Camping during flood in Iran, year 2019

Resilient and Sustainable Modular System for Temporary Sheltering in Emergency Condition

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ABSTRACT

During the hazard impact, it is very important to manage the emergency condition. Temporary sheltering is one of the preliminary and main requirements of disaster management. COVID 19 poses the necessity of using fast and modular temporary sheltering in the crowded cities to improve treating and curing services for the hospitals. However, successful emergency management for current societies is achievable if the resilience approach has been implemented in all procedures of emergency management. The concept of resilience could make a new sense of motivation in disaster management while recent research shows that resilience makes a significant improvement in the traditional approach of safety and security during disasters. Temporary shelters play an important role in the temporary settlement and also commanding the emergency condition during a disaster period. This study aims to develop a resilient modular design of shelters based on a sustainable industrialized Building system (IBS) under the main critical success factors with the approach of resilience and sustainability. Critical success factors (CSFs), resilience and sustainability criteria are extracted from literature and the CSFs are evaluated based on the questionnaire survey and using VIKOR as a multi-criteria decision-making method. The reduction of mortar usage, IBS, and Interconnected structure are the most impressive factors. Based on these factors, the symmetric orthogonal modular system was selected. The robustness of the selected system was calculated under the explosive load test. Interconnectivity, modularity, mortar-less erecting, disassembling and reassembling abilities are some of the advantages. They improve rapidity, transformability of this structure following capacities of resilience.

KEYWORDS

1.   INTRODUCTION

The emergency condition is an unneglectable issue in societies. Current Wadi flash flood in Shiraz- Iran in March 2019 or emergency condition due to an earthquake in Kermanshah in 2017 are examples of an emergency condition in Iran. One of the important issues during and after any disaster is the logistic of emergency management. Shelter is the main principle (Nappi et al., 2019). Thus, a serious issue is temporary sheltering for the operational and recovery time of disaster management. However, bio-threat such as pandemic flu engages so many people in the society and also in emergency condition, therefore overwhelming hospitals capacity. The mounting risk of a COVID 19 poses numerous potentially devastating consequences for the cities and even for the hospitals. Ascending rate of infection and limited capacity of hospitals create serious concern about treating and curing services to the patients. Temporary hospitals and also temporary shelters for the time of recovery of the patients who should be quarantined from not-infected people rises the necessity of using fast and modular temporary shelterin the crowded cities. UNICEF tries to define community temporary shelter as a place where temporary roof and protection and also food, clothing, drinking water, health, is provided to the group of displaced and affected victims and urban residents for a short period (UNICEF, 2008). Evacuation shelters were classified into different categories. Some of the researchers classify them into three categories as emergency shelter, fixed shelter, and central shelter. Moreover, there is another categorization as emergency evacuation/ refuge bases, regional refuge shelters, and city refuge shelters (Tsai and Yeh, 2016, Xu et al., 2016). Totally for these types of sheltering at least reduce of 2 Km is necessary for the service area and 2 m^2 should be assigned per each resident (Xu et al., 2016). Different criteria should be considered for all types of sheltering. But the important consideration is about time and speed.

Often, decisions on how and what type of shelter should be used; only taken after a catastrophic event, when there is not sufficient time for a precise reflection on the principals that should lead choosing and building temporary shelters (Omidvar et al., 2013). The speed of assembly and erection and the speed of disassembly and also the potential of storage and reuse.

Figure 1.
Temporary shelters in Sar-Pol Zahab, Kermanshah, Iran
a) residence area b) small business.

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There should be a consistent path between the sheltering and recovery period. Otherwise, human dignity and human survival should be considered for an early stage of emergency shelter (Nappi and Souza, 2017). Experiences in Iranian disasters show the lack of rapid response at the early stages because of geographical constraints. Furthermore, the period of settlement in temporary shelters also continues to an unsupervised period which makes obvious disorder in the urbanization system. Figure 1 shows the residency of some earthquake victims of Sar-Pol Zahab in Kermanshah, even after 3 years. Based on these considerations some of the research pointed on criteria such as mass-efficiency and customer co-creation (Bunster and Bustamante, 2019).

Different criteria focus on costumers or residents' satisfaction, some of them are based on technical feasibility and others rely more on one government or provider satisfaction. However, there are different flows of integration that could be implemented for policies of temporary sheltering. These approaches started with sustainability consideration while humanitarian action integrated with sustainability perception (Nappi and Souza, 2017, Nappi et al., 2019, Nappi and Souza, 2015). However, the

complexity of criteria for choosing policies and types of shelters need a modified sustainable approach with emergency circumstances and recovery policies (Chen et al., 2017, Bunster and Bustamante, 2019, Xu et al., 2016). Resilience is a critical approach that can improve current policies.

Technical feasibility is one of the main concerns for designing shelters. But normally there are some common design or prefabricated systems such as 3D sandwich panel Conex or tents using to protect people. As it is shown in figure 3, using 3D sandwich panel Conex and also small units of precast wall and tents are used normally for temporary settlement and also commanding the emergency condition during the disaster period (Deeb et al., 2018).

However, facing with the aggressive climate in the prone area is making these shelters too vulnerable. The previous experience shows that the most vulnerable area after each disaster is the settlement area. The other problem ihas to do with temporary shelter after the recovery period as they are still placed in the same position which is evacuated. It causes abnormal strain to the urban area. It affects health, security, and visualization of the city besides making informal habitation. Thus, it is very important to develop a new

Figure 2.
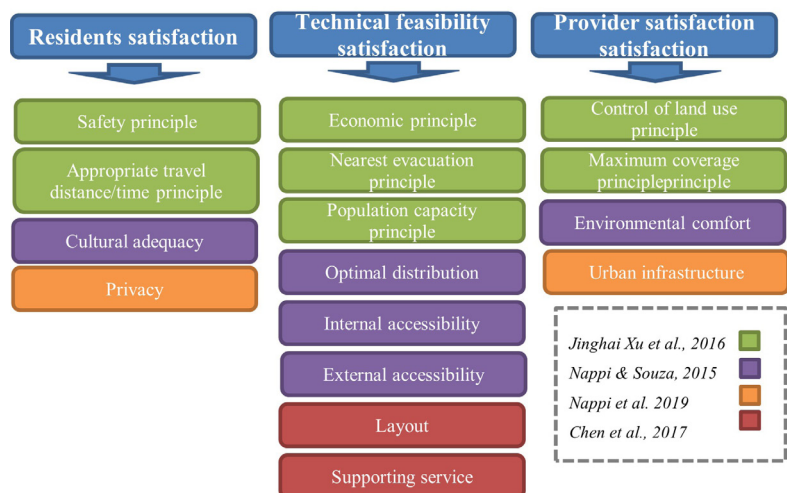*The complexity of criteria for choosing policies and types of shelters.*

Figure 3.
The vulnerability of conventional temporary shelters.

modular design for these types of shelters with the approach of resilience and sustainability.

Nowadays, the literature shows the importance of resilience policies among leaders and policymakers following disaster management.

There are different concepts and descriptions of resilience in the literature. During hazard impact, normally the first assets and properties to be affected could be the first to ''bounce back to their normal state". For instance, the simply constructed homes are much easier to rebuild than more sophisticated ones (Lewis, 2011, Reghezza-Zitt et al., 2012, Levine et al., 2012). On the other hand, some of the researchers focusing on the term of the resilience as a recovery promotes a post-disaster rescue and rehabilitation approaches, rather than reducing underlying risk factors, or prevention, on which disaster risk reduction (DRR) measures and policies should be focused (Lewis and Kelman, 2010).

The movement to see resilience in light of "bouncing forward," taking into consideration underlying causes of vulnerability as well as improving capacities to recover after a disaster (Manyena et al., 2011). In 2005, Homeland Security Advisory Council formed the Critical Infrastructure Task Force (CITF) to provide recommendations on national policy and objectives. The resilience was introduced as the all-encompassing strategic objective with the ability of synergistic actions. It helps to make balance across components of risk and protection (Vugrin et al., 2010). Resilience is defined in other documents as the capability of an asset, system, or network to maintain its function during or to recover from a terrorist attack or other incidents." (Haimes et al., 2008). It is important to assess performance outcomes simultaneously with the intrinsic characteristics that contribute to system resilience.

Accordingly, it is very important to identify the main categories of resilience as its capacities. Resilience constructed on three system capacities that formulate the determination of system resilience based on the inherent properties of a system. System resilience constructed on two main concepts, which are systematic impact and total recovery effort. These capacities were defined as absorptive capacity, adaptive capacity, and restorative capacity (Gopalakrishnan and Peeta, 2010). There are different features of the system that can increase one or more of the system capacities even while, the modular system is assigned. These capacities are affected by resilience enhancement features. For more clarification, these capacities with their sub-capacities were extracted from literature and illustrated in table 1.

The concept of resilience could make a new sense of motivation in disaster management while recent researchers believe that resilience marks a shift away from more traditional liberal ideas of security.

They indicated the resilient life as an art of living dangerously (Duffield, 2015). According to the complexity of criteria for choosing policies and

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CAPACITY	SUB-CAPACITY	REFERENCE
ABSORPTION	Resourcefulness and Saving	(Manyena et al., 2011, Manyena, 2014, Reghezza-Zitt et al., 2012, Cutter et al., 2010)
	Redundancy	(Cutter et al., 2010, Cutter et al., 2013)
	Robustness	(Cutter et al., 2010, Manyena et al., 2011, Manyena, 2014, Aldunce et al., 2014)
ADAPTION	Adaptive resource substitution	(Cutter et al., 2010, Manyena et al., 2011, Cutter et al., 2013, Manyena, 2014, Foster, 2012, Levine et al., 2012, Duffield, 2015, Reghezza-Zitt et al., 2012)
	Adaptive import substitution	
	Adaptive conservation	
	Transformability	
RESTORATION	Rapidity	(Cutter et al., 2010, Manyena et al., 2011, Manyena, 2014, Vugrin et al., 2010, Aldunce et al., 2014, Levine et al., 2012, Zobel, 2011, Reghezza-Zitt et al., 2012)
	Learning	
	Integration	
	Agile structure	

Table 1.
Categorization of resilience based on literature.

types of shelters and the necessity of engagement of integration approaches such as sustainability and resilience. Sustainability factors that can make an impact on the design of the shelters mostly on technical feasibility analysis and extract in table 2.

It is essential to provide a new framework that helps to provide a more flexible and resilient design for temporary sheltering, especially during natural and manmade disasters. Thus, factors such as explosion, landslide, earthquake, and flood should be considered simultaneously.

This study aims to evaluate the main critical success factors for an innovative modular design of shelters based on a sustainable industrialized Building system (IBS). Then, the alternative designs are compared, and the best alternative was selected and evaluated for explosive forces.

1	Knowledge-based	(Borghei et al., 2013, Ortiz et al., 2009)
2	Industrial cooperation	(Chao Zhang et al., 2011, Spence and Mulligan, 1995, Kenai et al., 2014, Ortiz et al., 2009, Halldórsson et al., 2009, Petala et al., 2010)
3	Societal	Taherkhani et al., 2012, Mohamad et al., 2012, Chiou et al., 2005, Cutter et al., 2013, Barbier, 1987, Henry and Kato, 2011)
4	Economy	(Markovska et al., 2009, Haynes et al., 2008, Barbier, 1987)
5	Agile Procedure	(Markovska et al., 2009, Spence and Mulligan, 1995, Petala et al., 2010, P. Kumar Mehta*, 2001, Henry and Kato, 2011)
6	Environmental impact	(Damtoft et al., 2008, Wilbanks et al., 2003, Wilbanks et al., 2015, P. Kumar Mehta*, 2001)
7	Biosphere Stewardship	(Folke et al., 2016)

Table 2.
A content analysis of the main factors of sustainability approach.

2. METHODOLOGY

This section describes the methodology for developing new modular resilient and sustainable shelter for temporary sheltering during emergency response. This research contains six main steps which are mentioned accordingly:

- Extracting the critical success factor for temporary shelter development by interview.
- Deliberating sustainability and resilience criteria versus critical success factors for developing new resilient modular shelters.
- Choosing the most important CSF for temporary shelter development.
- Choosing the best alternative design
- Analyzing the best design under the explosion
- Conceptual interconnected community based on the best design

According to the extended scope of this research, figure 4 tries to illustrate the step by step methodology of this research and its engagement with various data collection and data analysis.

Figure 4.
*The framework of the
methodology procedure*
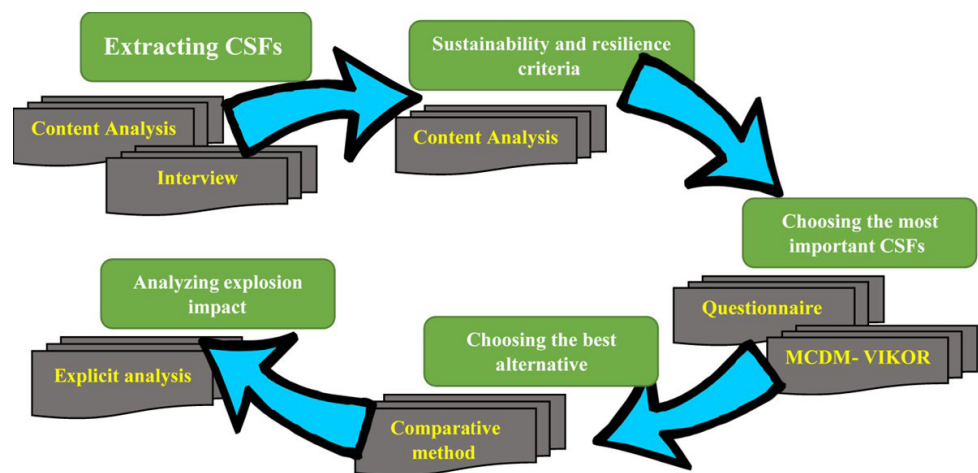
2.1 CRITICAL SUCCESS FACTORS FOR DEVELOPING NEW RESILIENT MODULAR SHELTERS

In the first step, the critical success factors for developing new resilient modular shelters have been extracted and tabled form interviews with a panel of experts. The interviewees are from Iranian policymakers from Iran Civil Defense Organization, Crisis Management Organization of Iran, two famous Iranian construction companies with extended international experiences (Moshanir Co. and LAAR Co.) and finally 3 international university experts from Canada, Malaysia, and Iran. The interview was held in the open-ended but semi-instructed system. All of the interviewees replied to the issue of proposing critical success factors for developing new resilient modular shelters by online interviews except two organizations

that answers were replied in a physical meeting. The critical success factors for developing new resilient modular shelters were achieved evaluated and categorized as it is defined in table 3.

2.2 SUSTAINABILITY AND RESILIENCE CRITERIA

In the next step, the resilience criteria and sustainability criteria have been extracted from literature and trended as it is shown in table 4. The content analysis and related research for each factor were mentioned in tables 1 and 2. As it is mentioned in table 4, resilience factors are summarized in the capacities introduced for it as absorption, adoption, and recovery. Otherwise, sustainability has a wide range that caused so many factors extracted from literature. However, the seven most common factors under sustainability based on previous research were selected and applied for current research.

Table 3.
*Critical success factors for developing
new resilient modular shelters.*

Symmetric structure	Strengthening by changing material	Easiness of fabrication	Modularity
Interconnected structure	Local material usage	Using byproduct materials	IBS
Integrated supply chain management	Workability	Re-fabrication ability	Reduction of mortar usage
Multi-face design	Light-weigh	Conventional design	Strengthening by high tech

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Table 4.
*The resilience criteria and sustainability criteria
have been extracted from the literature*

1		Knowledge-based
2		Industrial cooperation
3		Societal
4	Sustainability	Economy
5		Agile Procedure
6		Environmental impact
7		Biosphere Stewardship
1		Absorption
2	Resilience	Adoption
3		Recovery

2.3 CHOOSING THE MOST IMPORTANT CSF BY MCDM – VIKOR

For evaluating the most effective factors, the decision-making model is needed to evaluate the results of a questionnaire survey. Sometimes, using a questionnaire is the best and only way to integrate new ideas on one issue based on a large number of responders. The main advantage of the questionnaire survey is the ability to perform the statistical tests to validate the result which is extracted from respondents. It is an effective, convenient, and economical investigation tool for obtaining data and sampling the opinion of individuals in spatially diverse locations. The concept of the critical success factors for modular resilient shelter was developed under resilience and sustainability criteria. A questionnaire survey was done among 56 respondents from different regions in Iran. All regions were selected from hazardous zones.

The mathematical formulation for the VIKOR approach which is modified by this study is illustrated in the following steps.

The high and low scored alternatives concerning each criterion, as denoted by X_j^++and X_j^+-(Eq. 1) were determined where j is the index for criteria and i is the index for alternatives.

$$X_j^+ = Max_i(X_{ij}) \quad and \quad X_j^- = Min_i(X_{ij}) \qquad Eq.1$$

Then the values S_i and R_i were computed. Equations 2 and 3 were used for this step. By these parameters, the extent of deviation from ideal or non-ideal alternatives was specified. R_i is referred to the importance of maximum regret. Since R_i was only a portion of S_i, S_i must exceed R_i. S_i is emphasized more than R_i in the traditional VIKOR method, although in a practical situation the maximum regret is usually taken into account.

$$S_i = \sum_{j=1}^{p} W_j \times (X_j^+ - X_{ij})/(X_j^+ - X_j^-) \qquad Eq.2$$

$$R_i = Max\left[W_j \times \left(\left(X_j^+ - X_{ij}\right)/\left(X_j^+ - X_j^-\right)\right)\right] \qquad Eq.3$$

The values of Q_i were determined in the seventh step by the following relation (Eq.4).

$$Q_i = v \times (S_i - S^+)/(S^- - S^+) + (1-v) \times (R_i - R^+)/(R^- - R^+) \quad Eq.4$$

Where S^+/ R^+ and S^-/ R^- are the maximum and minimum values achieved in each category. v is introduced as a weight for the strategy of maximum group utility. The value of v lies in the range of 0 to 1. In Eq. 4, $v > 0.5$ indicates that S is emphasized more than R, while for < 0.5, R is emphasized more. When v is equal to 1, it represents a decision-making process that could use the strategy of maximizing group utility, as occurred in the traditional VIKOR approach. Whenever v is equal to zero, it shows a process that could apply a minimum individual regret strategy that is found among maximum individual regrets/gaps of lower-level criteria for each alternative. The factor would affect the ranking of the alternatives. Hence, it is usually determined externally by the experts. Alternatives were sorted based on the values of respective parameters S, R and Q.

The best compromising alternative, A(1), was determined by satisfying the two VIKOR constraints below. The best alternative was the one that has the best rank measured by minimum Q.

Constraint 1: if A(1) indicates the highest ranked alternative and A(2) follows it in the ranking list, then:

$$Q(A^{(2)}) - Q(A^{(1)}) \geq DQ \qquad \qquad Eq.5$$

$$DQ = \frac{1}{m-1} \quad \text{(If m<=4, DQ=0,25)} \qquad Eq.6$$

Constraint 2: Acceptable stability in decision making: Alternative A(1) must also gain the best rank for S or/and R. This compromise solution is considered a stable solution within the decision-making process,

- by majority rule, for $v > 0.5$;
- by consensus, for $v = 0.5$;
- with veto, for $v < 0.5$.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed as following:

- both alternatives A(1) and A(2), if only "Constraint 2" is not satisfied, or
- Alternatives A(1), A(2),..., A(M) if "Constraint 1" is not satisfied; A (M) is evaluated by the relation Q(A(M)) - Q(A(1)) < DQ for maximum M (the positions of these alternatives are "in closeness").

2.4 DATA COLLECTION

One important factor which can affect the results is "the experience of the respondent". Figure 5 illustrate the experience distribution among respondent.
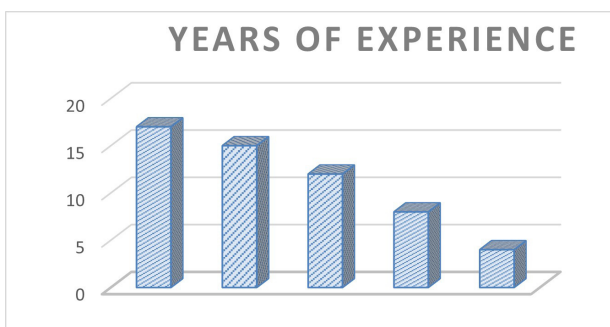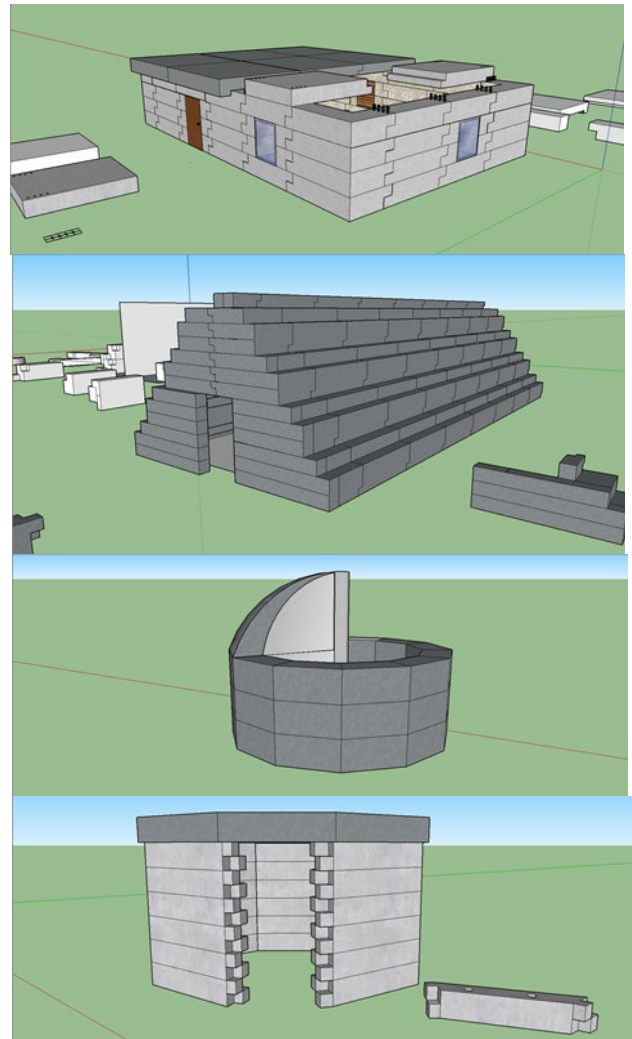

YEARS OF EXPERIENCE

Figure 5.
Years of experience for responders.

In the next step, 4 different types of modular designs have been developed based on their operational procedures. The first type is based on modularity with elevating ability. The second type is a concrete industrial shed. The third one is circular with an axial column. The last type is symmetric octagonal. Figure 6 illustrates all of the alternatives.

In the previous section, the strength of the selected

Figure 6.
Four different types of modular design.

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modular design was evaluated against the explosion to confirm the robustness of its structure against the worst condition. For this reason, the simulation software has been used for all components of the modular design. Figures 7 and 8 show the meshing of elements and connections for boundary conditions and meshing in simulation. In this study explicit analysis is performed based on explosion load and extensive load. Thus, the extensive load is loaded statically and became steady then, the explosion is loaded on the model with a time lag. Figure 9 illustrates the model of loading accordingly.

Figure 7.
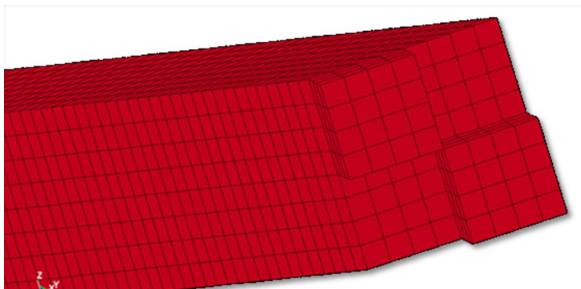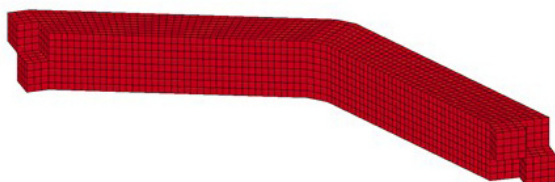*Meshing of the component in the simulation procedure.*

Figure 8.
Meshing of one connection in the simulation procedure.

Figure 9.
The model of loading.

5 defines the evaluation of each factor based on the resilience and sustainability approach. The S_i and R_i were assessed based on maximizing group utility and minimum regret. Then the S^+ and R^+ as the maximum values are achieved in the matrixes. The S^- and R^- as the minimum values are achieved in each category. To define the value of Q_i, the ν is introduced as the weight of the strategy of 'the majority of attributes' (or 'the maximum group utility'). The value of ν lies in the range of 0 –1. When $\nu > 0.5$, this indicates that S is emphasized more than R, whereas when $\nu < 0.5$, R is emphasized. Table 6 illustrates the result of VIKOR evaluation for the best performed critical success factor for resilient modular shelter when the $\nu = 0.25$, 0.5, and 0.75.

Based on the results of VIKOR analysis, both constraints of VIKOR are satisfied. Thus, Interconnected structure, IBS and Reduction of mortar usage are the most impressive factors to make a successful resilient and sustainable modular shelter. Based on these three main critical success factors all alternatives had been evaluated according to the illustrated graph in figure 10.

3. RESULTS AND DISCUSSION

As it was mentioned in the previous section, the mean score for the questionnaire survey was calculated for each critical success factor under each criterion. Table
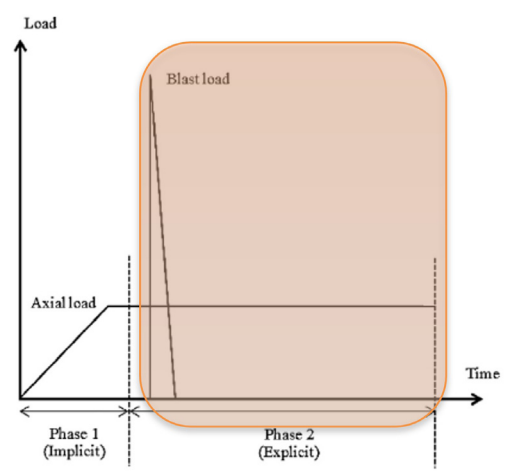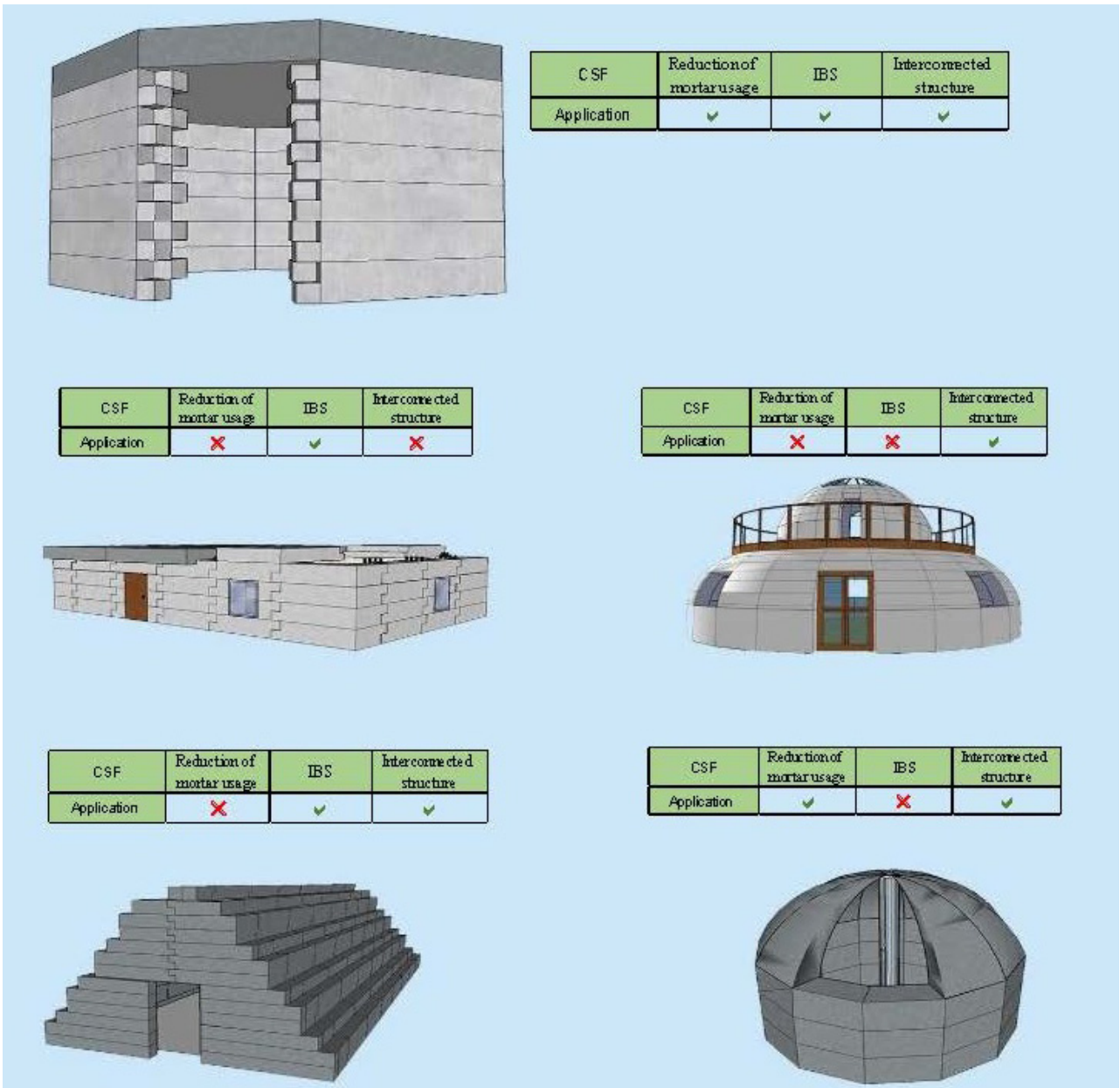
	Knowledge based	Industrial cooperation	Societal	Economy	Agile Procedure	Environmental impact	Biosphere Stewardship	Recovery	Adoption	Absorption
Interconnected structure	2.5	3.7	3.5	4	4.8	3.5	5	3.7	4.2	4.8
IBS	2.7	3.3	3.5	3.9	4.5	3.3	4.3	3.9	3.9	4.5
Reduction of mortar usage	3.6	3.8	3.7	4	4.1	3.1	4	3.8	3.2	3.5
Modularity	3.9	3.5	3.9	4.2	4.5	3.4	4.4	3.6	3.9	4.1
Strengthening by High tech	3.7	3.4	3.9	4	4	3.7	5	4.1	4.3	4.1
Symmetric structure	3.8	4.1	4.3	4.4	4.8	3.7	4.6	3.9	4.2	4.3
Local material usage	4.1	3.6	4.1	4.3	4	3.1	4.1	4.1	3.8	4
Using by-product materials	3.4	3.9	4.1	4.3	3.5	4.5	4.1	3.8	3.6	4
Strengthening by changing material	4.2	3.8	4.7	4.7	4	4.8	4.8	4.3	4.6	4.6
Integrated supply chain management	4.1	4.2	3.7	3.9	4.3	4.3	4.3	3.4	3.5	4.1
Workability	3.8	4	3.6	4	4.5	3.2	3.8	2.8	3.2	3.7
Re-fabrication ability	3.3	3.9	4.2	4	3.8	4.8	4.6	3.6	3.6	4.1
Easiness of fabrication	4.5	4.5	4.2	4.4	4.8	3.6	4.8	4.7	4.4	4.8
Multi-face design	4.2	3.6	4.3	3.9	5.1	3.5	4	3.6	4.3	4.2
Light weighting	3.8	3.5	4.2	4.3	3.6	3.7	4.7	3.9	4.2	4.1
Conventional design	3.3	3.5	3.5	4	3.5	3.8	4.1	3.4	3.7	4
Type of Criterion	+	+	+	+	+	+	+	+	+	+
W	11	9	9	10	11	8	9	9	9	9

Table 5.
The evaluation of each factor based on resilience and sustainability approach.

	ν=0,75	ν=0,25	ν=0,5	(R)	(S)
Interconnected structure	0.0598	0.0779	0.0202	11	47.9884
IBS	0.0882	0.0827	0.1198	10	64.7002
Reduction of mortar usage	0.2338	0.2647	0.2184	9	71.0882
Modularity	0.5039	0.4962	0.5853	7.5	52.8199
Strengthening by High tech	0.5239	0.5304	0.5866	8.75	49.0635
Symmetric structure	0.5617	0.544	0.6019	5.1765	33.6614
Local material usage	0.6027	0.5699	0.6272	8	54.2859
Using by-product materials	0.6053	0.6037	0.6359	11	54.192
Strengthening by changing material	0.6156	0.6163	0.6624	7.5625	19.2419
Integrated supply chain management	0.624	0.6948	0.6682	10	53.1284
Workability	0.6295	0.704	0.6969	9	70.8698
Re-fabrication ability	0.6431	0.7228	0.7547	8.9375	52.0228
Easiness of fabrication	0.7902	0.757	0.8583	5.6471	17.9953
Multi-face design	0.8318	0.8263	0.9013	10	46.3106
Light weighting	0.8743	0.8719	0.9044	10.3125	49.6889
Conventional design	1	1	1	11	71.788

Table 6.
The result of VIKOR evaluation for the best performed critical success factor.

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Figure 10.
*Comparetive graph for alternative
resilient and sustainable modular shelter*

The final design of shelters based on the industrial building system and modular system is drafted accordingly in figure 11.

The maximum stress for components and connections was simulated and it was in the acceptable range. The connections are completely mortar-less and modular. It can help developers to erect, assemble, unassembled and reassembled it. Figure 12 shows the maximum compressive stress in concrete components and figure 13 illustrates the maximum compressive stress in connections due to explosive design load.
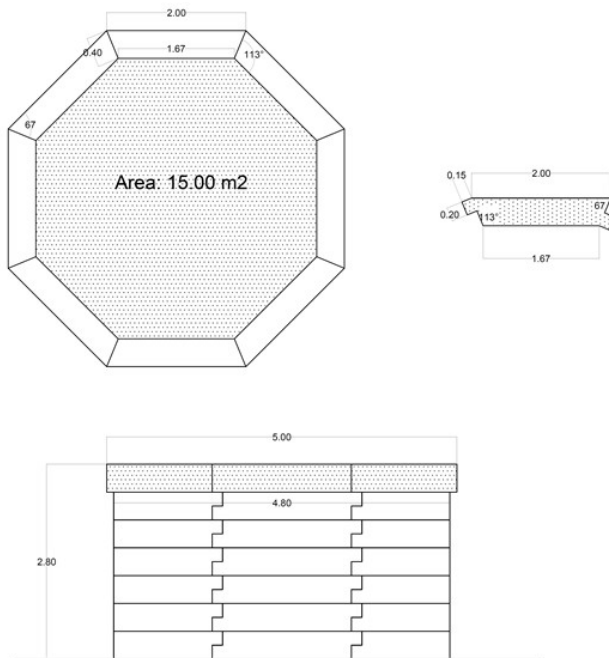
4. CONCLUSION

This study covers comprehensively the development of modular shelter as a sustainable and resilient modular system for the disaster-affected area as a temporary shelter in Iran. Accordingly, the main three critical success factors for resilience and sustainability of this designed modular system are extracted among all of the important CSFs as Reduction of mortar usage, using IBS and interconnected structure. All suggested alternatives are compared based on these three main CSFs. Finally, the symmetric orthogonal design was selected as the most successful design. This modular system also simulated under explosion load. Interconnectivity, modularity, mortar-less erecting, disassembling and reassembling abilities are some of the important factors, which improve rapidity, transformability of this structure. Thus, this modular system helps to improve technical feasibility while the total system is expandable and connectable. All three capacities of resilience are satisfied by this modular design. Robustness and redundancy are satisfied as sub-capacities of absorption. Substitution and recover-ability are also satisfied as sub-capacities of adoption and recovery.

Figure 11.
A modular system for shelter.

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Figure 12.
The maximum compressive stress in concrete components.
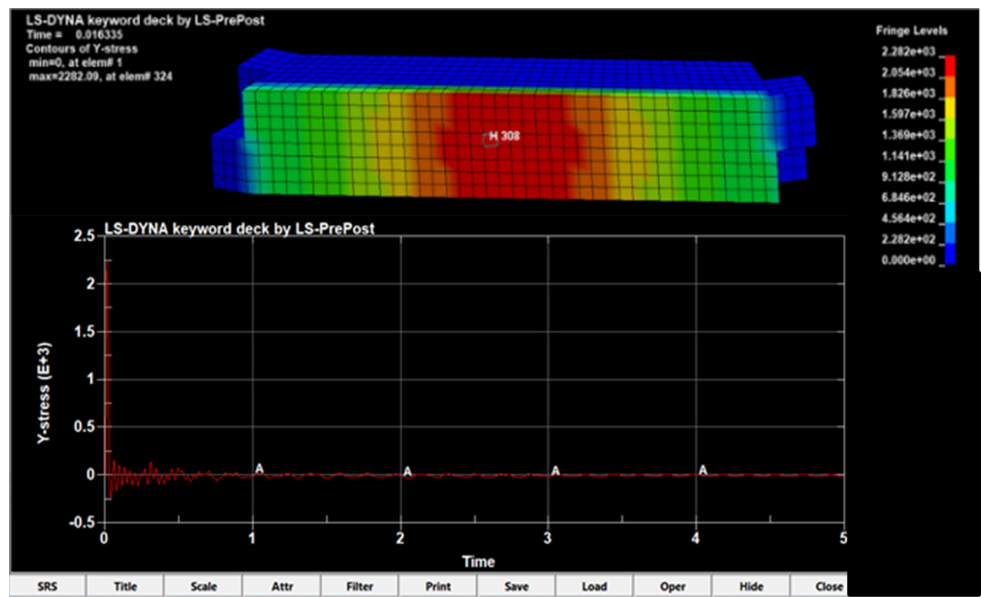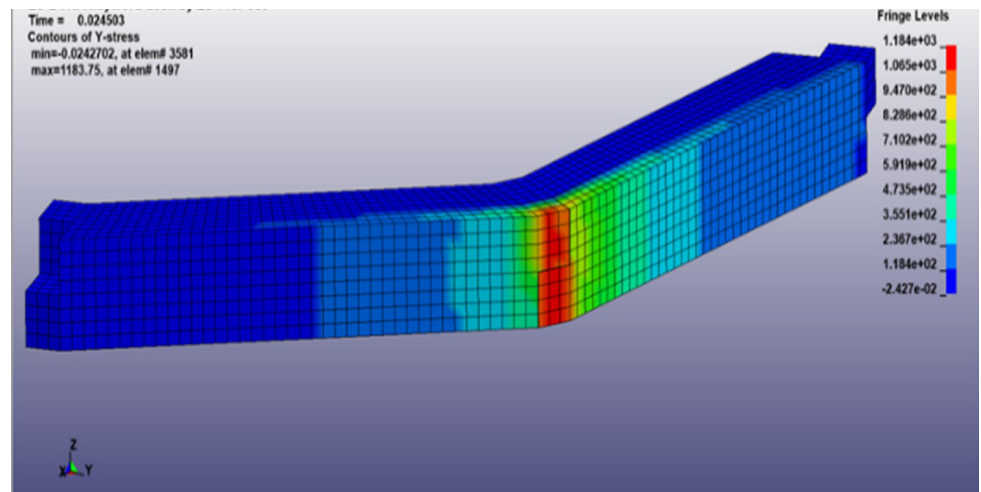

Figure 13.
The maximum compressive stress in connections due to explosive design load.

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