1st Croatian Conference on Earthquake Engineering
1CroCEE
22-24 March 2021 Zagreb, Croatia

DOI: https://doi.org/10.5592/CO/1CroCEE.2021.181

Overview of post-earthquake housing alternatives for enhanced architectural and structural performances

Azin Shahkar[1], Caner Gocer[2], Oguz C. Celik[3]

[1] Istanbul Technical University (ITU), Graduate School, Maslak, Istanbul, Turkey, *azin.shahkar@yahoo.com*

[2] Istanbul Technical University (ITU), Department of Architecture, Taskisla, Taksim, Istanbul, Turkey, *gocercan@itu.edu.tr*

[3] *Professor*, Istanbul Technical University (ITU), Department of Architecture, Taskisla, Taksim, Istanbul, Turkey, *celikoguz@itu.edu.tr*

Abstract

Natural disasters (including earthquakes) negatively impact the physical environment and human being in many ways. Among them, post disaster housing needs have triggered multidisciplinary approaches to better address and resolve this problem. The urgent need for shelter is very high, especially after a devastating earthquake. In seismically vulnerable areas, post-disaster housing is one of the options that could be considered for mitigation after the quakes' sorrow. Post-disaster housing with different plans, constructions, and structural features has been applied with many materials and systems in the world. Based on the duration of occupancy and stability of the structure, post-disaster housing can be categorized into four: emergency shelters, temporary shelters, temporary housing, and permanent housing. Note that temporary housing could be transformed into permanent housing units. As the place of establishment, climatic condition, duration of occupancy, and user's expectations are effective in the type of post-disaster housing, an identical model could not be useable for all regions around the world. However, evaluation of these parameters for the definition of the effective criteria and sub-criteria for different geographical locations is possible. In this respect, the implementation of temporary houses in various regions after an earthquake seems to be a rational solution. In this paper, temporary dwellings implemented in various regions of the world have been examined and evaluated. Based on such evaluations, sub-criteria of the temporary houses following an earthquake are determined depending on plan, material, constructive establishment, construction system, and structural features. Results from this study would provide significant data for both architectural and structural designs of new post-disaster housing and for the rehabilitation of existing post-disaster housing.

Key words: post-disaster housing, earthquake, architectural performance, structural performance

1 Introduction

After a disaster, demand for contemporary shelters for people who missed their dwelling is majorly addressed by either governmental or private institutions. Based on the duration of occupancy of the shelters post-disaster housing is categorized into two main categories. One is for the immediate response to the dwelling demand in the damaged area that is entitled as the "immediate shelter" while; the other one is permanent and is built for the long term settlement named as the "permanent housing" (Turan & Cengizkan,, 1983). The difference between these two types of post-disaster housing is significant especially from architectural design perspective. For example, "permanent housing" has close features to ordinary housing under normal circumstances while; the "immediate shelter" totally differs and is a unique category for itself (DİKMEN, 2005). Each of these two categories includes two sub-groups. Sub-groups of the "immediate shelters" are emergency and temporary shelters. Based on the short-term occupancy, these sub-groups require a limited financial budget and give a short-term occupancy for the few basic services (Cole, 2003). As for the sub-groups of "permanent housing", temporary and permanent housing are considered. Since these groups give services for a longer period for a wider range of utilities, they require a stronger structure with a higher financial budget (Akünal,, 1986).
Selection of the right type of post-disaster housing requires identifying the needs and the knowledge of the shelter. In this paper, the above-mentioned criteria of post-disaster housings are discussed in plan, material, construction, and structural performance. Moreover, eight case studies of post-disaster housing around the world are evaluated based on four main domains of the user's expectation, structural feature, physical feature, and constructional features. The aim of this evaluation is to possibly achieve the optimum form, structure, and constructional features for post-disaster housings to address the victims' dwelling requirements in an efficient and proper way. The developed evaluation chart together with a proposed ranking system is indicated by scaled colors. A parameter that is fulfilled by the case study in an optimum way indicated in green and the poor function indicated in crimson.

2 Post-disaster housing

The four main subgroups of a post-disaster housing are; (Cole, 2003):

- Emergency shelter,
- Temporary shelter,
- Temporary housing, and
- Permanent housing.

Each of these subgroups varies based on the occupancy duration, structural stability, and type of materials used. The following presents these four subgroups of housing in detail, Figure 1.

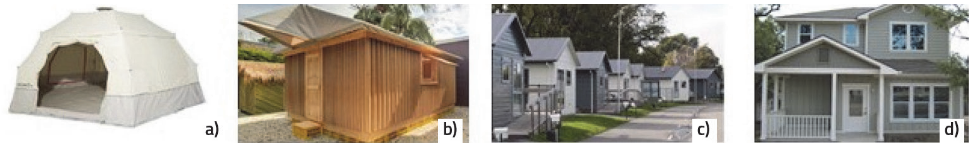


Figure 1. a) emergency shelter; b) temporary shelter; c) temporary housing; d) permanent housing (DİKMEN, 2005)

2.1 Emergency shelter

This type of shelter is used for brief periods to deliver life-saving support and is the most basic kind of shelter support (Shelter after disaster, 2015), This kind of shelter commonly does not allow for the extensive preparation of food or prolonged medical services. Figure 1.a shows a sample of an emergency shelter (Cole, 2003).

2.2 Temporary shelter

These types of housings are used for sleeping rooms, medical service rooms and provides basic needs of victims (Cole, 2003). This type of shelter is meant for short-term use; a simple tent or a public mass shelter is used for a few weeks following a disaster. According to the IFRC, the duration of stay in such shelters may be limited, and therefore, prioritizing speed and limiting costs should be taken into account when constructing this kind of shelter (Shelter after disaster, 2015). Figure 1.b shows a sample of temporary shelters.

2.3 Temporary housing

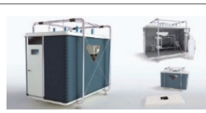
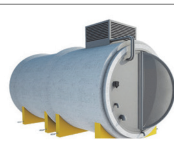
Temporary housing is the stage of a disaster housing built after the short period of a disaster occurs, providing better living conditions than temporary and emergency shelter, but it is still considered as a temporary solution to evacuate the displaced (Gursu, 1986). However, this type of housing is distributed for long-term periods such as six months to three years such as rental houses and prefabricated units, but they are located at a very critical point where the temporary house might turn into a permanent one. Figure 1.c shows a sample of temporary housing.

2.4 Permanent housing

Permanent housing, which is the last and best stage of housing type, basically purpose to the final solution after disaster providing individual houses like to feel live in their real homes and stay much longer than the other types of housing (Akünal, 1986). Figure 1.d shows a sample of permanent housing.
Based on the above discussion in chapters 2.1 to 2.4, the temporary post-disaster housing type is a rational option. Since this type of housing is stable enough to be used in a wide variety of utilities for a considerable duration with a cost-effective budget. This

means that this type of housing would provide a better function than the emergency, and/or temporary shelters. It is also financially effective than permanent housing. That is why, in this paper, the considered case studies are from this category.

Table 1. Case studies of temporary houses with their properties

Name of the system	Images	Structural properties	Shape of the plan	Other properties	Area	Country
Abeer Seikaly		-high strength -Tensegrity -Stretchable material	Looks like a dome	-Air circulation -Water storage - Battery	19 m^2	USA
Abelnock		-Steel insulated panel system -Adjustable footing foundations	Rectangle	-Water storage - Solar panel	--	USA
Hex House		SIP system	Hexagon	-Water storage -Solar panels	35 m^2 67 m^2	USA
New York post Disaster homes		Solar shading Thick insulation	Rectangle	Ability to be stacked like Legos	---	USA
Tentative		SIP system	Rectangle	-Fiberglass water -Water storage	9 m^2	Turkey
Ice age shelter		Compact and lightweight steel frame	Dome	Adjustable legs	23 m^2	Russia
IKEA House		Steel frame	Rectangle	Solar reflection	57 m^2	United Nations
O-pad water pipe		Concrete	Cylindrical	Low-cost	30 m^2	China

3 Temporary post-earthquake housing samples

Several design ideas for temporary housing solutions that have been built all over the world are listed and reviewed. The survey of these houses is based on factors such as structural and physical characteristics, type of plan, area, and country in which it was built. The main reason for examining these factors is to determine the impact of such factors on the optimal design of a prefabricated housing unit. A summary of these studies is provided in table 1.

4 Evaluation of temporary post-earthquake housing typologies

In designing prefabricated houses, some points should be considered to identify the problems that exist in this type of house for the residents. For the optimal design of this type of house, there are some parameters that should be considered and evaluated prior to final design. The most important parameters are: 'User's expectation, Physical performance, Construction performance, and Structural performance'. To address these issues, in the first step of research for each general assessment, a sub-assessment is listed, and a brief explanation for each of the sub-assessments is provided. According to these written sub-assessments, the related scores were assigned for each mentioned criterion. The evaluation and scoring system are as follows: 5 grades are defined for the evaluation, namely excellent, good, moderate, bad, and very bad. Each of these is displayed an assigned color. In this respect, green is for excellent, yellow for good, orange for mediocre, red for bad, and crimson for very bad. In a more numerical way, these colors could be referred as follows: green (5), yellow (4), orange (3), red (2), and crimson (1). Note that the overall cost is excluded in this work.

5 User's expectation

One of the most important parameters is the user's expectation. Post-disaster houses are designed for homeless people whose houses have been destroyed by an earthquake. These shelters will be used for an almost long period of time, so they must meet the expectations and demands of the residents. Users' expectation has 7 evaluation subgroups. The first subgroup is safety, meaning that in the early stages of a disaster, shelter is a key component in terms of the mental and physical, safety of the homeless. In addition to the victim's survival, the house must be able to withstand severe weather conditions and increase disease resistance (emergency.unhcr.org, 2015). The second subgroup is considered to be thermal comfort. Definition of home for human beings is a place that has any comfort in the scope of whether physical, mental, or thermal comfort. Temperature is the most important factor for the thermal comfort of residents, many climatic factors and the layout of houses also play an important role either. (Boduch & Fincher, 2009) The third subgroup is privacy. The first place that comes to mind in the discussion of privacy is the house where the person lives. Housing is the place of residence and tranquility of people who can live and rest in peace and security. The fourth subgroup is security against theft. Therefore, these types of houses must also be designed in such a way that they are sufficiently secure against theft, possible attacks by thieves, and possible attacks by terrorists. The fifth subgroup is ergonomics and space circulation in which, ergonomics or human factors are other factors to better understand the needs of users at this type of house. After a catastrophic accident, houses designed based on human anatomical needs are one of the design priorities. The sixth subgroup is identity. A great design can maximize the ability of dwellers to feel identity and pride in their place of residence. Assuming a homeless person, after losing their home and taking refuge in a post-disaster house that has no previous experience of living in these houses before, this condition highlights the necessity of the context of the identity-based design of the post-disaster housing (Bemanian & Gholamirostam, 2010). The seventh subgroups are flexibility. Here, the term flexibility refers to "the ease of setting up a system to handle different conditions and the ease of adapting to the situation in different climates." (Tafahomi & M. Egyedi, 2008)

Table2. The evaluation of temporary post-earthquake housing typologies according to user expectation criteria

Excellent / Good / Moderate / Bad / Very-bad

Samples		Safety	Thermal perform.	Privacy	Security	Ergonomics	Identify	Flexibility
Hexagon	Hex house	Excellent	Bad	Bad	Excellent	Excellent	Excellent	Excellent
Rectangle	New York post-d.	Excellent	Excellent	Good	Excellent	Excellent	Excellent	Good
	Ablenock	Excellent	Very-bad	Good	Excellent	Very-bad	Good	Moderate
	IKEA	Very-bad	Bad	Excellent	Excellent	Very-bad	Very-bad	Moderate
	Tentative	Very-bad	Very-bad	Very-bad	Excellent	Very-bad	Very-bad	Very-bad
Hemi-sphere	Abeer seykali	Bad	Bad	Good	Very-bad	Bad	Bad	Very-bad
	Ice-age shelter	Very-bad	Very-bad	Moderate	Bad	Bad	Bad	Very-bad
Cylindrical	O-pad shelter	Moderate	Moderate	Moderate	Good	Moderate	Moderate	Bad

6 Physical performance

Another main purpose of this study is to focus on the requirements that should be considered in the physical performance of this type of house for the homeless during the design. Material is one of the main factors that identify the physical performance of post-disaster housing. Physical performance of the materials is considered for the emulation. This parameter is divides into 6 sub-assessments. The first sub-assessment is fire resistance being, another significant issue that would be frightening for the earthquake victims. Therefore, it is a vital point that a post-disaster housing unit be resistant against a potential fire. For this aim, the considered materials for the construction of the housing should be based on the available standards to meet the mandated requirements. The second parameter is thermal performance which plays a very important role in this type of housing units because the criteria for thermal performance can vary in different climates. Considering local conditions of the region, they must be compatible with the surrounding climatic conditions and should provide the well-being of the residents of the house (Potangaroa & Hynds, 2008). The third subgroup is water impermeability, that protects against external factors and seasonal changes. Therefore, required insulation for preventing water leakages inside the house should be considered in design for the physical and psychological health of the residents (Yuksel & Hasirci, 2012). The fourth subgroup is the wind performance in which, the wind forces/ pressures play an important role in creating danger and creating a sense of terror for the residents of these houses. Therefore, when designing such types of housing units, the local wind values in the construction area should be considered and used in design accordingly. The fifth subgroup is solar performance (utilization of sunlight), due to the fact that the house benefits from sunlight, which is the source of peace and light of the house. So, the number and size of windows in each unit based on the amount of penetrating sunlight inside the unit are factors to be considered for evaluation. These types of houses must benefit from natural light and natural heat that should be considered in the design. The sixth subgroup is sound impermeability. Inducing a sense of peace, privacy, and normal life like before is the best thing that can be done to a homeless person, but since these types of houses are not carefully designed, it has become a big problem.

Table 3. The evaluation of temporary post-earthquake housing typologies according to physical performance criteria

Excellent / Good / Moderate / Bad / Very-bad

Samples		Thermal perf.	Water perf.	Moisture perf.	Solar perf.	Wind perf.	Sound perf.	Fire resistance
Hexagon	Hex house	Excellent	Excellent	Good	Good	Moderate	Good	Excellent
Rectangle	New York	Excellent	Excellent	Good	Moderate	Excellent	Excellent	Excellent
	Ablenock	Excellent	Excellent	Good	Good	Moderate	Excellent	Excellent
	IKEA	Very-bad	Moderate	Excellent	Very-bad	Good	Good	Good
	Tentative	Very-bad	Excellent	Excellent	Bad	Very-bad	Moderate	Very-bad
Hemi-sphere	Abeer seykali	Bad	Very-bad	Excellent	Very-bad	Good	Very-bad	Very-bad
	Ice-age shelter	Very-bad	Excellent	Excellent	Moderate	Good	Excellent	Moderate
Cylindrical	O-pad shelter	Excellent	Good	Good	Bad	Bad	Excellent	Excellent

7 Construction performance

Construction stage is one of the most important and accurate steps in designing these houses. Such units must be designed and executed with high sensitivity and without error, because there is nothing more dangerous than living in an unsafe house for a homeless person. This parameter is divided into 6 subgroups. The first subgroup is easy to transport when a natural disaster such as an earthquake with a high magnitude damages an area and destroys the houses in that area. Probably, the first essential thing that must be sent to that area is the post-disaster houses in which the earthquake victims can live. Therefore, in designing these houses, prefabricated houses should be considered as an easy transportation item so that a large number of houses can be transported in a semi-truck (Humanitarian Shelter and Settlements Guidelines, 2017). The second subgroup is easy to set-up. As explained in the previous subgroup, setting up a prefabricated house in a short time is one of the advantages of such housing units that would be a big plus in design. The third subgroup is persistency against seasonal conditions. Post-disaster housing units must be highly resistant to changing seasons such as snow, rain, tornadoes, floods and etc. In addition, they must be fully compatible with their surrounding environment (emergency.unhcr.org, 2013). The fourth subgroup is integration with service systems. After a natural disaster, the house service system for the proposed units should be the same as ordinary houses, such as electricity, water services, and air conditioning required by the residents. The fifth subgroup is building and ground adaption. It is apparent that prefabricated houses should always be built on flatlands and topographies, but in exceptional cases, the building and ground on which it will be erected must be in harmony and balance even when the unit is placed on uneven places. The sixth and last subgroup is reusability, the most important item in evaluating post-disaster houses. Reuse of these houses after each disaster is a must. They should have a good service system for several years and a long period (Félix, Branco, & Feio, 2013).

Table 4. The evaluation of temporary post-earthquake housing typologies according to the construction performance criteria.

Excellent | Good | Moderate | Bad | Very-bad

Samples		Easy to set-up	Easy to transport	Reusability	Building and ground adaption	Integration with service systems
Hexagon	Hex house	Moderate	Good	Excellent	Bad	Excellent
Rectangle	New York post-disaster	Good	Very-bad	Excellent	Bad	Excellent
	Ablenock	Moderate	Excellent	Good	Excellent	Excellent
	IKEA	Good	Excellent	Very-bad	Very-bad	Very-bad
	Tentative	Bad	Excellent	Bad	Bad	Very-bad
Hemi-sphere	Abeer seykali	Good	Bad	Very-bad	Very-bad	Very-bad
	Ice-age shelter	Bad	Very-bad	Moderate	Excellent	Very-bad
Cylindrical	O-pad shelter	Good	Very-bad	Good	Bad	Moderate

8 Structural performance

After the construction phase, evaluating the structural performance of the prefabricated house is significant because examining the durability and resistance of this type of house to the expected loads, is one of the most important issues. This parameter is divided into 4 subgroups. The first subgroup is strength against earthquake loads. In the discussion of evaluating the performance of the unit against earthquakes, one of the important and basic components is weight. In this manner, lightweight units have a great effect on contracting with earthquake loads. The second subgroup is strength and stability against wind loads/ pressures. Note that post-disaster housing units usually possess lesser weights that may lead to stability problems when wind effects are not well studied. The third subgroup is performance against snow loads. Increasing the slope of the roof of this type of houses, results in lesser snow accumulations. In fact, worse performance would be expected for flat roofs, since resistance against snow loading is reduced. However, it is prevalent that flat roofs could also be safe when the roof system is well engineered for snow accumulations. Scoring is done not only according to the slope and load of snow but also according to the structural system and material strength of these types of houses. As such housing units are temporary, lower safety factors (or higher allowable stresses) could be allowed in structural design since the expected natural loads may not be that much high when considering the lifetime of these units.

Table 5. The evaluation of temporary post-earthquake housing typologies according to structural performance criteria.

Excellent / Good / Moderate / Bad / Very-bad				
Samples		**Durability against EQ loads**	**Durability against wind loads**	**Durability against snow loads**
Hexagon	Hex house	Good	Moderate	Excellent
Rectangle	New York post disaster house	Excellent	Good	Excellent
	Ablenock	Good	Moderate	Excellent
	IKEA	Good	Moderate	Moderate
	Tentative	Moderate	Very-bad	Moderate
Hemi-sphere	Abeer seykali	Very-bad	Very-bad	Very-bad
	Ice-age shelter	Good	Excellent	Excellent
Cylindrical	O-pad shelter	Excellent	Excellent	Good

9 Conclusions

Post-disaster homes are divided into 4 types, among which temporary housing is the best choice for long-term and optimal use for earthquake victims being the homeless. To better understand the design of this type of housing unit, 8 cases from temporary housing types all around the world are examined with all features such as structural information, type of plans, area, country of manufacture, and other physical features. The results and recommendations obtained in this study are summarized below:

Four general assessments are recognized and listed as user's expectation, physical performance, construction performance, and structural performance. Each general assessment consists of some sub-assessments that explain and evaluate each case studies.

In the user's expectation part, the New York post-disaster home is the best option than other case studies since it has a high-performance level in terms of safety, thermal comfort, security, ergonomics, and identity. In addition, this system also shows relatively good performance in the case of privacy and flexibility.

Considering physical performance, the New York post-disaster home is the optimum choice among the listed case studies since it has a high-performance level in terms of thermal, wind, water, sound performance, and fire resistance. Also, the system shows relatively good performance in the case of moisture and solar performance.

As for the construction performance, Abelnock home displays a better performance than other case studies since it has high-performance level in terms of easy to transport, building and ground adaption, and integration with service systems.

O-pad home option is the best solution for structural performance since, it has high-performance level in terms of strength/overall stability against earthquake, wind, and snow loads.

Evaluation results of the design, physical, construction, and structural properties of the applied post-earthquake houses are important for the development (or improvement) of future's post-earthquake houses. Considering these results in new applications it will help the designer to use available resources rationally. By this way, comfort and security of residential users can be guaranteed at the best level.

References

[1] Boduch, M., Fincher, W. (2009): Standards of Human Comfort (Relative and Absolute). UTSoA - Seminar in Sustainable Architecture (pp. 1-9). Texas: The University of Texas at Austin School of Architecture.

[2] Boduch, M., Fincher, W. (2009): Standards of Human Comfort (Relative and Absolute). UTSoA emergency.unhcr.org. (2013, May 3). Retrieved from The UN Refugee Agency: https://emergency.unhcr.org/entry/36774/emergency-shelter-standard

[3] Boduch, M., Fincher, W. (2009): Standards of Human Comfort (Relative and Absolute). UTSoA Gunawardena, T., Duc Ngo, T., Mendis, P., Aye, L., Crawford, R. H. (2014). Time efficient post-disaster housing reconstruction with prefabricated modular structures. Open House Internationa, 59-69.

[4] Boduch, M., Fincher, W. (2009): Standards of Human Comfort (Relative and Absolute). UTSoA Aghniya, E., Montazer, M., Nabavi, M. (2014). The role of privacy in Islamic-Iranian architecture. National conference of native architecture & urbanism of Iran, (pp. 1-10). Tehran.

[5] Akünal, S. (1986): Proposal for an Alternative Post-Earthquake Housing and Contribution of this Alternative Case to the Existing Condition. Ankara: METU,Unpublished master's thesis.

[6] Asefi, M., Ahangar Sirus, F. (2012): Transformable Shelter: Evaluation and New Architectural Design Proposals. Social and Behavioral Sciences, 961-966.

[7] Bemanian, M.R., Gholamirostam, N. (2010): Identity-building elements in the traditional architecture of Iranian houses- a case study of the house of the Rasulyaneyazd. Journal of Islamic Art Studies, 55-68.

[8] Cole, P.M. (2003): An Empirical Examination of the Housing Recovery Process Following Disaster. Texas: Texas A&M University.

[9] Dikmen, N. (2005): A Provision Model And Design Guidelines For Permanent Post-Disaster Housing In Rural Areas Of Turkey Based On An Analysis Of Reconstruction Projects In Çankiri. Ankara: A Thesis Submitted To The Graduate School Of Natural And Applied Sciences Of Middle East Technical University.

[10] emergency.unhcr.org. (2015): Retrieved from The UN Refugee Agency: https://emergency.unhcr.org/entry/57186/shelter-solutions

[11] Félix, D., Branco, J.M., Feio, A.O (2013): Temporary housing after disasters: A state of the art survey. Habitat International, 136-141.

[12] Gursu, H. (1986): Design Recommendations for Temporary Pneumatic Structures in Design Areas. Ankara: METU, Unpublished master's thesis.

[13] Hjalmarson, J. (2014): Ergonomics at Home- Design for Safe Living and Home Care (Doctoral thesis). Stockholm: School of Technology and Health- Royal Institute of Technology, (2017).

[14] Humanitarian Shelter and Settlements Guidelines. European Civil Protection and Humanitarian Aid Operations. (2015): Minimum Standards in Shelter, Settlement and Non-Food items. The Sphere Project.

[15] Nations, U. (2014). The Right to Adequate Housing. Geneva: Office of the United Nations High Commissioner for Human Rights.

[16] Potangaroa, R., Hynds, M. (2008): Thermal Comfort Tools for Emergency Shelter in Major Disasters. Proceedings from International Conference on Building and Research (BEAR) (pp. 1457-1472). Salford: School of the Built Environment, University of Salford, UK. (2015). Shelter after disaster. Switzerland: International Federation Of Red Cross and Red Crescent Societies.

[17] Tafahomi, M.M., Egyedi, T. (2008): Defining Flexible Standards for Post-Disaster Emergency Sheltering. Delft: Delft University of Technology.

[18] Turan, M., Cengizkan, A. (1983): An Ecological Study of Three Housing Types In a Rural Environment Prone to Disaster. Socio-Architectural Aspects of Housing in Earthquake-Prone Areas of Turkey, 64-65.

[19] Yuksel, B., Hasirci, D. (2012): An analysis of physical and psychological expectations of earthquake victims from temporary shelters: A design proposal. METU Journal of the Faculty of Architecture, 225-240.