TERRABAYT

DESIGN

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AR3B011 EARTHY

2018

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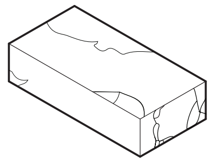

01 CONCEPT

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The current housing layout of the Al Za'atari refugee camp set in place by the UNHCR does not fit the spatial, functional and cultural needs of its inhabitants. This is visible in the fact that the inhabitants are already modifying the orthogonal layout set by the UNHCR to their own demands: prefabricated units are moved to form courtyards or semi-open spaces, additional rooms such as bathrooms and shops are added to the units with makeshift materials, and commodities such as private gardens are introduced (Figures 1-4). The people of Al Za'atari are already making the camp their home.

Subsequently, as the refugee crisis in Jordan increased, aid providing organizations and the local government were pushed to the limit in providing infrastructure on limited budgets. Thus, many families are still left living in suboptimal housing (tents), awaiting for these organizations to provide a more permanent shelter in the form of prefabricated containers... In the light of this context, we ask ourselves the following:
Can architectural solutions help relieve the pressure by making the camp inhabitants more self sufficient and self reliant?

With this situation as a point of departure, project **Terrabayt** seeks to investigate the potential of using earthy architecture as a means to rethink the current camp housing situation. This approach aims to improve living conditions of the camp inhabitants, but also make things easier for camp managers (camp equity), external NGO organizations (camp economy) and the environment (camp ecology).

terra /ˈtɛrə/ - *lat.* earth

bayt /bajt/ - *ar.* house

Figure 1: Al Za'atari inhabitants moving their caravan

Figure 2: Private garden

Figure 3: House (caravan) extension with recycled materials

Figure 4: Visible alteration of the initial UNHCR block layout

In order to ensure the replicability of the proposed intervention strategy and completely exclude personal architectural aspirations we chose to start with an approach, rather than a location/site within the camp. The design of these houses was intentionally looked at as an organizational problem and a rules-based approach was used to tackle it.

"*As architects we want to provide beautiful solutions but we should not provide people with predesigned shelters. It has proven more effective to provide them with the tools to build their own home...*"

Corine Treherne - Senior officer, shelter & settlements,International Federation of Red Cross & Red Crescent Societies

Using the abovementioned words as guidelines, the outcome of this project is a computational tool that allows for the involvement of the end user in the process of designing and constructing of his house. The tool ultimately generates housing typologies more in line with the needs of its inhabitants, whose topological and geometrical characteristics are based on traditional Syrian ones; hence the name Terrabayt

From a practical point of view, the existing containers are combined with earthy additions to form the new typology. The existing structures and materials are utilized to minimize waste, and allow the camp inhabitants to remain in their units during construction. As the inhabitants build the earthy extensions, their sense of ownership, and self reliance will inevitably increase. This will allow for a transition from a state of "refugee" to that of a "homeowner", and a transition of Al Za'atari from a "camp" to a "settlement" (Figure 5).

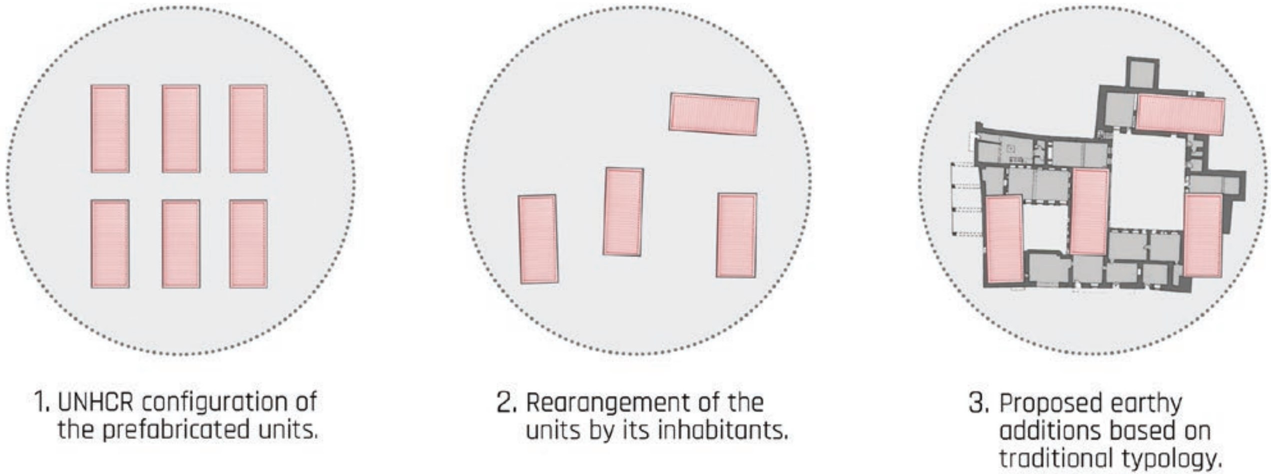


Figure 5: Concept

"As soon as camps lasts beyond the emergency phase, they transform into a space with which people begin to identify"

Michel Agier - french anthropologist

Ultimately, with this tool we merely seek to alleviate and facilitate the settlement process already set in motion by Al Za'atari inhabitants. The resulting layout helps the inhabitants experience the housing typology they are familiar with and build a sense of ownership, self reliance, dignity and accomplishment, having built it themselves. This will also facilitate greater social interaction as community involvement during the construction is of paramount importance. On the long run, we envision for this project to aid these displaced communities rebuilt their lives in Al Za'atari but also serve as an exemplar in changing the paradigm of refugee camp design and management.

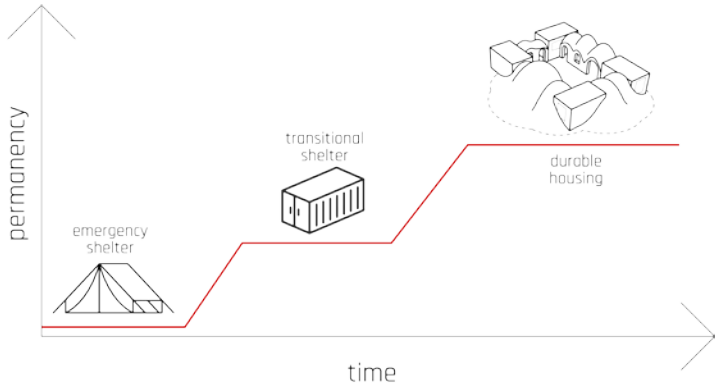
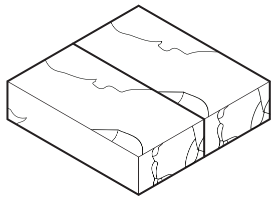


Figure 6: Necessity of more permanent dwellings within Al Za'atari



02 ANALYSIS OF AL ZA'ATARI CAMP

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02.01 Introduction

Al Za'atari Camp is one of the most well known refugee camps of the Syrian Civil War. Located in the Mafraq Governorate in the north of Jordan, it is located at 50km from Amman and only 11km from the Syrian border. Due to its proximity to war-torn regions, it has seen many Syrian refugees since its founding in July 2012, with a total of over 461.000 Syrians having been through the camp since its founding by the UNHCR.

02.02 History of the Camp

After its founding in July 2012, the camp immediately reached a population of 15.000 in August. Subsequent months showed an increase in the population, reaching a peak in March 2013 at 156.000 inhabitants. Currently, the population has declined to a more manageable 79.000 thanks to the opening of other refugee camps.

The camp is controlled by a joint effort of the UNCHR (United Nations HIgh Commissioner for Refugees) and the JHCO (Jordanian Hashemite Charity Organization). However, many NGO's are also active to contribute to the well-being of the camp dwellers, either by providing education or ensuring infrastructure and sanitary needs are covered.

Throughout the years, the camp has seen considerable expansion. Organized in multiple phases, the camp has grown westward along a central axis and is subdivided into multiple districts in a grid layout. Prefabricated caravans have been supplied to the inhabitants in the camp in order to improve living conditions compared to the tents that were distributed initially; after all, it was never expected to serve for longer than a year.

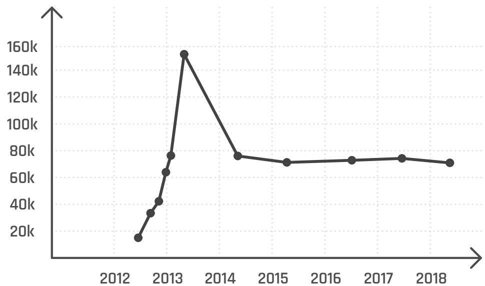



Figure 7-8: Population growth of the camp and an aerial view of it

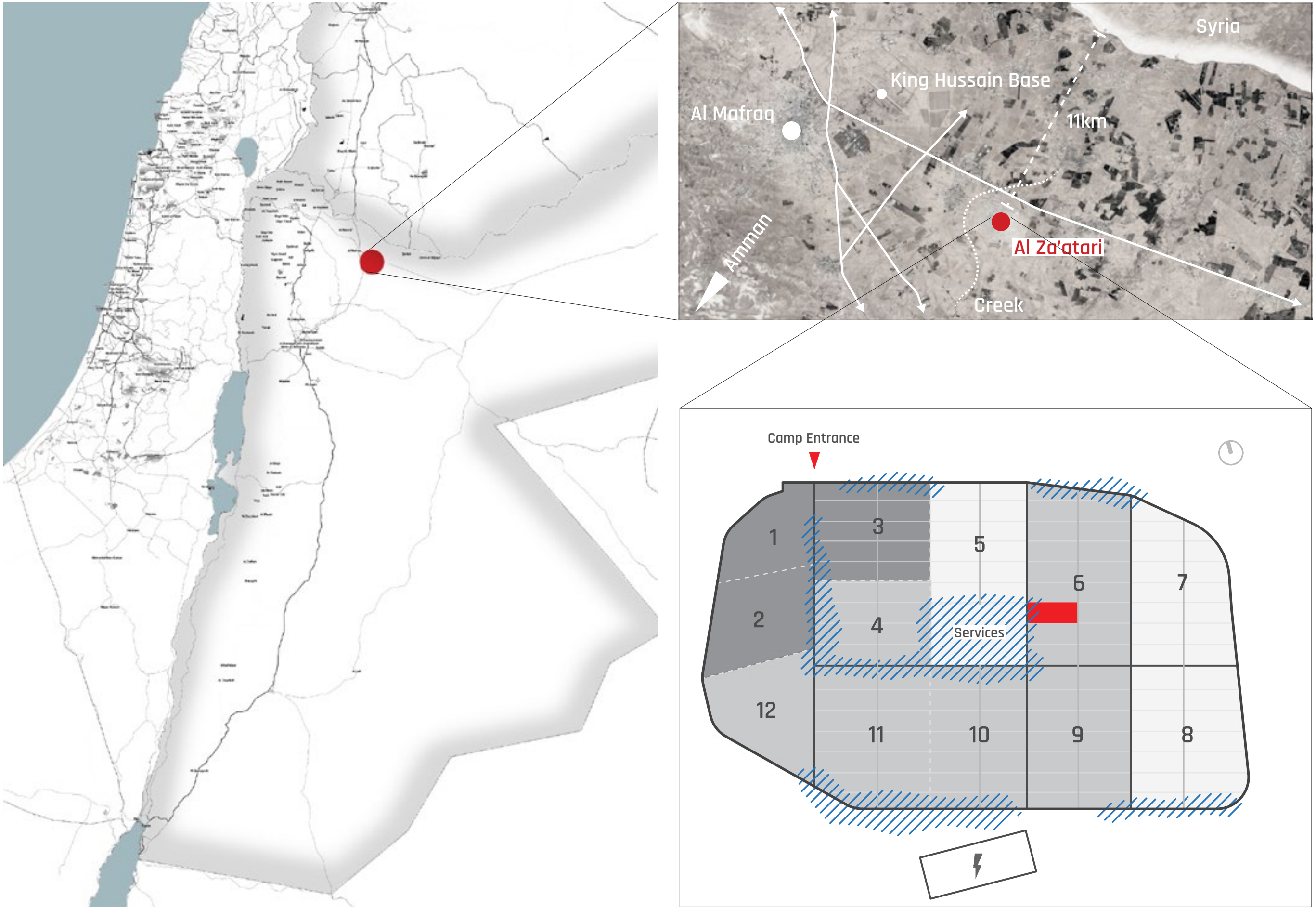


Figure 9: Location of Al Za'atari camp and the basic structure of the camp with its historical buildup

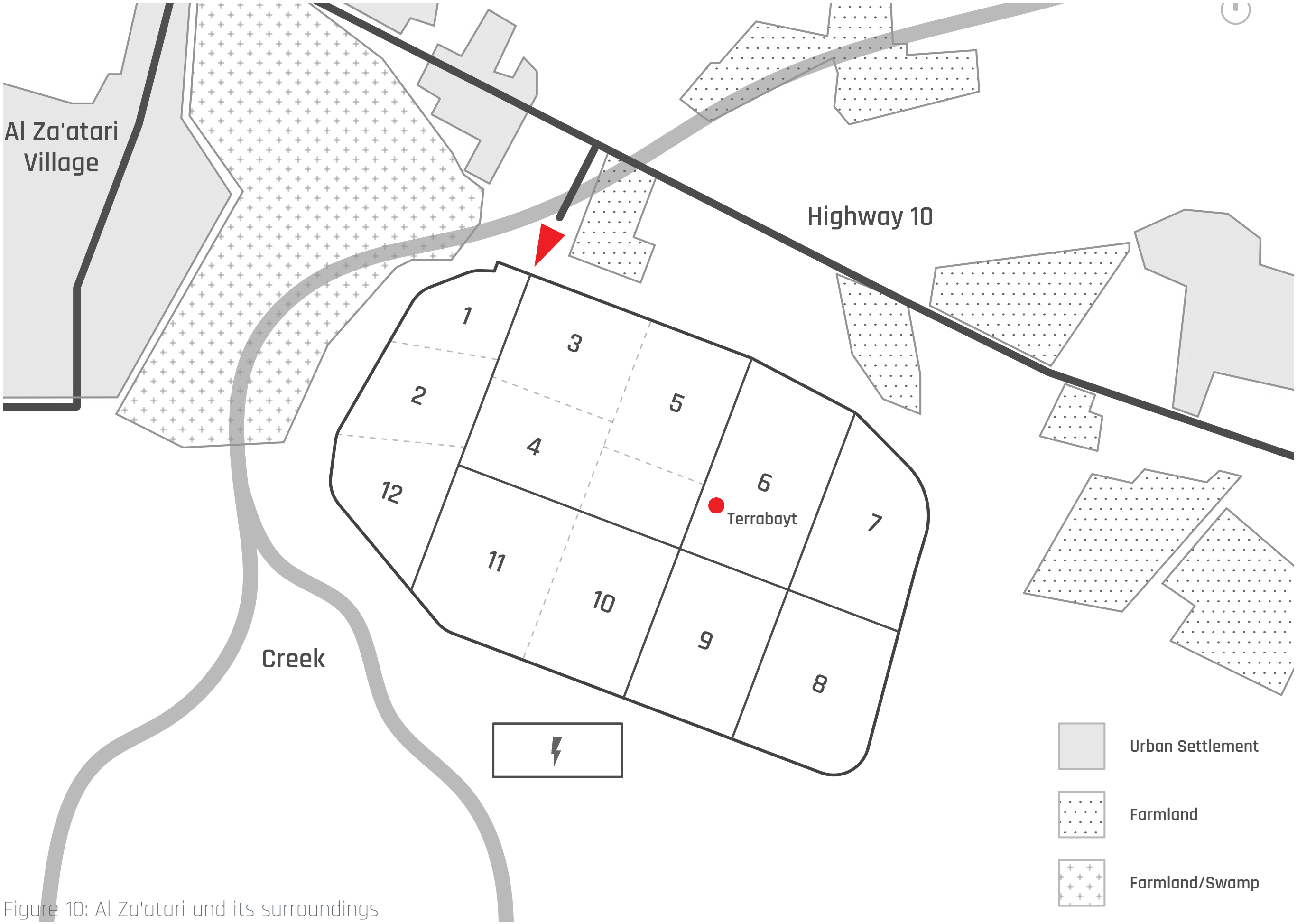


Figure 10: Al Za'atari and its surroundings

02.03 Demographics and Economy

Between 80 and 90% of the inhabitants in the camp originate from the Daraa province of southern Syria, with the rest coming nearly fully from rural Damascus. The age structure is noticeably young, with over 57% of the population being under 24 years of age and 20% being under 5 years. Even today, there are over 80 births per week.

Currently, Al Za'atari has a functioning economy despite restrictions set forth by the Jordanese government in an effort to prevent the camp becoming permanent. 65% of the population is employed, with a bustling informal economy spread across 3000 shops, of which 680 large. These are mainly distributed along the main avenues of the camp, of which the most famous one is labeled "Champs-Élysées". The total contribution to the Jordanese economy amounts to over 13mln$ per month, while the costs are in the range of 15mln$ per month. These costs are spent providing basic amenities to the camp such as electricity and water. Electricity, however, is merely a small fraction of the running costs at 3%.

The residents of the camps are known for being skilled in construction, agriculture and manufacturing. Although they are not allowed to freely roam outside the camps, nor trade with the outside world, an informal economy is widely present. Sadly, most of the refugees still live in bad conditions, with over 26% of Syrian refugees in Jordan feeling so hopeless they do not want to live. Over 19% feel unable to carry out daily activities, while 32% of the people who receive psychological aid in Al Za'atari are children.

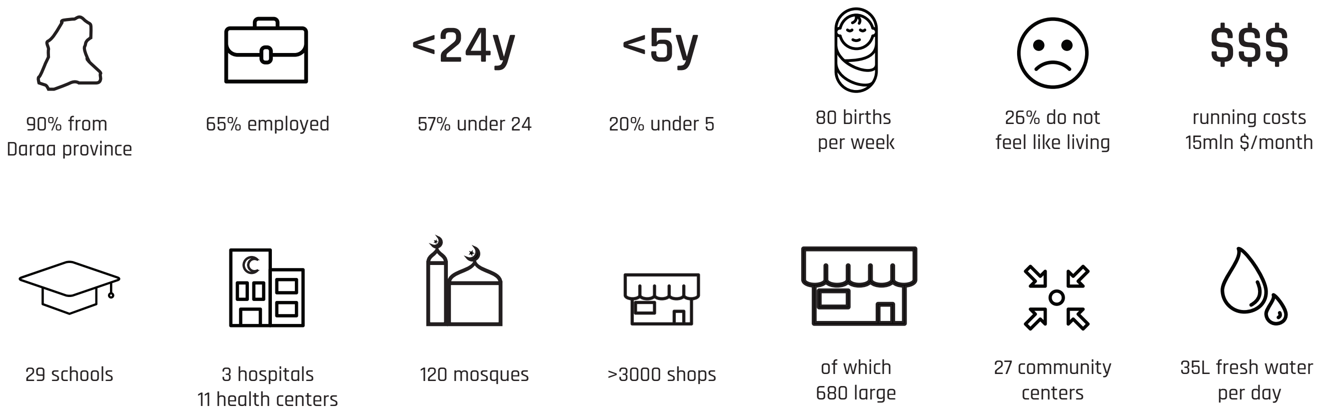


Figure 11: Basic figures on the camp

02.04 Lifestyle

Even though life is harsh in the camp, many people have tried to make the best out of the conditions they are in. Many families are living grouped together, either sharing caravans or living in adjacent ones. The initial grid layout is already transformed to a more traditional Syrian one, in which the people have formed courtyards and have added gardens and other spaces to their homes, often from "appropriated" public elements.

NGO's and volunteers actively contribute by providing education, especially on the topic of WASH (water, sanitation and hygiene). Although 29.000 children attend school in 29 schools, especially education regarding road safety and hygiene still remain points NGO's focus on heavily.

An important aspect in the everyday lives of the residents is the restrictions imposed by the Jordanese government: it is not possible to exit the camp, nor have cars or self-built structures. Similarly, work permits are very limited, with many of the Syrians not being able to formally work in Jordan at all.

02.05 Infrastructure

The main layout of the camp has been designed in accordance with UNHCR guidelines for the construction of refugee camps. Basic services were provided at communal level. Water, which is currently consumed at around 3 million liters per day or 35 liters per person per day, is supplied through three internal water wells and trucks. These are operated by ACTED (Agency for Technical Cooperation and Development) and UNICEF.

Figure 12: Water tanks in the camp are an everyday part of life in Al Za'atari

Figure 13: Images from Al za'atari

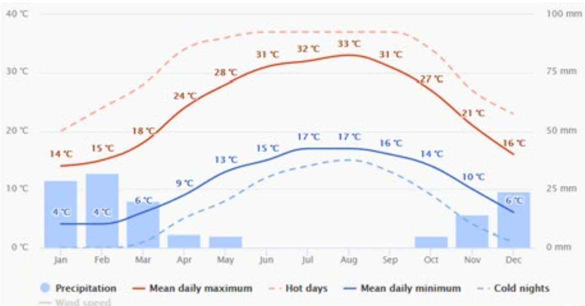
Additionally, a wastewater treatment plant is available too, with a fully piped system being constructed to connect each house to the sewage system. This follows a general trend in the camp, where communal bathrooms and toilets are "privatized". Over 98% of the houses are reported to have a private toilet, although nearly half of them were deemed unsuitable by UNICEF standards, mainly due to the fact they lacked proper partition walls.

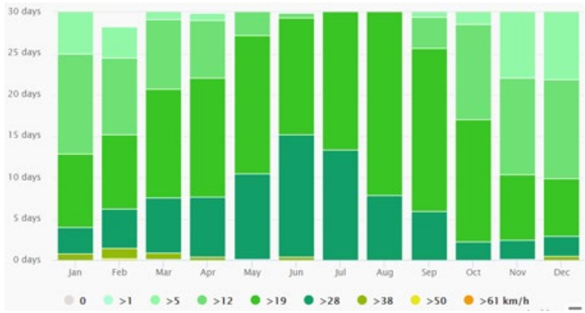
Over a third of the population reported not using the free water provided to them, mainly due to the fact they perceived it as not being clean. Even so, nearly 90% of the inhabitants disposed of their waste water through concrete tanks, with only 7% reporting they threw it on the streets.

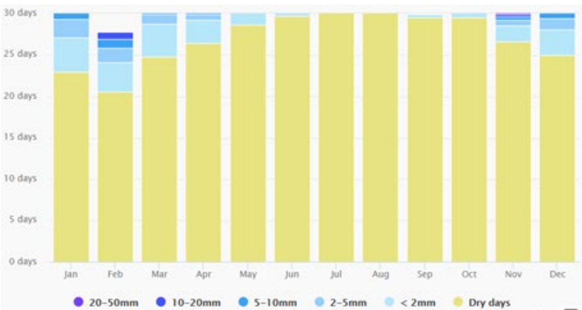
Al Za'atari luckily does have a set of public services. Over 29 schools and 27 community centers are present to provide for education and leisure for the camp dwellers. The camps also contains three hospitals and 11 smaller healthcare centers for medical needs. The best-represented public amenity is however mosques, with over 120 mosques being present in the camps.

02.06 Climate & Soil Conditions

Located in the Middle East, Al Za'atari's climate is a "BSk Cold semi-arid climate" according to the Köppen classification. It experiences hot and dry summers and cold winters, with large diurnal swings in temperature. The average annual temperature is 16.6C with a rainfall of around 184mm. Average high temperatures reach 32.3C in August and 12.5C in January, while average low temperatures reach 16.4C in August and 2.2C in January.







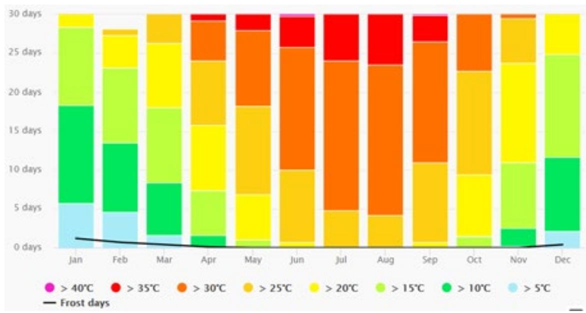


Figure 14-17 (clockwise from top left): temperature values, wind speeds, temperature distribution and rain levels

Compared to other Middle Eastern cities, Al Za'atari is between Damascus and Ramallah regarding climate. In winters, it is hotter than either one of them, but in summers it experiences more heat than Ramallah but less heat than Damascus.

Sun and wind is aplenty, with over 300 sunny days per year and an annual irradiation of 2000 kWh/m2a, nearly double The Netherlands. Winds are from a dominantly western direction with average speeds between 5 to 10km/h. Speeds increase in summer and become lower in winter. However, extreme conditions such as sand storms or heavy rainfalls do occur.

The soil around Al Za'atari is mainly of calciorthid type containing relatively high amounts of silt and lime and no organic matter. Immediate bedrock is nearly completely unavailable within digging distance, but the first 30cm of soil contains over 75% mixed sand, 20% of clay with sand and additionally silt and lime. The camp site itself has been flattened with a layer of debris, which makes the soil immediately at street level unusable for farming or construction.

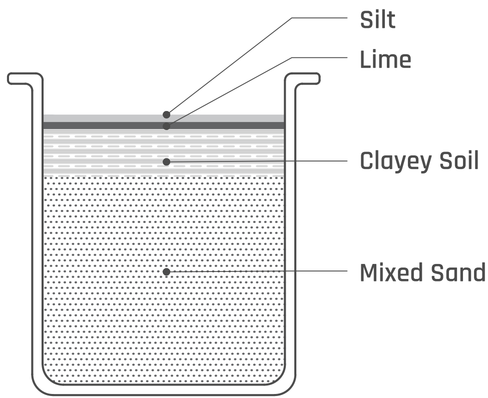


Figure 17: Soil composition around Al Za'atari

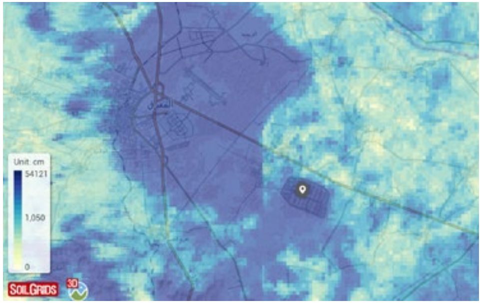


Figure 18: Bedrock depth (SoilGrids)

Figure 19: Fine sand at 30cm (SoilGrids)

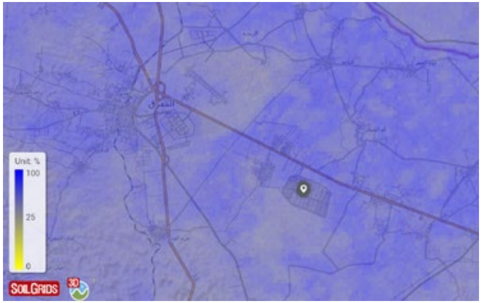


Figure 20: Silt at 30cm (SoilGrids)

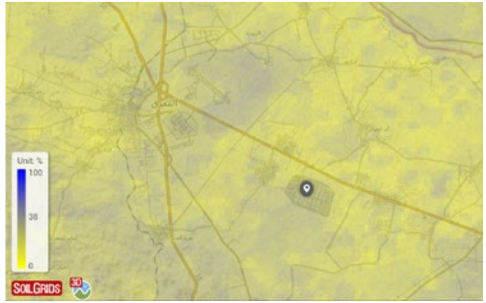


Figure 21: Sand at 30cm (SoilGrids)

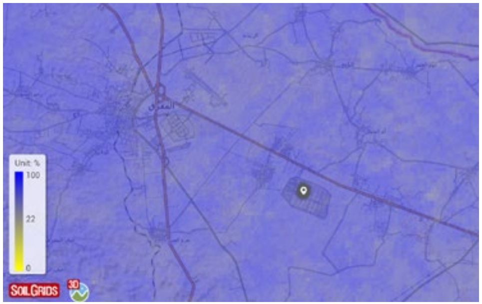


Figure 22: Clay at 30cm (SoilGrids)

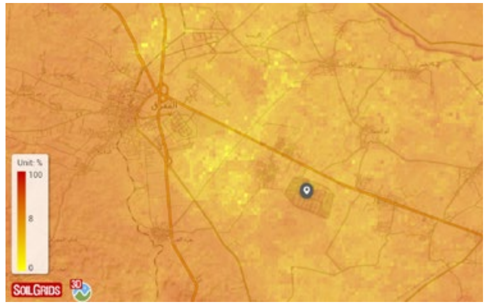
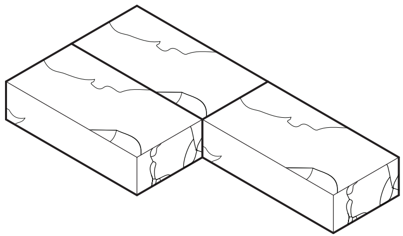


Figure 23: Coarse sand at 30cm (SoilGrids)



03 ANALYSIS OF TRADITIONAL HOUSING

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03.01 Researched Geography

For the purpose of our design, we limited the study of traditional housing and settlements to the geography of our target group: Syria and Jordan. Although we investigated other Middle Eastern houses as well, the focus lies mainly on traditional and often rural houses from the aforementioned countries.

03.02 Settlement Character

The layout of settlements vary depending on the geography they are located in. Looking at research from Al Asali and Shahin (2016), the layout of rural settlements in Southern Syria (where Al Za'atari's refugees come from) are classified as "merging" villages. Such nucleated villages are formed by clustering residences around a central spot.

This is of course vastly different than the initial grid layout of Al Za'atari Camp. A trend in which people already rearrange their houses in more organic urban layouts is visible within the defined blocks (districts) of the camp. Letting this trend be, we do not propose a modification to the whole block layout.

03.03 Traditional Housing Typologies

Traditional housing has various typologies of housing that are commonly found throughout the geography. In our case, we analyzed both traditional houses from Syria as well as Jordan from different literature. We classified them into four common/basic types that are also found in Al Za'atari and that we want to use as basis for our design.

The four main typologies consist of the simple house, central hall/iwan house, the riwaq house and the

Figure 24: Location of our analyzed geography for traditional housing

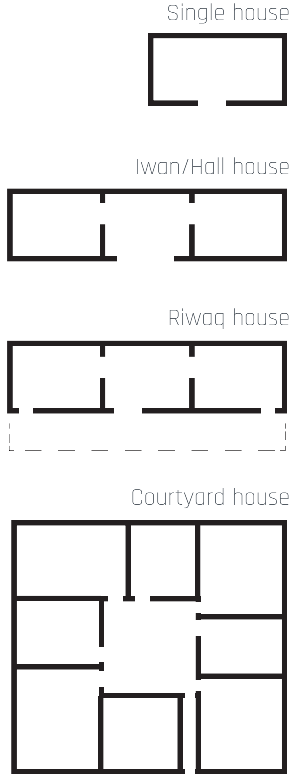


Figure 25: Four basic topologies from our research

courtyard house. Interestingly, a study from Stromme Framgard (2013) shows how the inhabitants of Al Za'atari have already rearranged many caravans to suit their needs more: depending on family size and available materials, many have converted their separated caravans into courtyard or central hall-style homes, adding various closed and semi-open spaces, making their "houses" more like "homes". Upon further investigation, it is possible to see that the rearranged caravans actually resemble traditional housing in typology very much.

For each of the traditional typologies we investigated, we drew up their graph charts, justified graphs and REL charts to determine the relation between spaces. This was then compared to the rearranged caravans in Al Za'atari and used as a base for further design of our earthy additions.

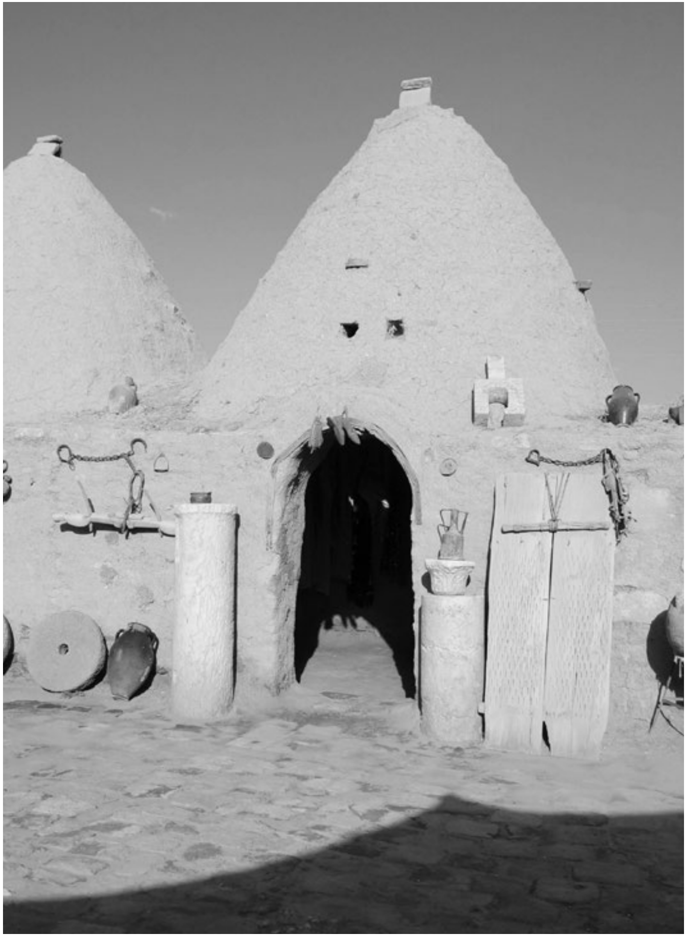
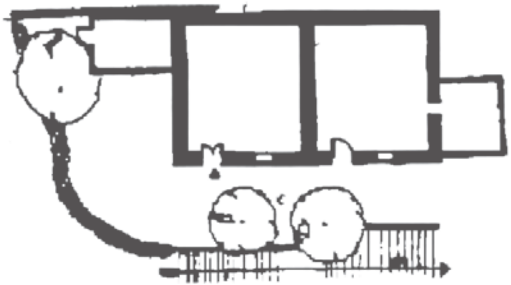
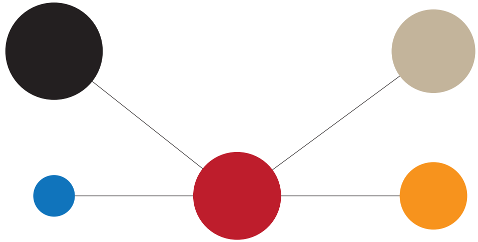


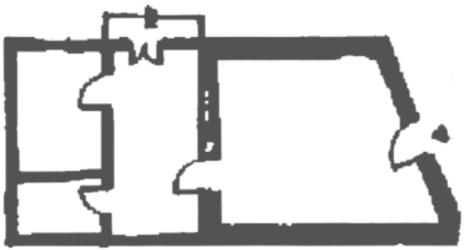
Figure 26: A simple adobe house

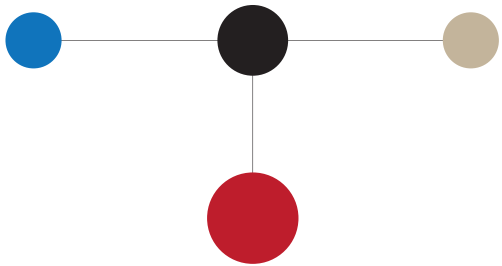
Figure 27-31: Traditional Jordanese houses

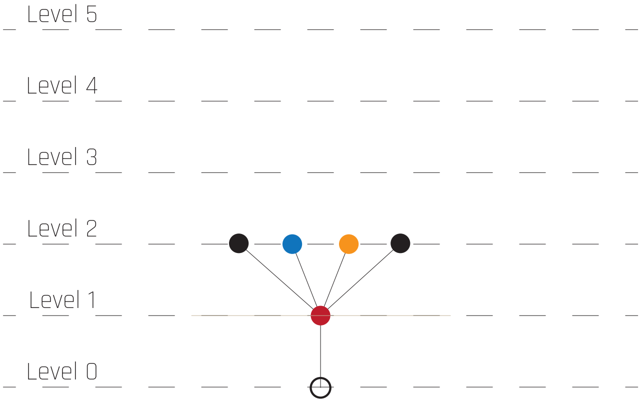




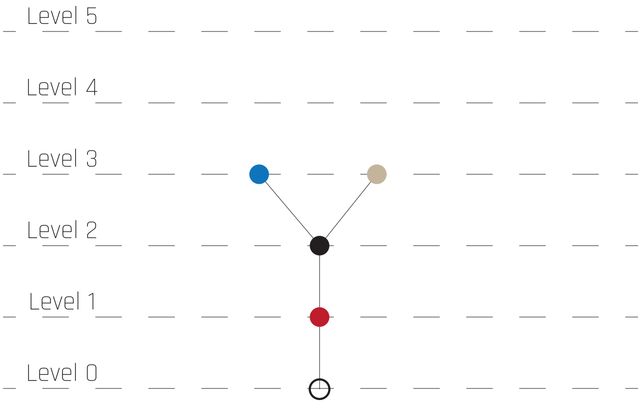
Entrance
Multi-Purpose
Courtyard
Iwan
Riwaq/Portico
Bedroom
Living Room
Kitchen
Bathroom



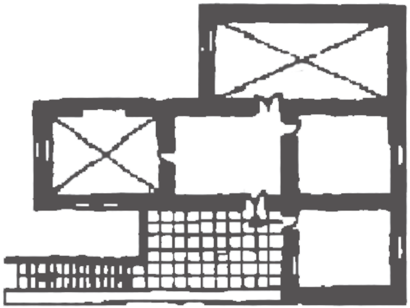


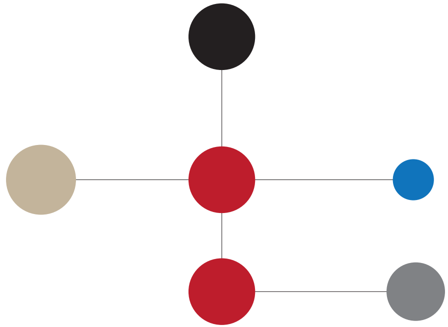


	Courtyard	Bathroom	Multi-Purpose	Multi-Purpose	Kitchen
Courtyard		1	1	1	1
Bathroom			0	0	0
Multi-Purpose				0	0
Multi-Purpose					0
Kitchen					

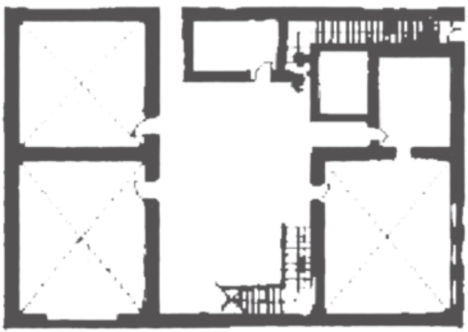


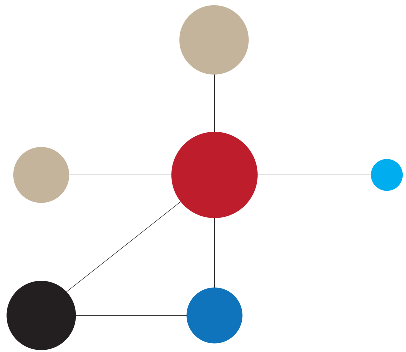
	Courtyard	Multi-Purpose	Bedroom	Kitchen
Courtyard		1	0	0
Multi-Purpose			1	1
Bedroom				0
Kitchen				

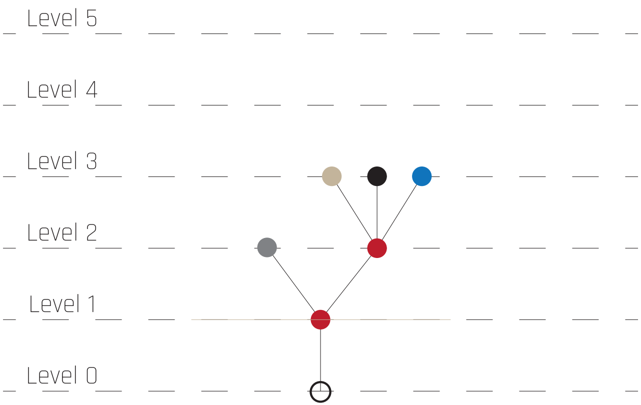




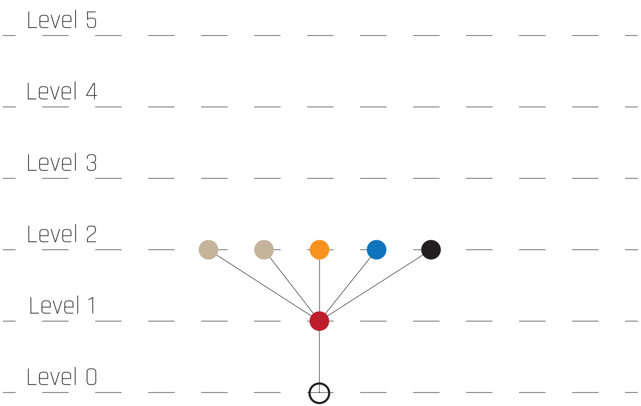
Entrance
Multi-Purpose
Courtyard
Iwan
Riwaq/Portico
Bedroom
Living Room
Kitchen
Bathroom





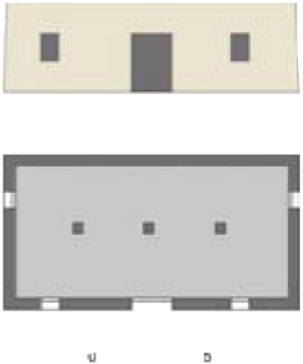


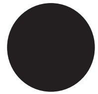
	Courtyard 1	Living Room	Courtyard 2	Multi-Purpose	Bedroom	Kitchen
Courtyard 1		1	1	0	0	0
Living Room			0	0	0	0
Courtyard 2				1	1	1
Multi-Purpose					0	0
Bedroom						0
Kitchen						



	Courtyard	Bedroom 1	Bedroom 2	Multi-Purpose	Kitchen	Bathroom
Courtyard		1	1	1	1	1
Bedroom 1			0	0	0	0
Bedroom 2				0	0	0
Multi-Purpose					1	0
Kitchen						0
Bathroom						

Figure 32-34: Traditional Syrian houses





- Entrance
- Multi-Purpose
- Courtyard
- Iwan
- Riwaq/Portico
- Bedroom
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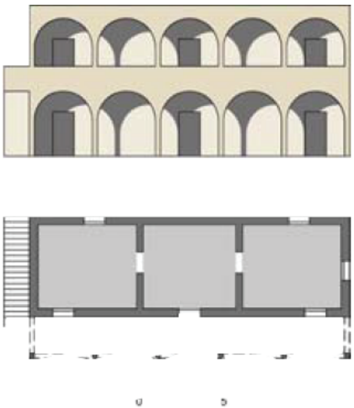
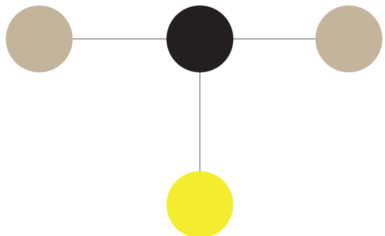
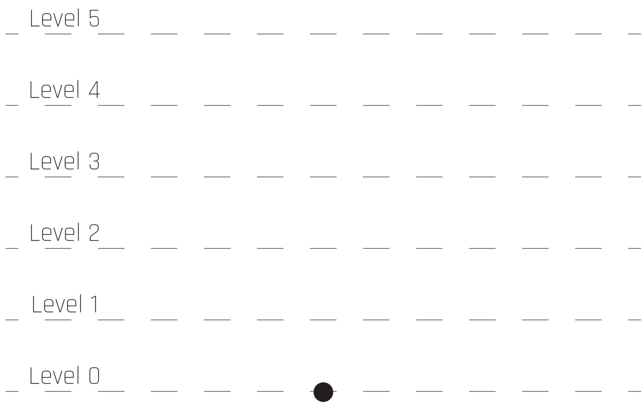
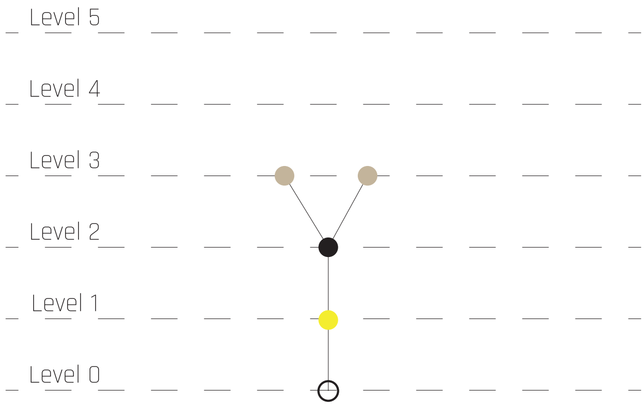
- Kitchen
- Bathroom

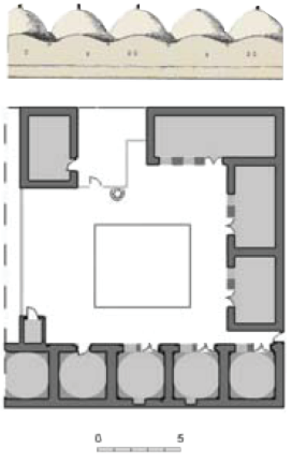


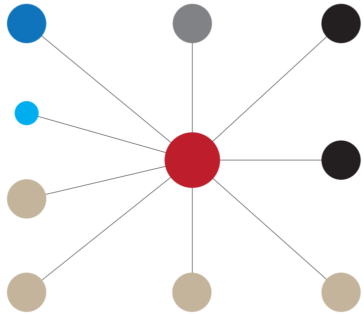






	Riwaq	Multi-Purpose	Bedroom	Bedroom
Riwaq		1	1	1
Multi-Purpose			1	1
Bedroom				0
Bedroom				





Entrance

Iwan

Living Room

Multi-Purpose

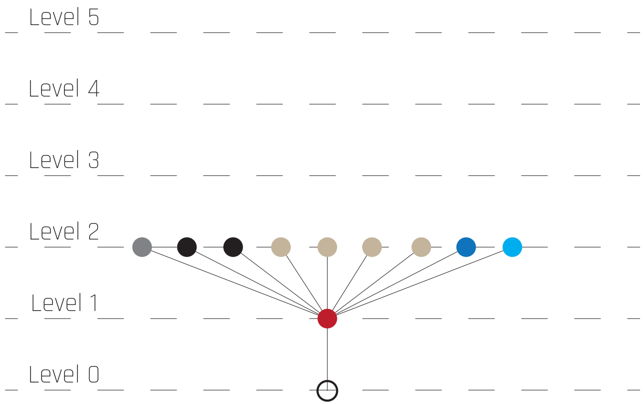
Riwaq/Portico

Kitchen

Courtyard

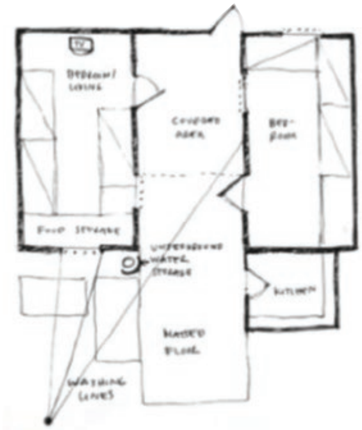
Bedroom

Bathroom

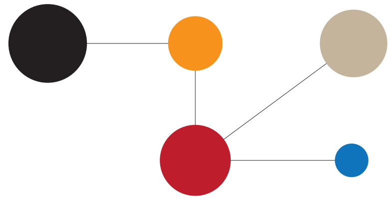


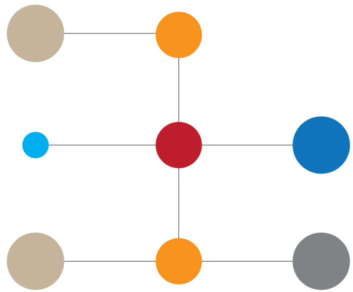
	Courtyard	Multi-Purpose 1	Multi-Purpose 2	Bedroom 1	Bedroom 2	Bedroom 3	Bedroom 4	Kitchen	Bathroom
Courtyard		1	1	1	1	1	1	1	1
Multi-Purpose 1			0	0	0	0	0	0	0
Multi-Purpose 2				0	0	0	0	0	0
Bedroom 1					0	0	0	0	0
Bedroom 2						0	0	0	0
Bedroom 3							0	0	0
Bedroom 4								0	0
Kitchen									0
Bathroom									

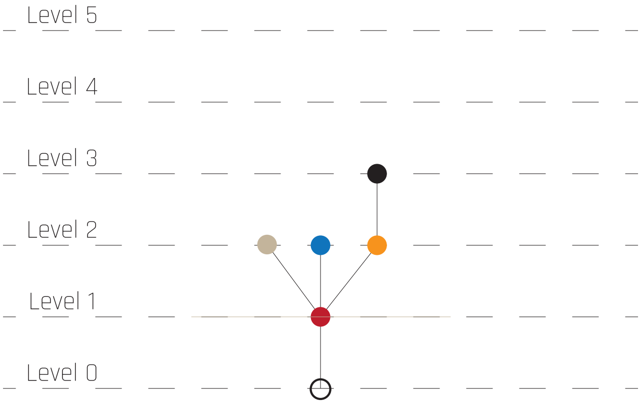
Figure 35-38: Houses in Al Za'atari



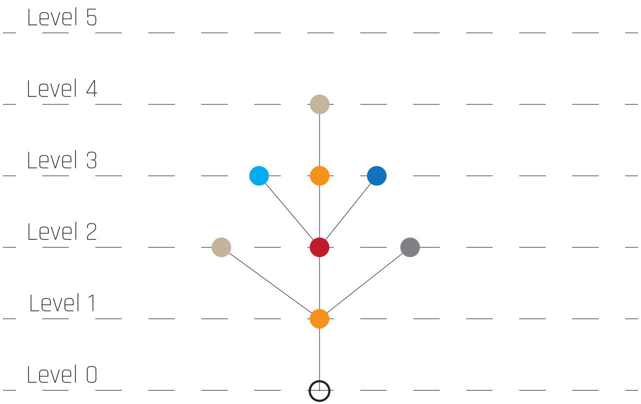
- Entrance
- Multi-Purpose
- Courtyard
- Iwan
- Riwaq/Portico
- Bedroom
- Living Room
- Kitchen
- Bathroom



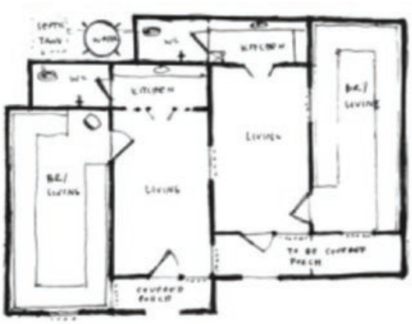


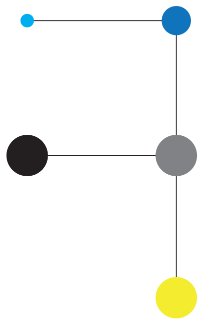


	Courtyard	Bedroom	Iwan	Multi-Purpose	Kitchen
Courtyard		1	1	0	1
Bedroom			0	0	0
Iwan				1	0
Multi-Purpose					0
Kitchen					

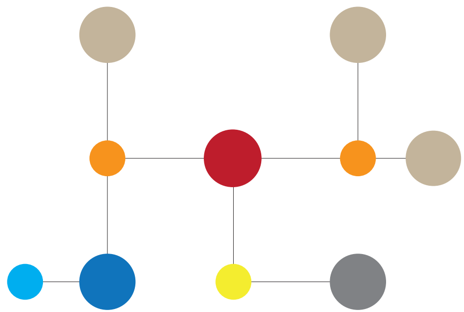


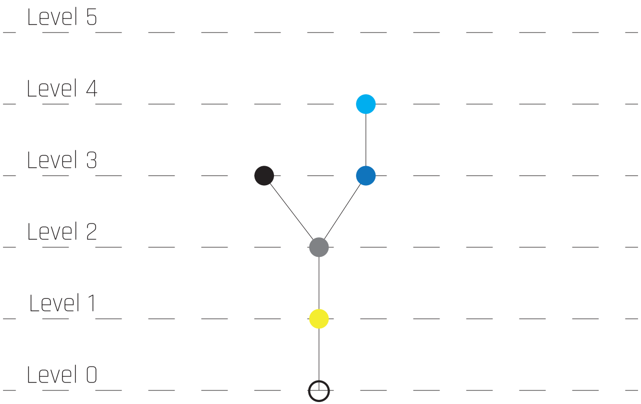
	Iwan 1	Living Room	Bedroom 1	Courtyard	Kitchen	Bathroom	Iwan 2	Bedroom 2
Iwan 1		1	1	1	0	0	0	0
Living Room			0	0	0	0	0	0
Bedroom 1				0	0	0	0	0
Courtyard					1	1	1	0
Kitchen						0	0	0
Bathroom							0	0
Iwan 2								1
Bedroom 2								



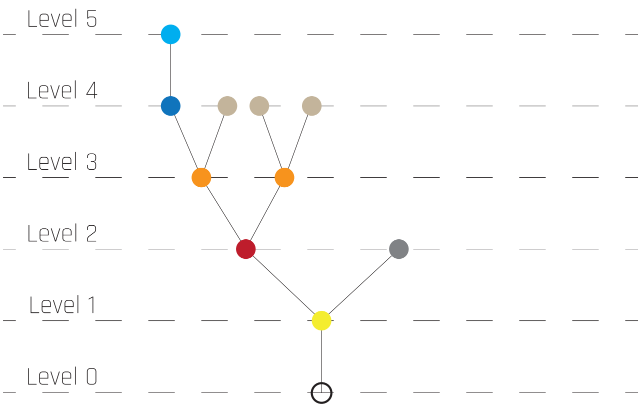


Entrance
Multi-Purpose
Courtyard
Iwan
Riwaq/Portico
Bedroom
Living Room
Kitchen
Bathroom

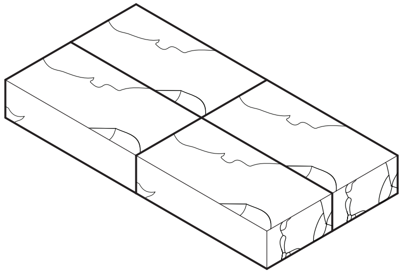




	Riwaq	Living Room	Multi-Purpose	Kitchen	Bathroom
Riwaq		1	0	0	0
Living Room			1	1	0
Multi-Purpose				0	0
Kitchen					1
Bathroom					



	Riwaq	Living Room	Courtyard	Iwan 1	Iwan 2	Kitchen	Bathroom	Bedroom 1	Bedroom 2	Bedroom 3
Riwaq		1	1	0	0	0	0	0	0	0
Living Room			0	0	0	0	0	0	0	0
Courtyard				1	1	0	0	0	0	0
Iwan 1					0	1	1	1	0	0
Iwan 2						0	0	0	1	1
Kitchen							1	0	0	0
Bathroom								0	0	0
Bedroom 1									0	0
Bedroom 2										0
Bedroom 3										



04 DESIGN

04 DESIGN

04.01 Approach

The design of the project was divided into four sections each corresponding to the scale of intervention. These include the urban scale, the topology scale, the geometry & structure scale, and ultimately the architectural detail scale (Figure 40).

Throughout the design process, and throughout all design scales, the use computation was of paramount importance. As was previously mentioned in the introduction section of this design manual, the decision to use computation and parametric design stems from the wish not to create a single architectural design but rather a design approach. This design approach is then embodied in a computational tool meant for the end user (house inhabitant).

In this way, instead of manually creating multiple versions of the design, we aimed to expose the critical parameters that drive the different variations (user preferences, material properties, structural restrictions, ...) and automatically generate different design variations by changing those parameters. In this way we ensured that the process would be stripped from any personal architectural aspirations and that the final design of the “house” is not the product of the designer but rather of the end user.

Our entire approach has been graphically represented as a design flowchart (Figure 40), later translated into a script, thus allowing us to view the design as a organizational problem and use a rules-based approach to tackle it

04.01 Urban Scale

The original layout of the urban camp blocks was in the form of a grid layout, developed according to the UNHCR handbook for refugee camps. Even though this functional and logical decision works well in plan point of view, it becomes a static, monotonous and non functioning solution from a human perspective. Due to this, people of Al Zaatari started modifying this layout to meet their own spatial, functional and cultural needs by moving caravans to form courtyards, adding additional rooms with available materials, and adding some commodities such as gardens.

On an urban scale, our computational tool aims to support and ameliorate this process by telling the users where to place their courtyards and where to move the caravans so as to maximize the available space for other house functions.

Figure 39: Mockup of the user interface showing the user selecting his family's caravans, which become the input for the urban script.

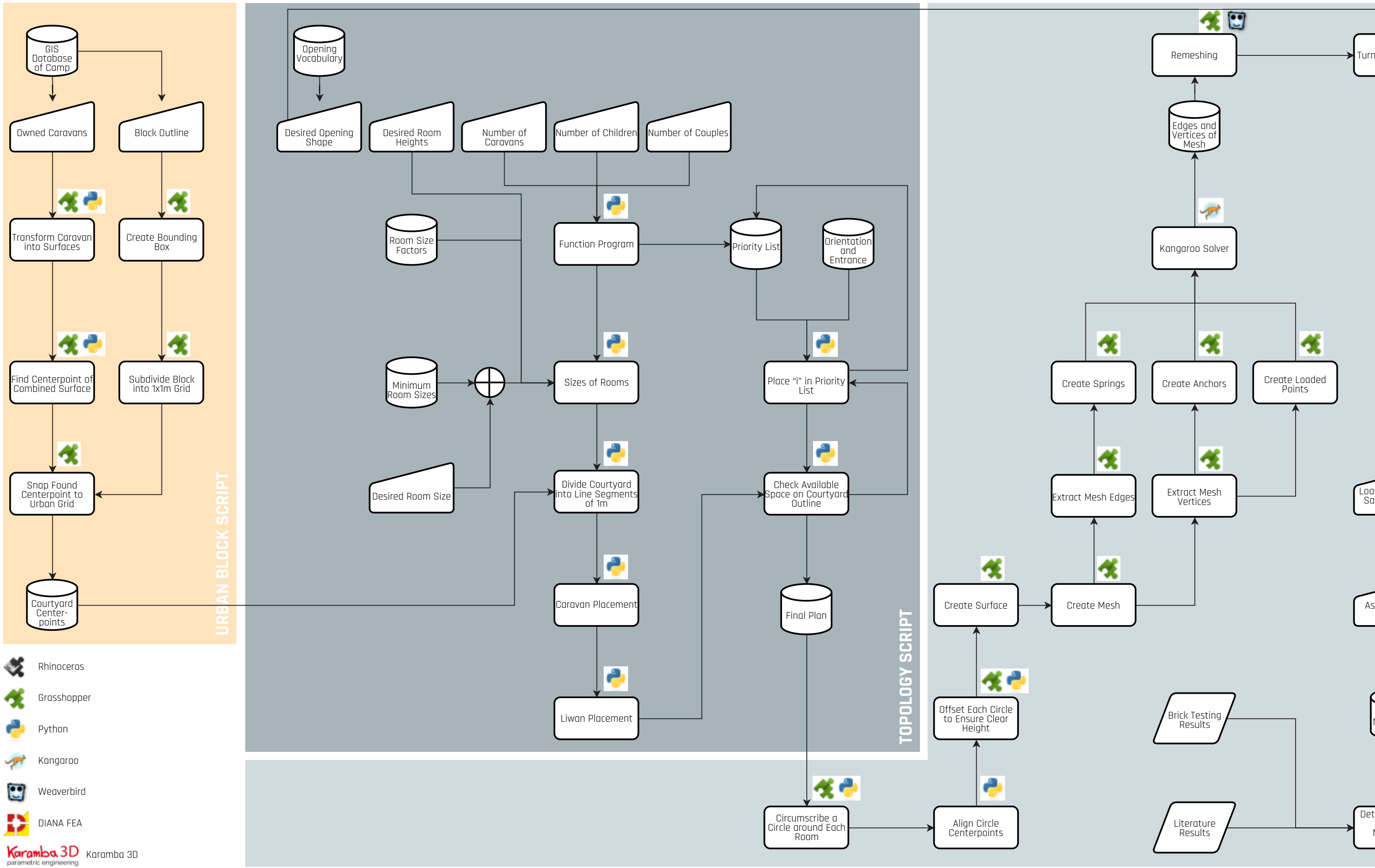
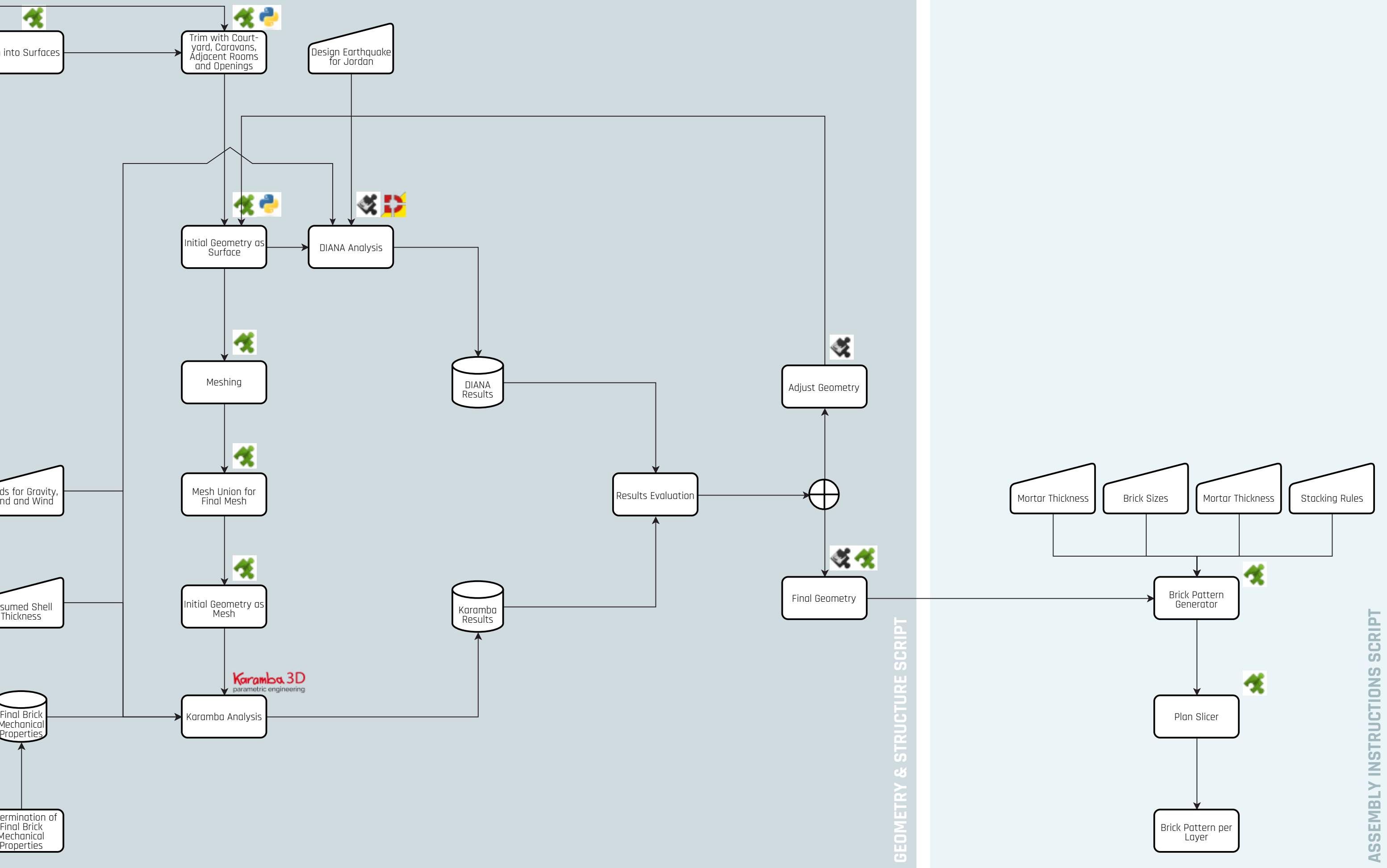


Figure 40: Detailed flowchart of Terrabayt


into Surfaces
Trim with Courtyard, Caravans, Adjacent Rooms and Openings
Design Earthquake for Jordan
Initial Geometry as Surface
DIANA Analysis
Meshing
DIANA Results
Adjust Geometry
ds for Gravity, nd and Wind
Mesh Union for Final Mesh
Results Evaluation
Mortar Thickness
Brick Sizes
Mortar Thickness
Stacking Rules
sumed Shell Thickness
Initial Geometry as Mesh
Karamba Results
Final Geometry
Brick Pattern Generator
Karamba3D
parametric engineering
Final Brick Mechanical Properties
Karamba Analysis
Plan Slicer
ermination of Final Brick Mechanical Properties
Brick Pattern per Layer
GEOMETRY & STRUCTURE SCRIPT
ASSEMBLY INSTRUCTION SCRIPT

The computational part of this process can be observed in the flowchart (Figure 40). In essence, once the user provides the information about which caravans belong to his family, the tool finds the center points of the courtyards and aligns them to the grid into which the entire block has been divided.

After the new earthy houses are created, the landscape of the block no longer resembles a container filled lot, but rather a natural landscape with hills or dunes. This "borrowed landscape" is best observed from the in-between-houses space. a public setting where other functions such as playgrounds, markets, or festivities can take place.

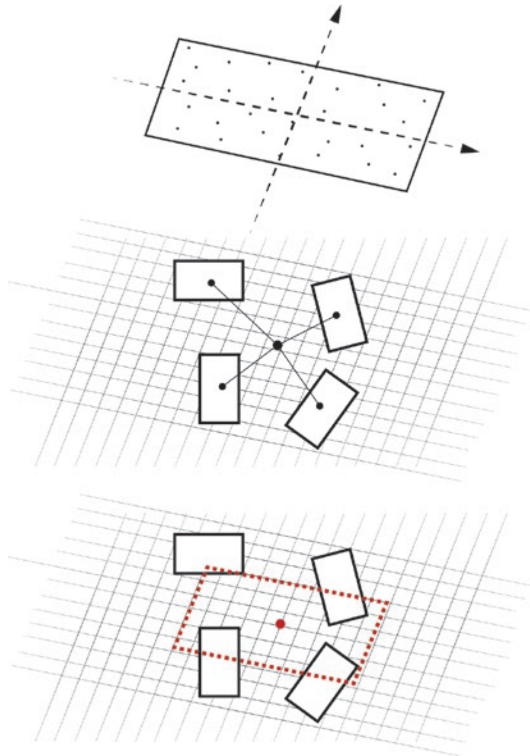


Figure 41 (top): From top to bottom: determining the principal vectors of the block, determining the courtyard centers, finding the courtyard size.

Figure 42 (right): Impression at urban level

04.02 Topology Scale

This scale primarily focuses on the generation of the house plan/layout. As was mentioned earlier, in order to ensure a fitting plan will be generated, an analysis of traditional typologies was performed, along with the analysis of the houses within Al Za'atari created by the inhabitants. The analysis consisted of comparing the graph charts, justified graphs and REL charts of each observed house to determine the relations between spaces. The results showed that the Al Za'atari inhabitants maintain the traditional spatial relations and topological characteristics when creating their caravan houses within the camp. This notion was of great importance, and was used as a base for further design of our earthy additions, with an intent for the new earthy spatial structures to afford the same social structures to which the people of Al Za'atari were accustomed to.

Furthermore, it was noticed that the house topology changes based on the family size and family structure. Therefore these two parameters were taken as primary inputs of the computational tool, thus being the main drivers of varying house plan outputs.

The working principle of the computational tool can be observed on the flowchart (Figure 40). In essence, the tool takes the information about the number of people within the family, number of couples, and number of children, along with the previously determined courtyard centerpoint and number of caravans the family owns. Then, it calculates what are the programmatic requirements of such a family and what are the sizes of the spaces the family needs. Once this information is calculated, an iterative process of arranging these spaces around the courtyard is set in motion, althewhile adhering to certain restrictions the user provides, such as the desired orientation of certain spaces (e.g. Iwan on south, entrance on west etc.), or the desired size of a particular room.

The sequence of space placement around the courtyard is based on a priority list. Firstly, the caravans are placed in the corners so as to make sure that the earthy additions don't block the existing doors or windows. Secondly, the liwans are added, as spaces which grant access to the caravans. From this point, other spaces of the house (iwans, kitchen, toilet, bathroom, living room etc.) are placed sequentially, trying to respect the user-specified restrictions concerning the desired orientation or size.

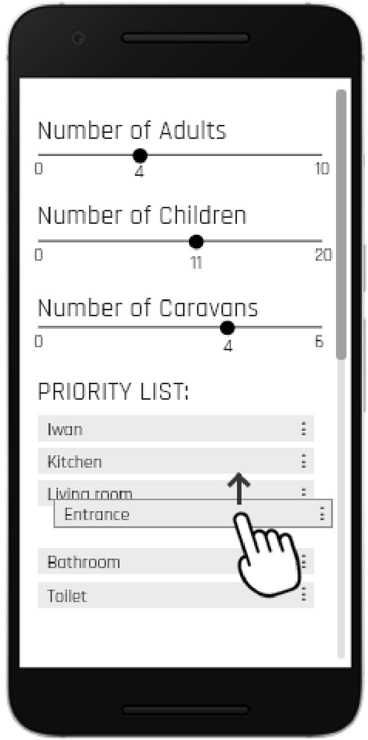


Figure 43: Mockup of the user interface showing the user providing the input for the layout generation script.

Figures 44-46 showcase possible outputs of the house layout script, based on the varying inputs provided by the user. Additionally, each added function is marked with a unique color, allowing the user to get a quick understanding of the generated layout, and evaluate if it is to his likeness.

It should be mentioned that the tool is still in the development phase, but still provides satisfactory results for the tested cases. It would be beneficial to implement a better logic of translating the REL charts and their graph representations into floor plans such as through the use of multi objective genetic algorithms (Nagy, 2017). Such an approach would ensure that the process of the final layout evaluation is also automated and based on concrete design metrics, and not left to the designer, hence being susceptible to subjectivity.

Figure 44: Generated house layout based on the following input: 2 caravans, 2 couples, 6 children, entrance on north side

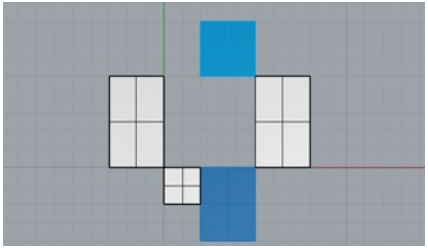


Figure 45: Generated house layout based on the following input: 3 caravans, 3 couples, 11 children, Iwan on the south side, entrance on the west side

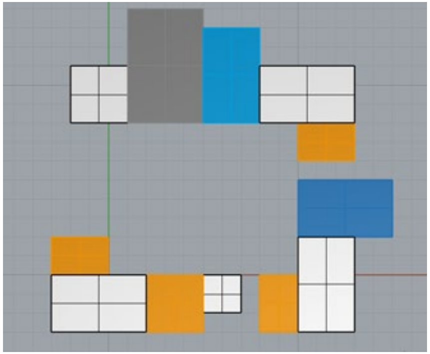


Figure 46: Generated house layout based on the following input: 4 caravans, 3 couples, 17 children, Iwan on the south side, entrance on the east side.

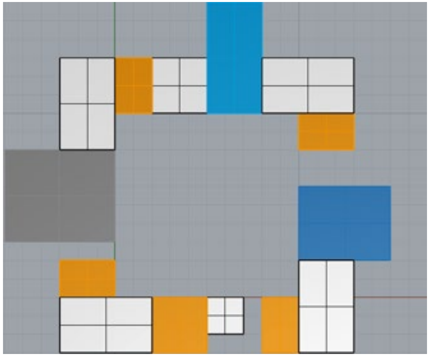


Figure 47: Floor plan of Terrabayt

04.03 Geometry & Structure Scale

In this phase, the previously generated floor plan is used as a starting input in the process of generating the house geometry (walls, roofs, other earthy additions). The process of designing this stage was conceptualized in a traditional way (sketching, modeling...), with an idea how the overall final geometry should look like. We were guided by traditional designs and best practices of adobe buildings, mainly of Syrian origin. But, again, the intention to completely follow a rules based approach towards the final form generation was kept. Thus the computational steps taken during the form finding process can be observed in the flowchart (Figure 40).

In practical terms, this is done by first circumscribing a circle around each space withing the floor plan, which are then turned into a surface and relaxed dynamically in Kangaroo to achieve a compression only structure, required by the type of material we are working with. The decision to dynamically relax circles instead of the rectangles from the floor plan, came after the realization that starting with a circle yielded a better performing structure, more optimized for construction and overall with a more pleasing aesthetics.

The resulting "relaxed" meshes, parabolic in shape, are intersected with each other, the caravans, and the outline of the courtyard, and then offset by the desired wall thicknesses to get the final geometry surfaces. In the end, openings are added manually in accordance with a previously defined vocabulary, and based on a user's preference. This shape is additionally refined by filleting it with the ground plane, in order to achieve the envisioned smooth transition and integration with the landscape.

At this point, it was necessary to verify the soundness of the achieved geometry, by performing a structural analysis. This was done computationally through the use of Finite Element Analysis software such as Karamba and Diana. A general overview of the process can be observed in the flowchart (Figure 49).

For the purposes of the structural verification, certain properties needed to be assigned to the geometry being tested. Namely the wall thickness, the material properties, supports, and loading cases.

When it comes to wall thicknesses, the decision to go for 40cm walls was based on best practices and information from literature. This decision was coupled with the material properties, whose specifications have also been obtained through personal testing but also literature study. Detailed elaboration on the material

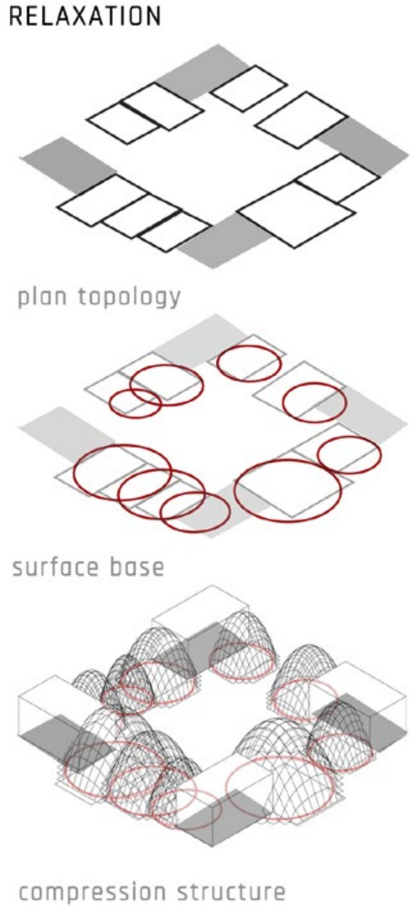


Figure 48: Structuring of Terrabayt

testing and choice of the material characteristics for the structural analysis are described in a separate chapter of this manual. In terms of the supports, they have been designed based on rules of thumb and best design practices from literature study. The structure was tested for four standard load cases: self load (gravity), wind, sand and earthquake.

After performing the simulations, the results were evaluated and a decision whether to make modifications to the final geometry was deliberated. As the structure performed well, no modifications were needed for the initial design. Thus, we acquired a final geometry which served as an input to the following step, which was concerned with creating additional architectural details.

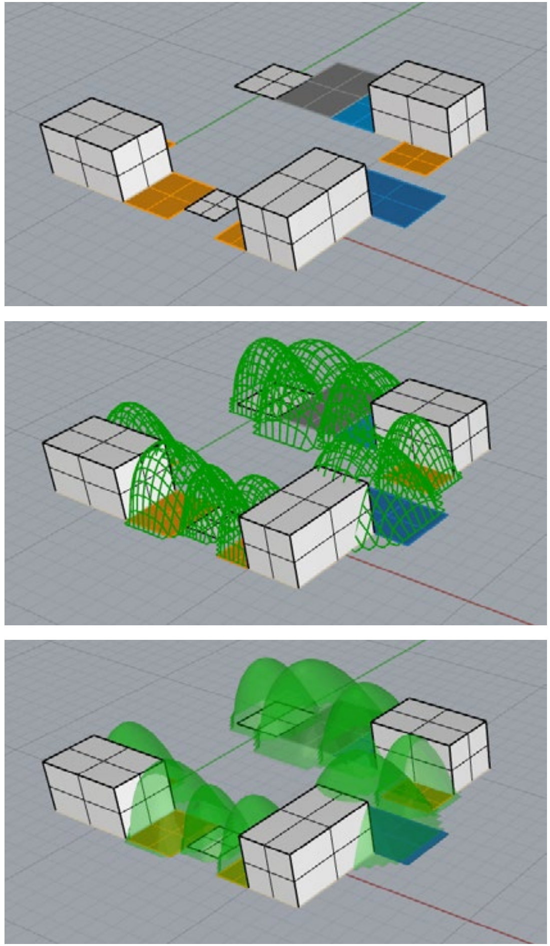


Figure 49: The geometrical development of Terrabayt

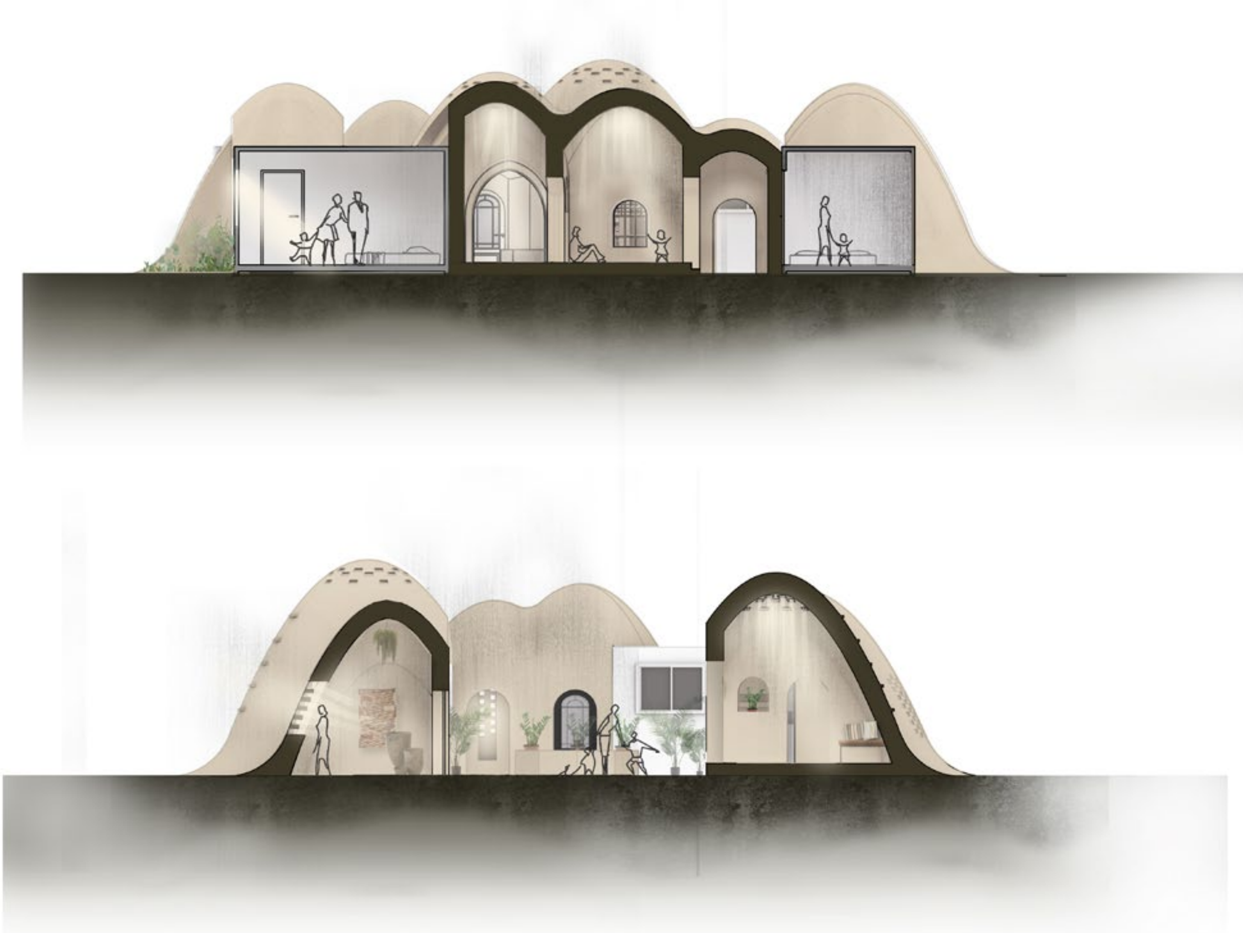


Figure 50: Sections

Figure 51: Impression of the house's entrance

Figure 52: Impression of the courtyard

04.04 Architectural Detail scale

At this point of the design process, we wanted to implement certain details which we believe would improve the quality of the final solution. This process was done manually and not using computational design, mainly due to time restrictions, which is not to say that the process could/should not be done in such a way.

The three architectural details that were implemented are the exterior earthy planters, door/window openings, as well as roof/wall mashrabiyas (Figure 53).

The decision to incorporate the earthy planters along the exterior perimeter of the house, stems from the wish to provide the inhabitants with the ability to grow plants - an incentive already taken up by many of the camp inhabitants, instrumental for establishing a feeling of being at home. The planters are placed at the very ends of the slopes, providing a physical separation between the street and the house, but also to enable the plants to be irrigated by the excess rainwater coming down the roofs.

The door and window openings are contained in an 'opening vocabulary', by which the user designing his house could choose the geometry of the openings of each individual earthy space. All types of openings contained withing this vocabulary are based on traditional openings found in middle-eastern architecture. A more elaborate explanation of the opening vocabulary and it's implementation are placed in the 'assembly instructions' part of this manual.

Lastly, a second type of openings in the form of mashrabiyas on the roof and wall surfaces was incorporated as a means of introducing more light into the spaces, allowing views towards the outside, and enabling natural ventilation to occur. Thus, spaces such as bathrooms and toilets have mashrabiya openings on the topmost sections of the shell to allow for the extraction of moist air and prevent moisture buildup on the ceilings, while spaces such as liwans, iwans or living rooms have openings in the middle sections allowing the views towards the outside Kitchens have both type of openings present. The sizing of this openings was based on the dimension of the adobe brick, but should be further verified through simulations for lighting and thermal comfort.

Figure 53: Photograph of the model, showcasing the three main architectural details: 1- earthy planters, 2-door & window openings, 3- wall & roof mashrabiyas

Figure 54: Impression of the Iwan from two areas

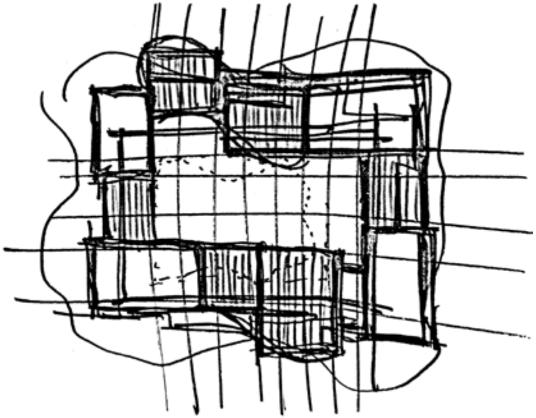


Figure 55: Floor plan according to the grid

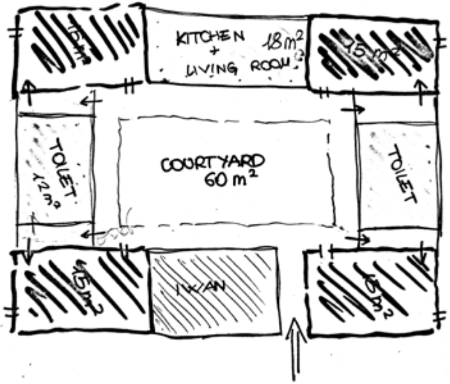


Figure 56: Floor plan with functions and area

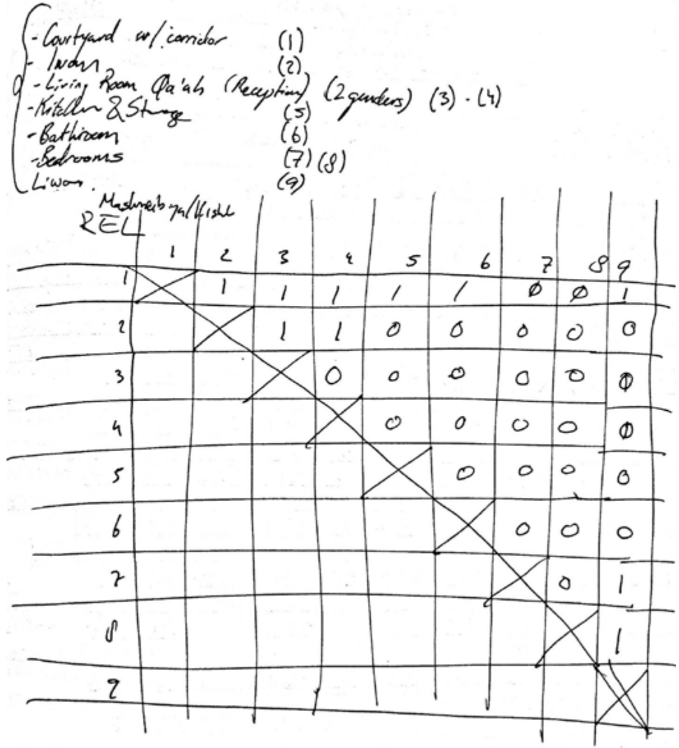


Figure 57: REL chart of the spaces

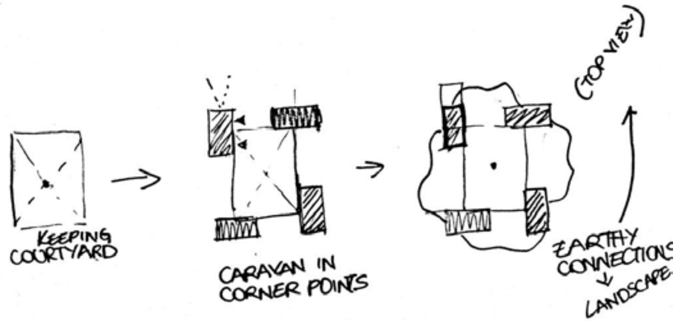


Figure 58: Geometry configuration

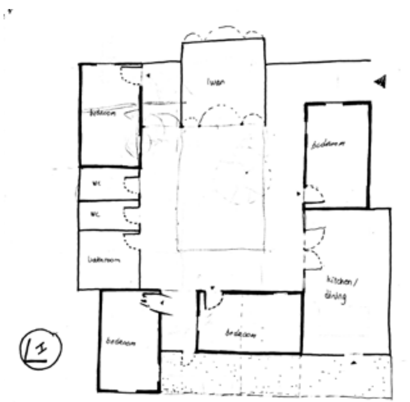


Figure 59: Floor plan with functions

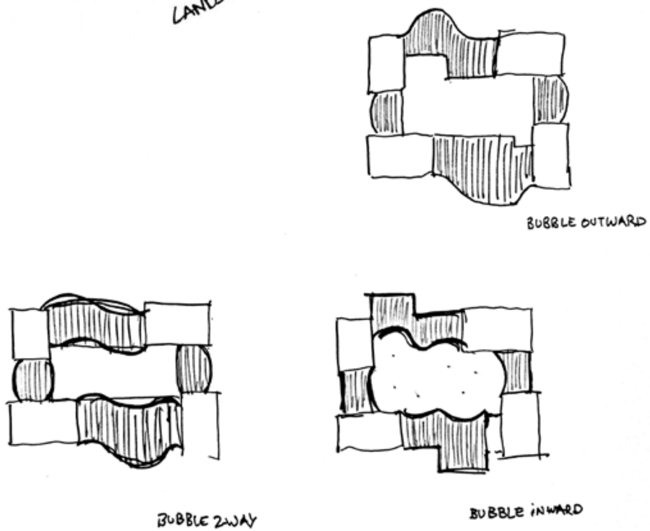


Figure 60: Floor plan combined with the form

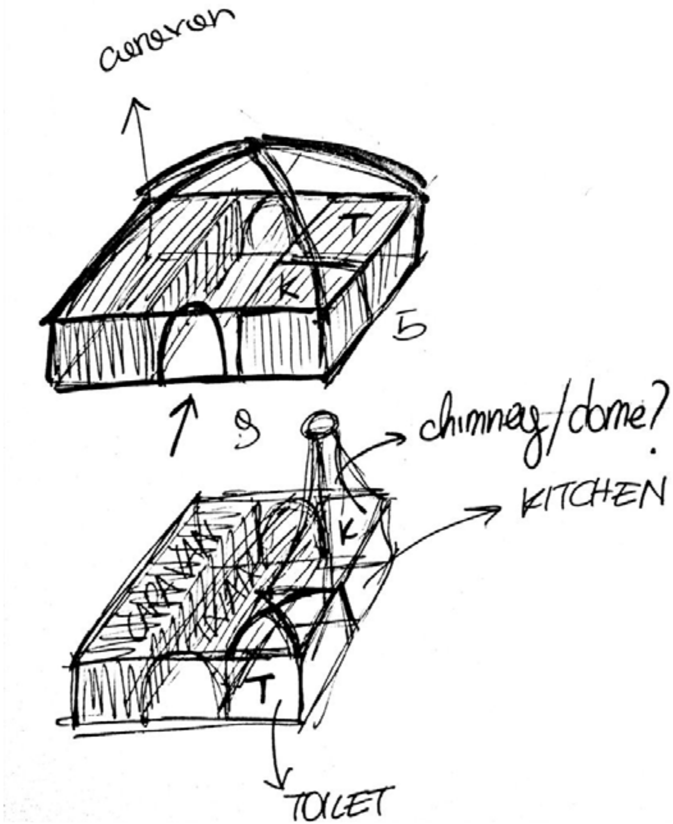


Figure 61: Form finding for the one caravan solutions

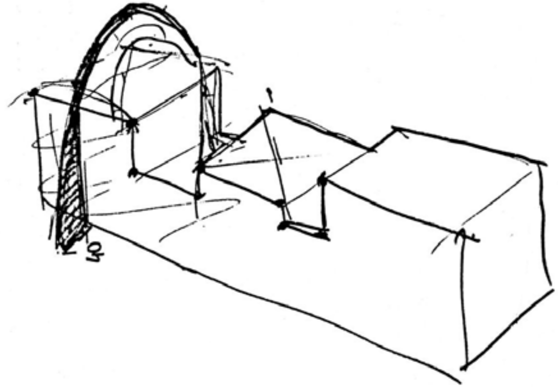


Figure 62: Form finding according to multiple sections

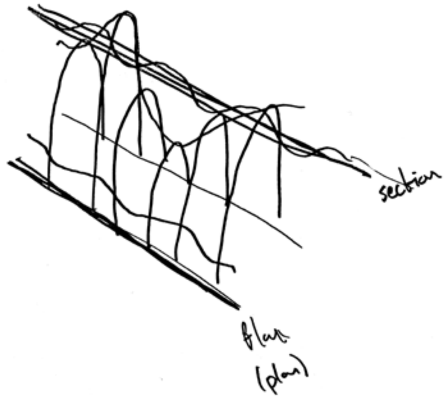


Figure 63: Form finding according to multiple sections

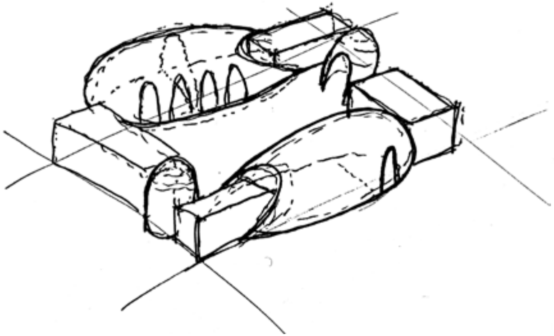


Figure 64: Form finding and openings

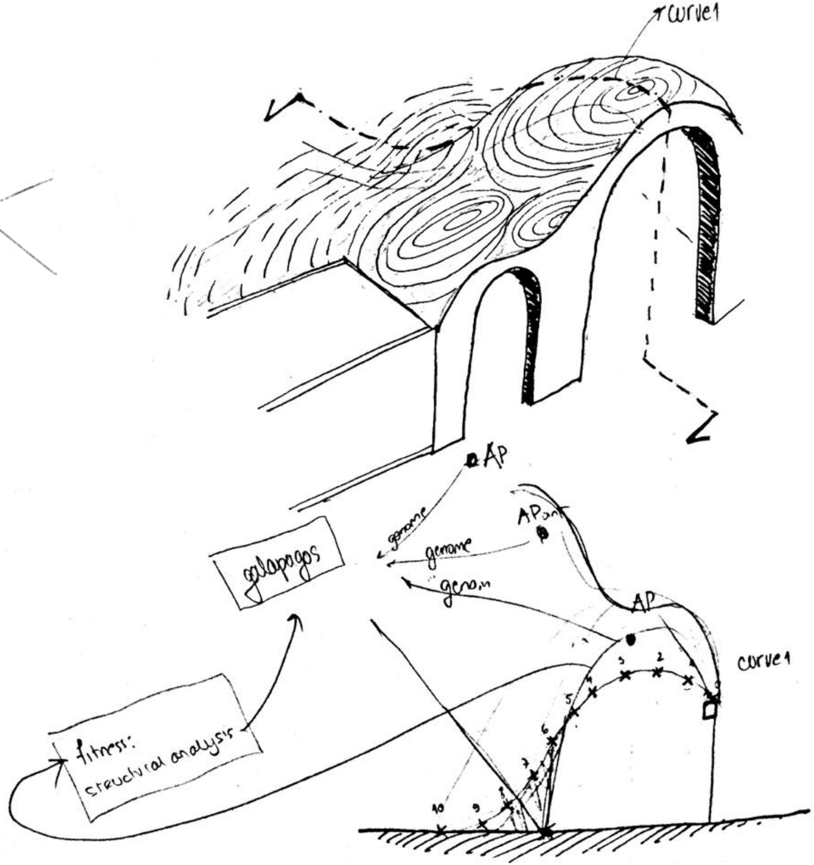


Figure 65: Form finding from the structural analysis

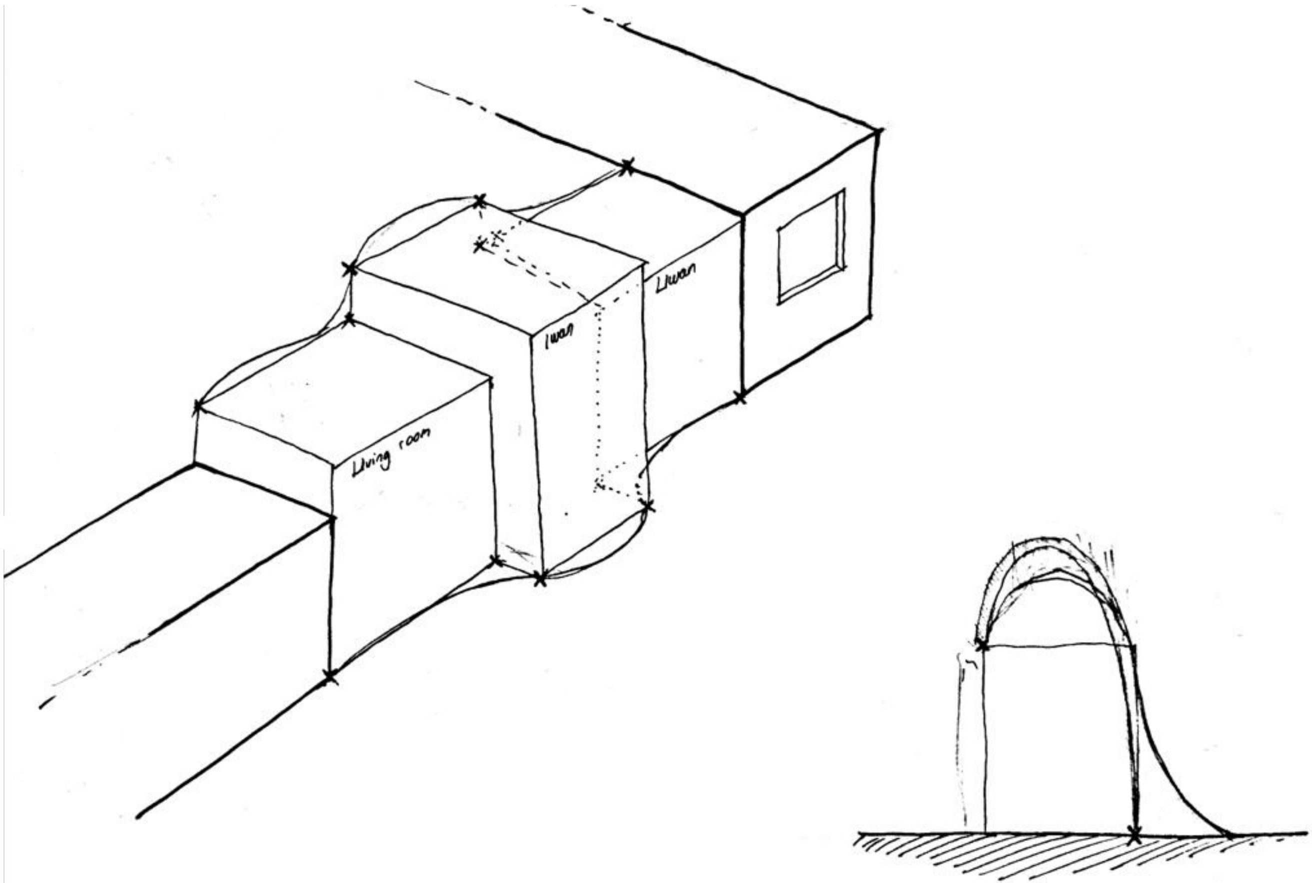


Figure 66: Form finding and structural optimization

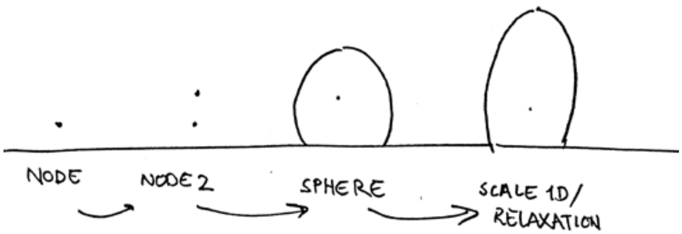


Figure 67: Steps of the relaxation process

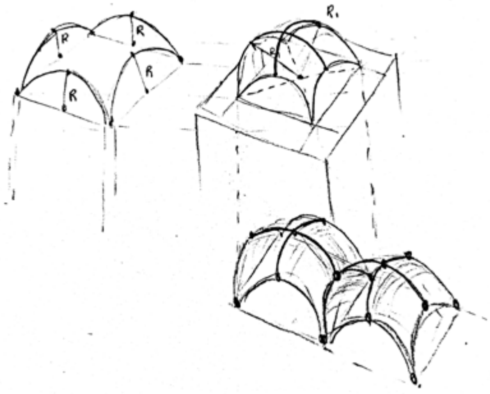


Figure 68: Mesh construction and division

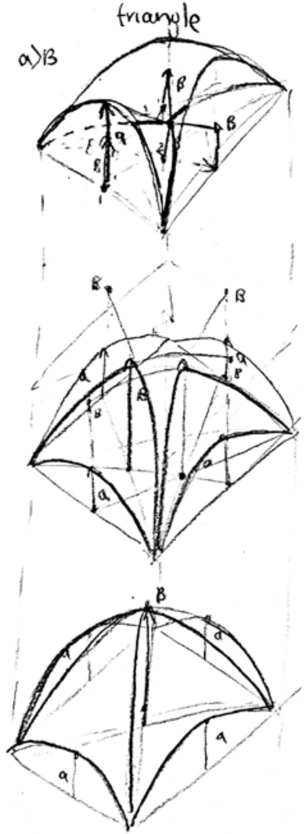


Figure 69: Mesh construction and division

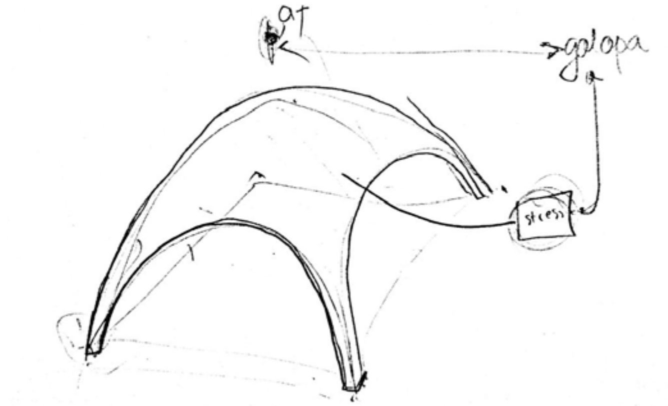


Figure 70: Form finding and structural optimization

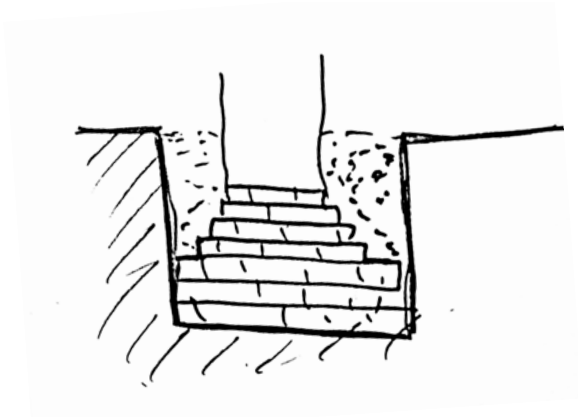


Figure 72: Foundation scheme

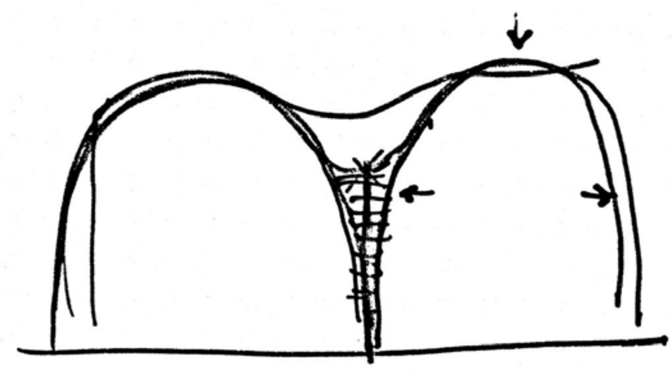


Figure 71: Separating walls and point loads

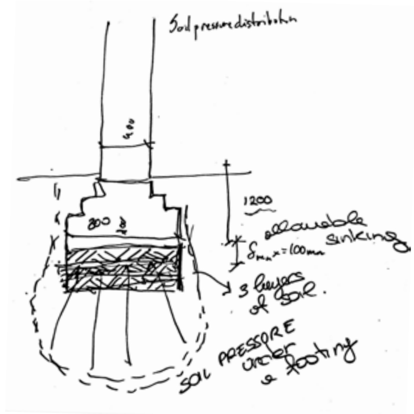


Figure 73: Foundation construction

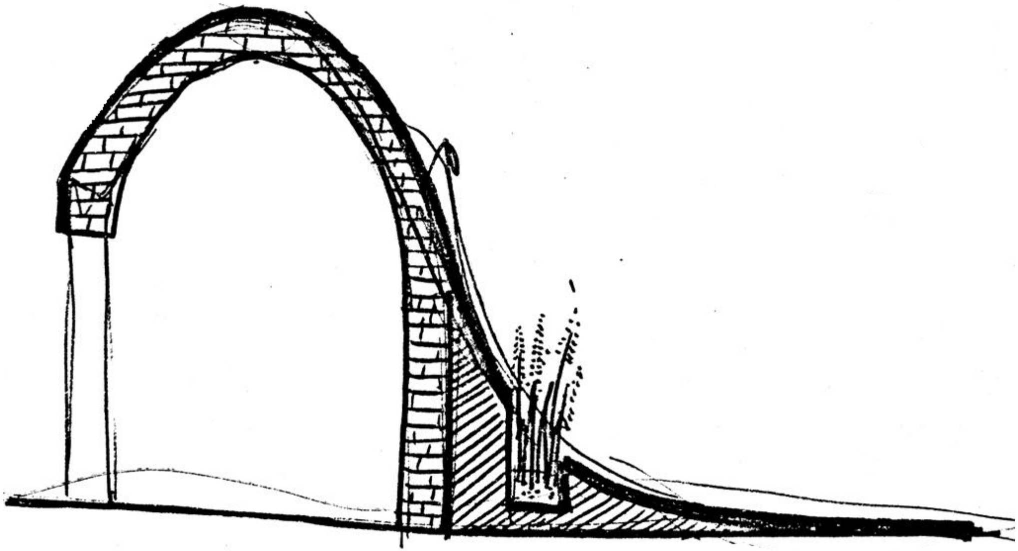


Figure 74: Section of the final shape with plant irrigation

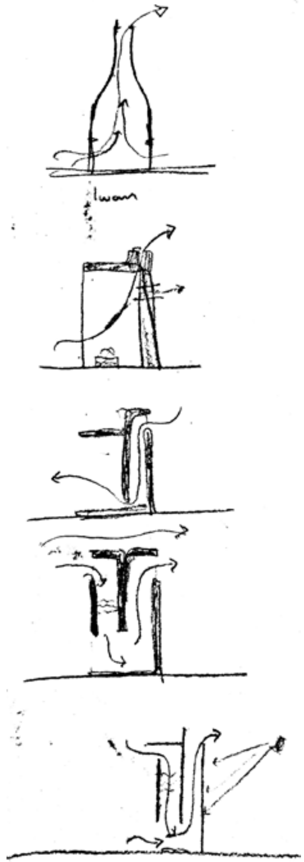


Figure 75: Ventilation principles

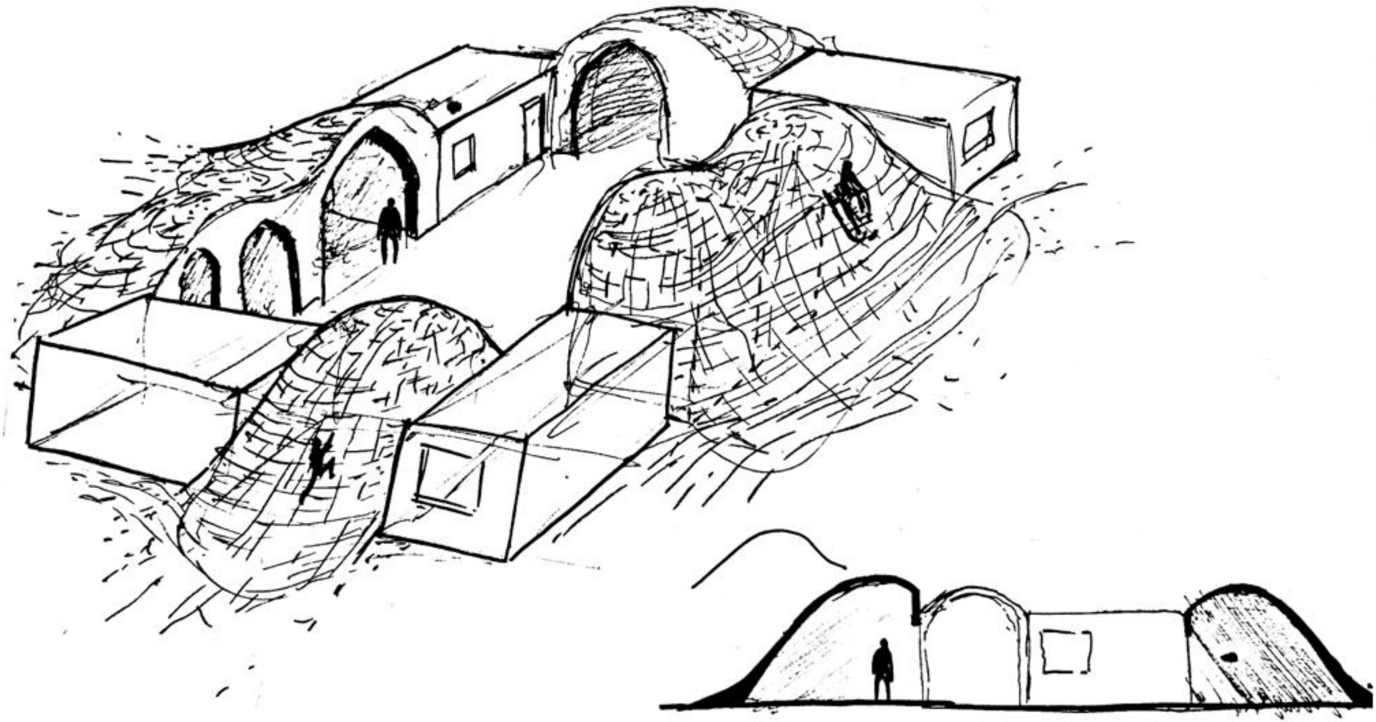
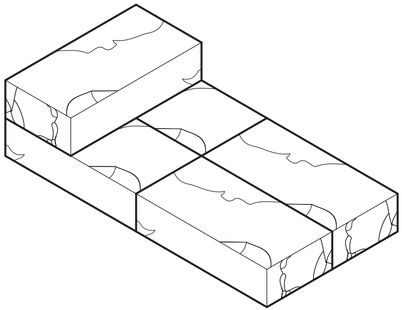


Figure 76: Axonometric sketch and section of the final design



05 MATERIALS

05 MATERIALS

05.01 Introduction

An essential aspect of Terrabayt is the materialization: we propose the usage of locally available materials that allow for a construction that can be built by the inhabitants themselves. The procurement and assembly sequence is further elaborated in the "Construction Process" chapter, while this chapter focuses more on the technical aspects of the used materials.

05.02 Bricks Testing

Previously, our group made 21 bricks of different sizes and compositions and tested them for their compressive strength. These values were elaborated in our previous report "Structural Report: on the determination of the compressive strength and safety factors for structural design of various types of handmade adobe bricks".

For those tests, we made 21 bricks, of which 11 large (145x90x65mm) and 10 small ones (110x65x68mm). They all had a mass ratio of 1-1-1.3-0.3 for clay-fine sand-coarse sand-water and were made from clean Dutch materials and tap water. Additionally, we tested the effects of adding 10% (volume) of wood chips, straw, plastic strips or a combination of wood chips and straw. The bricks were made in controlled conditions, pressed by hand and left to cure for 9 days in tents without direct sunlight at an average temperature of 14 degrees Celsius (KNMI, 2018).

Due to the small amount of samples and large variance, we decided to take the average of all our samples to determine the final compressive strength across various sizes and compositions. We used the averages of all our bricks due to the following reasons:

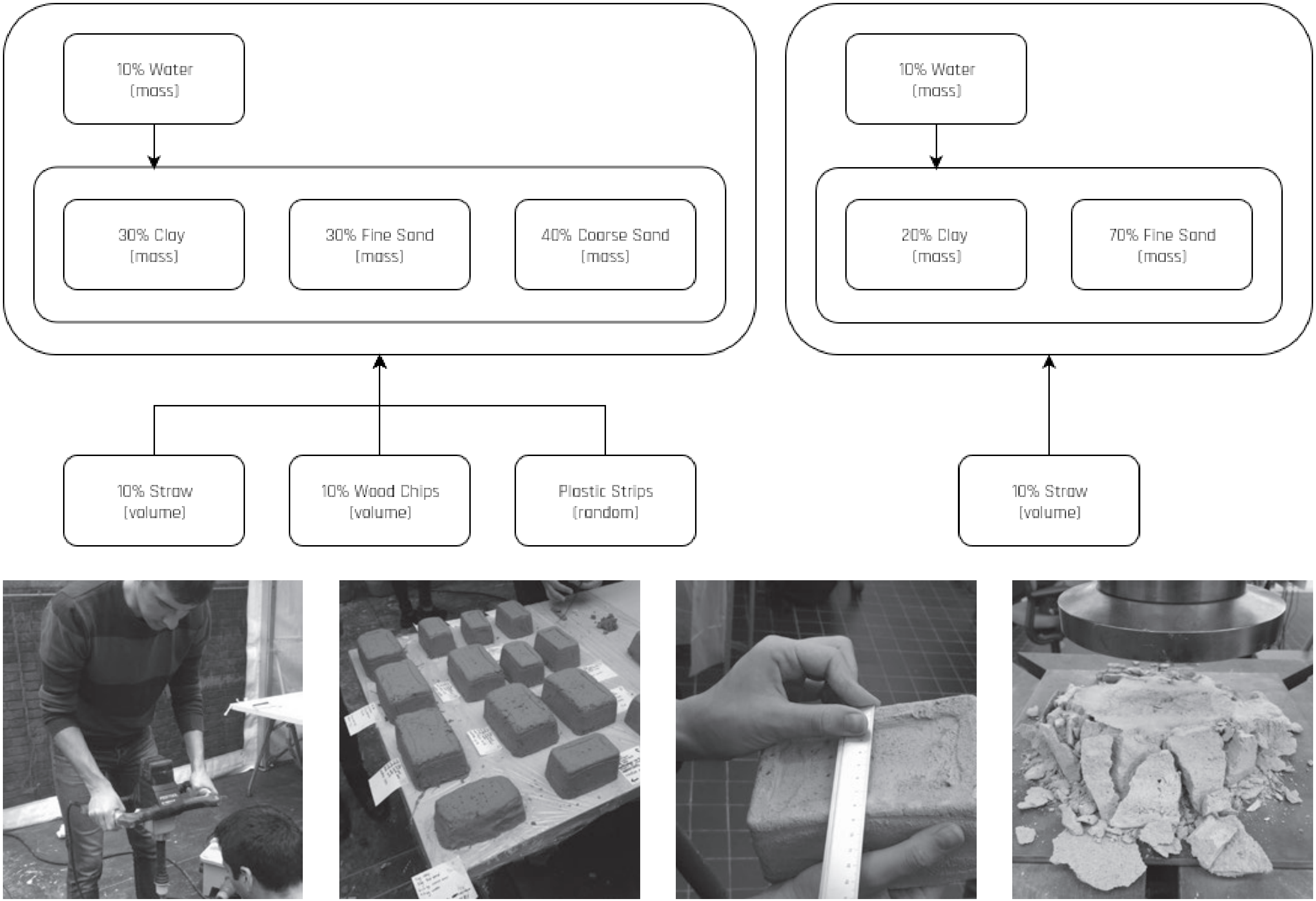


Figure 77: Brick composition for testing (top left) and for the final bricks (top right) and images from our manufacturing and testing (bottom)

1. The sample size we used was too small to determine the compressive strength of each brick type, as at least 6 of the same type are needed according to EN772-1.

2. Literature shows that the effect of brick size on ultimate strength is limited (Sasui et al., 2017), as was confirmed by (the large variance in) our results.

3. Literature shows that, for the composition we tested, adding straw should not add to the compressive strength of the brick (Quagliarini, 2017).

The results by taking this approach resulted in a final average ultimate compressive strength of 0.765 MPa. This was on the lower end of the spectrum we found from literature on adobe bricks but was still realistic. We assumed that the short curing period, high moisture content of the air and our lack of experience in making them reasonably contributed for the relatively low compressive values.

From our research, we also determined an appropriate safety factor of 3.5 for the design. This was based on the fact that combining the partial safety factors (load and material) for masonry structures would lead to a value between 2.7 and 4.5. As our building was of a lower safety and consequence class than the aforementioned Eurocode values, a safety factor of 3.5 was deemed acceptable for our design. Combining this with the average ultimate compressive stress we reached a target allowable compressive stress of 0.22 MPa.

It was clear from our brick making results that hand-made adobe bricks show great variance in their structural properties. While failing, the bricks with

Brick #	Inventory #	Clay [kg]	Fine Sand [kg]	Coarse Sand [kg]	Water [kg]	Moisture [%]	Length [cm]	Width [cm]	Height [cm]	Area [cm2]	Special	S_1.5% [MPa]	S_5% [MPa]	S_Final [MPa]
A1	35					42.1	11	6.5	6.3	71.5	none	0.052	0.537	0.448
A2	36					42.2	11.5	7.5	5.8	86.25	none	0.078	0.370	0.823
A3	37					41.7	11	6.5	6.9	71.5	wood chips 10%	0.092	0.544	0.576
A4	38					42.1	11	7	4.9	77	none	0.007	0.114	0.886
A5	39					41.9	12	7.5	5	90	random straw	0.133	0.651	0.589
A6	40					42.2	11	7	6.5	77	wood chips 10%	0.031	0.524	0.847
A7	41					42.3	11	6.5	6.7	71.5	wood chips 10%	0.105	0.845	0.929
A8	42					41.9	11	6.5	6.6	71.5	straw 10%	0.398	1.027	1.419
A9	43					41.9	11	6.5	5.8	71.5	straw 10%	0.333	0.629	0.814
A10	44					41.8	11	6.5	6.8	71.5	plastic strip layers	0.200	0.498	0.716
A11	45	5	5	6.7	1.7	42.1	10.5	6.5	6.5	68.25	straw 10%	0.583	0.826	0.964
B1	46					42.1	14.5	9.5	6.5	137.75	wood chips 10%	0.198	0.956	1.496
B2	47					42.1	14.5	9	6	130.5	none	0.006	0.254	0.228
B3	48					41.7	14.5	9.5	6.5	137.75	straw 10%	0.052	0.546	0.677
B4	49					42.2	14.5	9	7	130.5	none	0.109	0.456	0.507
B5	50					41.7	15	8.5	6.5	127.5	none	0.003	0.156	0.168
B6	51					42.3	14.5	9	6.5	130.5	wood chips 10%	0.027	0.447	1.336
B7	52					42.1	15	9	6.5	135	wood chips & straw 10%	0.095	0.489	0.795
B8	53					41.6	14.5	9	6.5	130.5	straw 10%	0.240	0.811	0.829
B9	54					42.2	14.5	9.5	6.5	137.75	straw 10%	0.148	0.583	0.562
B10	55					41.8	14.5	9	6	130.5	wood chips 10%	0.208	0.537	0.465
											AVERAGE	**0.152**	**0.562**	**0.765**

Figure 78: Specifications of the bricks we tested and their ultimate compressive strength

straw do stick better together and have increased workability during manufacturing. Additionally, curing is especially important, as longer curing times with a proper balance between heat and moisture results in better compressive strengths as shown in literature (Fathy, 1969). This is especially the case for fired bricks, that perform around 10 times better than regular adobe bricks (NBC, 2018).

05.03 Final Design Values for Our Bricks

Based on both our findings and findings from literature, we have defined the final values and brick composition that we want to use for our design. We have split the selection of the final composition into three steps: determine what material we want as additive, what the final material composition is and the final strength of that composition.

Firstly, we want to determine the additives we would like to have in the brick. Out of various options, the one that is the most simple yet has the biggest impact is straw: it increases the workability during manufacturing, decreases thermal conductivity and shrinkage during curing and also has a slight confining effect at failure loads (experienced during our tests).

However, it has no beneficial effect on the ultimate compressive strength unless the mixture has very little clay. Various sources indicate differing values, with 1-5% being a workable limit (Quagliarini et al., 2010, Silva et al., 2013). According to experiments performed by Colonel Debes (Fathy, 1969), increased straw content decreases the strength even, irrespective of the sand content. We therefore recommend a straw content of 1%, which yields the highest strength values from multiple sources. Additionally, if straw is incorporated

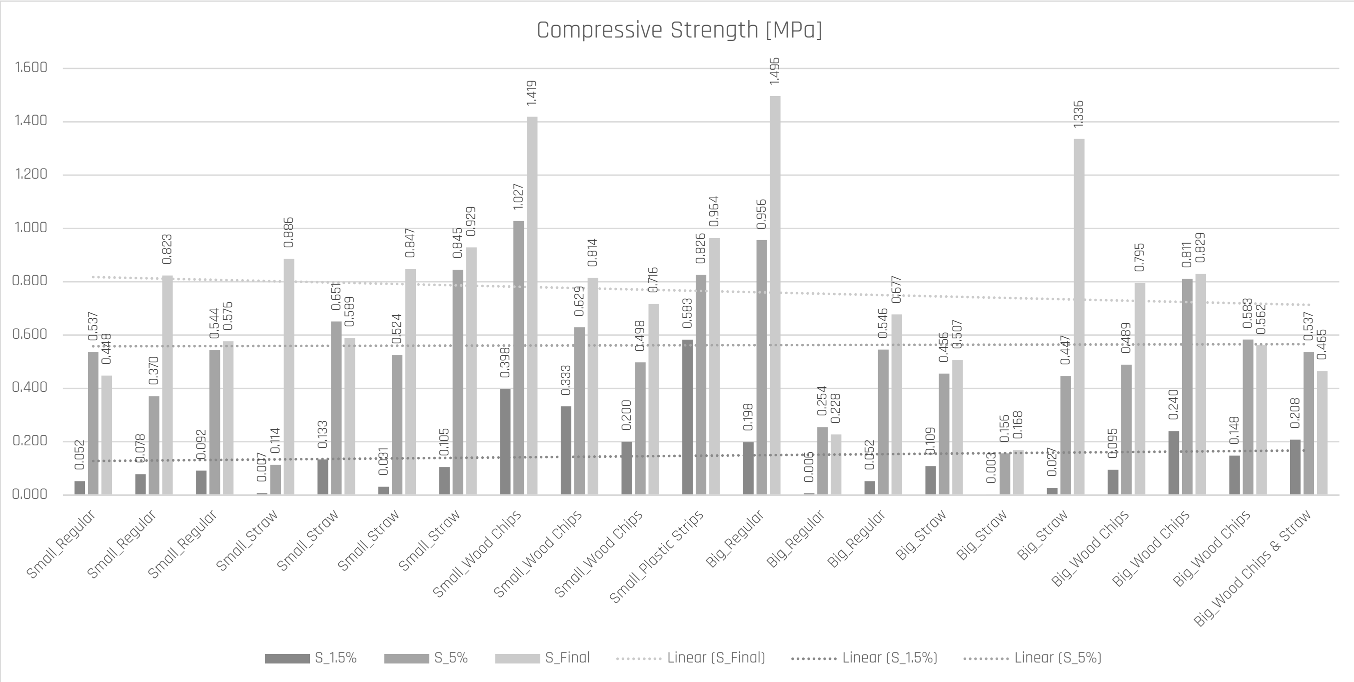


Figure 79: Compressive strength of our tested bricks

into the finishing plasterwork, and especially if combined with cow dung, the water resistance of an earthy structure increases greatly.

In order to determine the final mixture, we firstly determine that usage of both coarse and fine sand together would be difficult to achieve in Al Za'atari; after all, there are no tools to sort sand in large quantities. Therefore, limiting the mixture to one type of sand would be beneficial, resulting in a mixture of silty clay, sand and straw. Values from Colonel Debes indicate that large sand is very detrimental to the ultimate compressive strength, while using fine, small or medium sand is relatively identical.

Our analysis of the soil composition around Al Za'atari (to prevent permanent development, the camp itself has been flattened with a layer of debris which is undesirable for adobe bricks) indicates that fine sand and coarse sand together easily makes up nearly 75% of the soil (JOSCIS, 2018, Al-Qudah, 2001). Therefore, we can assume that the available soil will be in between ("medium sand"). Due to the more difficult procurement of clay and easy availability of sand, we propose a mixture that has a high sand content and low clay content of 80% medium sand and 20% clay, resulting in compressive stresses between 1.2 and 4.8 MPa depending on the curing period. Additionally, the soil around Al Za'atari has high lime content (Bsoul and Mazahreh, 2012), although the effect of the lime will be disregarded due to lack of further information.

Extrapolation from Debes' values indicates an expected limit of 1.1 MPa for 80% medium sand, 20% clay and 1% straw with a curing period of 7 days, resulting in a design compressive stress of 0.31 MPa. This is

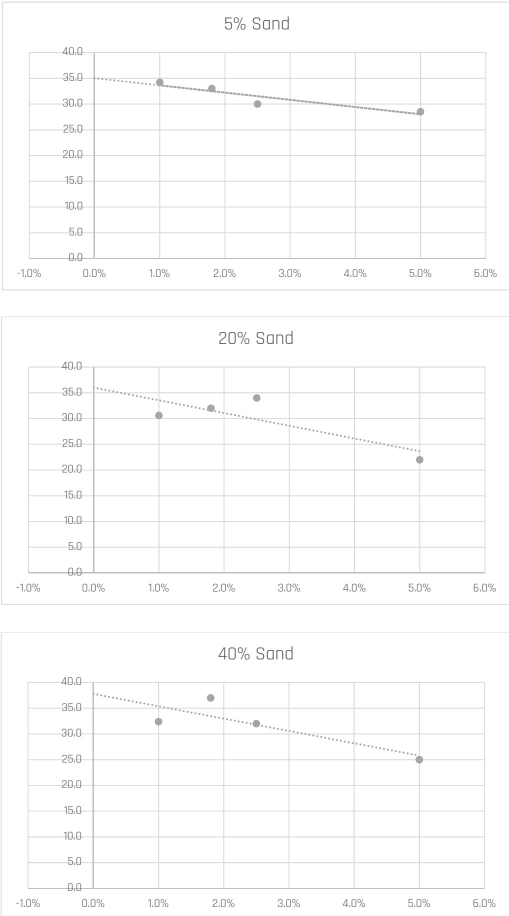


Figure 80: Extrapolation from Colonel Debes' values

% sand	%straw	7 days	30 days	90 days	180 days
5%	1.0%	34.2	53.6	48.0	47.3
	1.8%	33.0	48.0	43.3	45.9
	2.5%	30.0	45.0	40.0	42.2
	5.0%	28.5	40.0	37.0	35.6
20%	1.0%	32.4	44.1	40.3	40.5
	1.8%	37.0	48.4	46.5	47.5
	2.5%	32.0	44.6	37.6	39.0
	5.0%	25.0	27.0	35.0	34.2
40%	1.0%	30.6	36.6	34.5	35.4
	1.8%	32.0	37.0	36.0	35.8
	2.5%	34.0	39.8	38.2	36.0
	5.0%	22.0	32.0	30.0	28.2

Type	% sand	7 days	30 days	90 das	180 days
Fine	20%	44.0	56.9	55.7	52.0
	40%	38.3	44.0	38.5	34.2
	60%	22.9	28.3	25.3	24.0
	80%	6.1	6.1	4.6	4.5
Small	20%	42.2	61.3	51.0	47.0
	40%	33.4	42.4	36.3	29.0
	60%	20.9	29.5	22.7	21.0
	80%	11.3	11.7	13.1	13.5
Medium	20%	37.8	48.7	41.9	41.3
	40%	27.4	35.4	29.8	26.2
	60%	18.5	20.8	25.1	17.0
	80%	12.4	11.5	11.8	12.0
Large	20%	32.8	36.4	26.9	32.2
	40%	17.6	19.1	22.0	17.0
	60%	8.5	13.1	11.9	7.4
	80%	6.1	8.5	4.7	4.7

Figure 81: Values as tested by Colonel Debes in kg/cm2

because, on average, adding 1% straw decreases the compressive strength by 11%. As the curing period is proven to have little effect in such a high sand content mixture, curing it longer would not be necessary. Therefore, any curing period with a minimum of 7 days is recommended, with any additional time between manufacturing and construction being a bonus.

The reason why we can safely assume that the bricks will achieve such a value is twofold: firstly, because values from literature indicate that 1.1 MPa will be easily attainable, but secondly because it is more likely that knowledge on adobe construction is more prevalent in Jordan and Syria. Knowing that most of Al Za'atari's residents are skilled in construction (VNG, 2018), this is also safe to assume. However, for the safety factor we propose to keep our initial value. For simplification purposes, we neglect the higher safety factors that are normally used for wet areas with adobe walls. For allowable tensile stresses, we based ourselves on values from literature which stated that the allowable tensile stress is 10% of the compressive stress (Delgado et al., 2005). Therefore, in our case, the ultimate tensile strength would be 0.11 MPa and allowable stress 0.031 MPa.

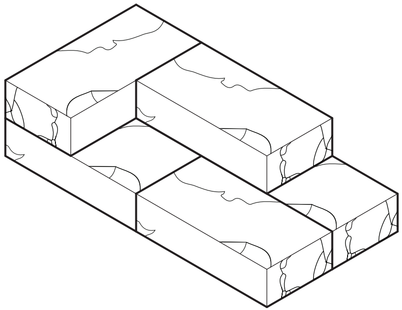
To determine the E Modulus of our bricks, we looked at values from our own tests and from literature. Calculations from our own brick test resulted in a value of 11.8 MPa, considerably lower than values in literature of 170 MPa (Tarque Ruiz, n.d.). Similarly, the calculated shear modulus was less at 5.36 MPa against 70 MPa from literature. Specific weight was determined at 1350 kg/m3, while the coefficient of thermal expansion was set at 0.000006/C.

	E_Final [MPa]	G_Final [MPa]	Density [kg/m3]	Th. Exp. Coeff.
Results	**11.8**	**5.36**	**--**	**--**
Literature	**170**	**70**	**1350**	**0.00006**

	S_Final [MPa]	SF	S_Design [MPa]
Results	**0.765**	**3.5**	**0.22**
Literature	**1.10**	**3.5**	**0.31**

	S_Final [MPa]	SF	S_Design [MPa]
Results	**--**	**3.5**	**--**
Literature	**0.11**	**3.5**	**0.031**

Figure 82: Final material properties that we used in the design



06 STRUCTURAL DESIGN

06 STRUCTURAL DESIGN

06.01 Design Procedure

The proposed procedure follows a shape approach that minimizes tensile stresses from vertical and lateral loads. Afterwards, enough thickness should be provided to take the thrust of the form-active shape and to resist lateral loading. Structural analyses should be conducted in order to measure the performance of the final shape under gravity, sand and wind loading. Basic analyses for earthquakes will then also be conducted, but are left outside the scope of the final design due to complexity and rareness of earthquakes in the area. The main goal is to not exceed allowable stress and strain levels and prove that the design is constructible and stable.

Our design started with the volumes for each space that came out of our script for generating the floor plan. Each space has a base area, centerpoint and necessary minimum ceiling height. Additionally, we know which space requires openings for doors and windows and which side they should face (courtyard or street).

The rectangular plan of each room is then taken as a base to create a circular one that is circumscribed around the rectangle. The plan is then converted to 3D by means of a dynamic relaxation procedure using Grasshopper and Kangaroo. This way, a zero-tension form (approximately a paraboloid) is constructed for each space, with the height predetermined by the space volume. The "paraboloids" are then intersected with each other and with adjacent caravans and the remaining surface is trimmed with the vertical projection of the courtyard to create a vertical wall towards the yard.

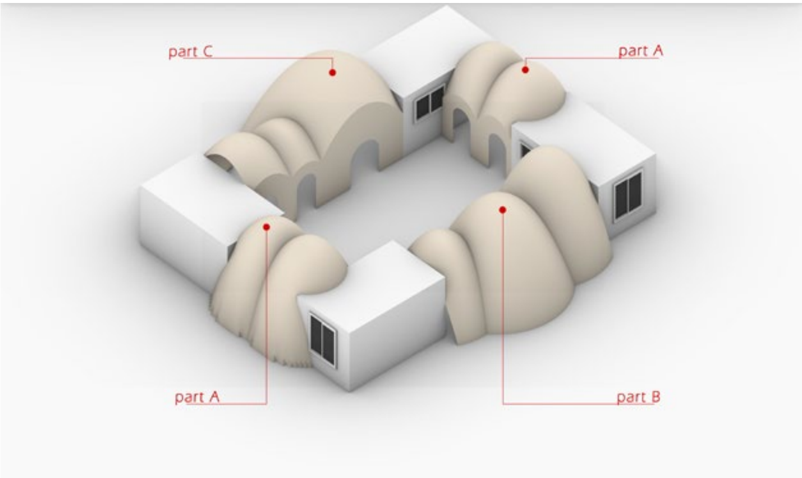


Figure 83: Parts of the structure that we analyzed

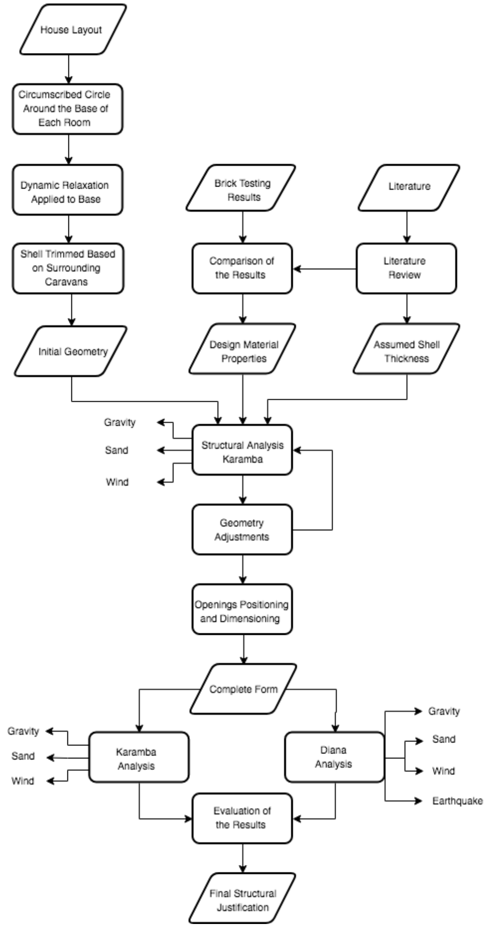


Figure 84: Structural design flowchart

In order to create openings towards the yard, sufficiently high vertical walls were needed. For this purpose, the paraboloids were widened by offsetting the base circle outwards for a maximum of 0.5 meters. This way the intersection with the courtyard projection is higher up on the paraboloid surface, consequently creating the higher vertical wall. Openings are sized and positioned on the interior and exterior walls after that. This way the complete form is obtained and further subjected to analysis to confirm its structural performance.

To verify the structural performance and minimize errors due to software tolerances, another finite element analysis model was constructed using Diana FEA software. The results of both analyses were then compared and final conclusions and tabulated results were drawn.

06.02 Analysis Settings

The analysis settings for the Karamba and DIANA model are different due to the slight difference in the way both softwares calculate and define materials. Our load cases are also different: we simulated gravity, sand and wind loads in Karamba, while simulating an equivalent earthquake additionally as well in DIANA.

The load cases were determined by calculating an equally distributed sand layer of 30mm over the whole structure. Additionally, a wind load of 0.7 kN/m2 was determined based on Jordanese values. Finally, an equivalent earthquake was also simulated with a peak ground acceleration (PGA) of 0.33g, the worst-case scenario in Al Mafraq.

To simulate the structural behavior of our proposal a script in grasshopper -that defines the form- and

Target	Guideline	Maximum	Unit	Valid For
Stress	-	0.31	MPa	All Load Cases
Strain	-	0.0081	-	All Load Cases
Deflection (V) (wall/roof)	H/500	10	mm	All Except for EQ
Deflection (H) (wall)	H/300	10	mm	All Except for EQ
Deflection (H) (roof)	H/300	14	mm	All Except for EQ
Ultimate Deflection	-	200	mm	Only EQ

<table>
<tr><th>Analyzed Elements</th><th>Method</th><th>Load Case</th><th>Vertical Load</th><th>Horizontal Load</th><th>Results</th></tr>
<tr><td rowspan="5">Earthy Additions</td><td rowspan="2">Karamba</td><td>Gravity + Sand</td><td rowspan="6">G + 0.4 kN/m2</td><td>-</td><td rowspan="5">Stress (prinicpal & local), deflection, strain</td></tr>
<tr><td>Gravity + Wind</td><td>0.7 kN/m2</td></tr>
<tr><td rowspan="3">Diana FEA</td><td>Gravity + Sand</td><td>-</td></tr>
<tr><td>Gravity + Wind</td><td>0.7 kN/m2</td></tr>
<tr><td>Gravity + Sand+ Earthquake (equivalent acceleration)</td><td>3.2 m/s2</td></tr>
<tr><td>Foundation</td><td>Manual</td><td>Gravity + Sand + Wind</td><td>0.7 kN/m2</td><td>Stress</td></tr>
<tr><td>Fundamental Period</td><td>Eurocode 8</td><td>-</td><td>-</td><td>-</td><td>T1 period</td></tr>
<tr><td>Plan Irregularity</td><td>Eurocode 8</td><td>-</td><td>-</td><td>-</td><td>Irregular or not</td></tr>
<tr><td>Wall Slenderness</td><td>Manual</td><td>-</td><td>-</td><td>-</td><td>Slenderness ratio</td></tr>
</table>

Figure 85: Maximum values for deflections and stresses (above) and the analysis settings and load cases (below)

one in Karamba structural analysis have been created. The material properties, the thickness and the loads which are applied on the shell have been determined manually. To both optimize the results of the analysis and the material use, different simulations with different thicknesses have been run to select the proper thickness of the structure.

In parallel, the change of the base form, ceiling height and the comparison of the structural analysis results each time helped determining the form that was optimized for both the architectural concept and the structural performance of the building. The resulting structure is simulated as a shell with openings and is subjected to self-weight, the load of sand and wind.

For the DIANA model, a surface model was imported from Rhino using the step file format. The geometry was meshed with an element size of 250mm using a triangular mesh with the mid-side node on the shape, the recommended setting for curved shells. This mesh size was determined after running the simulation with multiple mesh sizes and determine where convergence occurred. The material was defined as a "concrete and masonry" class using the "linear elastic isotropic" model. More advanced simulations containing the effects of creep, anisotropic behavior, plasticity or brickwork and mortar separately were not used for simplicity.

Supports for the earthy additions were modeled as fixed wall supports. Although the foundations are not fully stiff, it is reasonable to assume that they will behave more like fixed-end ones. Differences between assuming a fully stiff or a fully pinned support were within a 15% difference.

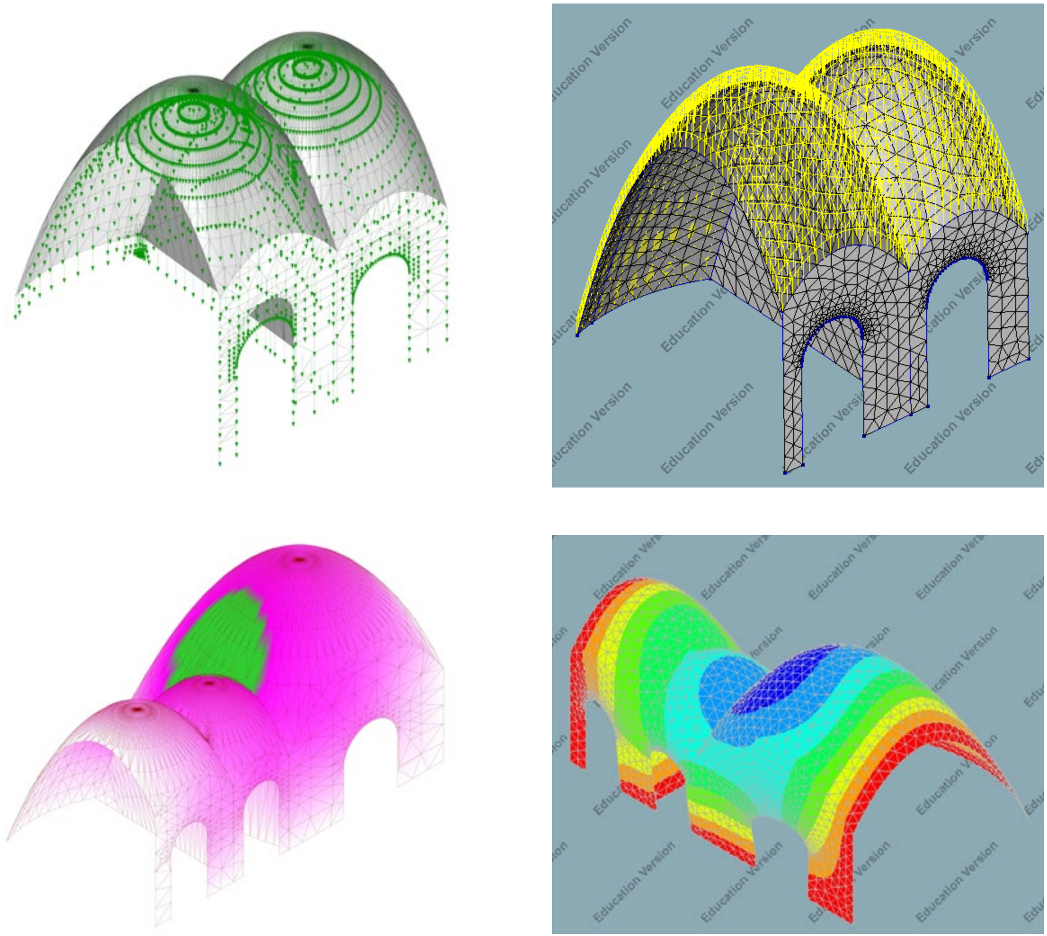


Figure 86: Images from the structural analysis in Karamba (left) and DIANA (right)

06.03 Analysis Results

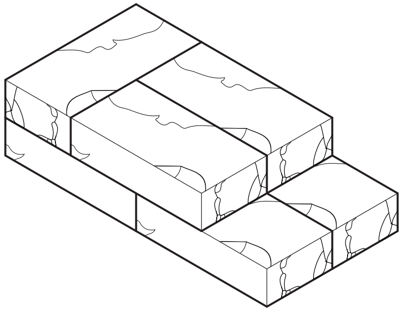
As can be seen from Figure 38, the various parts of our earthy additions perform well for gravity, sand and wind loads: in all cases the UC conditions are met. However, due to small meshing errors the tension values are consistently high at small stress concentrations. An example is where two shells meet and cause a sharp angle between two surfaces; this will never be the case in reality, as we propose this inner part to be filled. Therefore, when we look at the average tensile values, we can still say that the structure is well within allowable parameters.

It is important to note that the walls facing the courtyard, which are straight, experience most of the stresses. This is because they have a greater tendency to topple over due to the lateral load applied to them; the fact that the interior walls hold them back and the fact that the openings are relatively small mean that final stresses remain acceptable.

Interestingly, a design earthquake of 0.33g actually did not cause excessive damage in any direction as we expected. Again, tensile stresses around the supports and corners exceeded allowable limits, but also seem to be caused by the improper meshing as explained earlier. In general, it is possible to say that the equivalent acceleration in a single direction is not strong enough to topple the structure or cause excessive damage when only applied once: whether this is a fully realistic representation is a matter of discussion.

House Part	Load Case	Principle Stress 1 [C]	Principle Stress 1 [T]	Principle Stress 2 [C]	Principle Stress 2 [T]	Maximum Strain [C]	Maximum Strain [T]	Deflection Rooftop (V)	Deflection Wall (V)	Deflection Rooftop (H)	Deflection Wall (H)
A	GS	-0.000112	0.038800	-0.090300	-	-0.000553	0.000285	-0.360000	-0.730000	0.270000	0.170000
	UC	0.000361	1.251613	0.291290		0.068272	0.035185	0.036000	0.073000	0.019286	0.017000
	GS + Wind X	-0.000093	0.039000	-0.090300	-	-0.000472	0.000206	-0.370000	-0.740000	0.110000	0.290000
	UC	0.000300	1.258065	0.291290		0.058272	0.025432	0.037000	0.074000	0.007857	0.029000
	GS + Wind Y	-0.000062	0.038400	-0.096300	-	-0.000445	0.000195	-0.360000	-0.720000	0.270000	0.160000
	UC	0.000198	1.238710	0.310645		0.054938	0.024074	0.036000	0.072000	0.019286	0.016000
	GS + EQ X	-0.000078	0.049500	-0.100000	-	-0.000553	0.000285	-0.390000	-0.780000	0.300000	0.580000
	UC	0.000252	1.596774	0.322581		0.068272	0.035185	0.039000	0.078000	0.021429	0.058000
	GS + EQ Y	-0.000057	0.058600	-0.110000	-	-0.000491	0.000328	-0.360000	-0.710000	0.610000	0.230000
	UC	0.000183	1.890323	0.354839		0.060617	0.040494	0.036000	0.071000	0.043571	0.023000
B	GS	-0.000031	0.047800	-0.110000	-	-0.000589	0.000210	-1.200000	-0.600000	-0.480000	-0.500000
	UC	0.000100	1.541935	0.354839		0.072716	0.025926	0.120000	0.060000	0.034286	0.050000
	GS + Wind X	-0.000028	0.039800	-0.100000	-	-0.000534	0.000221	-1.220000	-0.800000	-0.320000	-0.520000
	UC	0.000092	1.283871	0.322581		0.065926	0.027284	0.122000	0.080000	0.022857	0.052000
	GS + Wind Y	-0.000024	0.034700	-0.110000	-	-0.000512	0.000195	-1.010000	-0.870000	-0.460000	-0.210000
	UC	0.000078	1.119355	0.354839		0.063210	0.024074	0.101000	0.087000	0.032857	0.021000
	GS + EQ X	-0.000028	0.057800	-0.130000	-	0.000321	-0.000591	-0.320000	-0.570000	0.670000	0.500000
	UC	0.000091	1.864516	0.419355		0.039630	0.072963	0.032000	0.057000	0.047857	0.050000
	GS + EQ Y	-0.000047	0.054900	-0.140000	-	-0.000491	0.000328	-1.080000	-0.810000	0.450000	1.060000
	UC	0.000152	1.770968	0.451613		0.060617	0.040494	0.108000	0.081000	0.032143	0.106000
C	GS	-0.000059	0.077600	-0.130000	-	-0.000516	0.000422	-1.050000	-0.660000	-0.630000	-0.500000
	UC	0.000190	2.503226	0.419355		0.063704	0.052099	0.105000	0.066000	0.045000	0.050000
	GS + Wind X	-0.000066	0.099400	-0.160000	-	-0.000553	0.000441	-1.220000	-1.060000	-0.370000	-0.610000
	UC	0.000212	3.206452	0.516129		0.068272	0.054444	0.122000	0.106000	0.026429	0.061000
	GS + Wind Y	-0.000071	0.076200	-0.120000	-	-0.000426	0.000370	-1.020000	-1.020000	-0.620000	-0.360000
	UC	0.000229	2.458065	0.387097		0.052593	0.045679	0.102000	0.102000	0.044286	0.036000
	GS + EQ X	-0.001000	-0.150000	-0.210000	-	-0.000684	0.000653	-1.060000	-0.660000	0.750000	0.590000
	UC	0.003226	4.838710	0.677419		0.084444	0.080617	0.106000	0.066000	0.053571	0.059000
	GS + EQ Y	-0.000067	0.085700	-0.100000	-	-0.000504	0.000477	-0.970000	-0.490000	0.660000	0.330000
	UC	0.000215	2.764516	0.322581		0.062222	0.058889	0.097000	0.049000	0.047143	0.033000

Figure 87: Final values from our DIANA tests for our geometries with unity checks (UC)



07 CONSTRUCTION PROCESS

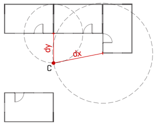
07 CONSTRUCTION PROCESS

Part of our concept on Adobe 2.0 revolves around ease of construction and building with locally available materials. Therefore, we have prepared a separate construction booklet that explains the residents how they can construct earthy additions to their houses.

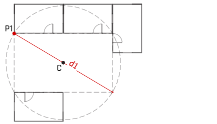
The construction process is split into the following main parts: work planning and materials procurement, brick making, foundations, flooring, walls, roofs, openings and finally the finishing and maintenance. The booklet contains information on practical aspects such as how to make tools and the construction, but also on how to procure the materials and how to handle them. Small tips on construction time for instance are also added.

The booklet is a supplement to the app that we propose: in reality, Terrabayt's construction could easily be followed from an app and even be assisted by VR or AR. The additional benefit of such digital methods is that they provide for extra customization on the information provided to the user.

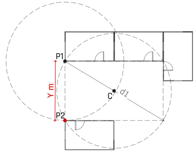
Figure 88: Mockup of the app, allowing you to choose what part of the structure you are working on



Mark courtyard center point C
in relation to the existing position of caravans.

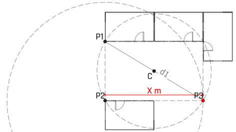


Having the courtyard center as the center point, mark
a circle with diameter equal to the courtyard diagonal.
Take the end point P1 as a starting point.

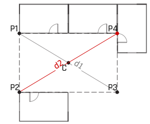


With P1 as a center, mark a circle of radius=Y.
Determine P2 position as the intersection between
the two circles.

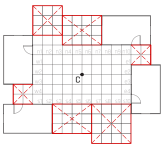
Align P1-P2 to the urban block side by rotating the
points on the circles.



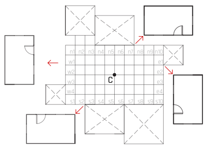
Having P2 as a center, mark a circle of radius= X.
Determine P3 as the intersection between the two
circles.



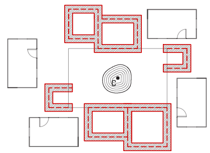
Determine P4 as the end point of diagonal d2,
d1=d2.



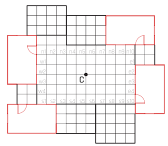
Mark the outlines of each space according to their
given dimensions and taking as a reference point the
perimeter of the courtyard.



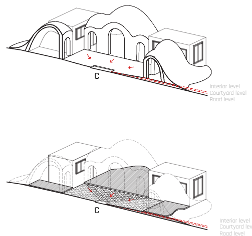
Move the caravans away from the outlines.



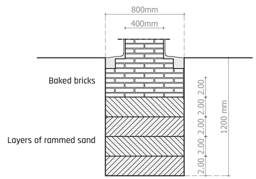
Dig trenches of 800mm wide (offset 400 mm from
each side of the space's outline) in a depth of
1200mm. Collect the extracted earth in the center of
the courtyard.

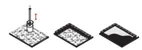


Place the caravans to their proper position, with
measurements based on the courtyard perimeter.



Flooring





Fill the trenches in with layers of 200mm rammed
earth. Then apply baked brick layers until you reach
the ground level. Keep the rest of the sand for the
flooring.

Figure 89: Parts of the construction as
elaborated in our booklet

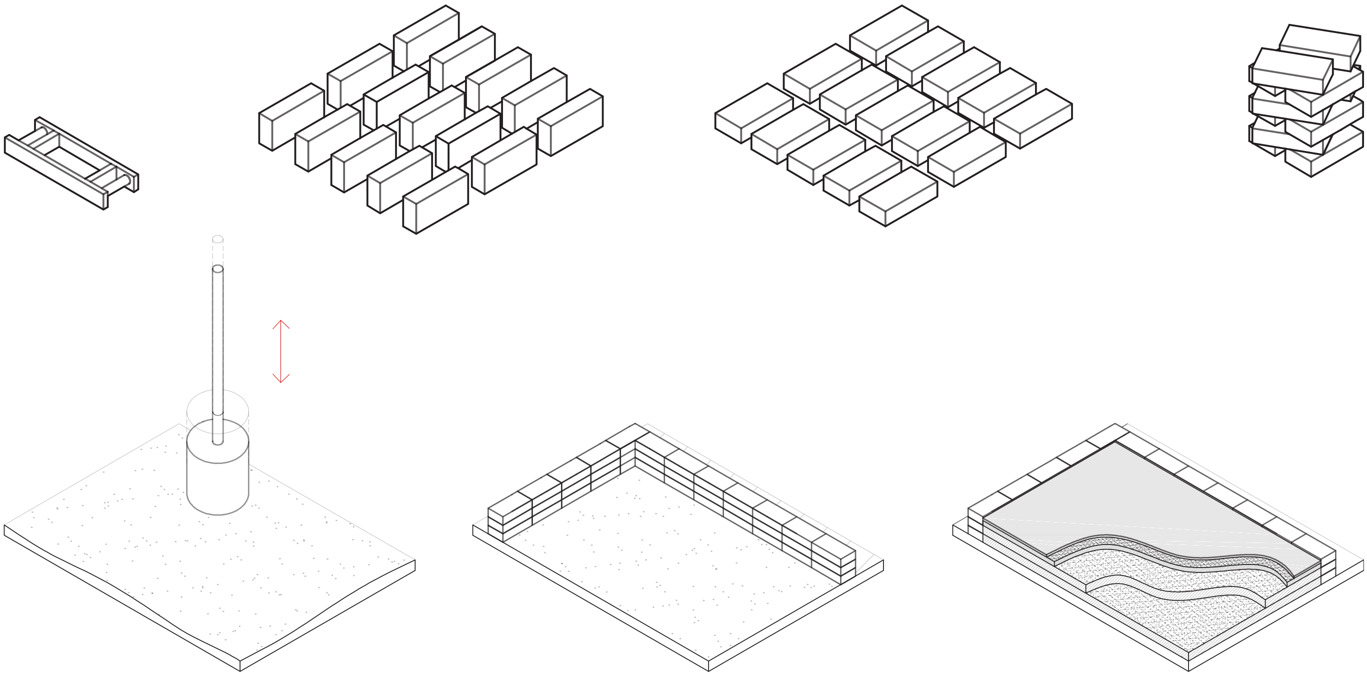


Figure 90: Construction diagrams on how to make bricks (above) and on how to prepare the flooring (below)

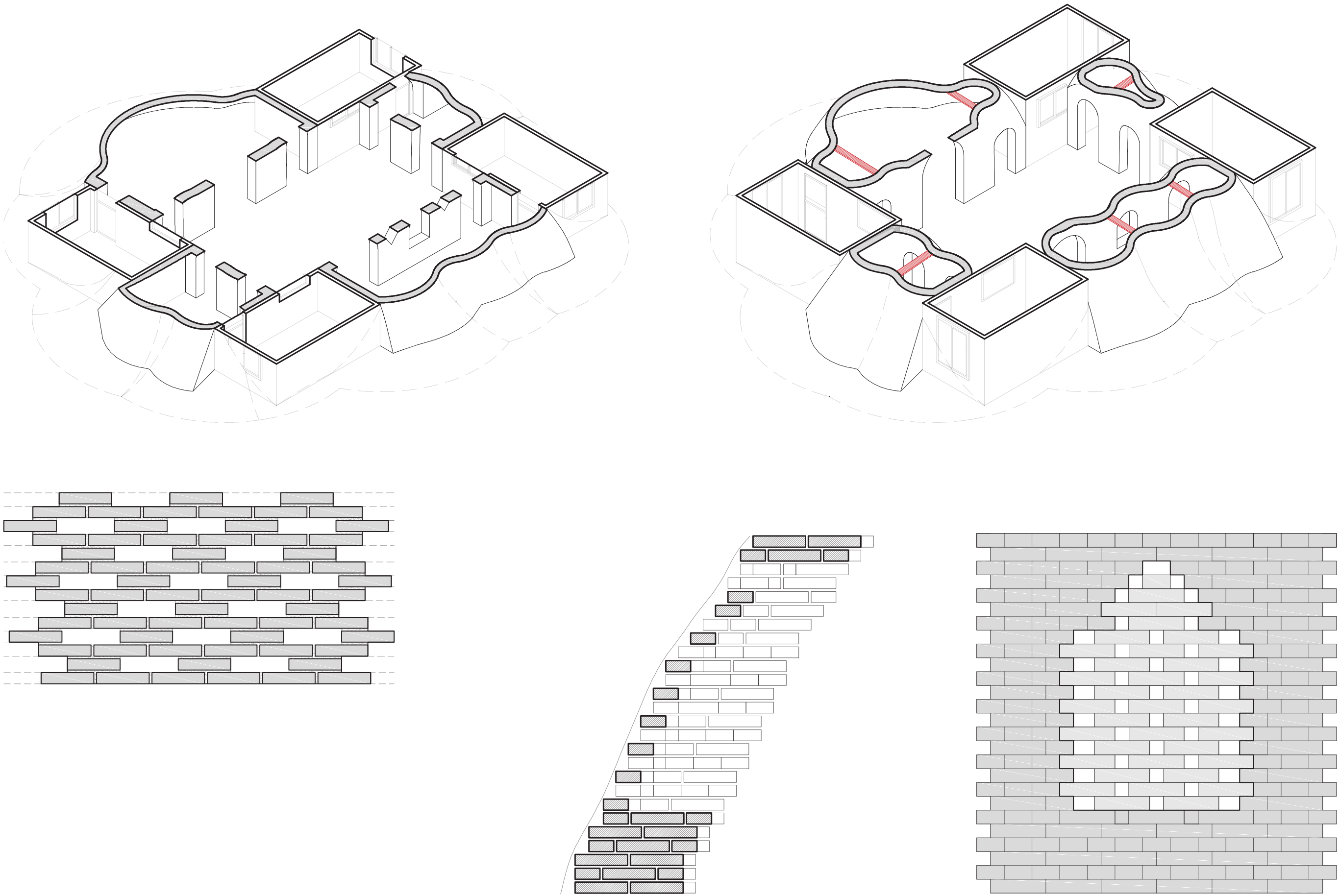
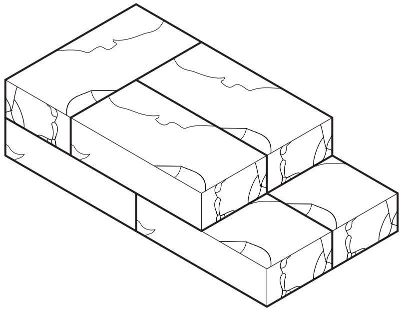


Figure 91: Construction diagrams on lateral supports during building (above) and drawings of the mashrabiya (below)



08 REFLECTION & CONCLUSION

08 REFLECTION & CONCLUSION

This report explained the design process and final result of Terrabayt, a computational tool that generates housing typologies more in line with the needs of its inhabitants, whose topological and geometrical characteristics are based on traditional Syrian ones.

As part of AR3B011 EARTHY of the MSc Building Technology program at the TU Delft, we learnt a lot in very diverse topics ranging from programming and adobe construction to structural design. To this extent we also had various issues both digitally and physically.

First of all, although adobe is very available in the geography of our project, experience in adobe design is something that we lacked and had to learn. Designing with a material that has relative mechanical properties 10-20 times less than even the simplest of construction concrete (C20) was difficult. For instance, the design of openings, large spans or complicated geometry was not possible with this material. Even more, due to the fact that the refugees themselves had to build the design, we chose for a more straightforward design with high levels of constructibility.

Secondly, we had many issues in modeling and scripting of various parts of Terrabayt. For instance, intersecting geometry and creating meshes from our initial mesh from dynamic relaxation was hard, with many mesh combinations not working in Weaverbird's experimental component. Similarly, the relaxation script in Kangaroo would often crash or not converge. This crashing was also a common part for many of our scripts: once loaded and opened together, they are relatively heavy and often yielded in an unworkable error message.

However, as a final conclusion we are very happy on the design of Terrabayt and the process we had in EARTHY. We learnt a lot on the design of earthy structures and how to use computation for its topological, geometrical and structural design. Although the course was very intense, we believe that the group project resulted in a design to be proud of, and to enjoy for years to come.

Figure 92: Rhino: "I have no idea what you want me to do" - we didn't either

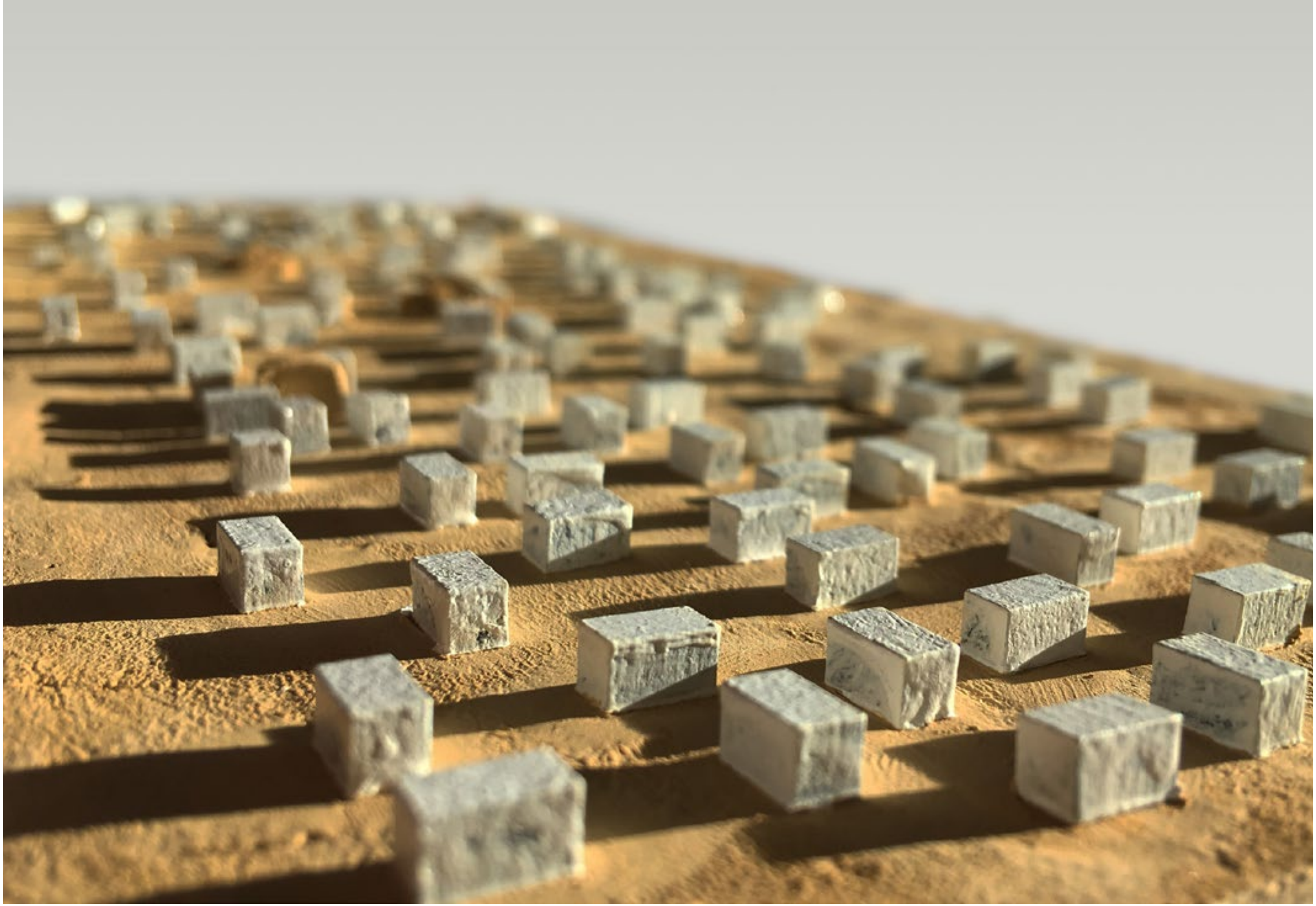


Figure 93: Our 1/750 urban model

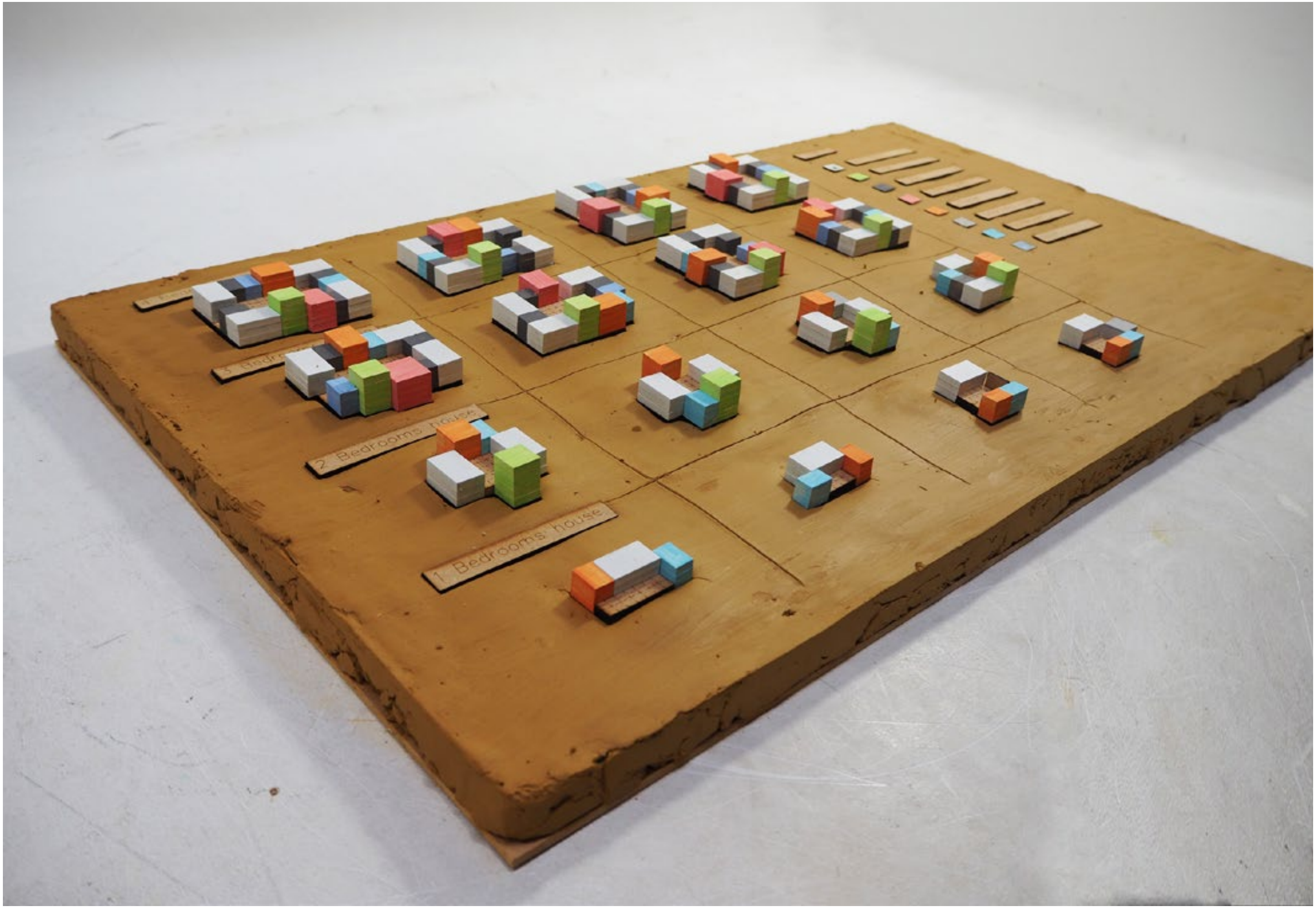


Figure 94: Our configurations model

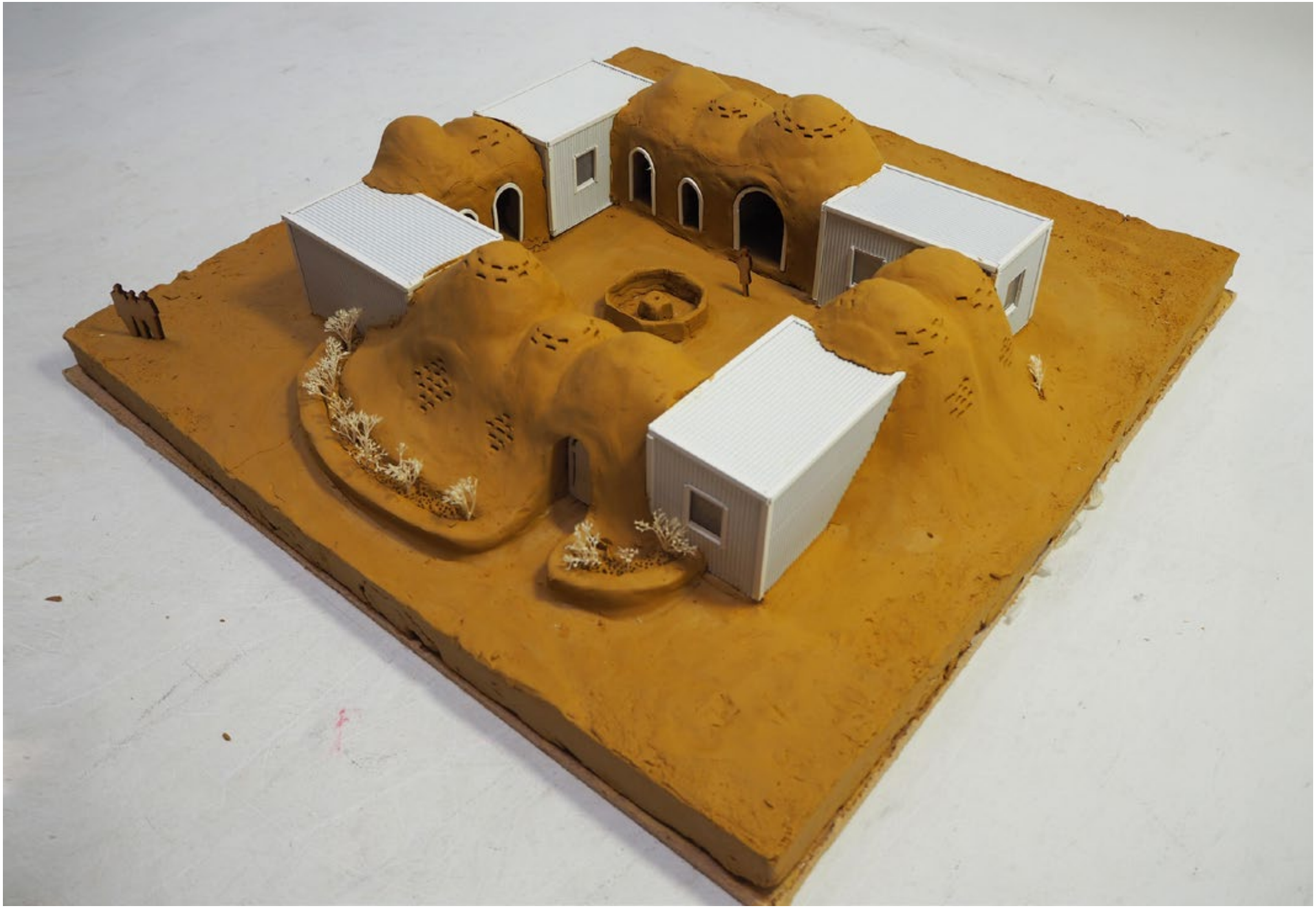


Figure 95: Our 1/50 model

Figure 96: Our 1/50 model's entrance

Figure 97: Our 1/25 model

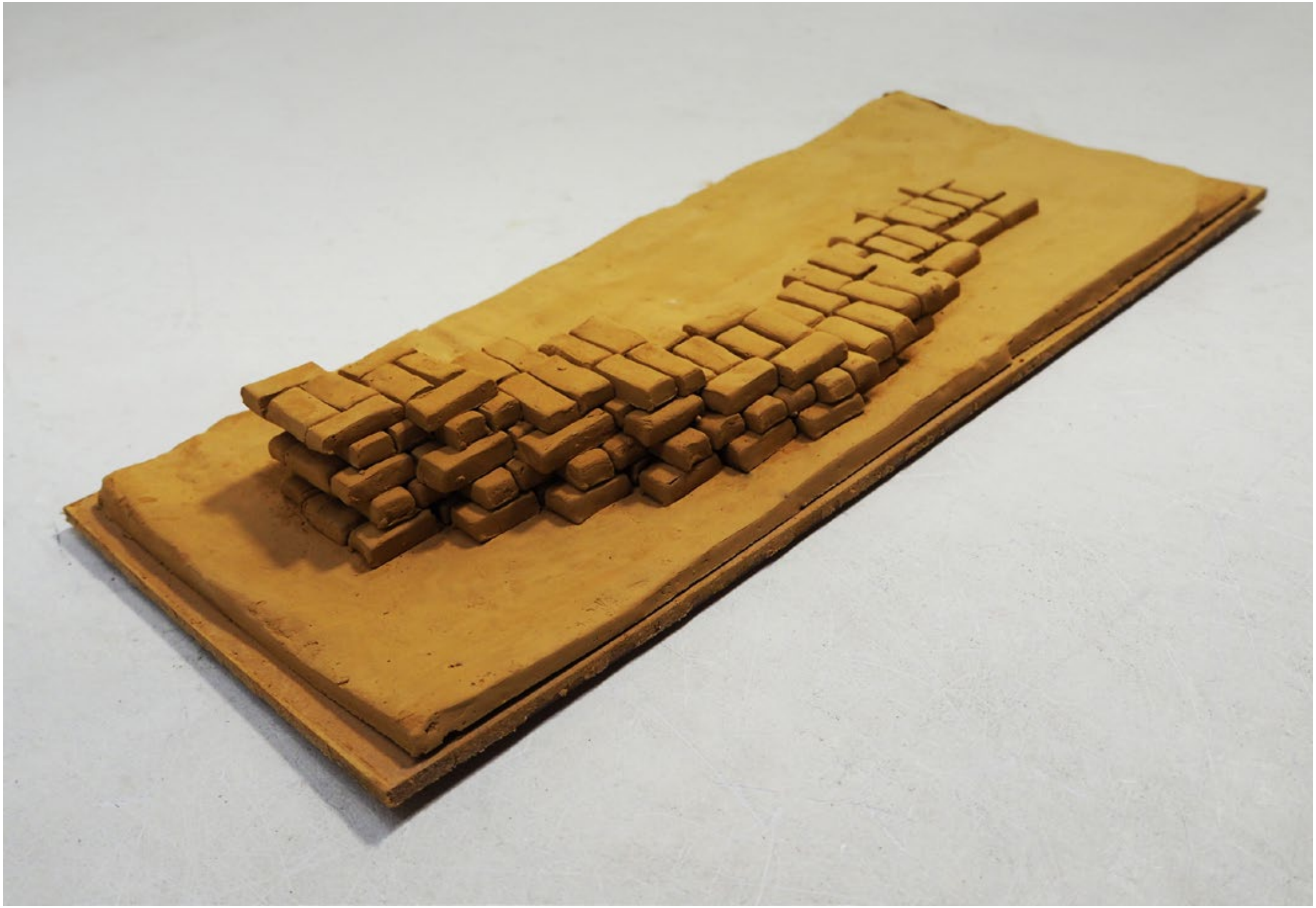


Figure 98: Our 1/10 model

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