.007

Davidson, C. H., Johnson, C., Lizarralde, G., Dikmen, N., & Sliwinski, A. (2007). Truths and myths about community participation in post-disaster housing projects. *Habitat International*, *31*(1), 100–115. doi:10.1016/j.habitatint.2006.08.003

Davidson, C., Lizarralde, G., & Johnson, C. (2008). Myths and realities of prefabrication for post-disaster reconstruction. *IRec (Information and Research for Reconstruction).*

Davis, I. (1978). *Shelter after disaster.* Oxford: Oxford Polytechnic Press.

Davis, J., & Lambert, R. (2002). *Engineering in Emergencies - a practical guide for relief workers* (2nd ed.). ITDG.

de la Fuente, A., Armengou, J., Pons, O., & Aguado, A. (2015). New Precast Concrete Tower System For Wind – Turbine Support And Tool To Assess Its Sustainability Index. *Civil Engineering and Management*. doi:10.3846/13923730.2015.1023347

del Caño A., de la Cruz M. P., Cartelle J. J., & Lara M. (2015). Conceptual Framework for an Integrated Method to Optimize Sustainability of Engineering Systems. *Energy and Power Engineering, 9,* 608-615. doi:10. 17265/1934-8975/2015.07.002

del Caño A., Gómez D. (2012). Uncertainty analysis in the sustainable design of concrete structures: A probabilistic method. *Construction and Building Materials, 37*, 865–873. doi:10.1016/j.conbuildmat.2012.04.020

Díaz, C., Jiménez, M., Navacerrada, M. A., & Pedrero, A. (2012). Acoustic properties of reed panels. *Materiales de Construcción, 62*(305), 55-66. doi:10.3989/mc.2010.60510

Dowrick, D. J. (2009). *Earthquake resistant design and risk reduction.* John Wiley & Sons.

DuPree, R. B. (1980). *Catalog of STC and IIC ratings for wall and floor/ceiling assemblies.* Calif. Dept. of Health Services. Office of Noise Control.

EERI Special Earthquake Report. (2011). *Learning from Earthquakes The March 11, 2011, Great East Japan (Tohoku) Earthquake and Tsunami: Societal Dimensions.*

El-Anwar, O. (2010). Optimizing Alternative Housing Projects in the Aftermath of Natural Disasters. *In Construction Research Congress 2010: Innovation for Reshaping Construction Practice,* (pp. 440-448). ASCE Publications. doi: 10.1061/41109(373)44

El-Anwar, O. (2013). Maximising the net social benefit of the construction of post-disaster alternative housing projects. *Disasters, 37(3), 489-515.* doi: 10.1111/disa.12000

El-Anwar, O., El-Rayes, K., & Elnashai, A. (2009a). Optimizing Large-Scale Temporary Housing Arrangements after Natural Disasters. *Computing in Civil Engineering, 23*(2), 110-118. doi:10.1061/(ASCE)0887-3801(2009)23:2(110)

El-Anwar, O., El-Rayes, K., & Elnashai, A. (2009b). An automated system for optimizing post-disaster temporary housing allocation. *Automation in Construction,* 18(7), 983–993. HYPERLINK "http://dx.doi.org/10.1016/j.autcon.2009.05.003" \t "doilink" doi:10.1016/j.autcon.2009.05.003

El-Anwar, O., El-Rayes, K., & Elnashai, A. (2009c). Maximizing the sustainability of integrated housing recovery efforts. *Construction Engineering and Management,* 136(7),. 794-802. doi: HYPERLINK "http://dx.doi.org/10.1061/%28ASCE%29CO.1943-7862.0000185" 10.1061/(ASCE)CO.1943-7862.0000185

Erdik, M., Kamer, Y., Demircioglu, M., & Sesetyan, K. (2012). 23 October 2011 Van (Turkey) earthquake. *Nat Hazards (2012), 64*(1), 651–665. doi:10.1007/s11069-012-0263-9

Fallahi, A. (2007). Lessons learned from the housing reconstruction following the Bam earthquake in Iran. *The Australian Journal of Emergency Management, 22*(1).

Fayazi, M., & Lizarralde, G. (2013). The Role of Low-Cost Housing in The Path From Vulnerability to Resilience. *Archnet-IJAR, International Journal of Architectural Research, 7*(3).

Félix, D., Branco, J. M., & Feio, A. (2013). Temporary housing after disasters: A state of the art survey. *Habitat International*, 136-141. doi:10.1016/j.habitatint.2013.03.006

Feng, Y. (2004). Thermal design standards for energy efficiency of residential buildings in hot summer/cold winter zones. *Energy and Buildings, 36*, 1309–1312. doi:10.1016/j.enbuild.2003.08.003

Garg, N., Sharma, O., & Maji, S. (2011). Design considerations of building elements for traffic and aircraft noise abatement. *Indian Journal of Pure & Applied Physics, 49*(7), 437-450.

Ghafory-Ashtiany, M., & Hosseini, M. (2008). Post-Bam earthquake: recovery and reconstruction. *Nat Hazards, 44*(2), 229–241. doi:10.1007/s11069-007-9108-3

Giovinazzi, S., Stevenson, J. R., Mason, A., & Mitchell, J. (2012). Assessing temporary housing needs and issues following Christchurch Earthquakes, New Zealand. *15th World Conference on Earthquake Engineering (15 WCEE).* Lisbon.

Hadafi, F., & Fallahi, A. (2010). Temporary Housing Respond to Disasters in Developing Countries- Case Study: Iran-Ardabil and Lorestan Province Earthquakes. *World Academy of Science, Engineering and Technology, 4*(6), 1219-1225.

Häkkinen, T. et al. (2012). *Sustainability and Performance Assessment and Benchmarking of Buildings.* Espoo.

Hammond, G., & Jones, C. (2011). *Inventory of Carbon & Energy (ICE).* Sustainable Energy Research Team (SERT), Mechanical Engineering. University of Bath.

Harris D. J. (1999). A quantitative approach to the assessment of the environmental impact of building materials. *Building and Environment*, 34(6), 751-758. doi: HYPERLINK "http://dx.doi.org/10.1016/S0360-1323%2898%2900058-4" \t "doilink" 10.1016/S0360-1323(98)00058-4

Havaii, M. H., & Hosseini, M. (2004). Bam earthquake from emergency response to reconstruction. *Seismology and Earthquake Engineering, 5*(4), 229-237.

HFIR (Housing Foundation of Islamic Republic of Iran). (2013). *Documentation of Bam earthquake reconstruction.* [In Persian]

HFIR (Housing Foundation of Islamic Republic of Iran). (2012). *Iran-Azarbaijan Sharghi Province Earthquake.*

IBC. (2009). nternational Building Code. International Code Council, Inc.

INBC part 18. (2009). *Iranian National Building Code part18.* Ministry of Housing and Urbanism IRI. [In Persian]

INBC part 19. (2011). *Iranian National Building Code part19.* Ministry of Housing and Urbanism IRI. [In Persian]

Ingberg, S. H., Mitchell, N. D., & National Institute of Standards andTechnology (NIST). (1944). *Fire Resistance and Sound Insulation Ratings for Walls, Partitions, and Floors.* National Institute of Standards and Technology.

International Masonry Institute. (2010). *Autoclaved Aerated Concrete Masonry Units.*

International Federation of Red Cross and Red Crescent (IFRC). (2012). Emergency appeal operation update Turkey: Van Earthquake.

IS 4407-1967. (2002). *Indian standard code of practice for reed walling.* New Delhi: Indian standard institute.

ISO 14040. (2006). *Environmental management. Life cycle assessment. Principles and framework.* International Organization for Standardization.

Johnson, C. (2007a). Impacts of prefabricated temporary housing after disasters: 1999 earthquakes in Turkey. *Habitat International, 31*(1), 36–52. doi:10.1016/j.habitatint.2006.03.002

Johnson, C. (2007b). Strategic planning for post-disaster temporary housing. *Disasters, 31* (4), 435 - 458. doi:10.1111/j.0361-3666.2007.01018.x

Johnson, C. (2009). Planning for temporary. In C. J. Gonzalo Lizarralde, *Rebuilding after disasters: from emergency to sustainability* (pp. 70-87). Taylor & Francis.

Johnson, C., Lizarralde, G., & Davidson, C. H. (2006). A systems view of temporary housing projects in post-disaster reconstruction. *Construction Management and Economics, 24*(4), 367–378. doi:10.1080/01446190600567977

Karatas, A., & El-Rayes, K. (2014). Evaluating the performance of sustainable development in urban neighborhoods based on the feedback of multiple stakeholders. *Sustainable Cities and Society, 14*, 374–382. doi:10.1016/j.scs.2014.05.011

Kennedy, J., Ashmore, J., Babister, E., & Kelman, I. (2008). The Meaning of ‘Build Back Better’: Evidence From Post-Tsunami Aceh and Sri Lanka. *Contingencies and Crisis Management, 16*(1), 24–36. doi:10.1111/j.1468-5973.2008.00529.x

Khatam, A. (2006). The destruction of Bam and its reconstruction following the earthquake of December 2003. *Cities, 23*(6), 462–464. doi:10.1016/j.cities.2006.08.008

Khazai, B., M.EERI, & Hausler, E. (2005). Intermediate Shelters in Bam and Permanent Shelter Reconstruction in Villages Following the 2003 Bam, Iran, Earthquake. *Earthquake Spectra*, *21*(S1), 487–511. doi:10.1193/1.2098907

Krank, S., Wallbaum, H., & Gret-Regamey, A. (2010). Constraints to implementation of sustainability indicator systems in five Asian cities. *Local Environment, 15*(8), 731–742. doi:10.1080/13549839.2010.509386

Kuwata, Y., Takada, S., & Bastami, M. (2005). Building damage and human casualties during the Bam-Iran earthquake. *Asian Journal of Civil Engineering (Building and Housing), 6*(1-2), 1-19.

Lall, S. V., & Deichmann, U. (2009). *Density and Disasters Economics of Urban Hazard Risk.* The World Bank Research Observer.

Lombera, J.-T. S.-J., & Garrucho Aprea, I. (2010). A system approach to the environmental analysis of industrial buildings. *Building and Environment, 45*(3), 673–683. doi:10.1016/j.buildenv.2009.08.012

Lombera, J.-T. S.-J., & Rojo, J. C. (2010). Industrial building design stage based on a system approach to their environmental sustainability. *Construction and Building Materials*, *24*(4), 438–447. doi:10.1016/j.conbuildmat.2009.10.019

Long, M. (2005). *Architectural acoustic* . Elsevier.

Lufkin, P., Abate, D., Romani, L., Towers, M., Dotz, R., & Miller, J. (2013). *The Whitestone Facility Maintenance and Repair Cost Reference 2012-2013.*

Mahdi, T., & Mahdi, A. (2013). Reconstruction and Retrofitting of Buildings after Recent Earthquakes in Iran. *Procedia Engineering), 54*, 127 – 139. doi:10.1016/j.proeng.2013.03.012

Marcillia, S. R., & Ohno, R. (2012). Learning from Residents' Adjustments in Self-built and Donated Post Disaster Housing after Java Earthquake 2006. *Social and Behavioral Sciences, 36,* 61-69. doi:10.1016/j.sbspro.2012.03.007

McConnan, I. (1998). *Humanitarian charter and minimum standards in disaster response* (Third ed.). Sphere Project.

McIntosh, J., Gray, J., & Fraser, M. (2009). The Implications of Post Disaster Recovery for Affordable Housing. INTECH Open Access Publisher, 2013. doi: 10.5772/55273

Miljan, M., Miljan, M.-J., Miljan, J., Akermann, K., & Karja, K. (2014). Thermal transmittance of reed-insulated walls in a purpose-built test house. *Mires and Peat, 13*(7), 1-12.

Miller, e., Doh, J.-H., Panuwatwanich, K., & Oers, N. v. (2015). The contribution of structural design to green building ratingsystems: An industry perspective and comparison of life cycle energyconsiderations. *Sustainable Cities and Society, 16*, 39–48. doi:10.1016/j.scs.2015.02.003

Mosteiro-Romero, M., Krogmann, U., Wallbaum, H., Ostermeyer, Y., Senick, J. S., & Andrews, C. J. (2014). Relative importance of electricity sources and construction practices in residential buildings: A Swiss-US comparison of energy related life-cycle impacts. *Energy and Buildings* , *68*, 620–631. doi:10.1016/j.enbuild.2013.09.046

Murao, O. (2015). Regional Comparison of Temporary Housing Construction Processes After the 2011 Great East Japan Earthquake and Tsunami. In *Tohoku Recovery* (pp. 37-50). Springer.

Nkwetta, D. N., & Haghighat, F. (2014). Thermal energy storage with phase change material—A state-of-theart review. *Sustainable Cities and Society, 10*, 87–100. doi:10.1016/j.scs.2013.05.007

Ophiyandri, T., Amaratunga, D., Pathirage, C., & Keraminiyage, K. (2013). Critical success factors for community□based post□disaster housing reconstruction projects in the pre□construction stage in Indonesia. *International Journal of Disaster Resilience in the Built Environment, 4*(2), 236 - 249. doi:10.1108/IJDRBE-03-2013-0005

Ormazabal, G., Viñolas, B., & Aguado, A. (2008). Enhancing Value in Crucial Decisions: Line 9 of the Barcelona Subway. *Journal of Management in Engineering, 24*(4), 265–272. doi:(ASCE)0742-597X(2008)24:4(265)

Pacheco-Torres, R., Jadraque, E., Roldán-Fontana, J., & Ordonez, J. (2014). Analysis of CO2emissions in the construction phase of single-familydetached houses. *Sustainable Cities and Society, 12*, 63–68. doi:10.1016/j.scs.2014.01.003

Papadopoulos, A. (2005). State of the art in thermal insulation materials and aims for future developments. *Energy and Buildings, 37*(1), 77–86. doi:10.1016/j.enbuild.2004.05.006

Pfundstein, M., Gellert, R., Spitzner, M. H., & Rudolphi, A. (2012). *Insulating materials: principles, materials, applications* (DETAIL book ed.). Walter de Gruyter.

Poluraju, P., & Rao, G. A. (2014). Behavior of 3D-Panels for Structural Application Under General Loading: A State-of-the-Art. *International Journal of Research in Engineering and Technology, 3*(16), 173-181.

Pons, O., & Aguado, A. (2012). Integrated value model for sustainable assessment applied to technologies used to build schools in Catalonia, Spain. *Building and Environment, 53*, 49-58. doi:10.1016/j.buildenv.2012.01.007

Pons, O., & Fuente, A. d. (2013). Integrated sustainability assessment method applied to structural concrete columns. *Construction and Building Materials, 49*, 882–893. doi:10.1016/j.conbuildmat.2013.09.009

Pons, O., & Wadel, G. (2011). Environmental impacts of prefabricated school buildings in Catalonia. *Habitat International, 35*(4), 553–563. doi:10.1016/j.habitatint.2011.03.005

Publication No.613, Cold formed Light Steel Structures Design and Construction Code (Nonstructural). (2013). Islamic Republic of Iran Vice Presidency for Strategic Planning and Supervision. [In Persian]

Publication No. 385, The Code of Practice for Design Specification Manufacturing and Construction of 3D Panel Structures. Management And Planning Organization of I.R. of Iran. [In Persian]

Quarantelli, E. L. (1995). Patterns of shelter and housing in US disasters. *Disaster Prevention and Management, 4*, 43-53.

Rafieian, M., & Asgary, A. (2013). Impacts of temporary housing on housing reconstruction after the Bam earthquake. *Disaster Prevention and Management: An International Journal, 22*(1), 63-74. doi:10.1108/09653561311301989

Rezaifar, O., Kabir, M., Taribakhsh, M., & Tehranian, A. (2008). Dynamic behaviour of 3D-panel single-storey system using shaking table testing. *Engineering Structures, 30*(2), 318-337. doi:10.1016/j.engstruct.2007.03.019

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research, 48*(1), 9–26. doi:10.1016/0377-2217(90)90057-I

Sadiqi, Z., Coffey, V., & Trigunarsyah, B. (2012). Rebuilding Housing after a Disaster: Factors for Failure. *International Institute for Infrastructure, Renewal and Reconstruction (IIIRR)*, 292-300. Kumamoto University.

Saghafi M. D. and Teshnizi Z. A. H. (2011). Building deconstruction and material recovery in Iran: An analysis of major determinants. *Procedia Engineering, 21*, 853-863, doi:10.1016/j.proeng.2011.11.2087

Sarcia, S. R. (2004). *Design and analysis of a concrete modular housing system constructed with 3D panels.* Doctoral dissertation, Massachusetts Institute of Technology, Mechanical Engineering.

Shiozaki, Y., Tanaka, Y., Hokugo, A., & Bettencourt, S. (2012). *Knowledge Notes, Cluster 4: Recovery planning.* World Bank.

Siembieda, W. (2012). *Multi Location Disaster in Three Countries: Comparing the Recovery Process in Japan, Chile and New Zealand.* Focus: Journal of the City and Regional Planning Dept. 9(1), 15.

Sobel, R. S., & Leeson, P. T. (2006). Government's response to Hurricane Katrina: A public choice. *Public Choice, 127*(1-2), 55-73. doi:10.1007/s11127-006-7730-3

Terim, B. (2004). *A Study on "Temporary Post Disaster Housing Unit" Constructed with-Light Gauge Steel Framing-(LGSF) System.* (Doctoral dissertation).

Transitional Shelter guidelines. (2012). Shelter Centre.

UN-Habitat. (2014). *Voices from slums*. UN-Habitat.

United Nations (UN). Dept. of Economic and Social Affairs (2014). *World Urbanization Prospects: The 2014 Revision*. United Nations Publications.

United Nations Centre for Regional Development. (2009). *Report on the Great Sichuan Earthquake in China.* UN.

United Nations Disaster Relief Organization (UNDRO). (1982). *Shelter after disaster: Guidelines for assistance.* New York: UN.

United Nations High Commissioner for Refugees (UNHCR). (1999). *Handbook for emergencies* (Second ed.).

United Nations Office for Disaster Risk Reduction (UNISDR). (2010). *Guidance note on recovery: shelter.* UNISDR.

Vejeliene, J., Gailius, A., Vejelis, S., & Saulius Vaitkus, G. B. (2011). Evaluation of Structure Influence on Thermal Conductivity of Thermal Insulating Materials from Renewable Resources. *Materials Science, 17*(2), 208-212. doi:10.5755/j01.ms.17.2.494

Viñolas, B., Aguado, A., Josa, A., Villegas, N., & Prada, M. Á. (2009). Aplicación del análisis de valor para una evaluación integral y objetiva del profesorado universitario. *RUSC. Revista de Universidad y Sociedad del Conocimiento, 6*(2).

Wallbaum, H., Ostermeyer, Y., Salzer, C., & Escamilla, E. Z. (2012). Indicator based sustainability assessment tool for affordable housing construction technologies. *Ecological Indicators, 18*, 353–364. doi:10.1016/j.ecolind.2011.12.005

What Is Cantex? (2013). (Cantex Ahwaz) Retrieved 2 5, 2015, from http://cantexahwaz.com/en/index.php/products/what-is-contex

Wuppertal institute for climate, environment and energy. (2011). *Intensity of material, fuels, transport services, food.* germany.

Yi, H., & Yang, J. (2014). Research trends of post disaster reconstruction: The past and the future. *Habitat International, 42*, 21-29. doi: 10.1016/j.habitatint.2013.10.005

Yonetani, M. (2014). Global Estimates 2014: people displaced by disaster. *IDMC.*

Footnote:

[1] There is complete information about MIVES methodology in previous studies, such as: Alarcon et al., 2011; Aguado, A. et al., 2012; del Caño, 2012, 2015; Cuadrado et al., 2015.

Fig. 1. Methodology for considering the TH process

Fig. 2. Plan of a THU constructed in Bam after the 2003 earthquake; the left plan is the 20 m^2 type and the right plan is the 18 m^2 type

Fig. 3. View of the four wall technologies; (a) autoclaved aerated concrete block (AAC Block), (b) concrete masonry unit (CMU), (c) pressed reeds panel, and (d) 3D sandwich panel wall

Fig. 4. Requirements tree designed for this model

Fig. 5. Value function types

Fig. 6. Value function of building cost indicator (I_1)

Fig. 7. Requirements values for the four alternatives

Fig. 8. Environmental indicator values for the four alternatives

Fig. 9. Sustainability indexes of the four technologies with different requirement weights (economic (Ec), social (S), and environmental (En))

Table 1. The use of THUs in previous TH programs

Method	Prefabricated		References
Natural disaster	Kit approach	Ready-made	
Mexico-1985	X		Johnson, 2007b
Japan-1995	X	X	Johnson, 2007b; UNISDR, 2010
Turkey -1999	X	X	Arslan, 2007; Arslan & Cosgun, 2008; Johnson, 2007a, b; Johnson, Lizarralde, & Davidson, 2006
Iran-2003	X	X	Fayazi & Lizarralde, 2013; HFIR, 2013; Mahdi & Mahdi, 2013; Rafieian & Asgary, 2013
USA-2005	X	X	McIntosh, Gray, & Fraser, 2009; Sobel & Leeson, 2006; UNISDR, 2010
China-2008	X		UN, 2009
New Zealand-2011	X	X	Giovinazzi, Stevenson, Mason, & Mitchell, 2012; Siembieda, 2012
Turkey-2011	X	X	Erdik, Kamer, Demircioglu, & Sesetyan, 2012; IFRC, 2012
Japan-2011	X	X	EERI Special Earthquake Report, 2011; Murao, 2015; Shiozaki, Tanaka, Hokugo, & Bettencourt, 2012
Iran-2012	X		HFIR, 2012

Table 2. Eight alternatives including wall materials, roof materials, and construction cost per square meter.

Alternative	Abbreviation	Wall	Roof	Building Cost * (IRR./m^2) ***	Total cost ** (IRR./m^2)***
Alternative 1	AAC-S	Autoclaved aerated concrete blocks	Sandwich panels	516528	716528
Alternative 2	AAC-C	Autoclaved aerated concrete blocks	Corrugated galvanized iron	491194	691194
Alternative 3	CMU-S	Concrete masonry units	Sandwich panels	563750	763750
Alternative 4	CMU-C	Concrete masonry units	Corrugated galvanized iron	538417	738417
Alternative 5	PR-S	Pressed reeds	Sandwich panels	596972	796972
Alternative 6	PR-C	Pressed reeds	Corrugated galvanized iron	571639	771639
Alternative 7	3D-S	3D sandwich panels	Sandwich panels	719672	919672
Alternative 8	3D-C	3D sandwich panels	Corrugated galvanized iron	694339	894339

* Cost of construction materials, excluding lighting and piping

** Total of construction material cost including the coefficients: site preparation, area conditions, overhead, etc.; which had been considered by HFIR

*** At the time, one US$ equalled 8500 Iranian Rials (IRR.) (Havaii & Hosseini, 2004)

Table 3. The main influential indexes of TH by guideline

Requirement	Category	Definition
Economic	Construction	Considers the need for public expenditures to provide THUs.
	Maintenance/Reuse	Assesses the investment demanded during the operation phase.
	Health	Takes into account mental and physical aspects, such as risk resistance, sanitary conditions, community participation, infrastructure, etc.

Social	Convenience	Embraces indicators concern to comfortable conditions.
	Local capacity	Considers local characteristics, such as facilities, skilled labours, etc.
Environmental	Consumption	Considers resource consumption.
	Land use	Assesses land use change.
	Solid waste	Takes into account the amount of waste management during the construction and the demolition phases.

Table 4. Exterior wall standards for residential buildings

	Exterior wall standards			References
Acoustic range	Iran		Bedroom: R'_w >45; Living room: R'_w >40; Kitchen: R'_w >35	INBC part 18, 2009
	USA		Grade 1:STC>55; Grade 2:STC>52; Grade 3:STC>48 (general STC>50)	Garg, Sharma, & Maji, 2011
	UK		$D_{nT,w} + C_{tr}$ >45	Building Regulations, 2010
	Germany*		Class A: R'_w >68; Class B: R'_w >63; Class C: R'_w >57	Garg, Sharma, & Maji, 2011
Fire resistance (h)	Iran		1	Publication No.613, 2013
	USA		1	IBC, 2009
Thermal Resistance	Iran **	Light	Group 1: R>2.8; Group 2: R>2.1; Group 3: R>1.5	INBC part 19, 2011
		Heavy	Group 1: R>1.9; Group 2: R>1.4; Group 3: R>1.0	
	UK		U-value: 0.3–0.4	Papadopoulos, 2005

* Row housing

** Light wall: surface mass < 150 kg/m^2

** Heavy wall: surface mass > 150 kg/m^2

R'_w : Weighted sound reduction index (dB); $D_{nT,w} + C_{tr}$: Airborne sound insulation (dB); R: Thermal resistance (m^2.K/W)

Table 5. Common materials for all alternatives

Component	Material
Foundation	Strap footing foundation, the height is 0. 35 m
Floor	lean concrete 150 kg/m^3, the thickness is 0.15 m and Iranian mosaic tile
Structure	Steel hollow square section
Footing (Plinth)	Brick or block, the height is 0.20 m
Window	Metal widow, the dimension is 1.00 m *1.00 m
Door	Metal door, the dimension is 2.00 m *1.00 m
Mortar	Cement mortar 1:6

Table 6. Major materials and their properties

Features Material	Density (kg/m^3)	Thermal conductivity (w/(m.k))	Embodied energy (MJ/kg)	Embodied CO_2 (kgCO^2/kg)	Water consumption (kg/kg)	References
Cement mortar (1:6)	1650	0.72	0.85	0.136	-	Hammond & Jones, 2011
Cement mortar (1:3)	1900	0.93	1.33	0.221	-	Hammond & Jones, 2011
Steel	7800	45	13.1	0.72	63.67	Hammond & Jones, 2011; Wuppertal institute, 2011
concrete 16/20 Mpa *	2350	2.2	0.70	0.100	3.42 *	Hammond & Jones, 2011; Wuppertal institute, 2011
Autoclaved aerated concrete block	500	0.16	3.50	0.24 to 0.37	13.42*	Hammond & Jones, 2011; Wuppertal institute, 2011
Concrete masonry block	2050	0.9	0.59	0.063	11.49 **	Hammond & Jones, 2011; Wuppertal institute, 2011
Reed	120-225	0.055-0.090	-	-	-	Hammond & Jones, 2011; Miljan et al., 2014; Pfundstein et al., 2012; Vejeliene et al., 2011
	76	0.076	***	***	***	
	75.6	0.08-0.09				
Polystyrene (E.P.S.)	15	-	88.6	3.29	137.68	Hammond & Jones, 2011; Wuppertal institute, 2011

Wuppertal institute, 2011

---

* General

** Cellular concrete 600 kg/m^3

*** Generic wood (As the embodied energy and CO_2 are not available in Inventory of Carbon & Energy (ICE), 2011, the parameters of generic wood have been used)

Table 7. The important features of the technologies

Technology (wall)	Components characteristics			Thermal resistance (m^2.k)/w	Fire resistance (h)	STC	Ductility	Construction time	References
	Material		Dimension (cm)						
Autoclaved aerated concrete blocks	AAC		60*10*25	0.625^a	4	35^a	Medium to low ^{b}	Low	Charleson, 2008; 1980; Hammond 2011; Ingberg, M NIST, 1944; Inte Masonry Institut
	in	Gypsum plaster	3						
	out	Cement plaster	2.5						
Concrete masonry units	CMU		40*20*30	0.222^a	1.75	43-48 ^{a}	Medium to low ^{b}	Very low	Cavanaugh & W Charleson, 2008; 2013; Ingberg, M NIST, 1944;
	in	Gypsum plaster	3						
	out	Cement plaster	2.5						
Pressed reeds	Reeds panel		5	0.667^a	0.5	$R_{w=}15$ ^{c}	Medium to low ^{b}	Medium	Charleson, 2008; Jiménez, Navace Pedrero, 2012; IS 1967, 2002; HFI
	in	Gypsum plaster	3						
	out	Cement plaster	2.5						
3D panels	EPS		5	R11 1.9373 ^{d}	1.5 ^{d}	40 ^{d}	Medium to high ^{a}	high	Charleson, 2008; 2013; Publication Poluraju & Rao, Sarcia, 2004
	Steel mesh		0.25/0.25/8/8						
	in	Sprayed concrete	3						
	out	Sprayed concrete	3						

[a] Without plaster

[b] General

[c] Weighted sound reduction index of 5 cm reeds without plaster / 1.8 cm MDF on each side and 5 cm reeds in the core R_w=39

[d] 1.5-inch layer of concrete on either side and 2.5-inch EPS in the core (1Btu/h.ft^2.°F = 5.678 W/m^2.K), and the sprayed concrete is 120 pounds per cubic foot .

Table 8. Parameters and coefficients for each indicator value function.

Indicator	Unit	X_{max}	X_{min}	C	K	P	Shape	References
I_1	currency/m^2	$13.5\cdot10^4$	$0.6\cdot10^6$	$1.4\cdot10^6$	0.1	2.3	DCx	HFIR, 2013; Khazai, M.EERI, & Hausler, 2005
I_2	currency/m^2	$5.6\cdot10^3$	$2.3\cdot10^3$	$0.8\cdot10^4$	0.01	1.5	DCx	HFIR, 2013; Iranian Publication No. 385; Lufkin, et al., 2012
I_3	pts.	1	0.00	1.5	0.8	2.5	ICx	HFIR, 2013; Pons & Aguado, 2012
I_4	pts.	1	0.00	0.25	0.2	2	IS	HFIR, 2013
I_5	pts.	1	0.00	0.5	0.8	2	IS	HFIR, 2013
I_6	pts.	1	0.00	0.35	0.1	1.8	ICx	HFIR, 2013
I_7	MJ	$2.5\cdot10^2$	$1.2\cdot10^2$	$0.2\cdot10^3$	0.8	1.6	DCx	Hammond & Jones, 2011; HFIR, 2013
I_8	kg	$2.15\cdot10^3$	$2.4\cdot10^2$	$2.1\cdot10^3$	0.2	1.6	DCx	HFIR, 2013; Wuppertal institute, 2011
I_9	%	20	5	30	0.6	2	DCx	Harris, 1999; HFIR, 2013; Iranian Publication No. 385; Saghafi & Teshnizi, 2011
I_{10}	kg CO_2	26	13	25	0.3	1.4	DCx	HFIR, 2013; Hammond & Jones, 2011

Xmax: maximum value indicator; Xmin: minimum value indicator; C: establishes, in curves with $P_i > 1$, abscissa's value for the inflexion point; K: defines the response value to C; P: is a shape factor

Table 9. Parameters and coefficients for each sub-indicator value function.

Sub-indicator		Unit	X_{max}	X_{min}	C	K	P	Shape	References
I_4	Natural Disaster Risk	pts.	1	0.00	0.55	0.8	2.5	IS	Charleson, 2008
	Fire Resistance	h(s)	4	0.00	2	0.8	3.5	IS	Cavanaugh & Wilkes, 1999; IBC, 2009; IS 4407-1967
I_5	Acoustic	STC	60	30	6	0.2	2	IS	Building Regulations, 2010; Garg, Sharma, & Maji, 2011; INBC part 18, 2009; Long, 2005
	Thermal Resistance	m^2.k/w	2.5	0.00	1.6	0.8	2.5	IS	Hammond & Jones, 2011; INBC part 19; Sarcia, 2004
I_6	Cultural Acceptance	pts.	1	0.00	1	0.8	2	ICx	HFIR, 2013; UNDRO, 1982
	Skilled Labour	pts.	1	0.00	2	0.1	2	ICx	Corsellis & Vitale, 2005; HFIR, 2013; UNDRO, 1982
	Flexibility	pts.	1	0.00	1.5	0.8	1.5	ICx	HFIR, 2013; UNDRO, 1982

Table 10. Requirements tree with assigned weights.

Requirements	Criteria	Indicators	Sub-indicators
	C_1. Implementation Cost (85%)	I_1. Building Cost (100%)	
R_1. Economic (45%)	C_2. Maintenance Cost (15%)	I_2. Reusability Cost (100%)	
		I_3. Construction Time (36%)	
	C_3. Safety (60%)	I_4. Risk Resistance (42%)	S_1. Natural Disaster Risk (50%)
R_2. Social (25%)			S_2. Fire Resistance (50%)
		I_5. Comfort (22%)	S_3. Acoustic (50%)
			S_4. Thermal Resistance (50%)
	C_4. Customization (40%)	I_6. Compatibility (100%)	S_5. Cultural Acceptance (45%)
			S_6. Skilled Labour (30%)
			S_7. Flexibility (25%)
		I_7. Energy Consumption (47%)	
R_3. Environmental (30%)	C_5. Resources Consumption (67%)	I_8. Water Consumption (18%)	
		I_9. Waste Material (35%)	
	C_6. Emissions (33%)	I_{10}. CO_2 Emissions (100%)	

Table 11. Sustainability index (I), requirements (V_{Rk}), criteria (V_{Ck}), indicator (V_{Ik}), and sub-indicator (V_{Sk}) values for the four alternatives

	I	V_{R1}	V_{R2}	V_{R3}	V_{C1}	V_{C2}	V_{C3}	V_{C4}	V_{C5}	V_{C6}
AAC	0.50	0.76	0.39	0.20	0.74	0.87	0.43	0.34	0.25	0.11
CMU	0.53	0.62	0.39	0.49	0.63	0.59	0.29	0.55	0.48	0.51
PR	0.53	0.55	0.19	0.79	0.55	0.52	0.21	0.15	0.74	0.9
3D	0.36	0.28	0.38	0.46	0.32	0.06	0.61	0.02	0.43	0.52

	V_{I1}	V_{I2}	V_{I3}	V_{I4}	V_{I5}	V_{I6}	V_{I7}	V_{I8}	V_{I9}	V_{I10}
AAC	0.74	0.87	0.2	0.83	0.04	0.34	0.1	0.55	0.3	0.11
CMU	0.63	0.59	0.11	0.41	0.36	0.55	0.79	0.03	0.3	0.51
PR	0.55	0.52	0.37	0.18	0.01	0.15	0.87	0.98	0.44	0.9
3D	0.32	0.06	0.52	0.65	0.7	0.02	0.33	0.66	0.44	0.52

	V_{S1}	V_{S2}	V_{S3}	V_{S4}	V_{S5}	V_{S6}	V_{S7}
AAC	0.40	1.00	0.13	0.08	0.66	0.49	0.15
CMU	0.40	0.39	0.72	0.01	1.00	0.57	0.15
PR	0.48	0.01	0.00	0.09	0.33	0.36	0.15
3D	0.85	0.25	0.43	0.75	0.09	0.06	0.15