Pre-Design of Transitional Rural Housing for Syria with Recycled Rubble from Destroyed Buildings

Naomi Morishita¹, Salah Haj Ismail², Rukiye Cetin²

¹ TU Wien, Research Center for Building Physics and Sound Protection, Institute of Construction and Technology, Faculty of Civil Engineering, Karlsplatz 13, 1040 Vienna, Austria
² Ankara Yıldırım Beyazıt University, Ayvalı Mh. 150. Sk., 06010 Etlik / Keçiören Ankara, Turkey
naomi.morishita@tuwien.ac.at

Abstract. The scale of destruction caused by seven years of on-going war in Syria has caused mass migration of the Syrian people within and outside of Syria. The situation calls for a means to provide the internally displaced persons (IDPs) within Syria with humane post-war affordable housing that can be quickly and easily built with few resources. Fossil fuel resources are not only scarce because of the war, but are also being used as a valuable commodity to finance the war economy, and thus, housing should minimize consumption of energy for heating and cooling because of the fossil fuel scarcity while providing high thermal comfort to the inhabitants. The housing parameters for the proposed solution are to integrate as much of the local building materials in the Aleppo region as possible using existing regional building traditions. Imported products such as building materials, machinery, equipment, as well as foreign labour and know-how are to be kept to a minimum while incorporating recycled rubble from destroyed buildings. A comparative study of current disaster relief housing illustrates the appropriateness of each design solution in relation to the above-proposed housing parameters. A detailed analysis of the physical properties of an existing case study building in Dabiq, a town 40 km northeast of Aleppo, outlines the strengths and weaknesses of the building tradition to determine which aspects of the construction may be improved for better thermal comfort and resistance against earthquakes. The simulation results from WUFI Plus show the building behaviour of the case study house. This paper offers a concept for transitional single-family housing for IDPs based upon the adobe tradition in the rural areas of Aleppo. Reducing the heating and cooling loads can also drastically reduce fossil fuel requirements during the construction and operation phases of the single-family homes while maintaining a high level of indoor thermal comfort. Traditional construction techniques can potentially employ more craftspeople combined with manual labour instead of using automated systems. The relative safety of the rural areas can thus be increased, as storage and use of fossil fuels in the villages will be decreased allowing for quicker resettlement with less disruption from war.

1. Introduction
Since antiquity, Syrians have migrated to rural areas during times of conflict, to return to urban centres once urban infrastructures are re-established [1, 2]. Thus, two types of people are expected: diasporans returning to the rural region around Aleppo, and migrating Syrians from other regions. The proposed post-war housing solution in this paper is based upon the local rammed earth housing tradition found in
the rural areas in Northern Syria. The vernacular design is to be optimized to be easily buildable and minimize energy consumption while offering high thermal comfort. The structural resistance is to be improved against earthquakes while reusing rubble from destroyed buildings.

2. Rebuilding Housing After Wars and Natural Disasters

A comparative study of current disaster relief housing is conducted to illustrate the appropriateness of each design solution in relation to the above-proposed housing parameters.

As a response to the major 2010 earthquake in Haiti, Konbit Shelter has been rebuilding housing using “Super-Adobe” construction, a design developed by the architect Nader Khalili and the non-profit organization Cal-Earth (California Institute of Earth Art and Architecture), [3], 4]. For this building technique, long tubular sacks made out of fabric or plastic are filled with a mixture of 90% sand, clay, fibrous material (sticks, straw and/or manure), water, and 10% cement. The earth bags are layered concentrically to create domed compression structures as seen in Figure 1.

![Figure 1. Completed "Konbit Shelter" house in Haiti (left) [3]; Baniniajar Refugee Camp Emergency Shelter, Khuzestan, Iran (right) © CalEarth [5].](image)

The walls and roof are able to share the overall structural load stabilising the building with little additional wood required. Walls are relatively thin with an approximate thickness of 30 cm [6]. The upper trefoil window in Figure 1 is made from recycled oil drums [3]. The project continued until December 2016 and has been successful because of close collaboration between Konbit Shelter and the local inhabitants, allowing for the individual needs of the villagers to be continually adapted in the architectural design. Local vernacular elements have been handcrafted as building decorations [7].

Fourteen disaster relief shelters for the Baniniajar Refugee Camp in Khuzestan, Iran were commissioned from CalEarth in 1995 as an initiative of the United Nations Development Program (UNDP) Tehran, in cooperation with the United Nations High Commissioner for Refugees (UNHCR) Tehran [5, 8]. The structures are visible in Figure 1. It is assumed that the structures were destroyed after the camp was dismantled. The social context of the housing units was misunderstood leading to inappropriate division of interior spaces mixing the sexes in a large room instead of providing separate rooms for different sexes. Cement blocks were produced and sold to generate income for the refugees in the camp. The refugees were also able to utilize cement blocks to build their own homes [8]. The same opportunities were not possible with the earth shelters, which resulted in a negative bias against earth construction. The same design is widely accepted in Haiti, but rejected in Iran due to the lack of inhabitant interaction in the design process.

“Better Shelter”, Ikea Foundation’s flat-packed refugee shelter project together with the UNHCR, was designed to last up to three years. The shelters are an alternative to tents and are designed as temporary shelters that the refugees can build on their own like Ikea furniture from instructions in flat-packed cartons, Figure 2. The shelters are being used on a wide scale in Africa, Asia, Europe and the Middle East, [9]. However, all materials must be imported, as the building materials are factory-manufactured steel and recyclable polyolefin panels.
Hex House by Architects for Society is a modular housing unit composed of galvanized steel and insulated metal panels. Similar to the Better Shelter, the housing units are to be shipped for assembly on site [11]. The International Humanitarian Relief Project, “We Will Be Back” is a series of 163 caravans on wheels that house Syrian refugees in the Northern Beqaa – Aarsal region of Lebanon [12], Figure 3. The refugees in the camp also build their homes themselves. The idea is that the refugees can return to Syria with their temporary homes and live in them until their new homes are built.

Transsolar has a climate-responsive school design for refugees in Bekaa, Lebanon. A wooden structure with earth tubes similar to the SuperAdobe technique is proposed for the walls with a wooden roof finished with corrugated steel, and hollow-core ducts under the finished floor to provide cooling. The design has been optimized using whole building simulations within the design process. It is planned to measure interior conditions and to incorporate user feedback in the designs to improve future buildings [13]. None of the above projects have proposed a new design based upon an existing regional building tradition. Only Konbit Shelter has utilized local vernacular elements with local artisans to decorate homes. Half of the case study projects propose self-assemblable housing kits with fully imported materials. The others use earth tubes to incorporate local soil for building material.

3. The Adobe Tradition in Rural Areas Around Aleppo
There are six to seven different earth construction methods in the rural areas around Aleppo; however, the most common techniques are cob construction and rammed earth. For this study, an existing rammed
earth house in the town of Dabiq has been chosen for a detailed analysis of the physical properties. The town lies approximately 40 km northeast of the City of Aleppo and 10 km south of the Turkish border.

4. The Case Study House
The case study house is a single-family single-storey house originally built in 1932 and was destroyed in 2014 by an ISIS bombing attack. The family has six members: two parents and four children. The floor plan and front elevation are visible in Figure 4. The floor plan and building section are based on a site survey taken by S. Haj Ismail. The spaces in the house are divided into three main zones: guest room, main room, and the “wet rooms”; rooms where water is used i.e., kitchen, bathroom and WC. All photos and sketches in Part 4 are also by S. Haj Ismail.

![Figure 4. House section (top-left), floor plan (bottom-left), and street view (right) of the case study house](image)

The mixture used for the rammed earth walls and the exterior finish for the roof structure is composed of clay with a typical composition as outlined in Table 1. An earth sample was chemically analyzed at a laboratory resulting in the chemical composition shown in Table 1. The earth is mixed together with 15 % wheat or barley straw per weight and fermented for 28 days. After the drying process, the wall resistance under pressure is 1.32 N/mm² with shrinkage of 10 % per weight. The material density ranges from 950 to 1,250 kg/m³ depending upon the professionalism of the workers.

| Layer Number | Material                | Composition in Per Cent (%) |
|--------------|-------------------------|-----------------------------|
| 1            | Aluminium oxide         | 34                          |
| 2            | Silicon dioxide         | 50                          |
| 3            | Magnesium and Lime      | 6                           |
| 4            | Iron oxide              | 8                           |
| 5            | Organics                | 2                           |

The organics contained within the earth composition in Table 1 are fermented straw or animal dung.
4.1 Walls
Rammed earth construction is widespread in the countryside as construction is relatively fast while maintaining low production costs. Exterior loadbearing walls are commonly 40 to 60 cm thick and interior partitions are thinner from approximately 20 to 40 cm in thickness. A row of small rough stones is laid between every second earth layer increasing seismic flexibility in the wall.

The traditional wall construction has a four-layer exterior finish: Sharina, Altaria, Alshaba’a, and Hawara. Each layer is composed of earth mixed with 15% wheat or barley straw fermented to varying degrees in each layer. The first layer, Sharina, is composed of a 3 to 5 cm thick layer of earth mixed with 3 to 4 cm long pieces of straw. The Sharina mixture is left to ferment for two weeks. The second layer, Altaria, is composed of an earth mixture with finer straw pieces with lengths from 1 to 3 cm. The Altaria mixture is fermented for two months. The Altaria earth mixture has fully decomposed straw, is black in colour and has a very soft and fine consistency. A 2 to 3 cm thick layer of Altaria is applied on top of the first (Sharina) layer. The third layer, Alshaba’a, is also composed of a mixture of earth with fermented straw. However, finely ground straw with lengths of up to 1 cm is used in this layer, and the mixture is left to ferment for up to six months. After the fermentation period, the consistency of the mixture is very viscous and sticky with a compact mass and it takes on a pungent odour. The Alshaba’a layer has an insulation effect due to the viscous properties of the mixture and has hydrophobic properties. The outermost layer is Hawara composed of Calcium dioxide produced by mixing Calcium oxide stones with water. Calcium oxide stones are famously abundant in the Aleppo region. The white colour of Calcium dioxide reflects heat from the building. Calcium dioxide absorbs humidity expanding upon contact and thus increases the degree of hydrophobicity of the outermost layer. The four layers altogether are from 6 to 8 cm thick. Figure 5 shows an interior view of the walls.

![Figure 5](image)

**Figure 5.** Finished interior wall of the case study house (left), sketch of connection detail between the floor slab and exterior wall (right) [14]

Alshaba’a and a finishing layer of Hawara or gypsum plaster instead of Calcium dioxide has been used as an internal finish for renovations after 1990. Other internal wall finishes include paint mixed with wood adhesive. The physical properties of the exterior wall without the stone layer are shown in Table 2.

Table 2, Table 3, and Table 4 show the estimated hygrothermal values of the case study house. The values are derived from a detailed quantitative study of the individual materials conducted by S. Haj Ismail. Comparable standard values are taken from DIN 4108-4 [15], DIN EN ISO 10456 [16], Mit Lehm ökologisch planen und bauen [17], and ÖNORM 8110-7 [18] to supplement missing values.

4.2 Roof
The roof rests on the loadbearing rammed earth walls and a wooden poplar post. Greek juniper trees, also called Juniperus excelsa (or Al-lizab in Arabic) are cut circularly or squarely for the roof beams, called "Al Samouk". The structure of the ceiling is made of horizontal main beams, pressed on the joint
post and opposing walls. Above these beams, an impermeable layer of reeds or branches, Hasaira, is laid perpendicular to the direction of the beams, Figure 6. The two central beams supporting the roof structure were added at a later point to support a second storey. A central wooden post (not shown) improves structural stability against earthquakes as it helps to distribute structural load [19].

**Table 2.** Case study exterior wall assembly hygrothermal values

| Wall Layer (interior to exterior) | Density (kg/m³) | Water vapour diffusion resistance factor (µ-value) | Thermal Conductivity (W/m.K) | Thickness (m) |
|----------------------------------|-----------------|-----------------------------------------------|-----------------------------|---------------|
| Hawara                           | 870.000         | 10.000                                       | 0.800                       | 0.002         |
| Alshaba’a                        | 30.000          | 4.100                                        | 0.298                       | 0.015         |
| Compressed Clay-Hay Earth Mixture| 800.000         | 0.500                                        | 0.250                       | 28.600        |
| Sharina                          | 28.500          | 2.350                                        | 0.270                       | 0.050         |
| Altaria                          | 28.500          | 3.850                                        | 0.277                       | 0.030         |
| Alshaba’a                        | 30.000          | 4.100                                        | 0.298                       | 0.015         |
| Hawara                           | 870.000         | 10.000                                       | 0.800                       | 0.002         |

**Figure 6.** Interior roof structure of the case study house (left), exterior view of the flat roof (right)

The next layer of the wooden roof structure is made with burnet or leaves. A multilayered cob level composed of straw bound with clay mortar is laid atop the layer of leaves. Each cob layer is flattened with a cylindrical stone roller with a wooden board on each side. The roller is rolled over the surface using a piece of rope. The use of massive wooden beams is part of the regional adobe vernacular. Rooms are typically 4 m x 4 m, requiring wood members with lengths of 5 to 5.5 m. The physical properties of the roof are shown in Table 3.

**Table 3.** Case study roof hygrothermal values

| Roof Layer (interior to exterior) | Density (kg/m³) | Water vapour diffusion resistance factor (µ-value) | Thermal Conductivity (W/m.K) | Thickness (m) |
|----------------------------------|-----------------|-----------------------------------------------|-----------------------------|---------------|
| Roof Beams (massive Juniperus excelsa logs) | 475.000         | 50.000                                       | 0.120                       | 0.250         |
| Wood Panels                      | 600.000         | 500.000                                      | 0.150                       | 0.015         |
| Reeds (Hasaira)                  | 90.000          | 10.000                                       | 0.075                       | 0.001         |
| Compressed Clay-Hay Earth Mixture| 800.000         | 0.500                                        | 0.250                       | 0.300         |
| Altaria                          | 28.500          | 3.850                                        | 0.025                       | 0.025         |
| Hawara                           | 870.000         | 10.000                                       | 0.800                       | 0.002         |
4.3 Floor Slab

Figure 5 shows the floor to wall connection. The ground floor slab from bottom to top is composed of 15 to 20 cm layer of compacted soil, a minimum depth of 50 cm coarse stone, 15 cm gravel, a layer of earth mixture with 15 % straw content similar to the walls, and the interior floor finish is a covering of Syrian Kilim rugs called “Labbad” in Arabic. The physical properties of the floor slab are shown in Table 4.

Table 4. Case study floor slab hygrothermal values

| Floor Layer (interior to exterior) | Density (kg/m³) | Water vapour diffusion resistance factor (µ-value) | Thermal Conductivity (W/m•K) | Thickness (m) |
|-----------------------------------|----------------|-----------------------------------------------|-----------------------------|---------------|
| Labbad (Kilim Rugs)              | 200.000        | 10.000                                        | 0.060                       | 0.010         |
| Compressed Clay-Hay Earth Mixture | 800.000        | 0.500                                         | 0.250                       | 0.020         |
| Gravel                            | 1800.000       | 0.300                                         | 0.700                       | 0.150         |
| Coarse Limestone                  | 1800.000       | 0.300                                         | 0.700                       | 0.500         |
| Compacted Earth                   | 1800.000       | 10.000                                        | 0.500                       | 0.175         |

4.4 Doors and Windows

All original window frames and doors are made of Greek juniper wood. The traditional window is divide into three horizontal parts but has no glazing. Kilim rugs are secured before the window openings in winter to provide additional resistance to the elements.

4.5 Room Heating, Domestic Hot Water (DHW) and Cooking

No centralized heating system exists in the home. A portable wood-burning stove provides space heating in the main room. However, a diesel boiler is also used for space heating in the main room when wood is not available. The guest room and wet rooms (kitchen, bathroom, and WC) are unheated (Figure 4). However, a separate diesel boiler is used in the bathroom for heating water for bathing. A gas stove is used for cooking in the kitchen.

5. Methodology

Using the building dimensions from the site survey, and the case study house’s building constructions, the hygrothermal behaviour of the case study house are simulated using WUFI-Plus building simulation software by the Fraunhofer Institute. A Meteonorm meteorological data file with hourly values based on the Test Reference Year for Aleppo has been used for the simulations.

It is assumed that the current comfort level within the house will be lower than standard buildings. As the goal is to bring the thermal comfort up to current thermal comfort standards, standard design values for new buildings have been used aside from the air change rate taking into account the draughtiness of the building. The selected design conditions for the simulations are seen in Table 5.

Table 5. Design conditions used in the building simulation

| Parameter                              | Value |
|----------------------------------------|-------|
| Min. temperature (heating) [°C]        | 20    |
| Max. temperature (cooling) [°C]        | 27    |
| Min. relative humidity (humidification) [%] | 40    |
| Max. relative humidity (dehumidification) [%] | 70    |
| Max. CO2-concentration [ppmv]          | 3000  |
| Infiltration ACH [1/h]                 | 10    |

A boiler with output 2 kW was used in the simulations to represent the diesel boiler used in the main room.
6. Results and Discussions
Open window openings ensure the indoor air quality is high within the traditional home. The maximum calculated indoor carbon dioxide concentration during the winter months is 630 ppm. The prevailing winds in winter come from a northeasterly direction. The house is protected from the prevailing winds from the property wall, and the main openings within the building are oriented on the south façade. Because the three main zones of the house are completely separate, there are no cross-draughts between interior rooms. However, the individual rooms allow for high air infiltration and are dark in winter as the window openings are covered with rugs.

As seen in Figure 7, the indoor temperature fluctuates between 12 °C and 34.7 °C and does not cross the dew point meaning that the interior conditions have a risk of mould for a few days at the beginning of March. The corresponding indoor humidity levels also predominantly remain within a range of 30 % to 60%. This is partially due to the low temperatures, high air infiltration, and arid climate.

Figure 8 shows the quality of the indoor environment according to percentage of time that the simulated zone falls into each environmental quality category of EN 15251. The overall indoor comfort of the room is very low, falling 78% of the time in the lowest Category, 4. According to the standard, indoor conditions should remain the majority of the time outside of this category.

![Figure 7](image1.png)
![Figure 8](image2.png)

**Figure 7.** WUFI output of indoor temperature conditions (left), and indoor humidity (right) for the simulated year, 2017

**Figure 8: WUFI output of indoor environmental quality for the simulated year, 2017 according to prEN 15251:2006 (20)**

The annual heating energy demand is 5679.8 kWh or 250 kWh/m²a and as no cooling was included in the calculation, no cooling demand results. Thus, although the indoor air quality is high, the indoor environmental quality and thermal comfort are very low with a very large indoor temperature range.

7. The Proposed Post-War Design
The building design is to be optimized to meet Category 1 environmental quality and thermal comfort standards while integrating as much of the local building materials and local labour in the Aleppo region.
as possible based on the base case building construction as seen in Section 4. The proposed solution is also based on the local building traditions. Imported products such as building materials, machinery, equipment, as well as foreign labour and know-how are to be kept to a minimum. Recycled rubble from destroyed buildings is planned for use in wall bases, and to replace the coarse stones used in the original floor slab in Figure 5. Rubble courses are also to be used in the new wall composition.

8. Conclusions and Future Work

This paper offers a concept for transitional single-family housing for IDPs based upon the adobe tradition in the rural areas of Aleppo building upon existing traditions. Unlike some other transitional housing solutions, which import prefabricated living units to disaster and war areas, this low-cost housing solution maximizes use of local materials and recycles building rubble from destroyed buildings to provide shelter in rural areas around Aleppo while boosting the local economy.

Improvements to the analysed weaknesses to meet Category 1 environmental quality and thermal comfort standards are proposed with minimal intervention from mechanical building systems. At the same time, possibilities to strengthen the structure against earthquakes are considered with minimal construction costs and low embodied energy of the construction materials for quicker housing construction for the displaced families. Minimizing the heating and cooling loads can also drastically reduce fuel requirements during the construction and operation phases of the single-family homes while maintaining a high level of indoor thermal comfort.

Traditional construction techniques can potentially employ more craftspeople and also manual labour stimulating the local rural economy. The trained locals learn a skilled trade and are able to work in the building industry in both rural and urban areas.

The design of the housing unit is currently under development. As design development continues, publications will follow illustrating more detailed simulation results for thermal comfort, overall building energy use, and resistance to earthquakes.

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