Rubble Employing for Prospective Housing Scarcity in Post-war Syria

Material investigation and material's thermal characteristics

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ABSTRACT: The aim of this study is to investigate an innovative building material for housing scarcity crisis, which will continue to affect the country as refugees begin to make the choice of moving back to their cities in a war-torn country. The volume of rubble in Syrian destroyed cities is estimated to be at least 80[1] million tons per city; therefore, including the rubble in a fast and affordable reconstruction process will be the basic principle of this project. Another key area of investigation was the thermal behaviour of this new material in hot and dry climate (Damascus city as a reference). More specifically, this design aspect seeks to reduce the heating and cooling demand in Syria, where more than 80% of the electricity network has been destroyed or rendered unavailable. Finally, the impact of orientation on thermal behaviour, within the same setting, was considered as another crucial part of the climate design.

The core part of this study was to investigate ways of including the rubble in the reconstruction process, which lead to two main uses for it. (1) The first solution arose through mixing the rubble with soil, which can behave as a stabilization material that holds the rubble parts together, and then using this mixture as the main building material. Another aspect of the study is to integrate this material in fast affordable construction system. Prefabrication building components system had been developed in this study. (2) The second use for the rubble arose was to use it as a footing material according to the Syrian construction design codes. Through these two previously defined methods, more than 50% of the rubble in destroyed Syrian cities could be re-used. Further investigation into the thermal behaviour of this defined materials resulted in reducing the heating and cooling energy demands. The IWEC Damascus weather station data was used in the evaluation prosses, along with TRNLizard and Trnsys software simulations of a reference house in Damascus. Investigation into orientation and solar exposure impact on energy demand had been also resulted in a significant impact. By adjusting the orientation and material properties, more that 60% of energy cooling demand will be saved and another 25% for energy heating demand.

INTRODUCTION

Three main aspects were handled in this study:

1- Material investigation included the rubble
2- Material using in modular system
3- Ways of reducing heating and cooling energy demand in hot and dry climate

1) *MATERIAL INVESTIGATION:*

Rubble has the potential to be a strong and cheap building material, especially in war-torn regions, but it needs to be mixed with a stabilization material that helps hold the rubble parts together. Examples of similar processes can be found in the past, such as during the Mesopotamian period, where many of the structures were built using a method called Rammed earth. This mixture is technically gravel that is held together with soil through a compression force. Rammed earth has been improved through the centuries and now can be prefabricated in very short times. This takes the practice to a new level and gives more options for flexibility and production timeline.

By replacing the gravel with rubble in the rammed earth recipe, while keeping soil as the stabilization material, the following advantages could be achieved:

- Rubble could help to better reduce water runoff on the building components (Figure 1).
- Faster to fabricate and to build when compared to regular earth bricks.
- Fabrication and building techniques require less skilled people and less manpower.
- Fabrication can be done either on or off site.
- Better and more upgradable compression strength compared to earth bricks.

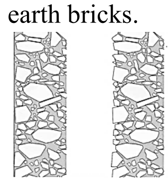


Figure 1 erosion effect during material's lifetime

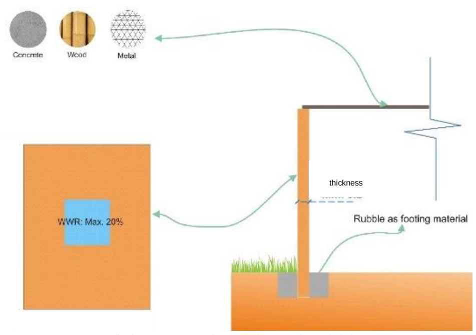
Three different rubble sizes have been tested (1.5, 4 and 10 cm) to view the impact of rubble size on material as well as the rubble percentage that could be included in the reconstruction process.

2) *MODULAR SYSTEM*

The developed material had been also integrated in building system that mainly focused on reducing construction time in frame of low cost buildings. Pre-fab

[1] What's left of Syria report - Al Jazeera research centre
[2] UNHCR, PEW research centre, EuroStat

wall components had been suggested as building components according to the predefined material. The possibility to make the components on or off site accelerates the building process by repeating similar components. It will need to be small enough to transport and light enough to build by using skilled-free equipment. Another key use of the rubble would be in foundation, where the rubble could support the walls against overturning forces. Structural design of the foundation and wall components have been done in accordance with the Syrian construction design codes.



Pre-fab rammed earth and rubble system

3) *CLIMATE DESIGN:*

Important criteria of the weather in Syria is the high solar radiation on south façade in winter time (Sep - Mar) (figure 3.1). another important feature of the south façade is the low radiation in summer time (Apr - Aug).

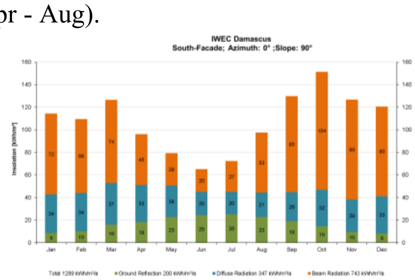


Figure 3.1 solar radiation on south façade

Through an iterative process, the new material and the orientation impact were investigated, tested, and finally optimized. Climatic hourly data from a relevant weather station, localised on Damascus city, was used as driving input for the climate behaviour research process. This climate design was used to investigate the material and orientation impact on indoor comfort as well as the total energy demand.

There is a potential of using thermal mass in Syria, since the temperature difference between day and night in summer time is high figure (3.2).

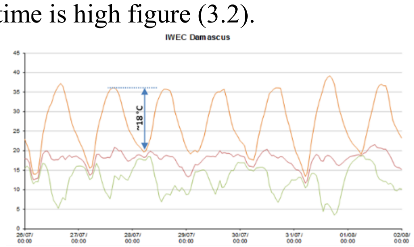


Figure 3.2 temperature difference between day and night

Evaporative cooling is a typical cooling strategy used often in Syria and specially in hot days, where people spray water in front of their houses to cool down soil surrounding their houses. By looking on the psychrometric chart of Damascus (figure 3.2); when the temperature exceeds 30 degrees, the air starts to be very dry. the potential of improving the indoor/outdoor comfort by adding water to the air is high.

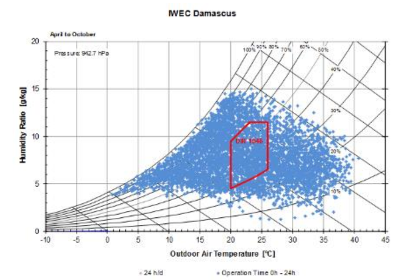


Figure 3.3.2 psychrometric chart

For assessing the results, the investigation was based on the following studies:

1. Assessment of the energy demand variants, using kwh/m^2 index in a reference house unit (100 m^2), done with TRNSYS, a computing program that uses weather based data and user based parameters.
2. Solar exposure using solar grid based radiation maps done with Ladybug for Grasshopper.
3. Solar exposure impact on energy demand done with TRNLizard.

METHODOLOGY

1) *MATERIAL INVESTIGATION:*

1.1 *Selection criteria for Natural Rammed Earth and rubble:*

A wide variety of sub-soils have been used for natural rammed earth buildings, with the exception of uniform coarse sands and gravels with no fines or cementing agents (Hughes, 1983). For earth wall construction, the soil should contain all four elements (McHenry, 1984). Ideally the soil should have a high sand/gravel content, with some silt and just enough clay to act as a binder and assist soil compaction (Keable, 1996). According to Norton (1997) any material coarser than 5-10mm should be sieved out. Previous experimental work indicates that increasing gravel size reduces the compressive strength of rammed earth cylinders (Patty & Minium). However more research is warranted to define grading for rammed earth, especially maximum gravel size and proportions. Proposals tend to converge toward a 30%-70% balance between clay/silt and sand proportions (Berglund, 1986; Dayton, 1991; Easton, 1996). Nevertheless, no soil is likely to be ideal with regards to all of the aspects considered (Saxton, 1995) and therefore researchers around the world usually publish upper and lower limits for each of the main soil elements. Figure 1.1.1 shows the lower range limits for clay, silt, sand and gravel for rammed earth construction, as proposed by various researchers. In general, the percentages are 'by mass', though in some cases (McHenry, 1986) stated by the author were 'by volume' or 'by mass'.

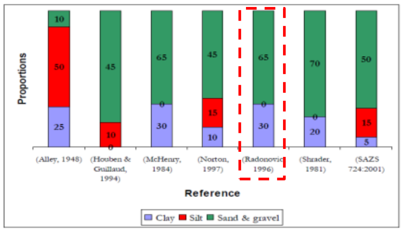


Figure 1.1.1 Lower range limits for particle size distribution for natural rammed earth

Radonovic selection had been used as a reference to test rubble and soil mixture. Regarding the rubble size, three varied sizes has been tested (1.5, 4 and 10 cm) (figure 1.1.2).

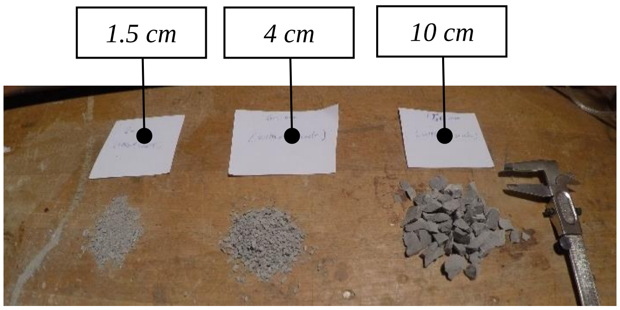


Figure 1.1.2 scaled rubble sizes (Scale 1/15)

1.2 Material testing:

To approach the new material properties, variant prototypes was built and investigated. The following parameters were tested:

- Rubble percentage (30, 40 and 50%)
- Rubble size (1.5, 4 and 10 cm)
- Material water absorption through on surface: by measuring the weight difference between dray and wet material.

All soil and earth materials had been sieved to avoid any organic matter. Also sieved samples helps in controlling the gradation and to be sure that we have Small, medium and then large particles. As first step, the clay mixed with water and left for a few days until it reaches optimum consistency. During this time, the clay was kept damp and protected from rain. A sample of clay and sand was mixed to determine the moisture content by a drop test from 1m height[3]. Mixing had been done manually with a particular care of having the clay around the rubble as it is the primary bonding agent.

Formwork is probably the main challenge of the entire process, because it is important that the formwork is easy to handle and to put up, strong enough to resist the pressure of ramming, big enough to avoid too many set up for the same wall. We used solid wood sheets (20 mm thick) held by screws and thick beams of wood (figure 1.2.1). wooden beams run horizontally and vertically in pairs on each side of the formwork and each pair is held together by brackets, bars and nuts. The ramming process had been done manually by ramming the earth with a hammer. The ramming effect creates a solid agglomerate of particles locked one into another, the finest finding some room between the bigger.

Figure 1.2.1 Rammed earth formwork

2) MODULAR SYSTEM:

2.1 *component dimensions and weight:*

Pre-fab components might need to be transport to the construction site. According to the Syrian regulation in roads design, the biggest lorry that allowed to drive on Syrian's roads is defined as following:

- Max. width 2.5 m with overall box width 2.6 m
- Max. length 18.75 m

The components also need to be moved inside the construction site in order to be built. By searching for what equipment's are available in the local market that need no skills to be used. We found that the weight of the component mustn't excess 3 tons to use skill-free equipment (Figure 2.1.1).

Maximum Wall Slenderness According to the Australian national rammed earth codes, and in case of simply supported element is defined as following:

Height and Length must not be greater than18 x thickness (25 cm).

$$H < 18t, L<18t$$

Figure 2.1.1 Recommendations for openings in earth walls:
-Total combined horizontal length of openings in a wall should normally not exceed one-third of the total wall length[4]
-The minimum distance between openings for a loadbearing wall of minimum thickness should be between 600mm-1000mm[5]
-Openings should be at least 750mm from the corner of the wall and with minimum450mm of wall above the crown[6], and for heavily loaded walls the total area of the openings should not exceed 20% of the total area of the wall[7]

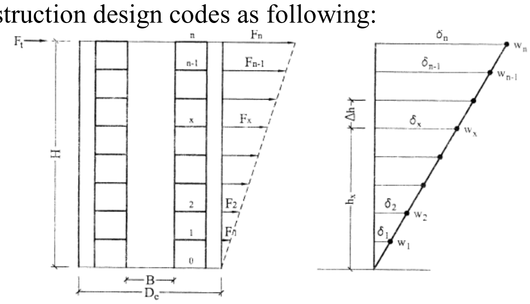
2.1 *Overturning Resistance:*

Overturning force (horizontal loads) appears as result of many different loads, but mainly wind, horizontal force of quake and tremors from far distance bombs. In order to withstand these loads, the components must be fixed tightly in the site with specific foundation dimension defined as following:

[3] Australian National Rammed Earth Codes
[4] Standards Australia, 2002; Easton, 1996; McHenry 1984, King, 1996
[5] Standards Australia, 2002; SAZS 724:2001, 2001; Middleton, 1992; King, 1996
[6] SAZS 724:2001 2001
[7] Standards Australia, 2002

Item	SAZ 724:2001,2001	Standards Australia, 2002	NZS 4298:1999,1999
Foundation width (Wf)	from equal to wall width (Ww) to max 500mm	from equal to wall width or 300mm to max 400mm	from equal to wall width or 280mm to max 450mm
Foundation depth	(Wf-Ww)/2 or Ww whichever is larger	300mm-400mm	min 150mm in rock or 300mm in other soils

The laying depth defined according to the Syrian construction design codes as following:



$$V = F_t + \sum_{i=1}^{n} F_i$$

$$F_t = 0.07 \times T \times V;$$

;T: Turn related to base shear

$$T = C_t (h_n)^{\frac{3}{4}}$$

$$C_t = \frac{0.0743}{\sqrt{A_c}}$$

$$A_c = \sum A_e \left[0.2 + \left(\frac{D_e}{h_n}\right)^2\right] \quad (m^2)$$

$$F_x = \frac{(V - F_t) \times W_x \times h_x}{\sum_{i=1}^{n} W_i \times h_i}$$

Secondary effect of Horizontal Displacement

$$(P - \Delta)_i = \frac{W_n \times \delta_i}{V_i \times h_i}$$

After calculating the concrete mass needed to support each wall, this mass has been translated into rubble mass as following:

$$\rho_{rubble} = \frac{\rho_{concrete}}{\rho_{e.\ rubble}} \times mass_{concrete}$$

; $\rho_{e.\ rubble}$: *Experimental rubble density*

3) CLIMATE DESIGN:

3.1 Orientation optimization

To approach the optimized orientation that maximize heat gain in winter time and minimize solar exposure in summer time, the sun altitudes was investigated to find altitude range in summer and winter time (figure 3.1.1).

Resulted altitudes applied next on sun path, where the sun rays were equivalent to load profile. Perpendicular load will represent the highest sun radiation on the investigated facade (south facade). To validate the sun path calculation, the solar radiation on three different orientation was investigated with Grasshopper tool (0°, 20° and 48°).

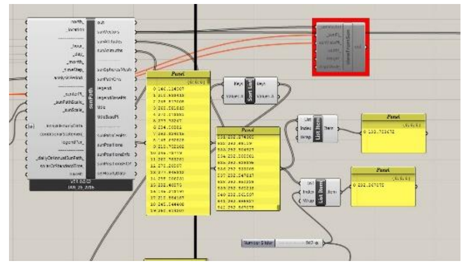


Figure 3.1.1 sun altitude range in summer time in Grasshopper

3.2 Solar exposure

In order to test the solar radiation impact on energy demand, a reference geometry in Damascus with the following properties was simulated:

Item	
Area	100 m²
Windows	Single layer, U_{value} = 1 w/m².k
Wall/window	50 %
ACH	1/h
Heating set temp.	20 °C
Cooling set temp.	25 °C

The solar radiation impact process is divided into three main performance-based assessments (table 3.2). The basecase is assessed firstly to identify reference energy demand for the predefined geometry of current situation, then later proposing different options. Since the sun altitude in Syria in summer time always high, the sun can be prevented easily on the south façade. The main challenge is how to reduce the radiation on the east and west façade, where the sun altitude is low.

V	Assessments	Descriptions
1	Basecase	Evaluating the current situation. Concrete as building material
2	Added overhang shading on south facade	The impact of adding overhang shading on the south façade in winter and summer time
3	Added movable shading on west and east facade	Presenting shading device that goes automatically on when the solar radiation exceeds 200 w/m²

Table 3.2: Cases for assessments.

3.3 New material thermal properties:

Two different thickness of the indicated material was tested (20 and 30 cm) to indicate thermal mass impact on energy demand.

Since the building material contain soil, material behaviour when the soil saturated with water was investigated. Beside the different material thickness, another two materials with 100% water saturation was simulated (table 3.3). The amount of energy that expected to release from the material was calculating as following:

$$Q = C_{pe} \times m$$

Q: *Released energy* $\left(\frac{kwh}{m^2}\right)$

C_{pe}: *Enthalpy heat capacity* $\left(\frac{kj}{kg}\right)$

m: *Water quantity* (kg)

In order to evaluate the potential of the system for the different configurations, the model material was simplified into one material layer (table 3.3). However, for the impact of fully saturated soil on indoor temperature, thinner material (lower conductivity) was modelled. The water saturation impact on energy demand can be assessment as the water will drive the stored heat during the day time faster from the building components (walls). This procedure will helps improving the outdoor comfort in night time. All the variants were compared to reference model, where concrete used as building material.

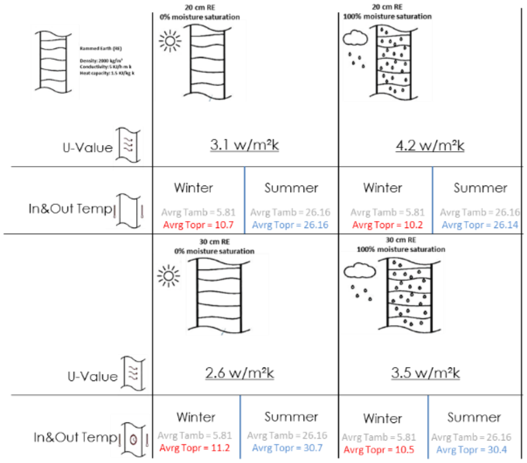


Table 3.3: simulation variants and material properties

RESULTS

1) *MATERIAL INVESTIGATION:*

Rammed earth and rubble material water absorption was related to the rubble size. The bigger the rubble parts are, the less water can the material absorb. Table 1.1 resulted the experimental priorities of rammed earth rubble material:

Rubble size (cm)	***Water absorption***	
	(gr)	*(l/m³)*
1.5	*80*	*103*
4	*30*	*39*
10	*18*	*23*

Table1.1: Rubble parts size impact on material water absorption

Rubble size has a huge effect on the material stability. the rubble size and percentage effect on the material stability was measured through testing. Once the material is no longer able to hold each other, the sample was signed as wrong (Table 1.2). That also mean that soil quantity is no longer enough to stabilize rubble parts to each other.

Rubble perce.* / *Rubble size (cm)	***30%***	***40%***	***50%***
1.5	✓	✓	✓
4	✓	✓	‖
10	✓	✗	✗

Table 1.2: rubble percentage in new material

✓ **stable** ‖ **stand** ✗ **Not stable**

2) *MODULAR SYSTEM:*

Regarding to the transportation criteria and construction regulation, the dimensions and the weight of the components had been defined as following (figure 2.1).

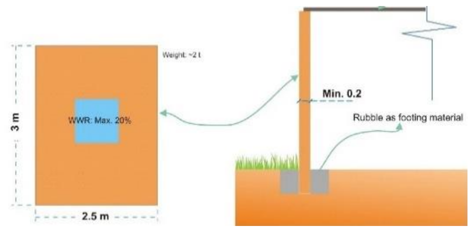


Figure 2.1 components dimension

The calculation resulted that around 0.5 m³ of concrete needed to hold each component (walls). Form the other hand, measuring the weight of rubble material (4 cm rubble size) leads to calculate the density of this material (1600 kg/m³).

3) *CLIMATE DESIGN*

Both of simulation and the calculation resulted the same orientation that is ideal to reduce sun exposure on south façade in summer time (Figure 3.1).

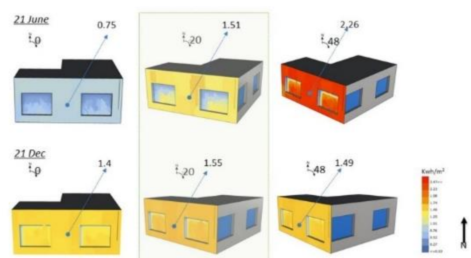


Figure 3.1 Sun radiation in south façade

After testing the predefined variants. result has been summarized in table 3.2 where each variant was valuated per his impact in reducing heat gain in summer time and increase it in winter time. 20° rotation combined with overhang shading is the perfect combination that reduce significantly sun exposure in summer time with little loss of heat gain in winter time.

	Rotation			Facade shape		Shading	
	0°	20°	48°	Vertical	Sloped	V. & Shading	S. & Shading
Summer	✓	!	✗		✓	✓	
Winter	✗	✓	!	✓		✓	
Rank	–	✔	–	–	–	✔	–

Table 3.2: variants evaluation

The impact of water on the material has been calculated and resulted as energy that can be release. The main conclusion that we came across is, the more water you add the more conductivity you have. That lead to more heat be transferred during daytime in winter into the house. As the same affection, will be helpful in night time in summer where the outdoor temperature range is between (20-30°C). Figure 3.3 shows the energy demand reduction of all the variants combined.

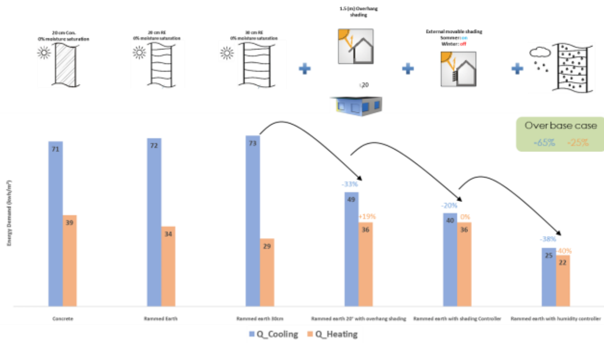


Figure 3.3 energy reduction strategies

CONCLUSIONS AND OUTLOOK

By using rubble size of 4 cm with 40%, up to 26% of the rubble can be reused in the new material. This will lead to reuse the rubble in the reconstruction, while the destroyed areas will be cleaned.
Around 0.75 m^3 of the rubble will be used also as footing material which is the same rubble volume that will be used in each component.
Another 25% at least can be used also as footing material. The total reusing of rubble percentage could reach 50%. In simple term, 50% of the destroyed cities will be reused in building new cities.
This paper helps to give inaugurate ideas for prospective housing scarcity in Syria. Further development and investigation is required in order to come up with holistic plan for the biggest human crisis in this century.

ACKNOWLEDGEMENTS

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