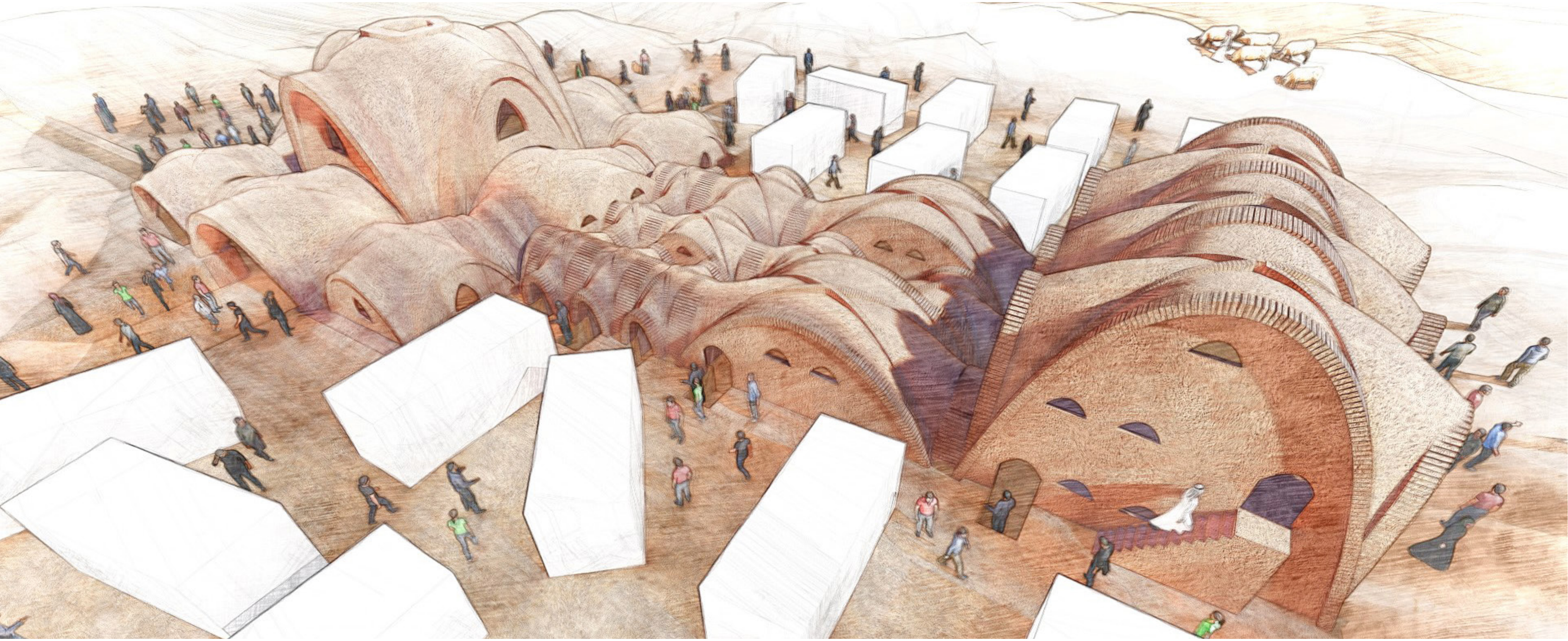
Bazaar

Methodoly for building a Bazaar



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Summary

Building with earth or adobe is almost as old as mankind and is one of the oldest forms of construction. The advantage of such a construction is that it is easy to shape adobe into spectacular and inspiring architecture ensemble with less skilled labor, minimum tools and less energy. Our task was to develop an innovative design and construction technique using adobe, by exploiting its properties, for the Zaatari refugee camp in Jordan. As other building materials are limited at the site, it gave us an opportunity to explore maximum use of the most available material, earth. For this we chose to analyze the past in order to design better for the future.

A steadily growing number of people are moving into refugee camps. At the moment, almost 80.000 Syrian refugees live in camp Zaatari as the result of war happening at their home country. The emphasis of refugee camps is on establishing temporary solutions. In reality, these camps will exist for years and it does not look like the people living in refugee camps will move back soon. Unfortunately, Camp Zaatari is not the only refugee camp. So we would like to design a modular system to give these people an urban object which reinstates the values the refugees lost in their past, in this case the bazaar. It could provide a meaning for their life, bring back cultural values, sense of belonging and identity. For this we propose a **modular computational method** instead of a design, which can be used in any refugee camp.

As adobe is relatively weak material, especially in tension, we looked into designing a strong structure through geometry. For this we looked into possibilities of forming the structure which is in compression and within the compressive strength limits of the material. In order to create such a structure, it was necessary to study 2D topology and different tessellations to form the 3D structure. For this, we explored the principles of Stiffness Matrix method, Geometric Stiffness method and Dynamic Equilibrium method. In theory, the form obtained, would have only axial forces and no bending moments. The objective was to obtain a structure that will be completely in adobe and the shape will meet the tension requirements in both principal directions within its compressive limit.

The process involved setting up guidelines for the design and the site analysis by means of betweenness and centrality study. In order to make a computational method for developing a bazaar, a script was written using python and grasshopper. This script takes an existing bazaar and user input for a new shop. Using these, together with implemented guidelines, the script gives five good locations for a new shop from which the user gets to choose. This is how the bazaar expands. The script simulates how the program will work, in real life the users would be able to use an app.

For the construction of the bazaar, an inflatable structure is chosen. The idea is to use a modular system for the bazaar. The benefits of this system are that the mould is compact for transport, framework and structural support in one and reducing the chance of mistakes as it is a 3D shape which is followed. Due to the modular approach of the design nine different types of inflatable mould are needed to make the bazaar.

Table of Content

List of symbols

Symbol	Definition
б	Imprecision correction
σ	Compressive stress (N/mm²)
ε	Strain (mm)
E	elasticity Modulus (N/mm²)
Mpa	Mega Pascal or (N/mm²)

1. Introduction

10 years ago the refugees in camp Zaatari (North Jordan) lived in beautiful cities in Syria. Due to the war, they had to leave everything behind and flew across the borders. Up to the present day, a steadily growing number of people still flee to refugee camps. At the moment, almost 80.000 Syrian refugees live in camp Zaatari. The emphasis of refugee camps all over the world is on establishing temporary solutions. In reality, these camps exist for years and years. As it looks now, the people living in refugee camps will not move back soon. We would like to give these people, not only the refugees in camp Zaatari, an urban object which will reinstate one of the cultural values the refugees lost in their past, in this case the bazaar. Next to this, a bazaar will give back a sense of identity and it will provide jobs, which will give more meaning to life. For this we propose a modular computational method instead of a design, which can be used in any refugee camp.

This report will not only content literature research regarding architecture, structural and constructional design, but also the computational approach for a modular system. Different software is used for this research e.g. Grasshopper, Microsoft Excel and Vision, FEM Ansys.

The structure of this report is as follows: first the analyses are described briefly concerning Camp Zaatari. Next, the design process is in general explained. Finally, the design itself is described. All detailed research can be found in the appendix. In the core of this report, an appendix will be mentioned when more information is written regarding the topic.

https://www.vpr.org/post/photos-worlds-second-largest-refugee-camp-syrians-live-day-day#stream/0

2. Problem statement & Goal

In this chapter, the problem statement and the goal of this project will be described.

2.1 Problem statement

A steadily growing number of people are moving into refugee camps. At the moment, almost 80.000 Syrian refugees live in camp Zaatari. The emphasis of refugee camps is on establishing temporary solutions. In reality these camps exist for years and years. As it looks now, the people living in refugee camps will not move back soon. We would like to give these people an urban object which reinstates one of the values the refugees lost in their previous lives, in this case the bazaar (figure 1). By doing this we want to create a safe and social environment where people can do their daily activities such as doing groceries, going to school, social interaction with other people, eat and traverse.

2.2 Goal

Camp Zaatari is not the only refugee camp in this world. Therefore, we would like to create a computational method which can be applied to all refugees where needed. As a bazaar can be placed on different locations in the camp or in future camps, we decided to develop a method. The method (figure 2) will be digital manual integrated in an app which is divided into seven sections:

1. **Where to plant the bazaar seed?** The location of the bazaar will be a starting point as it can grow whenever the demand is there. Therefore, an urban map will show the nodes where the start of the bazaar can be built based on pedestrian flows and functions in the camp. The administrator will choose one node from the proposed nodes.
2. For the junction, several options are shown to build it.
3. The admin of the camp will decide which option to choose and building the junction can start.
4. The data of the junction (incl. functionality) is looped to the database.
5. Rules for future development and instructions of how the bazaar should be build as a modulair item are also included in the database.
6. **Where to place a shop typology?** The type of bazaar is based on the street dimensions and functions in the bazaar. This is based on a drop down list in the app as the new entrepreneur can select his/her main function of the company and the needs in e.g. square meters, noise, water, needed supplies. From there, a location around or near the node will be chosen so guilds are not mixed. The future user can now use the application to select the wishes for a shop in a bazaar which is looped back to the database.
7. **How to build/ expend the bazaar?** When the user agrees with the location and other proposals, the user will also receive a building instruction how to build his part of the bazaar by using simple and understandable drawings. These will describe how to make the bricks and how to assemble it in the building. Therefore, we try to avoid language manuals as it should be accessible for all education levels. After the newly built part of the bazaar is added, the database in the app/program is updated and when a new customer wants to add a new shop, all previously added shops are taken into account.

Figure 1: Problem statement

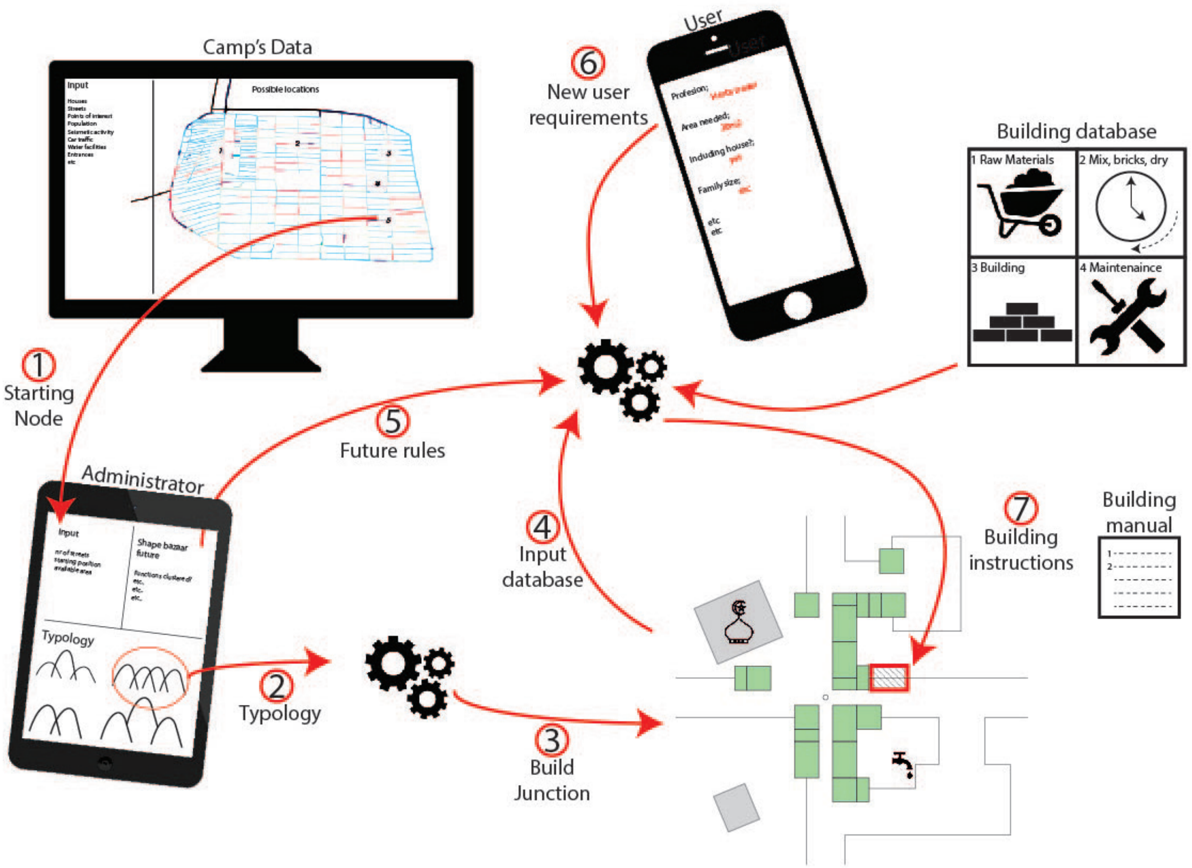


Figure 2: Goal scheme

3. Analysis

In this chapter, the context of the Zaatari camp, Jordan climate and the architecture needs of a bazaar will be described.

3.1 Context

The Zaatari camp (figure 3) is orientated North of the Jordan, 6km from the Syrian border (UNHCR, 2019). The origins of the Zaatari residents are mostly Dara'a (80%) and Rural Damascus (14%). Main functions which are important for the origin residents are also active in the Zaatari camp. This is shown in figure 4. As electricity is important in this camp for daily use, a solar plant is installed on the South side of the Zaatari camp. This solar plant is as big as half of the Zaatari camp. The functions in the camp will be used for later analysis to determine a starting node for the bazaar.

Climate

The camp has a BSH climate according to the Köppen climate system, in other words a 'hot- semi-arid' climate. This means that there are hot and dry summers for a long period and a short period warm to cool winters (ISC, n.d.). The average temperature in summer is between 20-32 degrees with some hot days of more than 40 degrees. Sometimes a sandstorm occurs, called the Shirocco, due to a hot and dry southern wind. The average temperature in the winter is around 13 degrees. See figure 5 for the schemes.

On average, 60mm rain falls in the period November and March. There is almost no rainfall between June and August. When it rains, it is often concentrated in storms, causing flooding Weatheronline, n.d.). The average wind direction during the year is West with a wind speed of 9kts , see figure 6.

Zaatari camp has no problem with the groundwater, because the camp lies 600m above sea level. The surroundings of the camp is mostly grassland, see figure 7. Below this grassland, the composition of the soil is divided in clay, sand and silt, see figure 8. Depending on the depth, the ratio of these soil types can be determined. 50% of the soil is made out of silt, this consists mostly Orthents (old landforms) and haplic Cambisols (fertile soil). At 2m depth rocks can be found in the soil, which need to be used for the foundation of the bazaar and first meter of adobe bricks (Soilgrids, n.d.).

Figure 3: Zaatari location

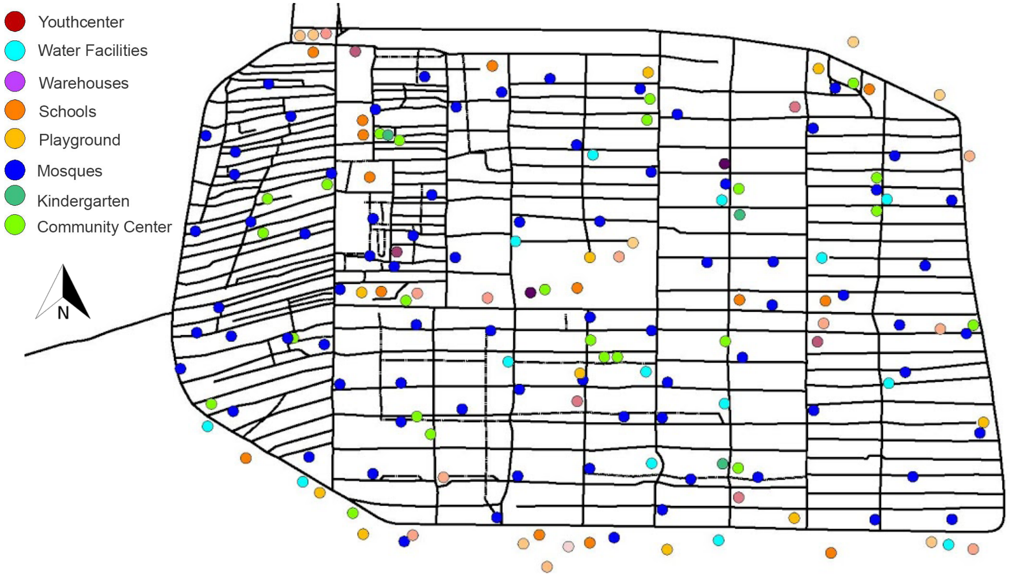


Figure 4: Functions in Zaatari camp

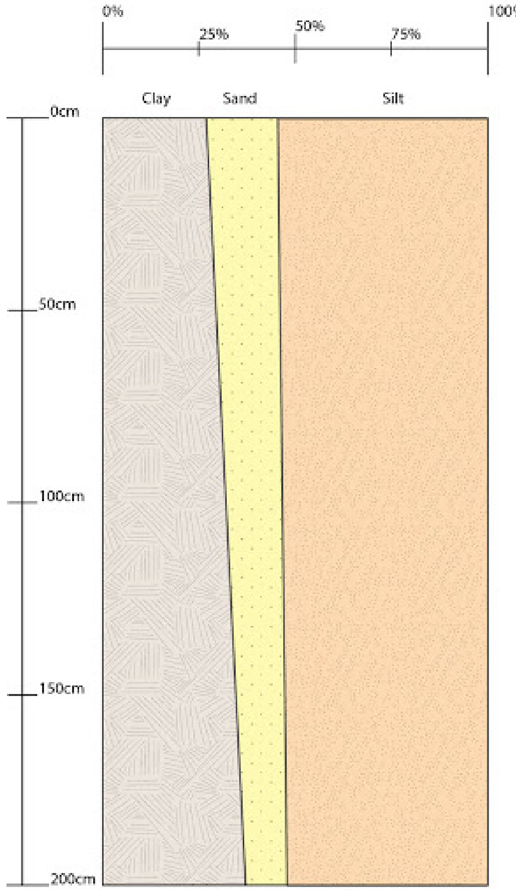


Figure 8: Soil Composition

Month of year	Jan 01	Feb 02	Mar 03	Apr 04	May 05	Jun 06	Jul 07	Aug 08	Sep 09	Oct 10	Nov 11	Dec 12	Year 1-12
Dominant wind direction													
Wind probability >= 4 Beaufort (%)	21	20	26	25	27	31	29	23	14	10	9	14	**20**
Average Wind speed (kts)	9	9	9	9	9	10	10	9	8	7	7	7	**8**

Figure 6: Average windspeed. Retrieved from Windfinder (n.d.)

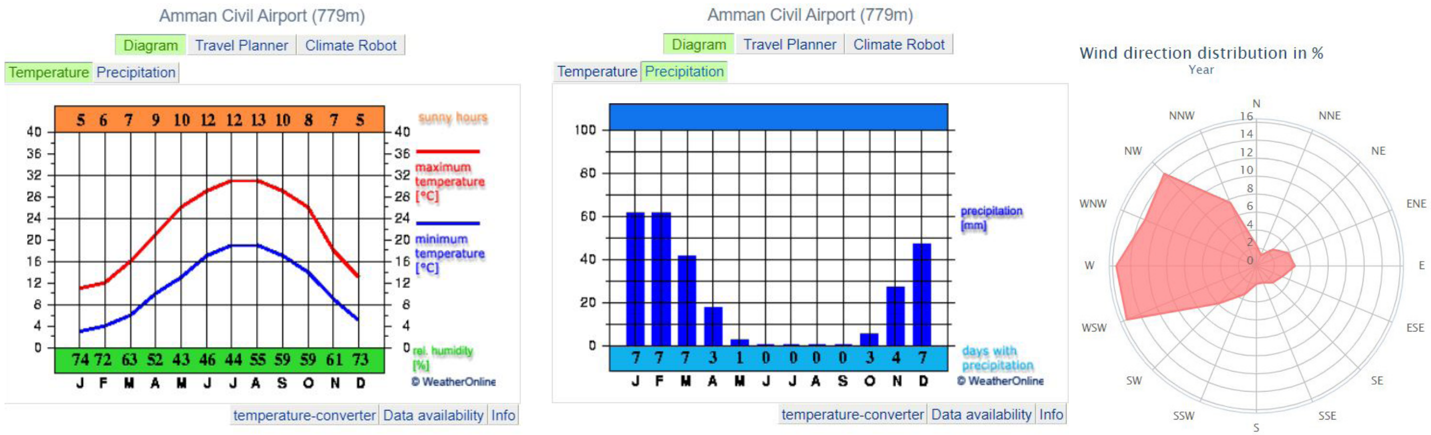


Figure 5: Average temperature (left), Average rainfall (middle) and wind force (right). Retrieved from Weatheronline (n.d.).

Figure 7: Surrounding of the camp. Retrieved from Google View (n.d.)

3.2 Bazaar

Traditional Architecture

The history of Iranian/ Persian architecture dates back to 5.000BC and has an abundance of symbolic architecture as base. Plans are often symmetrical with rectangular halls and courtyards. Pure forms such as circles and squares are used often.

Openings, arches and associated elements of Persian architecture

In traditional Persian architecture, the openings on the outer façade are small and the openings on the inner façade are bigger which overlook the courtyard. This distinction is made for privacy and environmental reasons. For building with mud, and especially making openings some strict guidelines should be used.

-The largest possible opening is 1.2 m by 0.9 m
-Small openings for ventilation are 20cm-40cm wide and 40cm height.
-Straight or arched lintels should be used above openings.

There are some general architecture elements that can be found in the Middle East which always come back:

Arches:
- For entrances and passages for important and religious buildings.
- For the Iwan in housing.
- To create short spans

Vaults:
- For covering long halls and passages.
- It can be seen in for example souks.
- Several types of vaults possible (see appendix K).

Mud Cupolas:
- For covering the space of a mud construction
- Mainly found in countryside of Syria

Stone Cupolas:
- For covering big spans in e.g. churches, baths and big houses.
- It can be found in all Syrian cities
- Different type of cupolas/domes possible (see appendix L).

When constructing with the self-made adobe bricks, only then these elements come back in the bazaar. Vaults are constructed with arches and can be found in the streets of the bazaar. The cupolas/ comes will come back in junction and shops. By including these elements, the traditional architecture of the refugees is used. By doing this, we can reintroduce the initial conditions and bring back some quality of life they had before. See figure 9 for examples.

Figure 9: 1.Vaults (left up), 2. Arches (Right up), 3. Mud cupolas (left down), 4. Stone cupolas (Right down). Retrieved from CORPUS Levant (2004).

4. Process

In this chapter, the process of this project will be described briefly. The process is divided into four phases: 1) Configuring, 2) Forming, 3) Structuring and 4) Constructing. Per phase, the major decisions will be described. All details of the process can be found in the referenced appendix. All flowcharts per phase are explained in detail in appendix C.

4.1 Configuration

A betweenness study is performed to understand the intensity of the pedestrians flows between functions in the camp. This will be used as input for determining the potential start nodes. Five potential nodes were found and manually was decided to go for location 2 which meets the urban guidelines and is closest to the most dense part of the camp, see figure 10. The betweenness study is the first step in designing a method for building a bazaar, as this study can be done for any refugee camp, it will be able to find the starting node not only for Zaatari, but anywhere in the world.For more information, see appendix D.

A study is performed to understand the needs of a bazaar in the Middle East with a focus on function and architecture. All details can be found in appendix A and B. The conclusion of this research is that a bazaar is more than just a shopping place as it is also a meeting place. Most of the shops are clustered in categories of 1) merchandise, 2) food stores, 3) community stores as tea houses, and 4) workshops which contains little factories in the back of the shop. Potential shops and their requirements are listed and clustered. The result of this list can be found in appendix D. Housing is not originally part of a bazaar, but we decided to add this above the shops to have social control when the shops are closed.

Based on these decisions, guidelines are set for the bazaar. This is described in chapter 5 Design. Based on these guidelines, a python script is written to automate the configuration of shops in the bazaar using the existing bazaar, the guidelines and a user input. This will result in potential locations and the new user can choose one of the proposed locations. This process is briefly described in this chapter, and visualised in chapter 5.2 'Expanding the bazaar'. For a more in depth description, see appendix G.

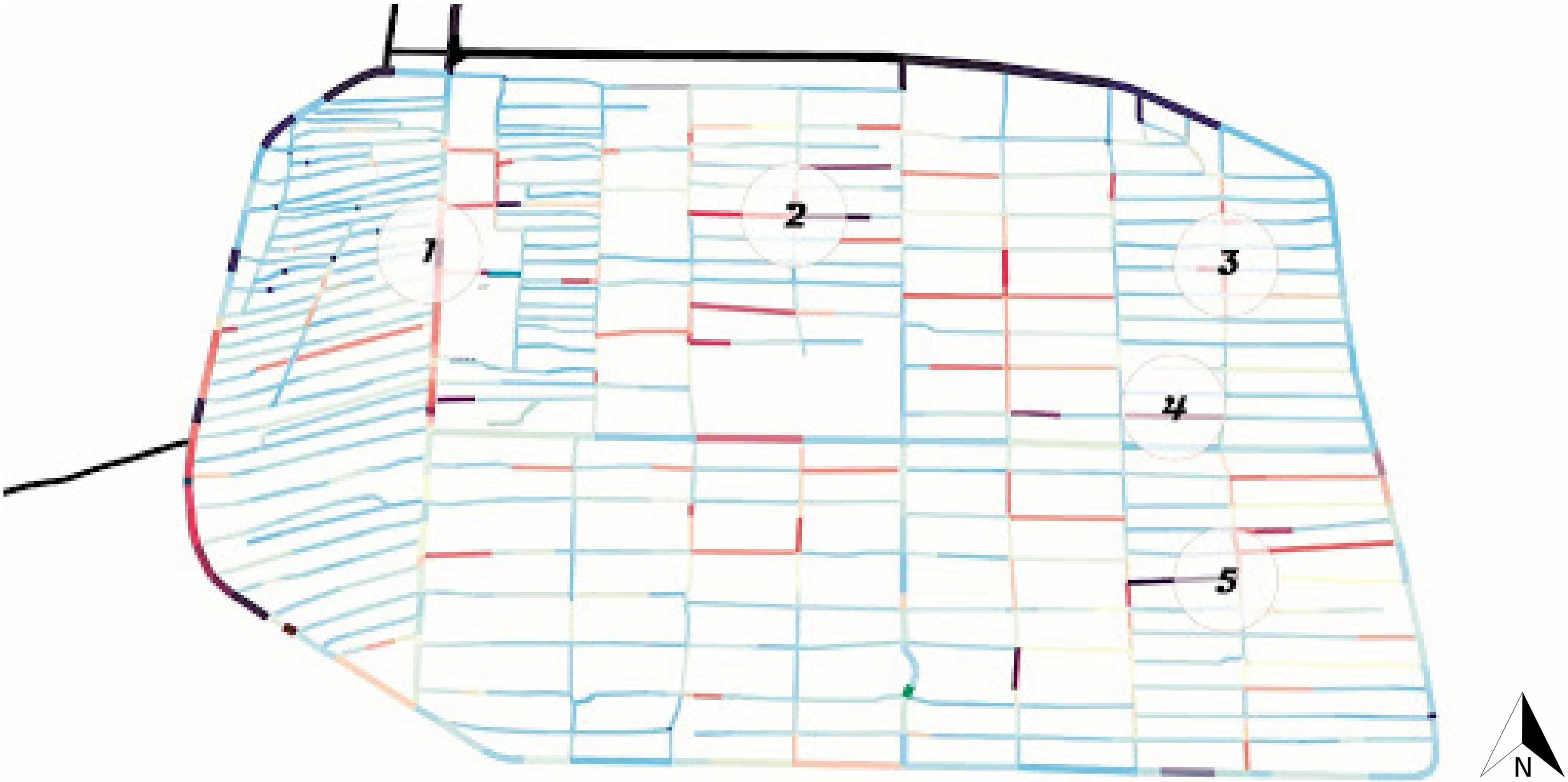


Figure 10: Decision drawing where to design an example bazaar.

Bubble diagram/REL Chart
To understand the relationship between the shops and the logistics within the bazaar a bubble diagram is made with 'Space Syntax' in Grasshopper (Rhino). The shops in the bazaar are clustered due to the following benefits:
- Lower costs thanks to shorter distances to transport goods;
- They can share information, skills and ideas. Called 'knowledge spillover';
- Customers know where to go in the bazaar for certain products;
- Production of noise is equal for nearby shops;
- Make use of your neighbors' customers;
- Similar modules & Good/service/Waste management.

Two disadvantages of clustering are:
- Less diversity in shops per m2 – Longer distance
- Competition

To understand the basic relations in the bazaar a first simplified bubble diagrams are made from the perspective of the junction and shop typology. An example is shown in figure 11. All other bubble diagrams can be found in appendix E.

Manual Scenarios
With the basic bubble diagrams and clusters described above different configurations can be made depending on the needs and wishes of the people in the refugee camp. Different scenarios are worked out manually, this is first done manual in an early stage of the design since doing it manual would take too long at this point. The bubble diagrams of these scenarios can be found in appendix E. Scenario 1 was based on combining the community stores on the junction, cluster the sectors in the walkway and squares are for low noise producing workshops and community. Scenario 2 was based on only merchandise stores in the bazaar. This means the junction and squares were empty and the walkways were filled with stores. Scenario 3 was like scenario 1, but the squares only allows workshops for clustering the noise. In all three scenarios housing was on top of the shops.

Some lessons are learned by generating these three different options manually. The rules are not set in stone but should be seen as guidelines. Otherwise problems as scenario two can occur. The application will give the future shop owner in the bazaar a few options ranked in what he thinks is the best spot to start a new shop. However, the future shop owner can decide where he or she is going to build. Later, these scenarios are automated with a Python script in Grasshopper, for an in depth description see appendix G.

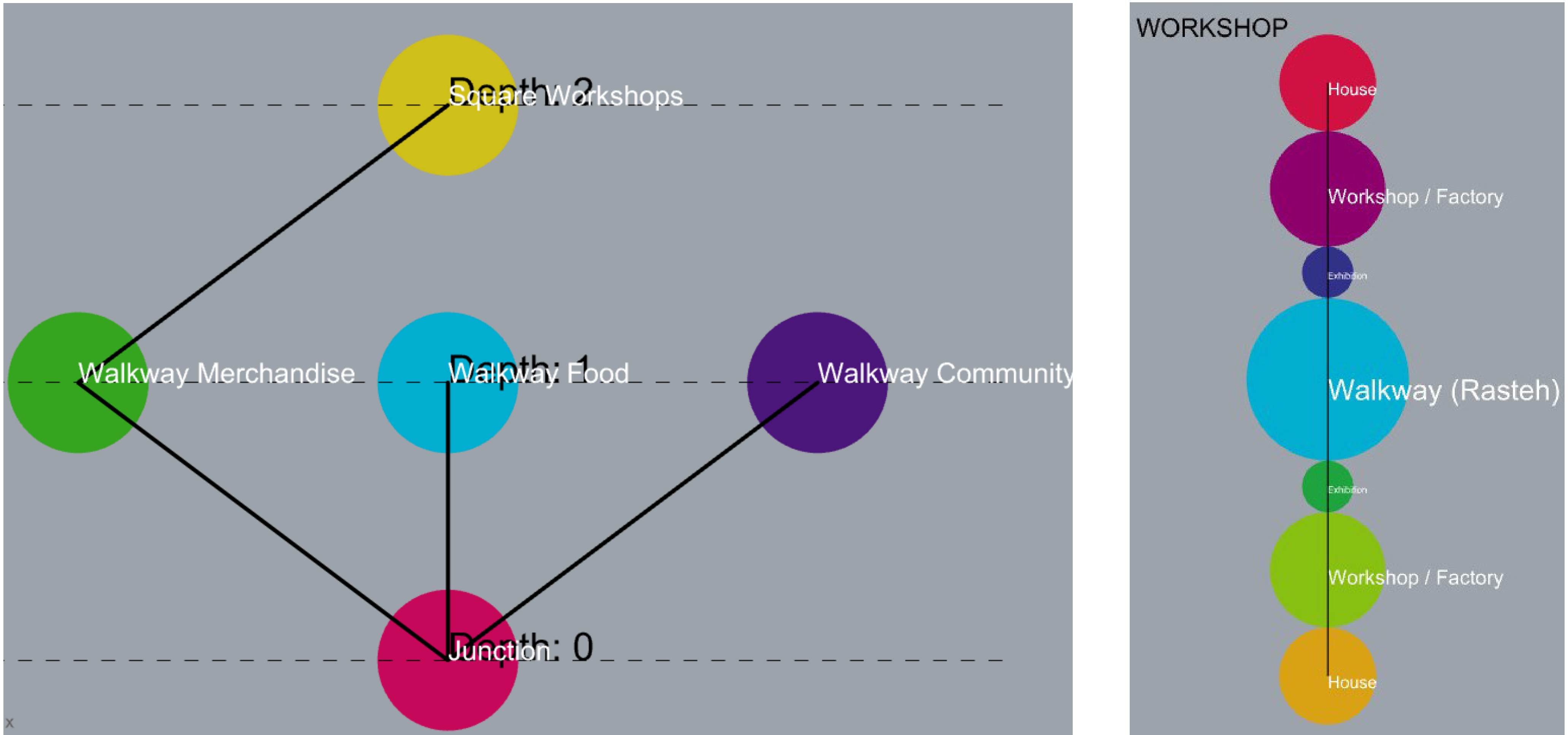


Figure 11: Junction perspective (left) and workshop relationship with bazaar logistics (right).

Automated Scenarios
For automating the growth of the bazaar, a script was developed in Python, see appendix G. Implementing all guidelines become extremely hard once important factors as distances are added and all values become numerical. For the computer, these numerical values are perfect, so using Python, the previously described manual process was made automated.

Basically, the script takes an existing bazaar as input, together with an user and an admin preference and places a new shop following the guidelines. The existing bazaar has a number of shops which have the following properties:

- House or no house
- Function
- Noise
- Pollution
- Distance to nearest house

These properties are then compared with the user input for a new shop, multiplied with the importance the admin gives to each guideline. From this, five optimal locations are found with the script and presented to the user. The user can then choose one of them, the new shop is set to occupied and the properties for this new shop are added. This way the existing bazaar is expanded and a new shop can be added, see figure 12.

In a later version of the script, the user is also able to provide a size he would like his shop: small, medium or large. This is important as the output found by the script (the outlines of the shops) are the input for the next step, the form finding of the bazaar.

This automation is the second step for designing a method for building a bazaar. From the first step a starting node is found, and using this script, the layout can be computed for any refugee camp. Using the lay-out computed in this step, the forms for the individual shops can be found and in theory, the bazaar could be made live in 3D.

Figure 12: A possible outcome of the bazaar building script, Showing the build shops which come in 3 different sizes, the different shop categories all shops fall in to (CMFW) and the specific shop type number, as well as additional housing on top of a shop in the form of a yellow plus-sign.

4.2 Forming

Due to climate and structural reasons, we decided to partially dig the bazaar. A backstreet is added to the bazaar as we do not want to impact the current residents around the bazaar's construction site. Next to that, the backstreet will ensure that no digging happens to render the structural properties of the digging in useless. Also, the backstreet can be used for delivery goods to the shops etcetera. A list of pros and cons is set per decision of the bazaar which is noted down in detail in appendix F.

Initial approach

The initial process involved custom generation of meshes on a flat surface which was based on the floor plans of the shops and streets, parametrically. These meshes were then used to form found by using 'Kangaroo' plugin for Grasshopper which is based on the principle of Particle Spring System. The custom mesh generation involved the division of a surface into finite number of particles, that were considered to be point masses connected to each other by springs that are elastic and weightless. Once the load is applied to the point masses the connecting springs oscillate until they reach an equilibrium. In this case, springs are expected to follow Hooke's Law. The grasshopper script was made in such a way that force applied can be controlled along with the external and internal spring stiffnesses. Every particle was given a force depending on the area it has to carry. The initial topology used was of rectangular tessellation. The results of this can be found in appendix J-2 and Q.

Form finding

Due to the structural strength of the locally available materials, form finding becomes really important, see material study in chapter 4.3 for the strength. Three aspects are central within the form finding process of connectable units.
- The ability to connect the units modular.
- The units should be self-standing, Connectable.
- The units should be constructable.

To find the final shape we used the dynamic equilibrium method. Important is that we ensured that our input gave the desired result. Background on different form finding methods and the input can be found in appendix I. The basic input for the meshing is the result from the automated layout script, as shown before, for details visit appendix G-1. Thus providing us with the boundary conditions for the modular units. By linking the form-finding process with the computational method for creating a 2D plan, we successfully created an automated method for building a bazaar on local user input. Where a potential outcome could be something as seen in figure 13. As seen in the figure the vertical walls enclosing the bazaars are missing, this is due to the fact that we want to ensure a flexibility to the end user, allowing them to create doors without having an impact on the structural integrity of the roof. These will be two seperate systems, more on this can be found in the part: 'Why 4 support points?'.

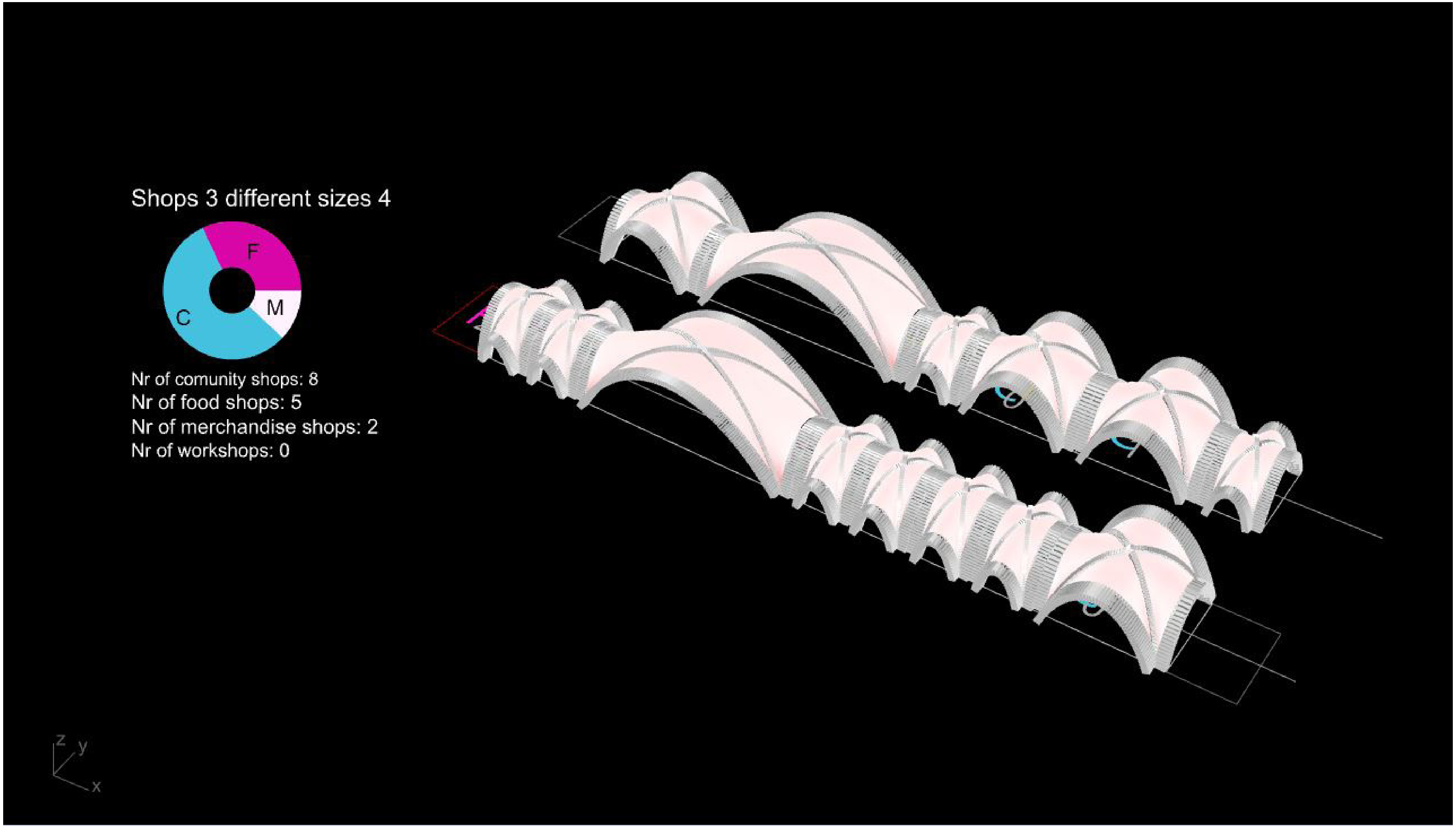


Figure 13: A figure depicting the output of what the bazaar building method could look like. Where the output of the betweenness study gives the desired starting node, which is then used to grow the bazaar in lay-out, which is then used for the forming of the modular.

Form finding topology
The topology, which serves as input to the dynamic equilibrium method, is crucial. The found shape is directly related to the chosen topology. Your topology defines the outcoming shape, In other words: the design space. Matching the design space with our inputs resulted in the following topology design (figure 14), more about the relationship of topology and forms can be found in appendix I.

Why 4 support points?
Our final model is based on the found topology named in appendix I, paragraph 'Form finding topology to 3D mesh'. This one was chosen due to his capability to be performed modular and the flexibility it gives to the end user by allowing it to be on four support points. Why making it more complex by four support points is a question we asked ourselves, but the benefits outweigh the disadvantages:

Advantages:
- Allows use to use the same support structure / structure for different modules (by separating walls and roof structurally)
- Makes it easier to integrate double levels as it allows for separation of structural systems of the first and second floor
- Gives flexibility to the user as walls are non-load bearing
- Gives flexibility to future use, for example store expansion or future uses.

Disadvantages:
- Adobe on four support points is structurally more challenging
- Constructability might be harder then wall supported roofs.

By studying the constructability of vault types, we realised that 4-point supported vaults are constructible. We did realise in the first form finding steps, when dynamically relaxing, the shape does not meet the required tension in the second principle direction. Therefore, we had to look for a way to improve the outcome of our form finding. Otherwise, we had to study other options. We eventually looked into optimizing the spring stiffness and the thickness, see figure 15.

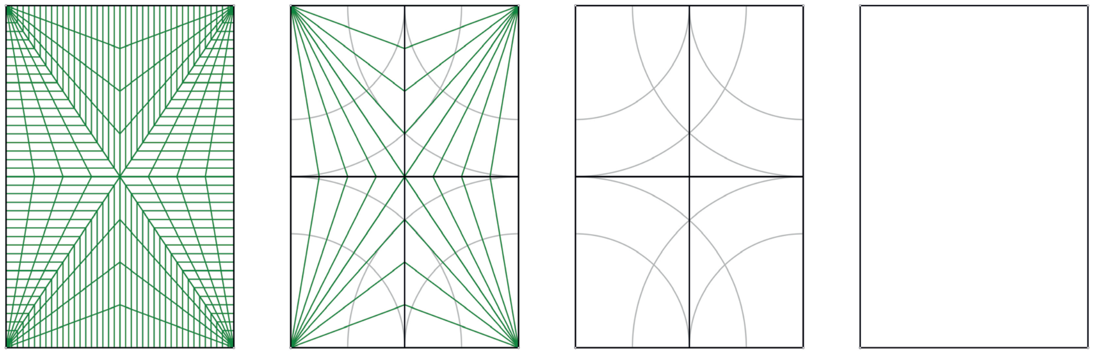


Figure 14: Topology design, From right to left: 1. Input shape with 4 corner supports, 2. Finding medial axis support points, 3. Generating closest lines to supports 4. Final mesh design meeting the three aspects.

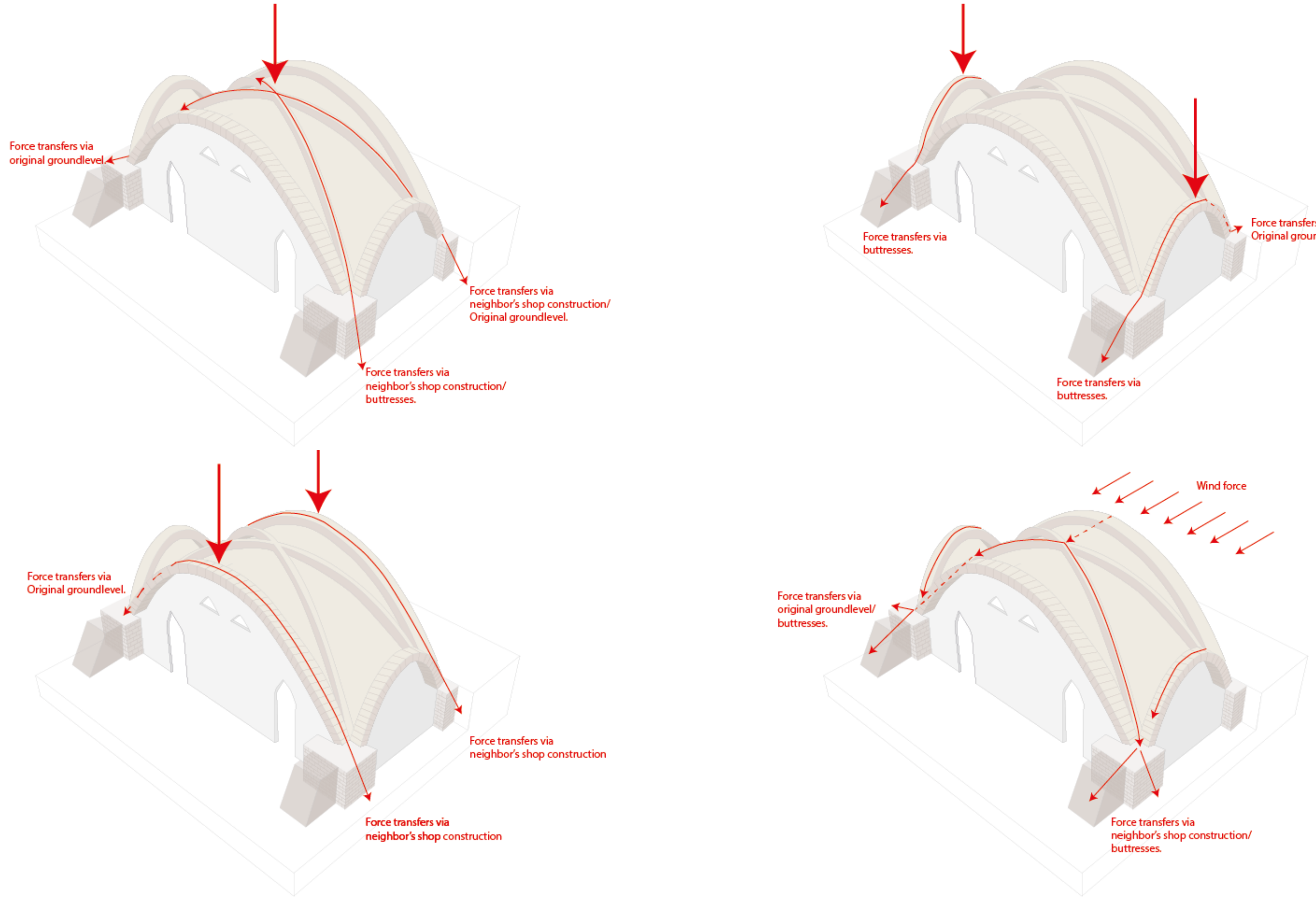


Figure 15: Forces in ta modular shop
(all shops are structural independent.When the walkway rib structure is built, it will be part of the equilibrium of the shop's structure.)

3D Forming
The 2D topology is then dynamically relaxed towards the optimal form, using Kangaroo for grasshopper. Crucial within this process is finding the right spring stiffness in accordance with the used material. To approximate the best spring stiffness we used a surrogate model optimization solver (RFbopt), based on weighted FEM results. more about this process can be found in appendix J-1 and in appendix T

The resulting form can be seen in the image below (figure 16) and meets the connectability and modularity criteria. If you look at structural results more can be found in chapter 4.3: Structural.

Junction
As the junction is 18 x 18 m in size, it was nearly impossible to span the whole junction with one single adobe dome. Therefore, we decided to go with 9 domes, we tried various designs. For the final option, it was decided to make each vault self-standing.

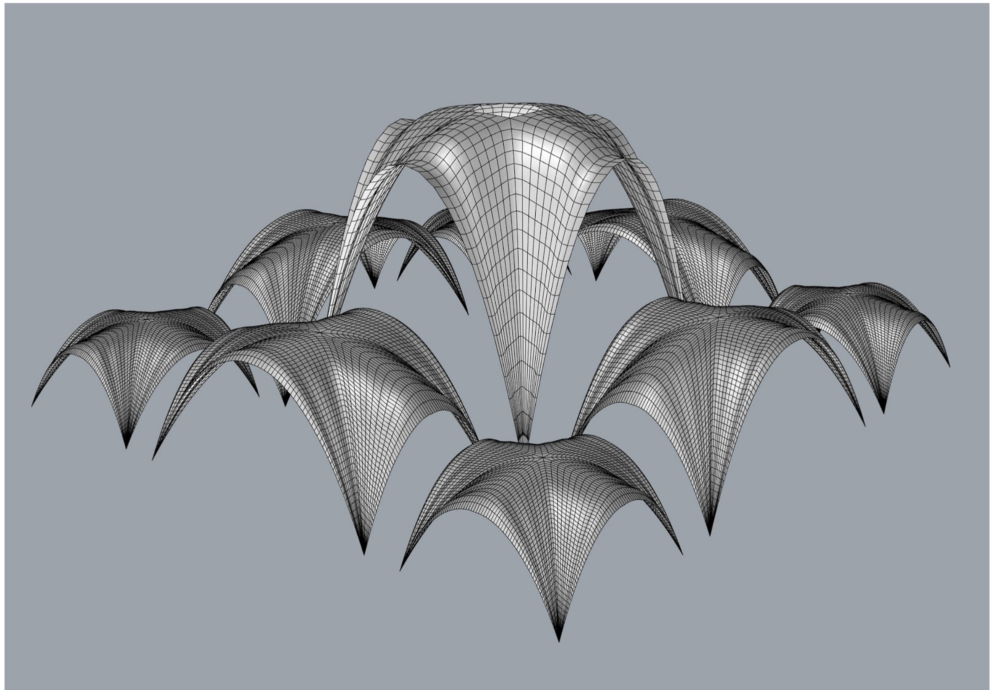


Figure 17: Junction form finding with topology. The 2D tessellation for the central vault was manually made and inputted to the script.

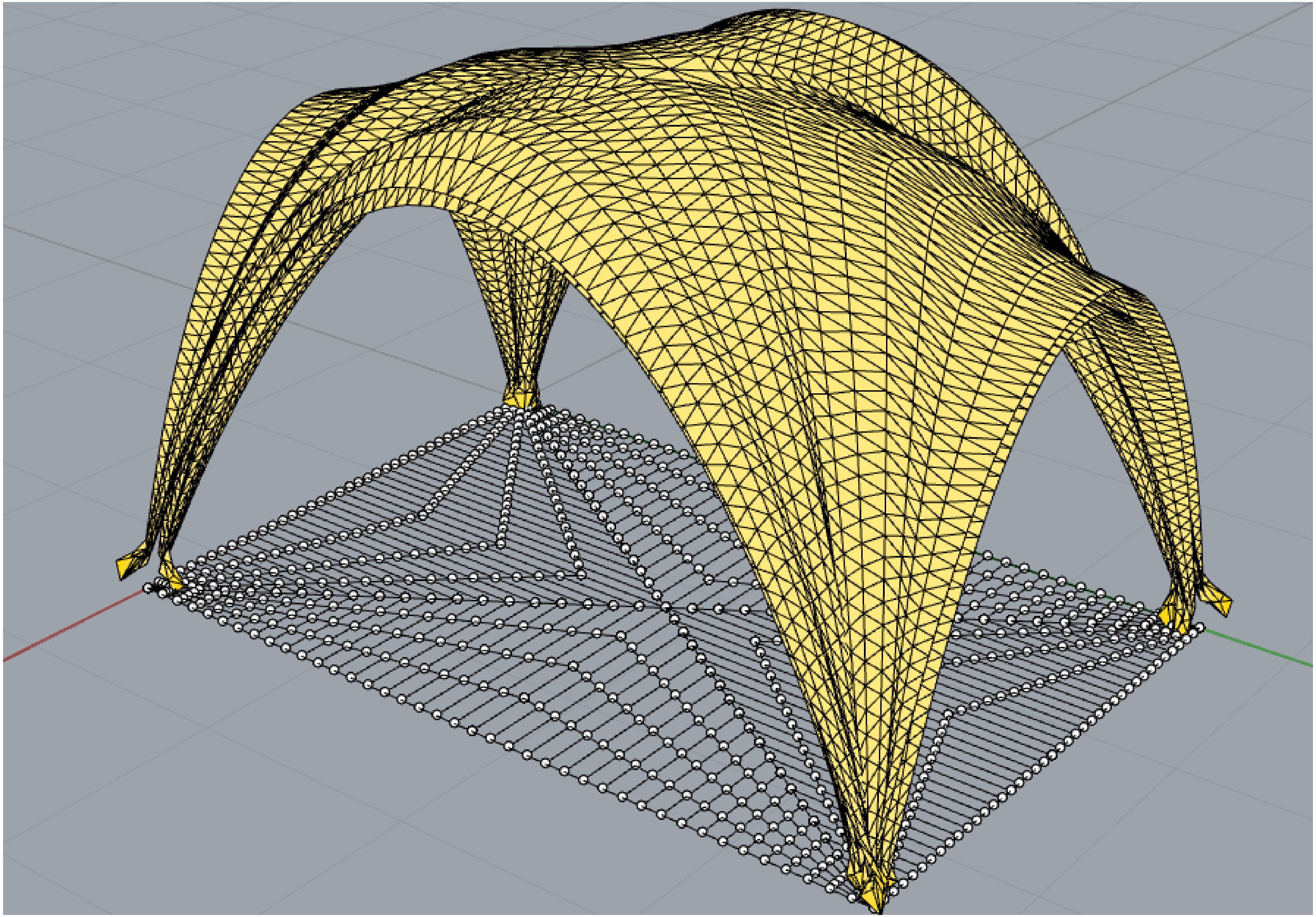


Figure 16: 2D topology with resulting 3D form

4.3 Structural

Vaults & Domes

There are different types of vaults created around the world in different periods of history, from ancient Egypt to the Gothic period in Europe. Below is a list of the most common type of vaults. The extended research can be found in appendix K.

Barrel vault:	Single curve extruded, semi-circular, originally with sun dried bricks.
Groin vault:	Two barrel vaults intersect, round/ pointed arch, difficult geometry.
Rib vault:	Two/ three barrel vaults intersect, pointed arch, smaller buttresses.
Fan Vault:	All the ribs have the same curve, flat central space between conoids.
Cloister Vault:	Two barrel vaults intersect, four concave surfaces, central.
Rampant vault:	Located on an inclined plane, one impost on one side is higher
Catalan vault:	Wooden formwork needed for curve, quick and less material required.

To conclude, for the design of the bazaar the rib vault is chosen. This type of vault is a little bit harder to construct then for example a barrel and Catalan vault but transfers the load much better. This is very important because the vault is built with self made adobe bricks which have a lower strength than normal bricks. The harder constructability is solved during the construction process, where a very intuitive inflatable mould is used.

Most used domes in the world are summed below. See appendix L for more information.

Corbel dome:	Beehive dome, superposition of smaller rings of bricks and stones.
Cloister dome:	Two barrel vaults intersect, four concave surfaces, meets in center.
Crossed arch dome:	Related to rib vault. Ribs are intertwined in the middle.
Geodesic dome:	Sphere like structure, Structural framework is needed.
Monolithic dome:	Casted as one piece (not applicable for bricks).
Onion dome:	Ogee (s-curve), Russian, not constructed with bricks.
Rotational dome:	Created when a circular arch is rotated around a axis.
Inflated dome:	Lightweight fabric of a double membrane skin with air inside

To conclude, the decision is made to work with the Crossed-arch dome and rib vault as domes. Crossed-arch dome is family of the rib vaults which were chosen as type of vault and are already in the design. This gives coherence in the architectural design. The rib domes are as the rib vaults good in transferring the load, see figure 18.

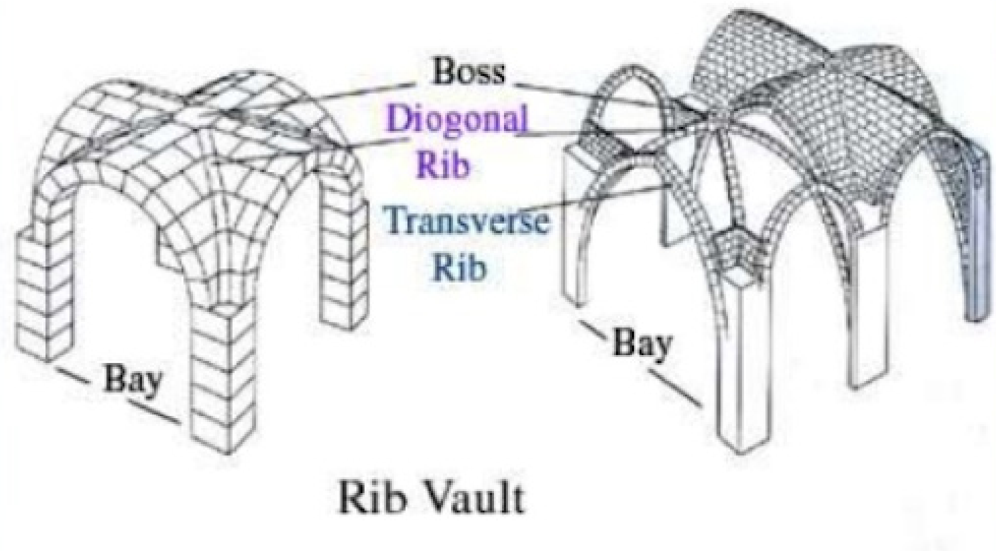


Figure 18: Rib vault. Retrieved from Mallikarjun (2017)

Constructability
Three of these vaults and one dome where tested on constructability by creating them by hand with model bricks. These tests were conducted to find out if it is possible to construct them without any skills in masonry. The test where also done to find out if any formwork or structural support is needed for building the arches. The false vault, the rib vault, the Nubian vault and a dome where tested. Structural support was needed for the false vault, rib vault and Nubian vault. For the rib vault, Nubian vault and dome formwork was needed. These results are taken into account for constructability and show that research needs to be done into formwork and structural support.

Material study
For understanding the properties of adobe bricks, a study is performed including making and testing own specimens. According to literature, the compressive stress of an adobe brick is between 0,45 MPa and 8,3 MPA depending where it is made. The quality of ingredients for adobe have significant effect, but for testing in The Netherlands, Dutch ingredients are used. According to literature, North European clay is more useful in the baked variant due to climate and quality.

Five different specimens were made to understand the effect the reinforcement materials in adobe. The specimens which are made are: 1) adobe only, 2) adobe + straw, 3) adobe + wood chip, 4) adobe + sorghum and 5) adobe + feathers. After making and testing specimens, only the adobe + straw and adobe + feathers mostly remain their original shape. After analyzing the results of the test, the compressive stress was higher than expected. This can be seen in table 1. However, the Elasticity modulus is lower than mentioned in literature, see table 2. Still, these two materials are chosen to be used for structural elements in the bazaar. Adobe only elements will be used for non-structural purpose e.g. fillers between structural elements. The combination of these three materials (figure 19) is used due to the limited availability of material in refugee camps. For example, feathers is a waste from birds who are kept for food purposes. Side notes regarding the reliability of the research and details of this research can be found in appendix M.

Figure 19: Adobe only (left), Adobe + straw (middle), Adobe + Feathers (right)

Young's Modulus [N/mm2]	Adobe only	Straw	Wood chip	Soghum	Feathers
	All	All	All	All	All
Min	6,62	15,44	13,72	9,23	11,54
Max	647,00	174,63	141,12	16,85	55,70
Average	68,13	63,64	54,05	14,36	30,40
Median	25,22	55,94	50,74	15,99	24,37
st. dev	115,08	41,27	36,74	3,14	15,69
Correction factor	1,96	1,96	2,20	2,78	2,37
n	42,00	22,00	12,00	5,00	8,00
Correction	34,80	17,24	23,33	3,90	13,15
Min E-modulus	33,33	46,40	30,72	10,46	17,25
Max E-modulus	102,94	80,89	77,38	18,26	43,55
Physical test result	Complete destroyed	Shape mostly remained	Complete destroyed	Complete destroyed	Shape mostly remained

Table 2: Results elasticity Modulus per specimen type.

Compressive stress [N/mm2]	Adobe only							Straw	Wood chip	Soghum	Feathers
	All	Limited range	Limited 0-5000mm²	Limited 5000-7500mm²	Limited 7.500-10.000mm²	Limited 10.000-15.000mm²	Limited 15.000+ mm²	All	All	All	All
Min	0,06	1,07	1,49	1,39	3,70	0,84	0,06	2,28	1,22	0,97	0,93
Max	24,23	6,93	24,23	12,94	11,26	8,83	3,35	10,48	7,55	1,61	7,95
Average	4,19	2,75	10,51	4,00	7,31	2,87	1,03	5,00	3,50	1,13	3,75
Median	2,13	2,13	9,01	2,62	6,79	1,47	0,76	3,81	2,84	1,04	3,25
st. dev	4,46	1,50	8,33	3,46	3,39	3,02	0,86	2,32	1,83	0,24	2,49
Correction factor	1,96	1,96	2,78	2,13	2,23	2,16	2,16	1,96	2,12	2,57	2,37
n	60,00	32,00	5,00	16,00	11,00	14,00	14,00	22,00	17,00	6,00	8,00
Correction	1,13	0,52	10,35	1,84	2,28	1,74	0,50	0,97	0,94	0,25	2,09
Min Stress	3,07	2,23	0,16	2,16	5,04	1,13	0,53	4,03	2,56	0,87	1,66
Max Stress	5,32	3,27	20,86	5,84	9,59	4,61	1,53	5,97	4,44	1,38	5,84
Safety factor	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00
Min Stress incl. factor	1,53	1,12	0,08	1,08	2,52	0,56	0,27	2,02	1,28	0,44	0,83
Max Stress incl. factor	2,66	1,63	10,43	2,92	4,80	2,30	0,77	2,99	2,22	0,69	2,92
Physical test result	Complete destroyed							Shape mostly remained	Complete destroyed	Complete destroyed	Shape mostly remained

Table 1: Results compressive stress per specimen type.

3D structural analysis

The main structural analysis is done using Karamba3D for grasshopper. Karamba3D is a structural engineering tool which provides accurate analysis of shells using the finite element method. three different limit states were tested in the analysis:

- The tension/compression in principle direction 1
- The tension/compression in principle direction 2
- The deflection of the structure

During structural analysis, we found out that the outcome of the brick making tests are not even close to what our structure requires. Therefore, we decided to go for literature numbers which are based on the adobe from the Middle East, see appendix P. The limits were based on the material and resulted in a maximum compression of 3 N/mm2, maximum tension of 0.3 N/mm2 Mpa and a maximum deflection of 1/200 span length. Optimising the spring stiffness and the amount of layers of stacked bricks eventually let to all modular units, from 1.675x2.4m till 9.4x3.6m to pass on the limit states (Gubasheva, 2017).

First, the shops and walkways are analysed. Later, housing above the big shop is included in the analysis to create a double layer construction.

Structural outcome (FEM)

All structural elements passed the UC checks based on the local available materials in Zaatari. two aspects need to be annotated:

- In modular vault 4.25m x 3.6m creep might cause the structure to deflect more than the given limit. Applying a sag of 14mm within the substructure (the deformation caused by self weight) solves this issue.
- The lower modular vaults (9.4x2.4 and 9.4x3.6) with high span have a force vector which risks leaving the column. We took three measures to prevent this: Increasing the weight near column on the structure.
- Creating a structural offset of the modular vaults of 0.45m, increasing the space for the structural vector
- Apply an extra load on the structural offset of 10.8kN, bending the force vector.
- Digging in the modular units helps providing support in horizontal direction, when other modular units are built the provide a counter force from the opposite direction.

To conclude the main structural problems that arise from the FEM studies are the horizontal forces of adobe 2.0 (high spans on 4 support points). During construction the use of buttresses is necessary for these spans, as most of the measures can only be applied after the structure is built.

For the junction, each vault is self-standing and was form found with kangaroo, then analyzed in Karamba3D and optimized with opossum to meet the tension requirements in both principal axes. As a result, 9 vaults were made with central one being the largest with dimensions 8.4 x 8.4 m, the corner vaults being 4.8 x 4.8 m and side rectangular vaults with dimensions 8.4 x 4.8 m. For the central vault, the maximum compression on principal axis was found a little over 3 N/mm2. The details can be found in appendix Q. Bricklaying scripts and other are described in appendix S and T.

Structural verification
The working of our final FEM model was verified by hand calculation and Ansys, More about this verification, an indepth of all the results and details of applied forces can be found in appendix P, Q and R.
FEM models showcase the ideal geometry works, without actual experiments we cannot validate the working in real life. (it remains theoretical) Definitely because the properties of the materials have a relatively high sigma (standard deviation). We looked closely at the mesh and increased the fineness where the forces were the highest. Besides this we tried to ensure that our FEM model was working correctly. We checked the input and working of the model with hand calculations.

Structural Analysis ANSYS
The secondary structural analysis was done in ANSYS, which is a FEM software, in which every part of the bazaar previously modeled with kangaroo and karamba was tested. This includes every individual part of the junction and every shop size (small, medium, large).
The material property used for the analysis in ANSYS is adobe, and a mesh of 30mm is used on every individual component.
A load of 2 kN equally distributed with a safety factor of 1.5 is considered in every element. This load represents the load of people walking on top of the vaults or domes in the construction phase or any other event. In addition to this, a permanent load of every individual structure is considered, with a safety factor of 1.2.
The values obtained during the brick making workshop were not sufficient due to imprecision and reliability of the research, therefore we used the values based on literature research, as described in appendix P.The material properties which are used have the same value as the ones used in the Karamba analysis.
The complete analysis in ANSYS can be found in the appendix R.

4.4 Construction

Dome and Vault

RRib domes are chosen as construction for the junction, shops and housing and rib vaults for the walkway. The original way to build rib domes and vaults is with a wooden structure, however this is a limited material in camps as Zaatari. Other solutions as cardboard, temporary brick structures, a radial arm, tent and inflatable structures were found and tested. The extended research can be found in appendix O.

For the construction of the bazaar, an inflatable structure is chosen. The idea is to use a modular system for the bazaar. As described above formwork and structural support is needed to make it possible for the people in the camp to build the bazaar. The pro of this system is that the mould is compact for transport, framework and structural support in one and reducing the change on mistakes as it is a 3D shape which is followed. Due to the modular approach of the design only 9 different types of moulds are needed to make the bazaar. 1. small shop, 2. small walkway, 3. medium shop, 4. medium walkway, 5. big shop, 6.big walkway, 7. house, 8. Junction a and 9. Junction b.

The major challenge is how to prevent deflection of the inflatable mould when bricks are stacked on it as shown in figure 20. Today, high air pressure tubes are used for concrete structures. To make this feasible, reinforced high air pressure tubes and chambers in these tubes in between the main structure is used to stabilize the mould. Stacking the bricks have to be done equally on both sides of the ribs to make sure the mould does not re-shape due to unequal load. All details of this research can be found in appendix O.

Wall openings

The forces in a wall need to be transferred when an opening is made to avoid tension in the adobe bricks. This can be done by adding an arch. The type of arch is depended on the architecture of the building, the type of bricks, and skill of the builder. A lancet arch (point arch) is most common in South-Syria, this has a similar look as the chosen rib domes and vaults, therefore this arch is chosen. The lancet arch can be made with a birth line or with a negative form which follows the intrados of the curve. The formwork can be made of cardboard in the case of Zaatari camp and should be designed in such a way that it can be reused due to a modular design.

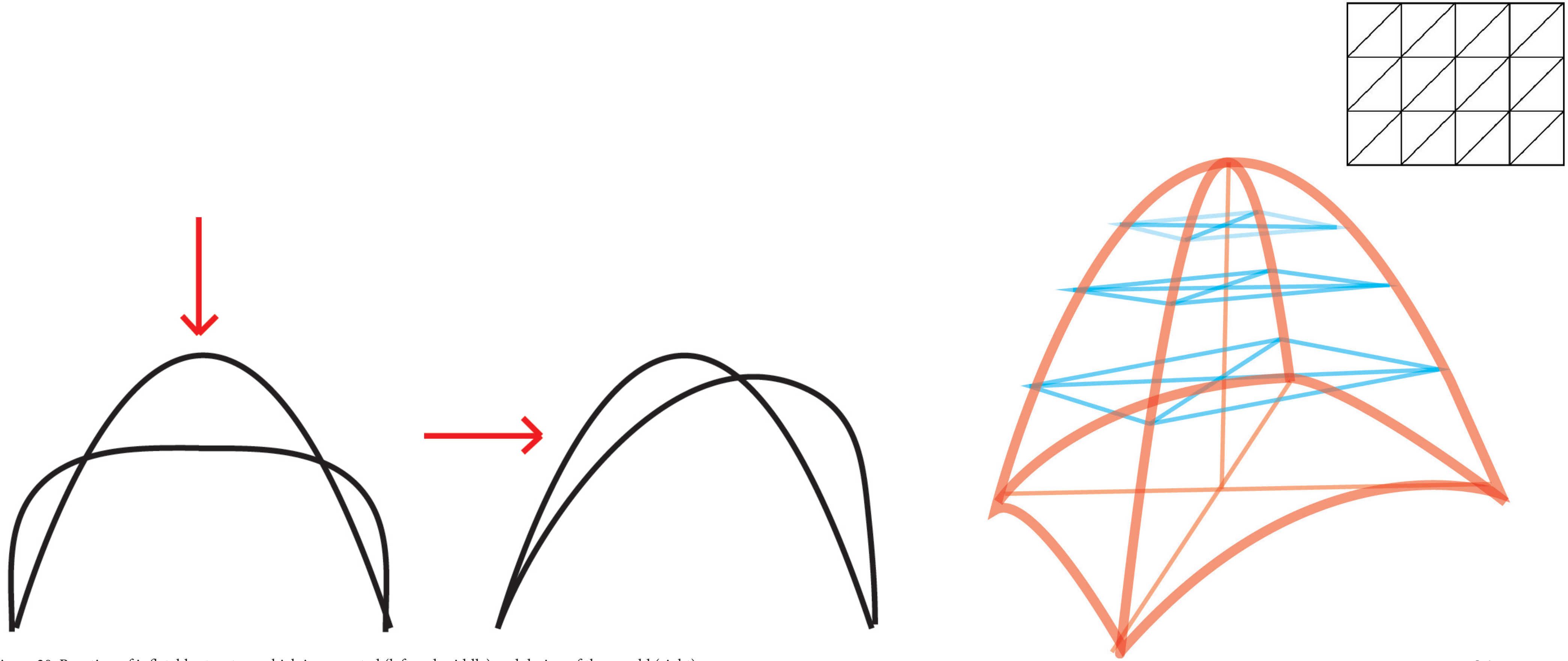


Figure 20: Reaction of inflatable structure which is unwanted (left and middle) and design of the mould (right).

5. Design

In this chapter, the design of the bazaar will be explained. First, the guidelines and scenario will be explained. Than, the design of the chosen scenario will be described.

5.1 Guidelines

Guidelines are set up to give the users a first impression of how to start a bazaar and how to expand when needed. The guidelines are not leading, but give an indication. The users are free in overruling these guidelines when the suits best in the situation. The guidelines are set up in three categories: 1) urban, 2) bazaar and 3) structural.

Urban guidelines

Near Mosque:

As mosques are important for the daily life of the residents in a Middle East refugee camp, the starting node of the bazaar should be near a mosque.

Near water tap point & Logistics:

As water is important for shops in a bazaar, this should be near too. Goods has to be supplied via the logistical points. Therefore, distance should be minimal.

No cars/ trucks:

For safety reasons, the bazaar should not be accessible for cars and trucks. Supply of goods can be done via the backstreet or by troller.

Intensive used pedestrian street:

To ensure the safety of the bazaar and the added value in a refugee camp, the bazaar has to be placed in a intensive used pedestrian route.

Bazaar follows urban structure:

The growth of the bazaar is limited by the urban structure. Current located objects should not move for the bazaar.

Street width >12m:

The minimum width of the street where the bazaar walkway and shops will be located is approx. 12 meters.

24+m street splits in 2:

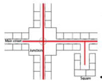
When the width of the street is bigger than 24m, the street can be splitted by adding a shop in the middle of the street.

Exit street every ± 50m:

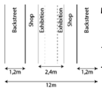
For safety reasons and connection with the urban structure, an exit street should available perpendicular on the wall street.

Bazaar guidelines

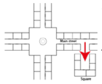
Main street connects junction and square:


The walk street is the connection between the junction and square. The junction and square are orientation points.

Street lay-out:


The walk street is in between of the shops and their exhibition space. Every shop has access to the back street.

Square parallel to main street:


The square is parallel orientated to the walk street and is only there when there is urban space.

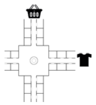
Cluster similar functions:


Functions with the similar cluster group are as much as possible together to avoid nuisance.

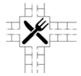
Pollution shops not near community/food:


noise and dust pollution shops are not near community/ food shops.

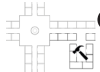
Food & merchandise in the street:


Orientate food and merchandise shops in street due to exhibition space.

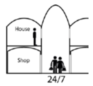
Community around junction or square:


Community shops in junction or square to create a meeting point.

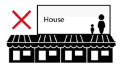
Workshop in square:


Cluster workshops in a square to concentrate the noise pollution.

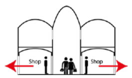
Social Control:


Houses above the shops to increase the social control and safety in the bazaar after closing time.

Space for housing:


There should be place for housing as this has to be included in the structure.

Backdoor in every shop:


Every shop has a backdoor to the back street for escape and goods supply.

Public seatings in junction/ square:

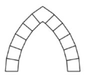

Public seatings in junction/ square as meeting point. No sleeping place.

Community seatings in junction:


Seatings in front of restaurants and teahouse as meeting point.

Structural guidelines

Rib arch structure:

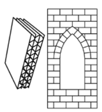


The structure will contain a rib arches which will be filled with bricks and openings.

Inflated roof support:

As support for the rib arch structure, an inflated roof support is used (owned by Unicef).

Window/ door support:



Small openings like doors and windows can be temporarily supported with cardboard.

5.2 Starting node and scenarios

The method which is developed for this project can be projected on every refugee camp. Zaatari is the case study to show the method. Therefore, first the starting point will be determined. Next, the scenarios will be shown what is possible in expanding the bazaar based on the guidelines. A scenario will be chosen and a complete design is shown in the next paragraph.

Starting point

Based on the guidelines, a betweenness study is performed to understand which streets have potential for the starting node, see figure 21. The study is explained in appendix D. The starting node which is chosen for this project is location 2. This junction is located North of the improvised market place and other community spots. Next to this, it is near a dense part of the camp. Therefore, this process is performed partially automated (betweenness study) and manual for the influence of the admins of the camp (chosen one location). The first shops will be built around the starting node which creates the junction. From here, the bazaar is able to grow.

Figure 21: Chosen location in Zaatari camp

Expanding the bazaar

After the starting node is found, and the first few shops are set-up, the bazaar can start to expand. This will be done following the above guidelines and user input, using the script which was previously described in chapter 4.1 configuration (more information in appendix G-1). This script will, for the user, take the shape of an app in which the user can fill in his demands and then choose an app.

Imagine that Kazem is entrepreneur who wants to start a restaurant. He will enter his shops requirements as :

1. What kind of shop do you want to start? (profession)
2. How much space do you need? (choice between small (10m2), middle (15m2) and big (20m2).
3. Do you want to add an house above your shop? (Choice yes or no)

TThe type of shop which is selected is connected to a cluster of shops. This determines the basic requirements of this show e.g. water usage and noise production. The details of clustering the shops can be found in appendix D. If a house is added to a shop, space should be available and the construction will be adjusted to it.

Five potential locations will be shown in the app where Kazem can choose from. He will choose one location he likes. The output from Kazem's decisions will be translated in a construction plan and sent to the construction team of the camp. The construction of the bazaar will be executed by a team who lives in the Zaatari camp. These are residents who are trained by Unicef and other charities. This way, we create job opportunities for people in the camp. Also, new residents of the camp can be trained during construction. Therefore, this team is not only train for the bazaar, but also for other projects in the refugee camp. When those people return back to their original home, they could use this new knowledge to rebuild their home.

There are also other potential entrepreneurs who could start a shop in the bazaar. The potential locations per shop type are shown in figure 22.

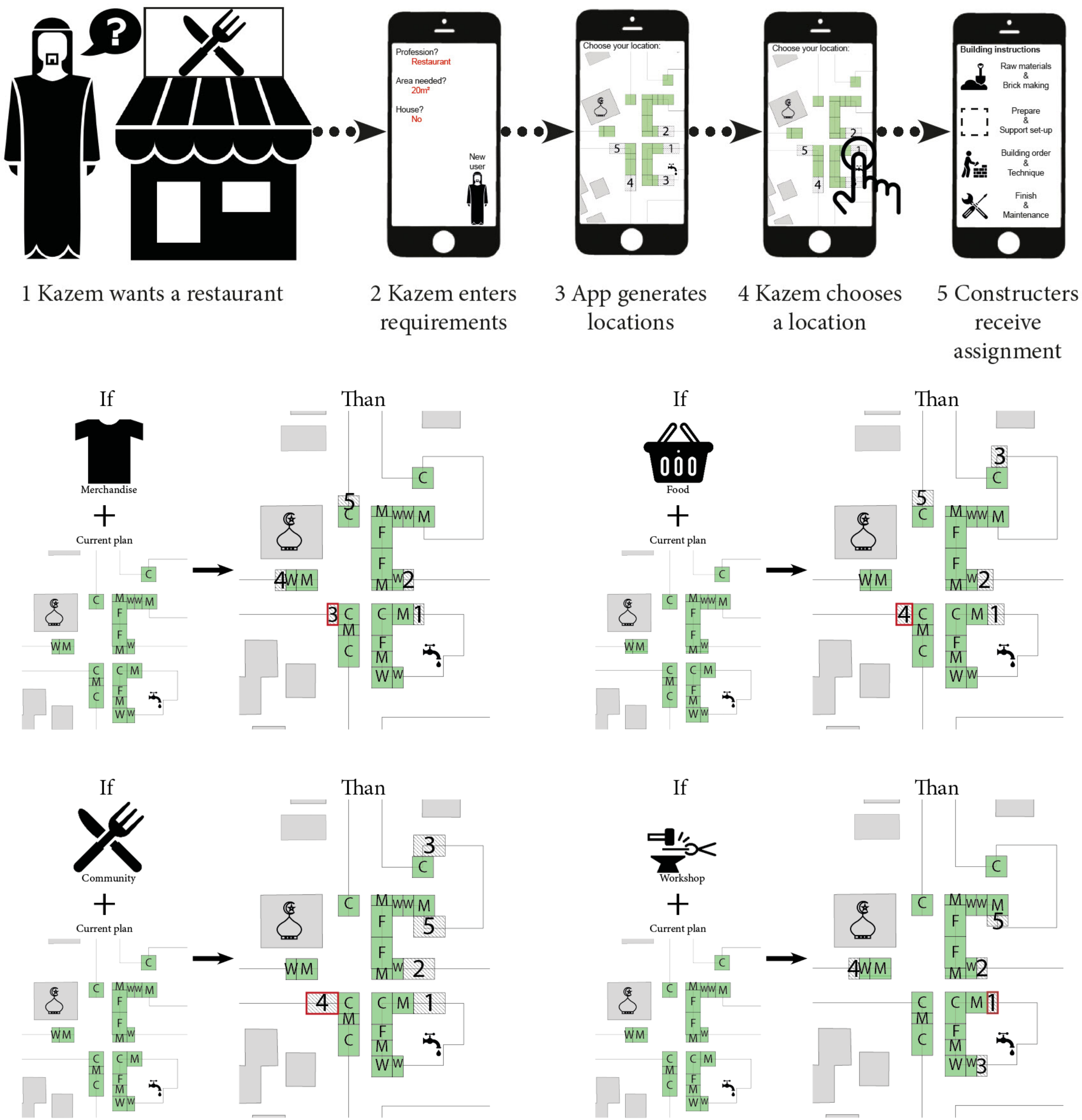


Figure 22: Potential situations depending on the shop type/ size request.

5.3 Outcome chosen scenario

Bubble diagram, floor plan, sections

This scenario shows that the junction is a clustered place for community stores and food stores. Due to the guidelines it is most likely to happen that there are community stores in the junction because this is what the app will show as preferred location. However, shop owners of a food store can also decide to overrule the app preferred location of the clustered food street and build his food store in the junction. The junction is connected to four streets, North, East, South and West. Walkway street east is again connected to a square. In this scenario the streets have mostly clustered types of shop. Walkway East is for food, walkway North and South is for merchandise and walkway west is a combination of merchandise and food stores. The square is a combination of workshops and community shops. This follows from the guidelines; Workshops in square and Community around junction or square (figure 23).

In figure 24-35 the floor plans, sections and impressions can be seen.

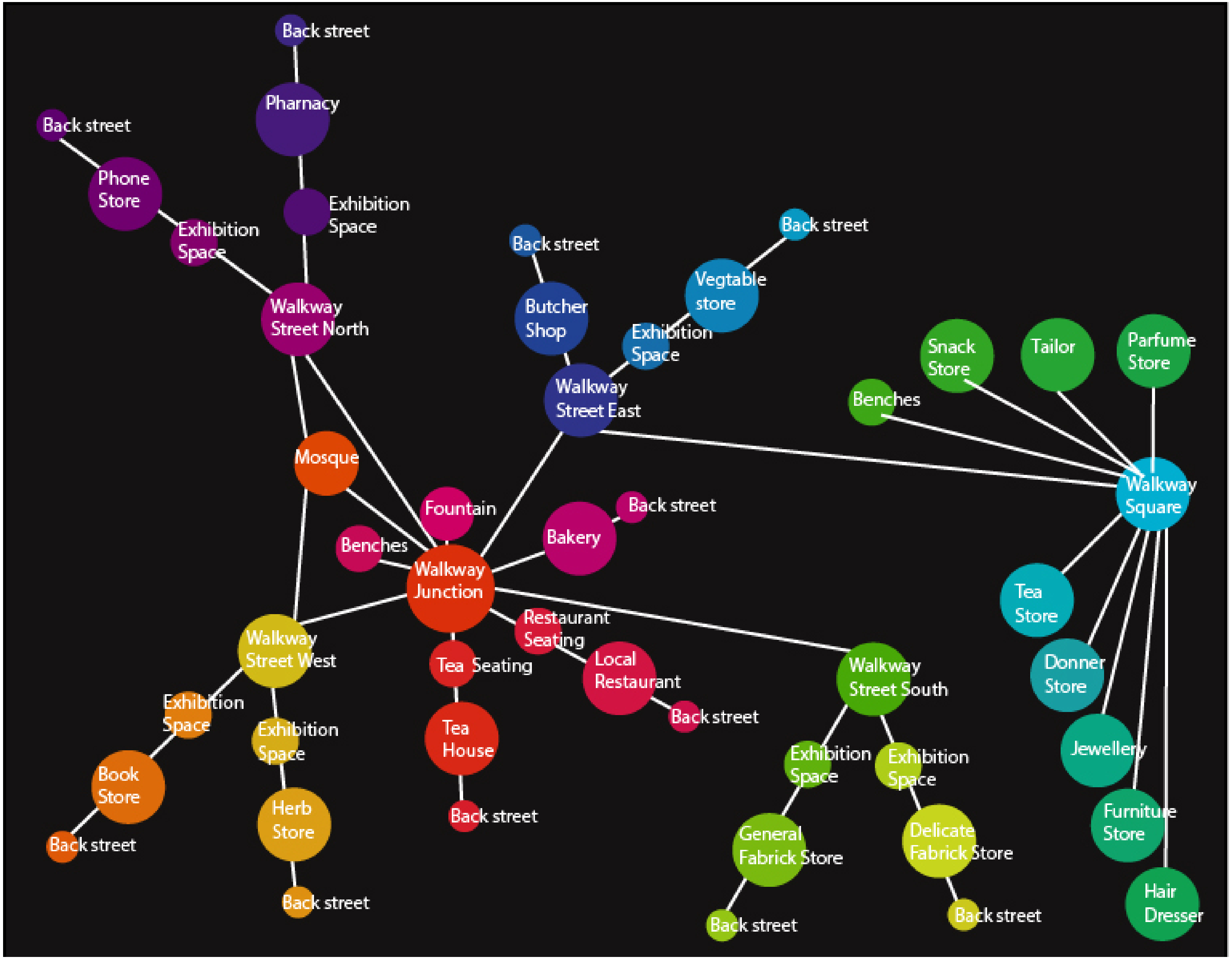


Figure 23: Bubble diagram chosen scenarios

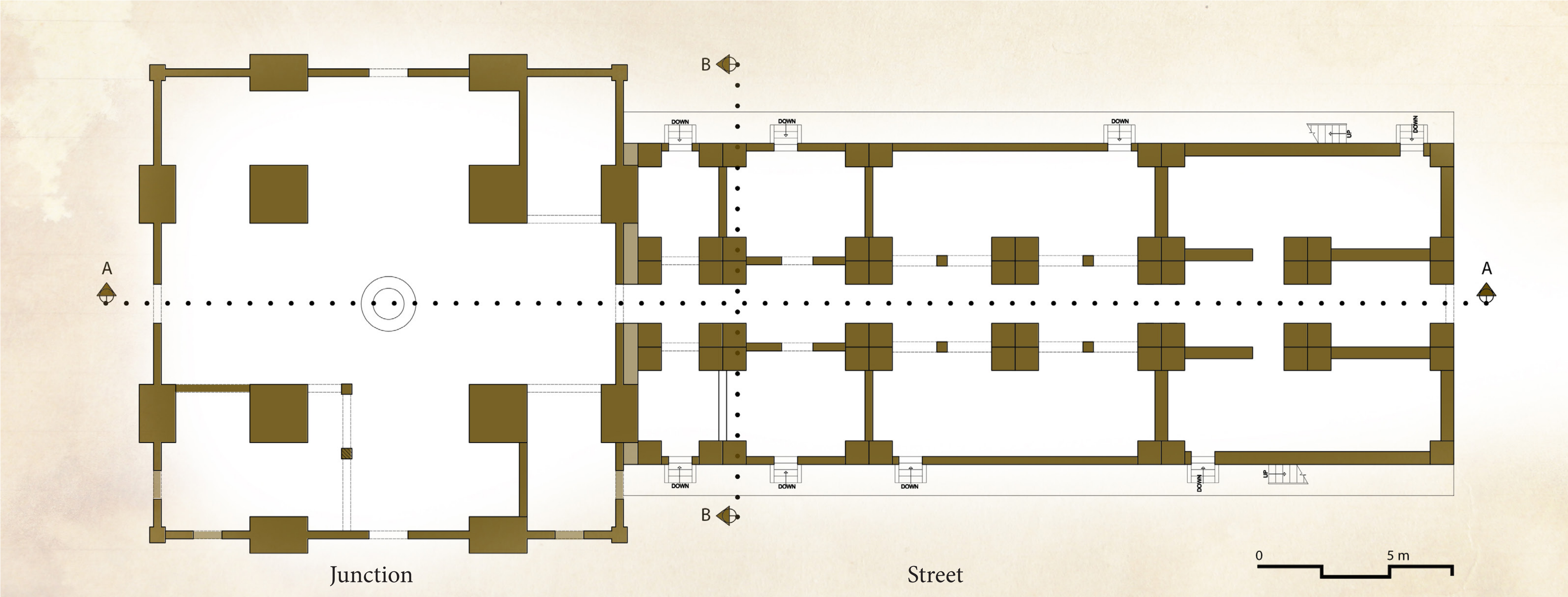


Figure 24: Floor plan chosen scenario

Figure 25: Detailed floor plan chosen scenario

Figure 26: Section junction/street chosen scenario

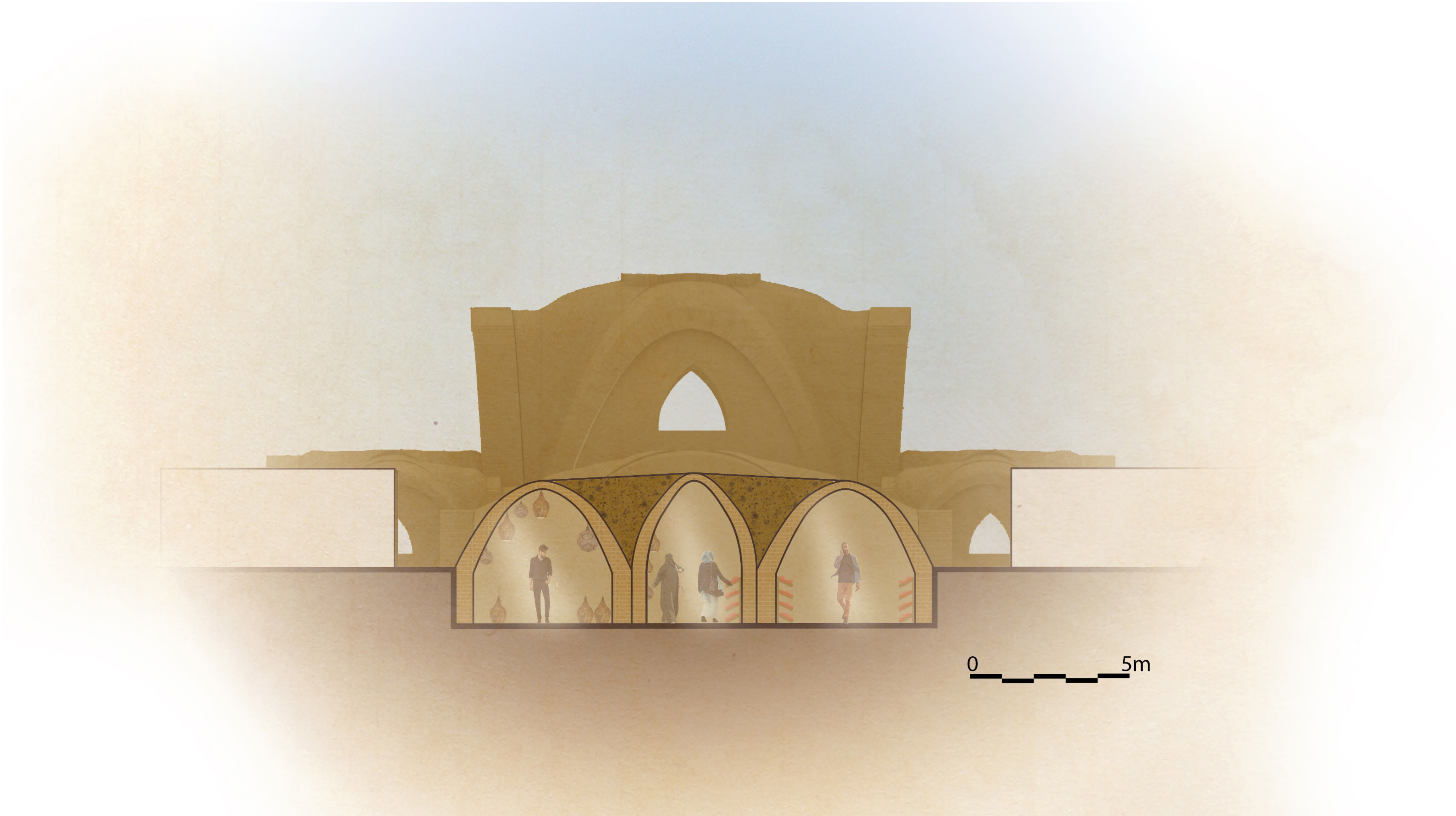


Figure 27: Section street chosen scenario

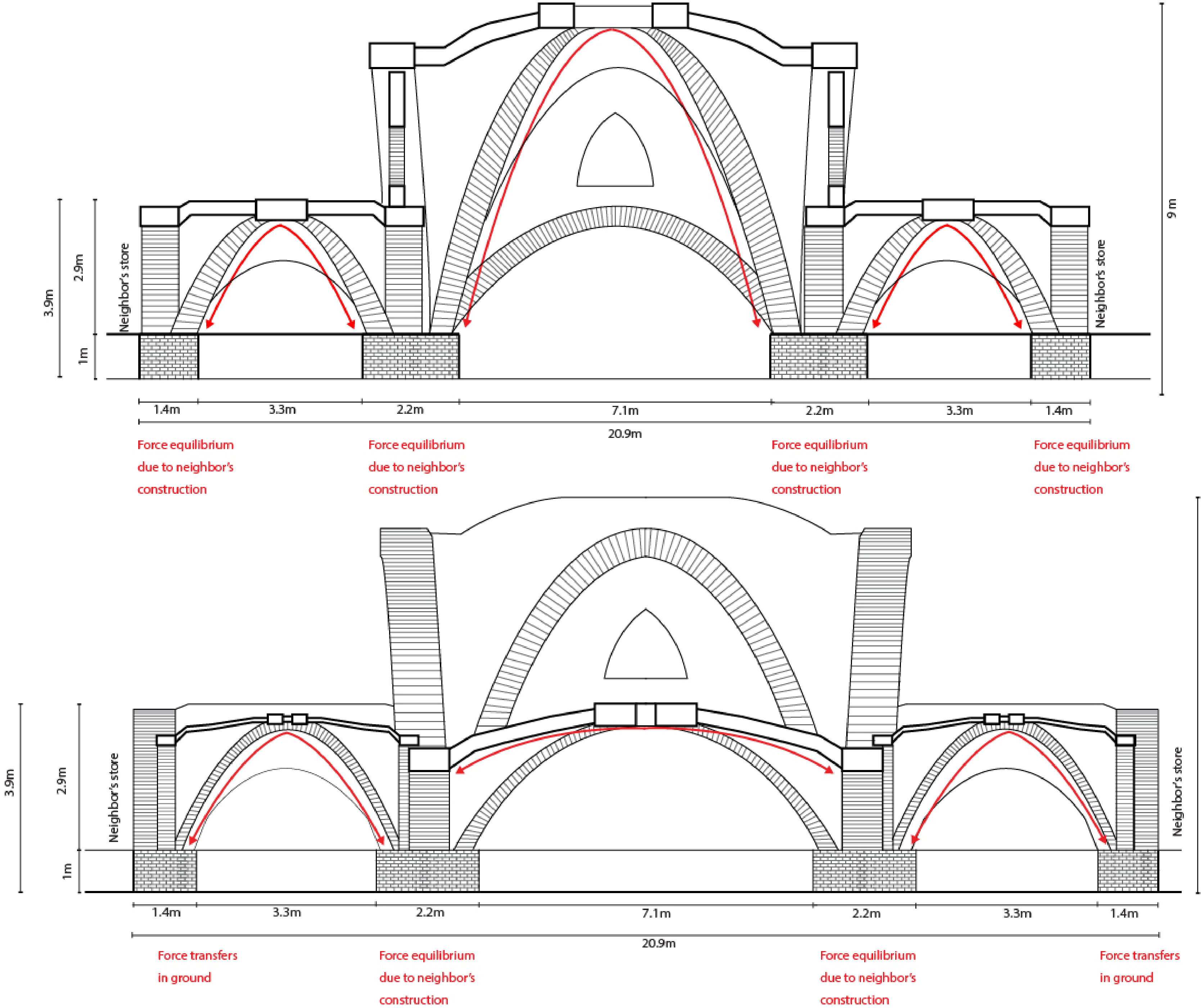


Figure 28: Technical drawing Junctions

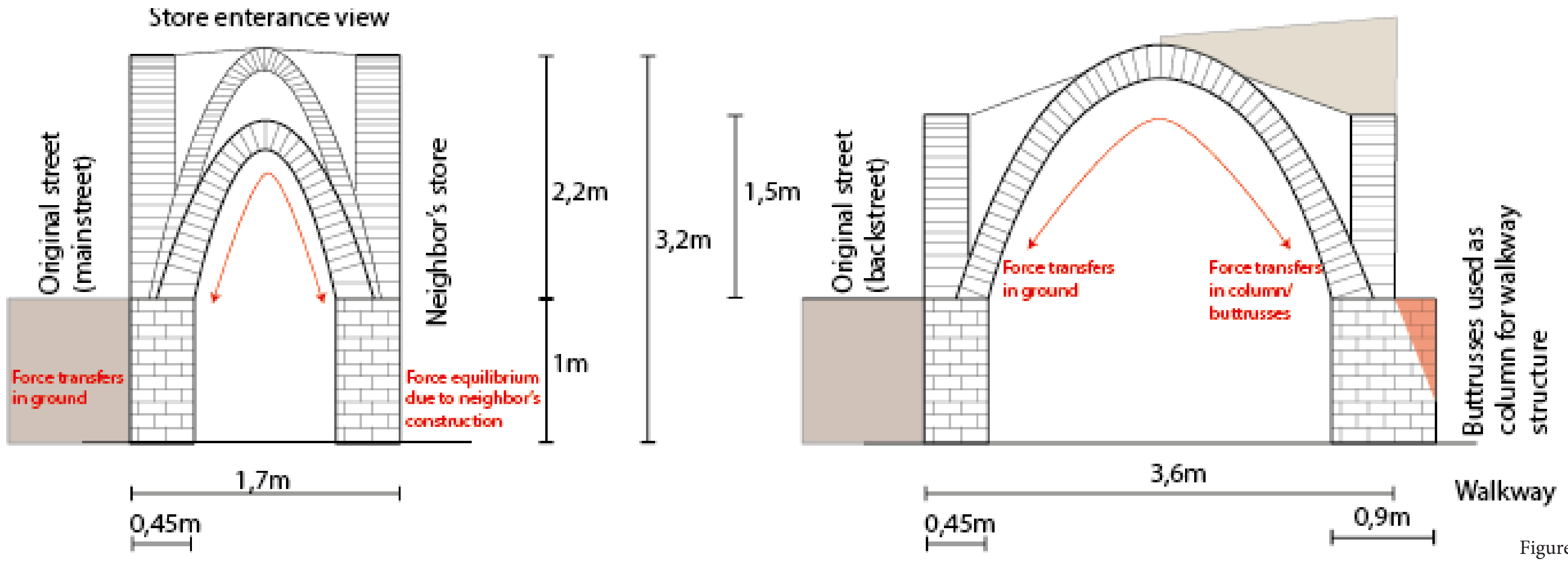


Figure 29: Technical small shop

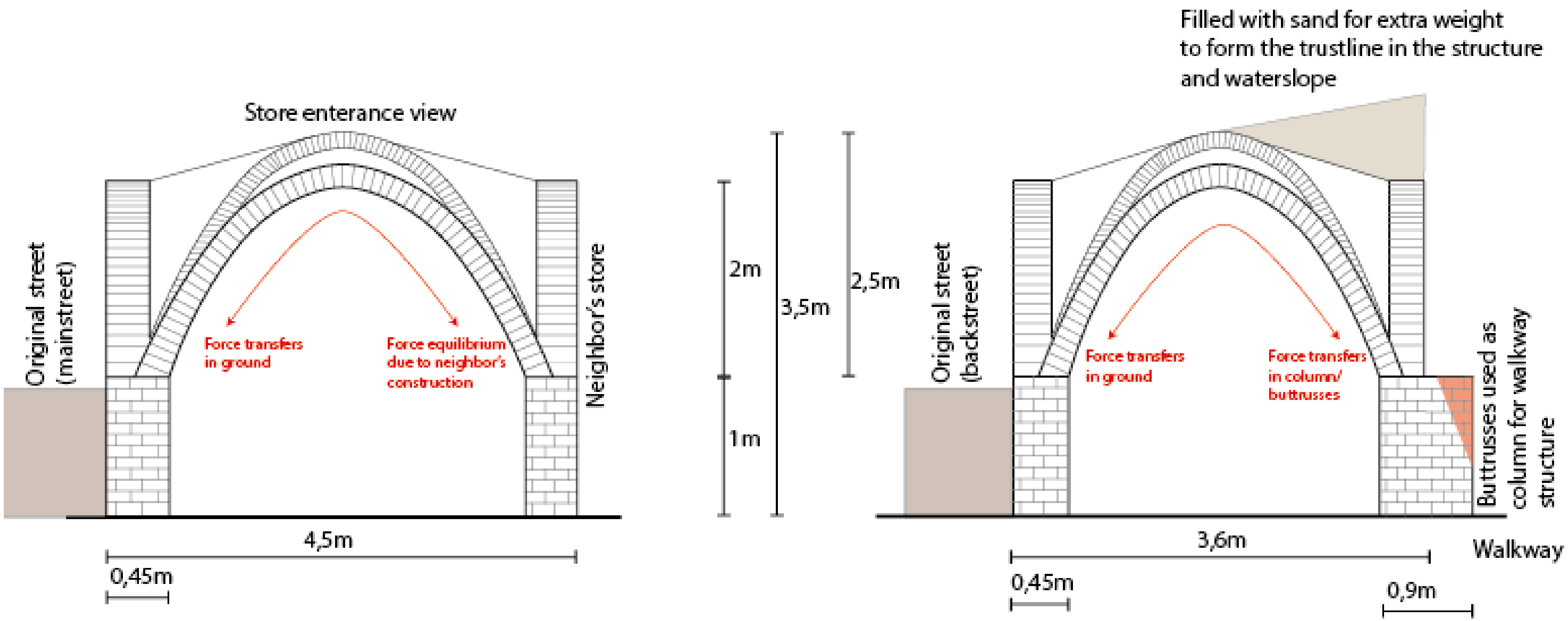


Figure 30: Technical Medium shop

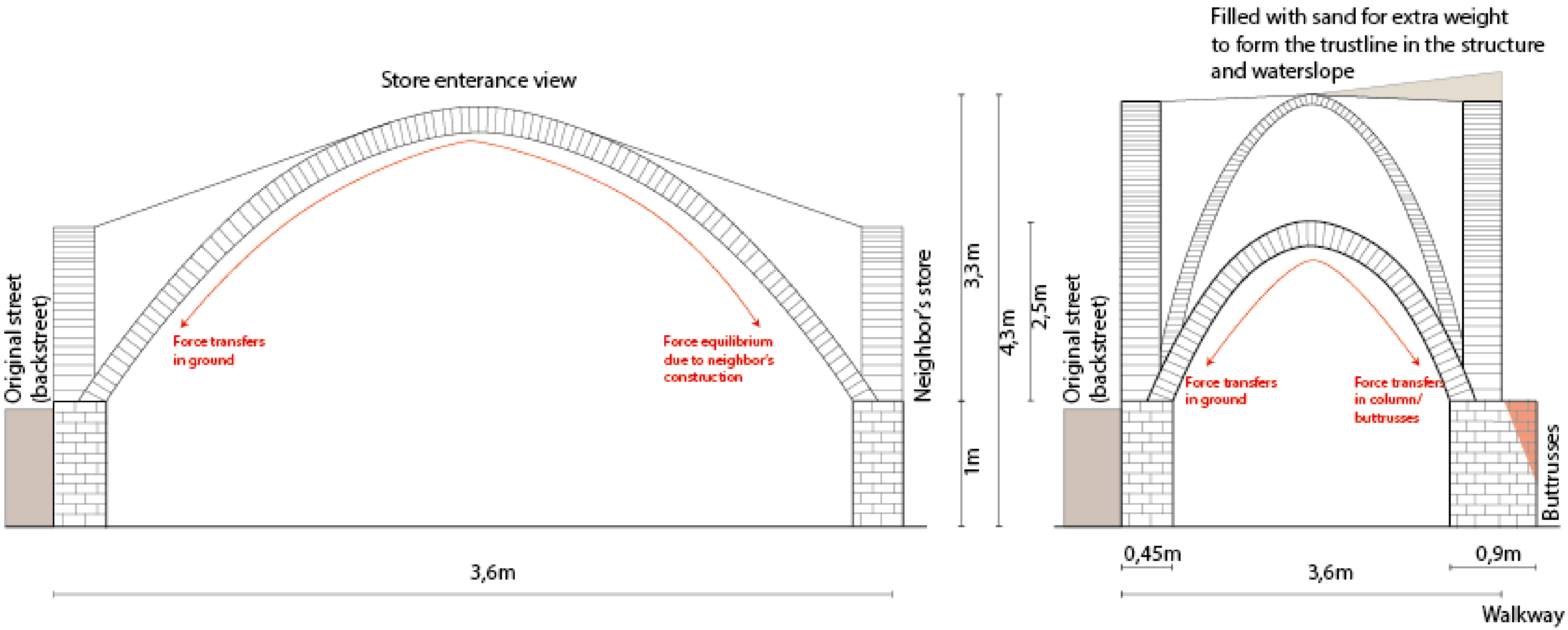


Figure 31: Technical big shop

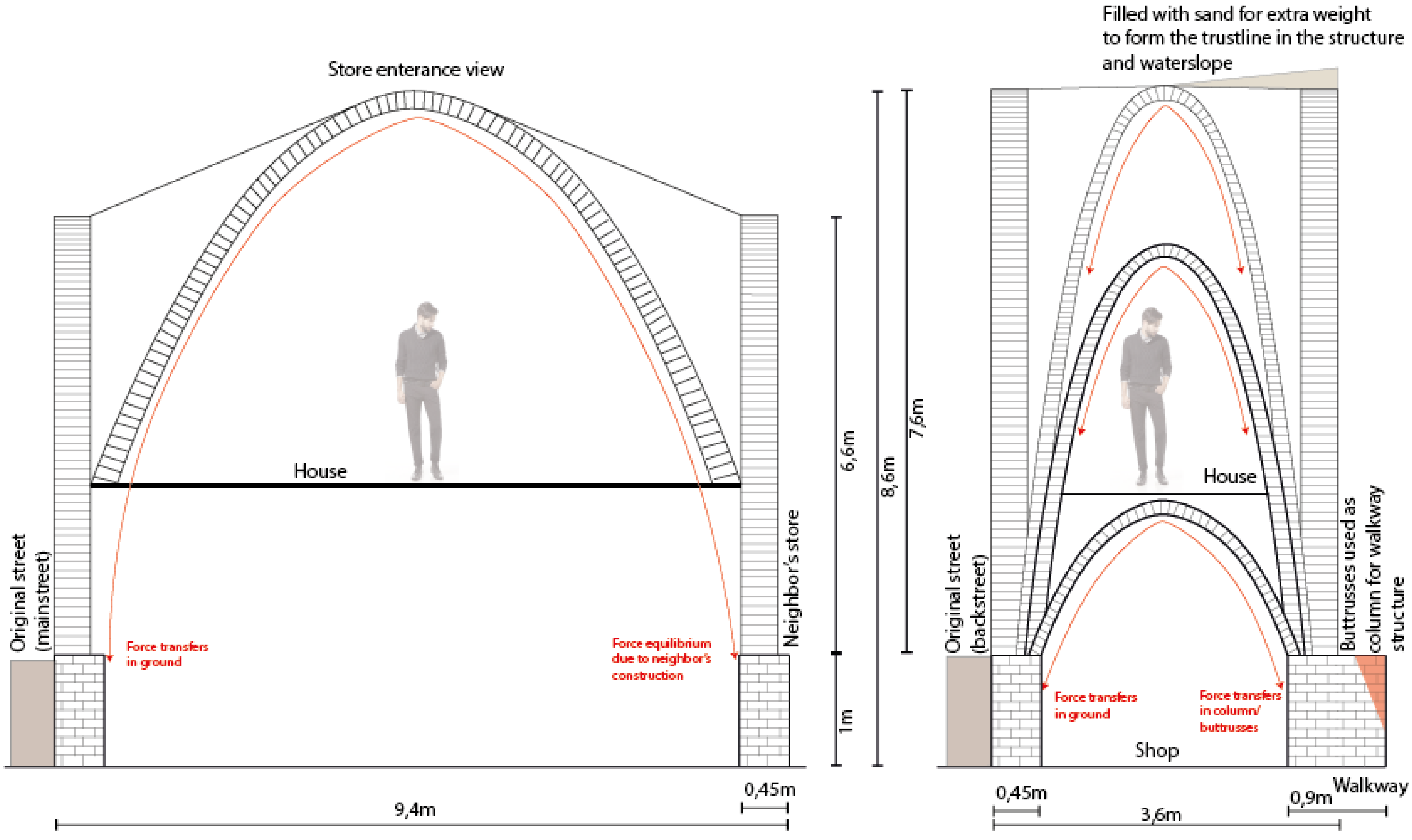


Figure 32: Technical big shop + house

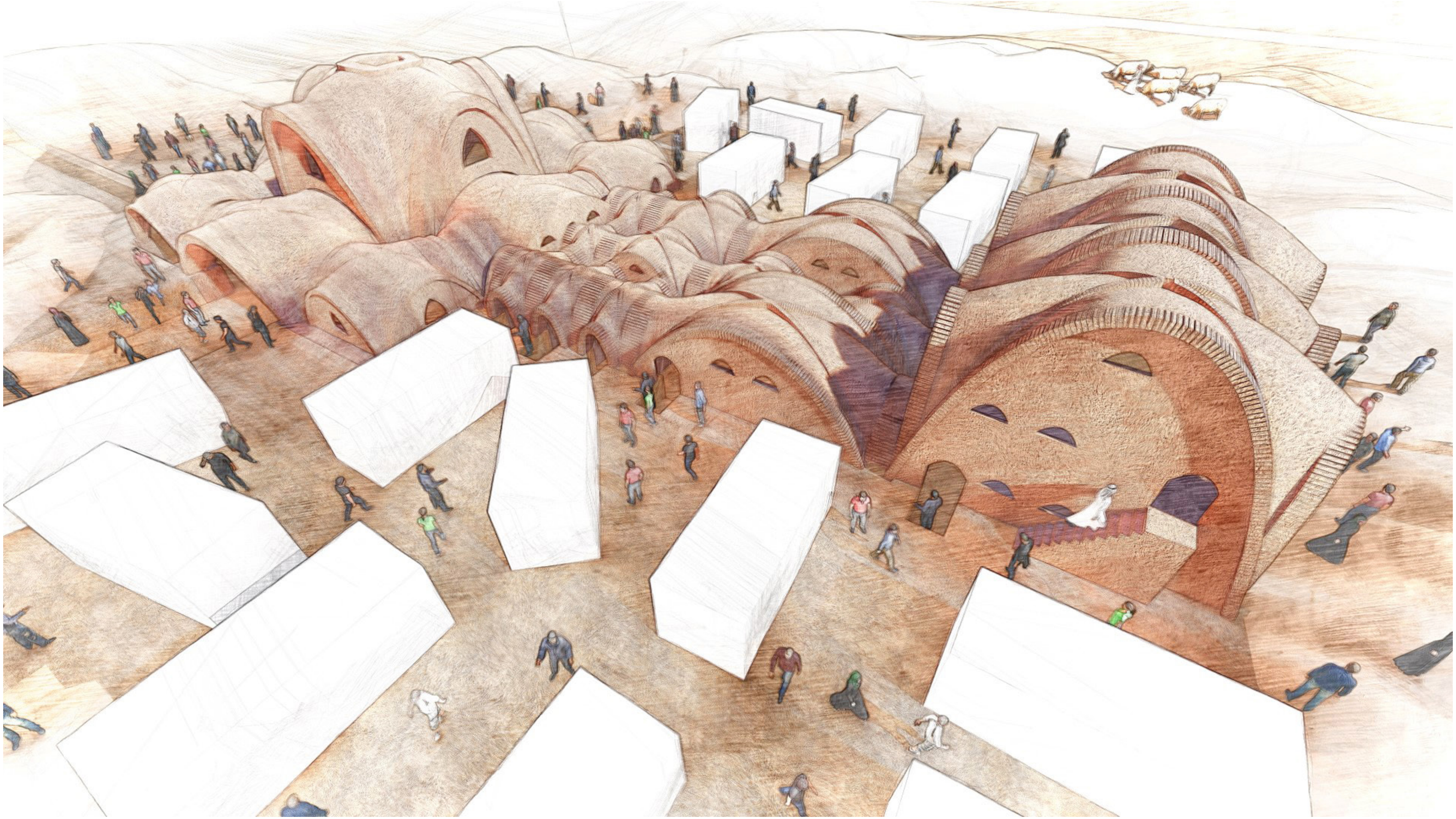


Figure 33: Bird's view

Figure 34: Extrerieur view

Figure 35: Interieur view

5.4 Structural

To conclude the structural part of this modular system, in modular vault 4.25m x 3.6m creep might cause the structure to deflect more than the given limit. Applying a sag of 14mm within the substructure (the deformation caused by self weight) solves this issue.

The lower modular vaults (9.4x2.4 and 9.4x3.6) with high span have a force vector which risks leaving the column. We took three measures to prevent this:

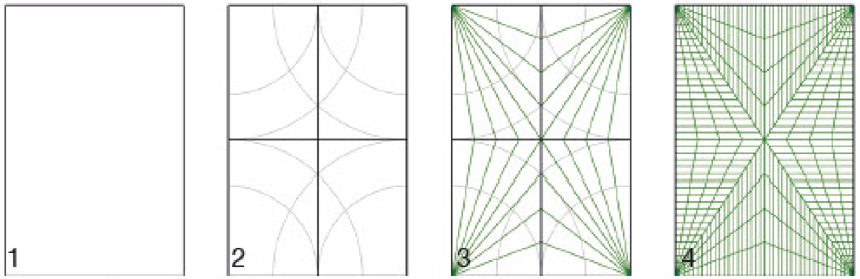
- Increasing the weight near column on the structure.

creating a structural offset of the modular vaults of 0.45m, increasing the space for the structural vector

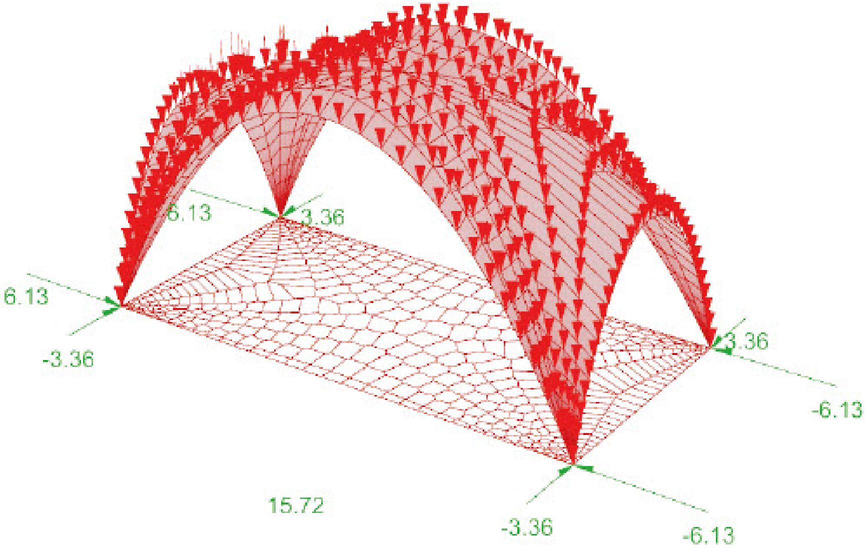
- Apply an extra load on the structural offset of 10.8kN, bending the force vector.
- Digging in the modular units helps providing support in horizontal direction, when other modular units are built the provide a counter force from the opposite direction.

To conclude the main structural problems that arise from the FEM studies are the horizontal forces of adobe 2.0 (high spans on 4 support points). During construction the use of buttresses is necessary for these spans, as most of the measures can only be applied after the structure is built.

Form Finding



1. Input shape with four corner supports, 2. Finding medial axis support points, 3. Generating closest lines to supports 4. Final mesh design meeting the three aspects.



Form Finding Optimilization

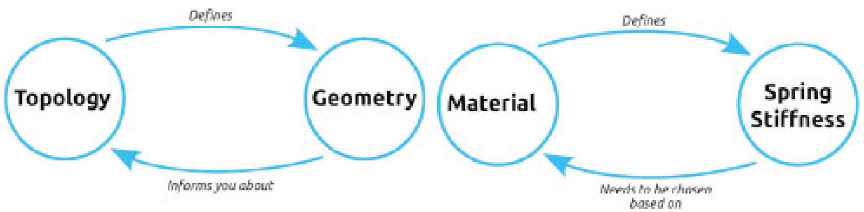


Figure 36: Structural forming and outcome.

Material parameters

Youngs modulus: 211 N/mm^2

Poisson ratio: 0.3 [-]

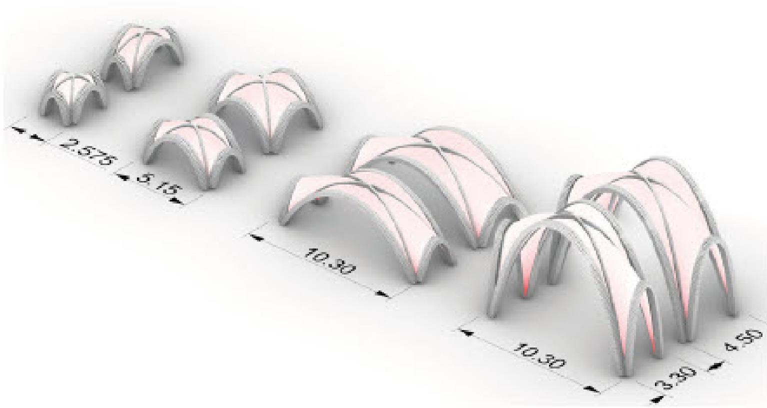
Shear modulus = Youngs modulus /(2 x (1+Poison ratio))

Specific weight: 1452 kg/m^3

Compressive strength: 3 N/mm^2

Distributed vertical load: 2.25 KN/m^2

Structure



2.575x3.30: Max. Comp: 2.60 N/mm^2 Max. Ten: 0.127 N/mm^2

2.575x4.50: Max. Comp: -2.34 N/mm^2 Max. Ten: 0.164 N/mm^2

5.15x3.30: Max. Comp: -2.64 N/mm^2 Max. Ten: 0.134 N/mm^2

5.15x4.50: Max. Comp: -2.86 N/mm^2 Max. Ten: 0.145 N/mm^2

10.30x3.30: Max. Comp: -2.44 N/mm^2 Max. Ten: 0.172 N/mm^2

10.30x4.50: Max. Comp: -2.59 N/mm^2 Max. Ten: 0.197 N/mm^2

5.5 Construction

For the construction of the bazaar, an inflatable structure is chosen. The idea is to use a modular system for the bazaar. As described above formwork and structural support is needed to make it possible for the people in the camp to build the bazaar. The pro of this system is that the mould is compact for transport, framework and structural support in one and reducing the change on mistakes as it is a 3D shape which is followed. Due to the modular approach of the design only 5 different types of mould are needed to make the bazaar. 1. small shop 2. medium shop 3. big shop 4. Junction a and 5. Junction b.
The mould is based on compartments and a kite system with leading edges and struts, see figure 37. The ribs, the primary structure, can be compared with the leading edge. This is a very stiff air compartment which can not be deformed by hand. The secondary structure, the struts, make sure that the mould will not deform when there is pressure on the sides.

Today, inflatable moulds are already used for concrete domes, together with post-tension tendons. The tendons make sure that the structure does not slide/deform. In the case of the inflatable mould for the bazaar the no horizontal and vertical deformation is wanted, see figure 38. Bricks are stacked on each other in compression. The bricks will not try to slide off each other like concrete, because they are leaning on each other. The construction can start simultaneously from all corners. Together with the substructure this makes sure the mould will not deform in horizontal direction. The primary structure, the leading edge, is very stiff. Together with the substructure and the blown in air this makes sure the mould does not deform in vertical direction. The structures and chambers can be seen in figure 39.
The mould is owned by Unicef and other charities who are active in the refugee camps. A group of people will be trained in basic construction knowledge and how to use the mould. There will always be a supervise of the charities who leads the group of constructors. In this way, the constructors can build more than only a bazaar and are able to use their knowledge to improve the quality of life in the camps.

Pictures of the physical models is shown in figure 40 - 45.

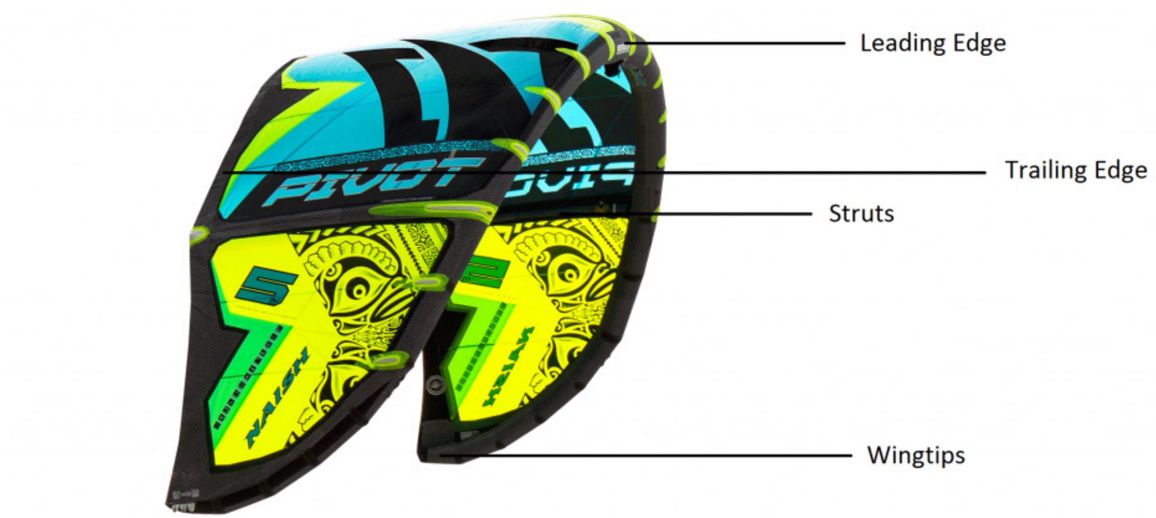


Figure 37: Kite principle. Retrieved from Kitefeel (n.d.).

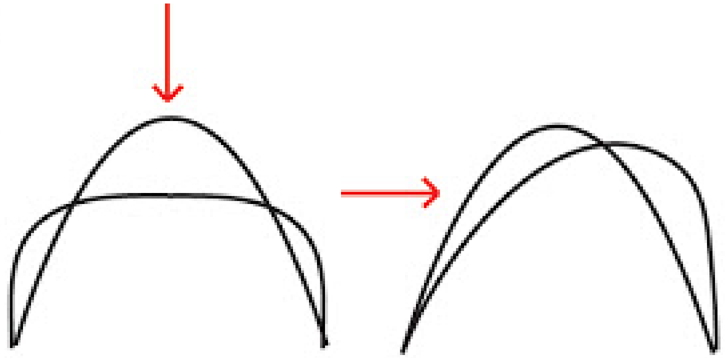


Figure 38: Reaction of inflatable structure which is unwanted.

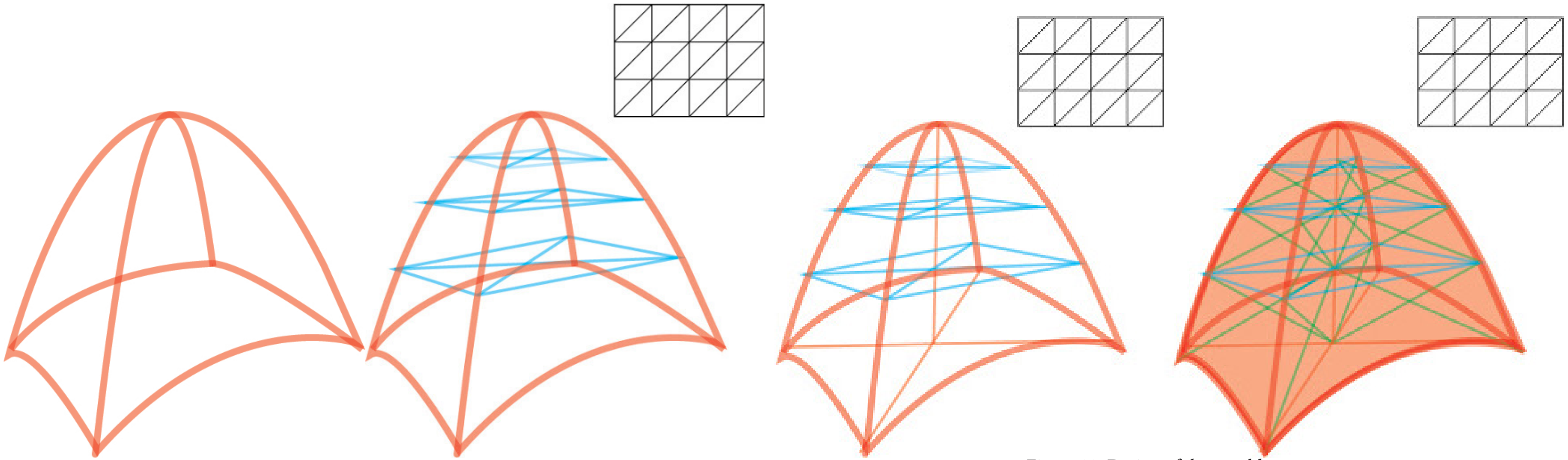


Figure 39: Design of the mould.

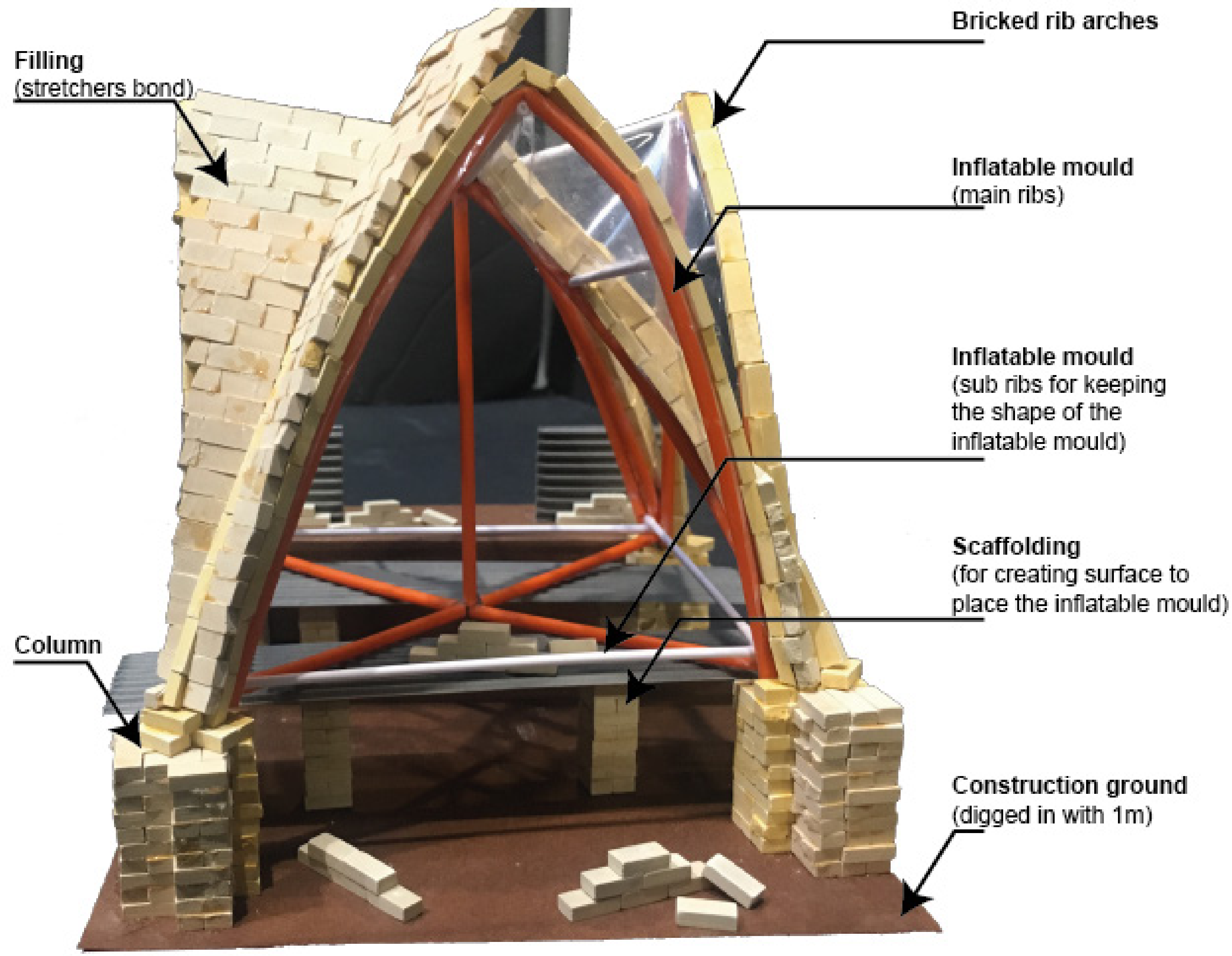
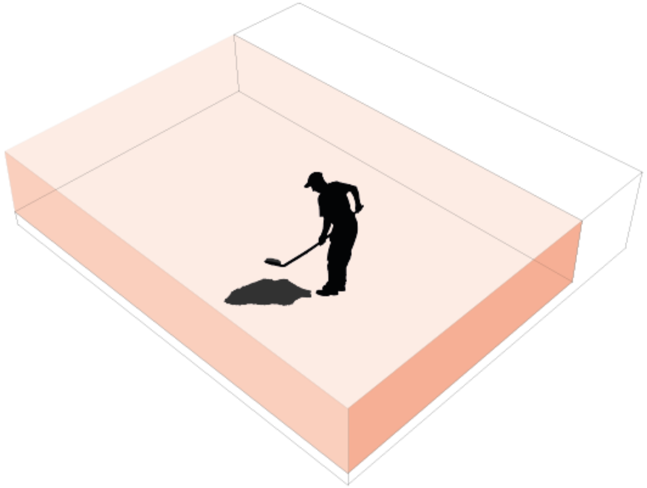
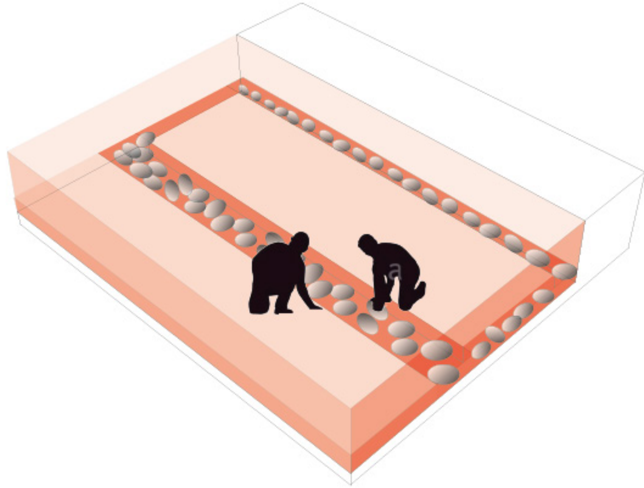


Figure 40: Physical model of the inflatable mould during construction.

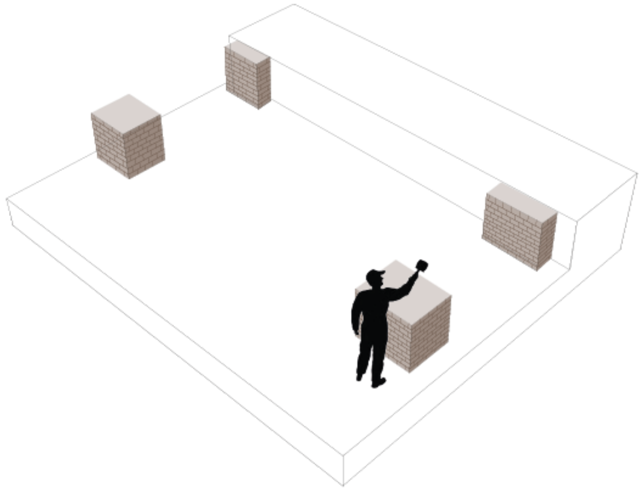
Construction phases



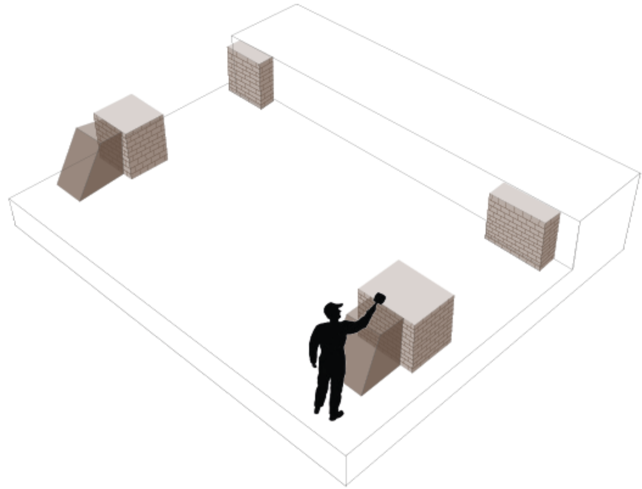
Phase 1: Digging the ground
The bazaar is being digged in for climate and structural reasons.



Phase 2: Foundation
The base of the columns and walls with stones

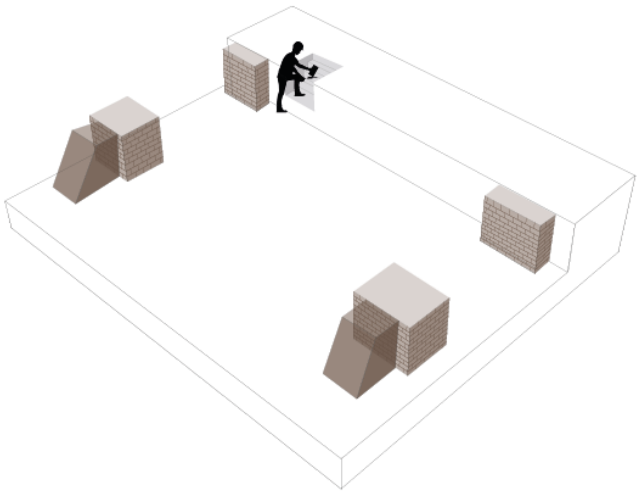


Phase 3: Bricklaying the columns
1m height to create usable walking space before the roof starts

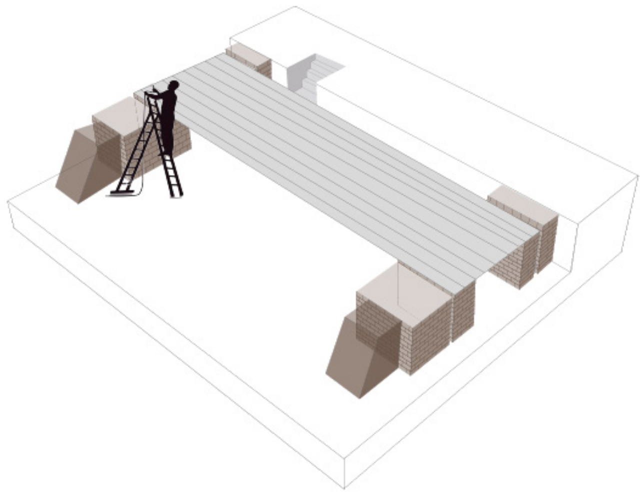


Phase 3a: Bricklaying the buttresses
Required for the trustline of the construction.
Buttresses can be used as columns when the rib arches are constructed of the walkway.

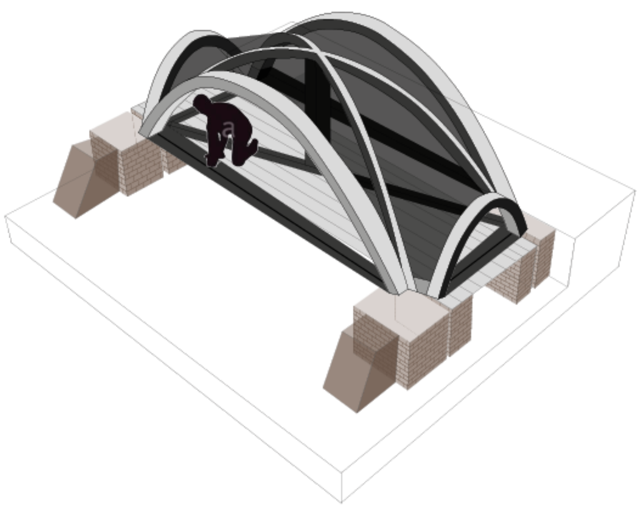
Construction phases



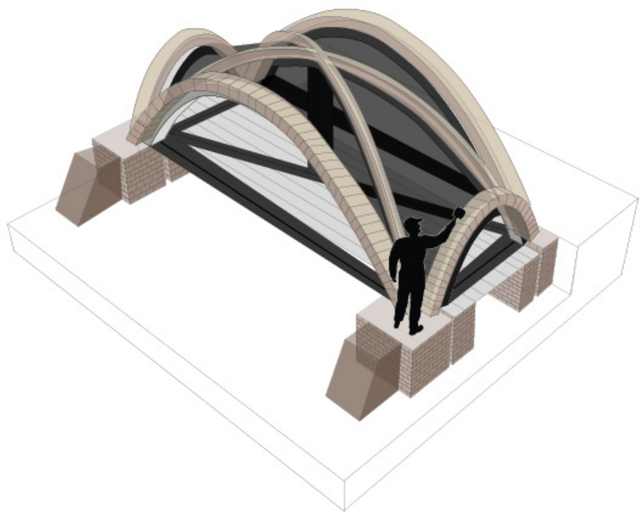
Phase 4: Stairs
To create back enterances for the shops.



Phase 5: Scaffolding
To create surface for the inflatable mould

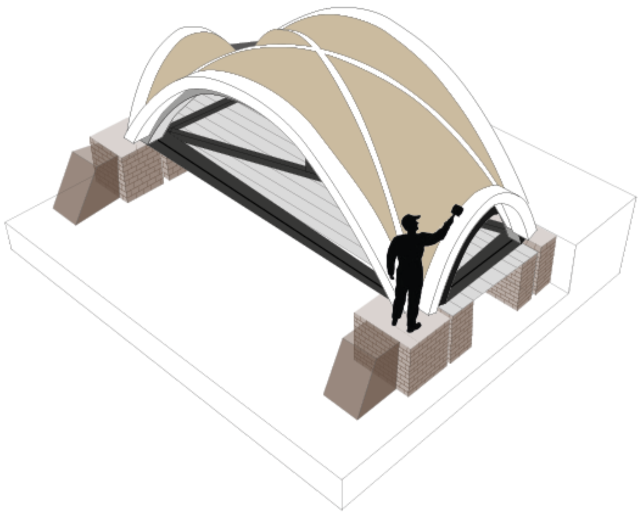


Phase 5a: Placing the inflatable mould
To create a support and guideline for bricklaying the rib arches

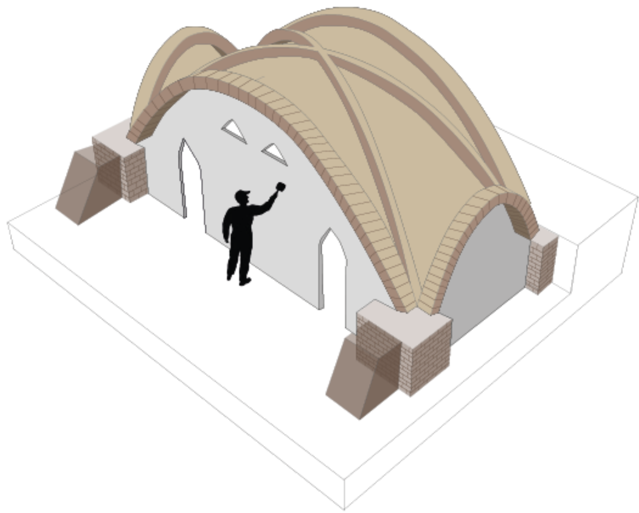


Phase 6: Bricklaying the arches
With a inflatable mould placed on scaffolding as support and guideline.

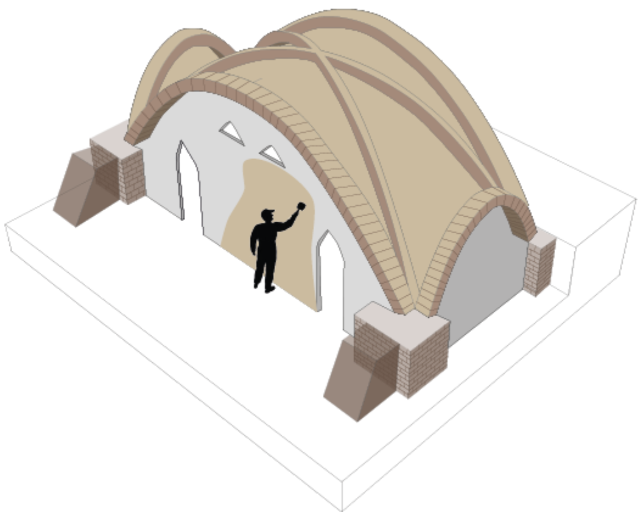
Construction phases



Phase 7: Bricklaying the fills between arches
With a inflatable mould as support and guideline.

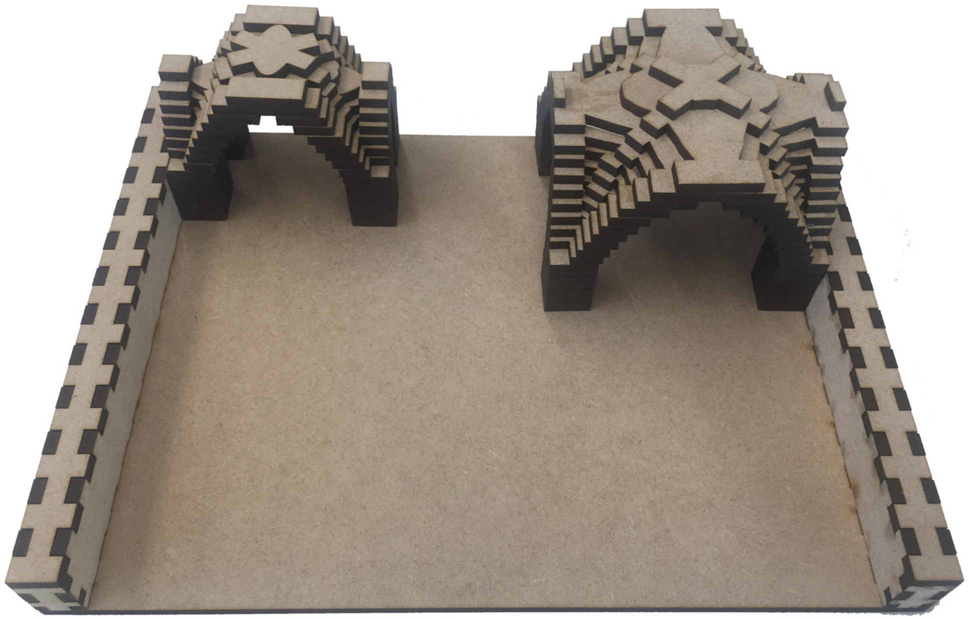


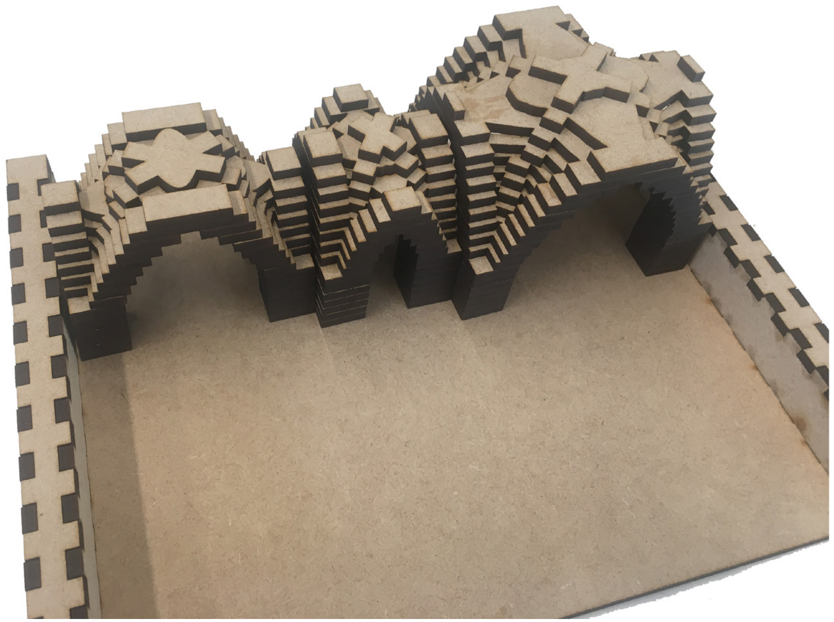
Phase 8: Bricklaying the walls and windows
Walls are not structural required for the the rib vaults.
Opening with cardboard support

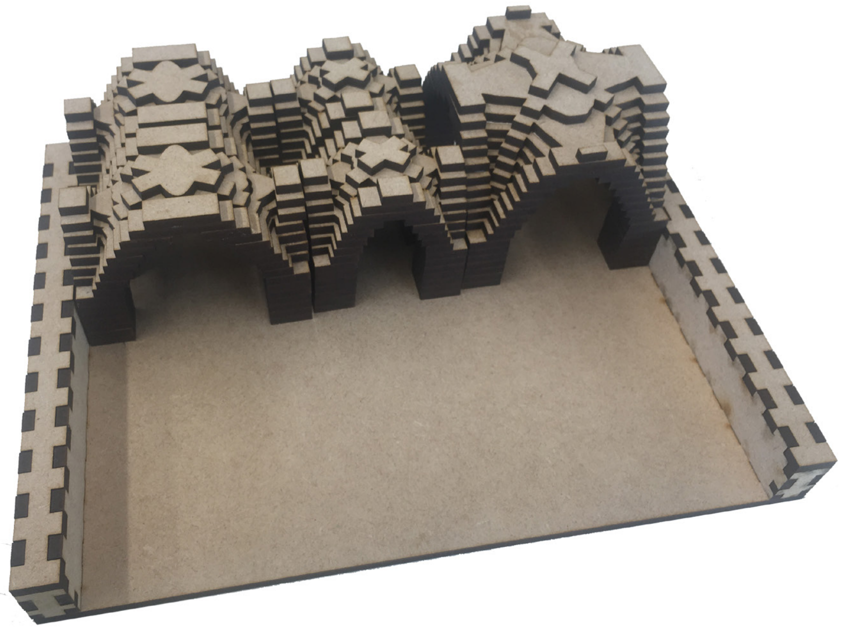


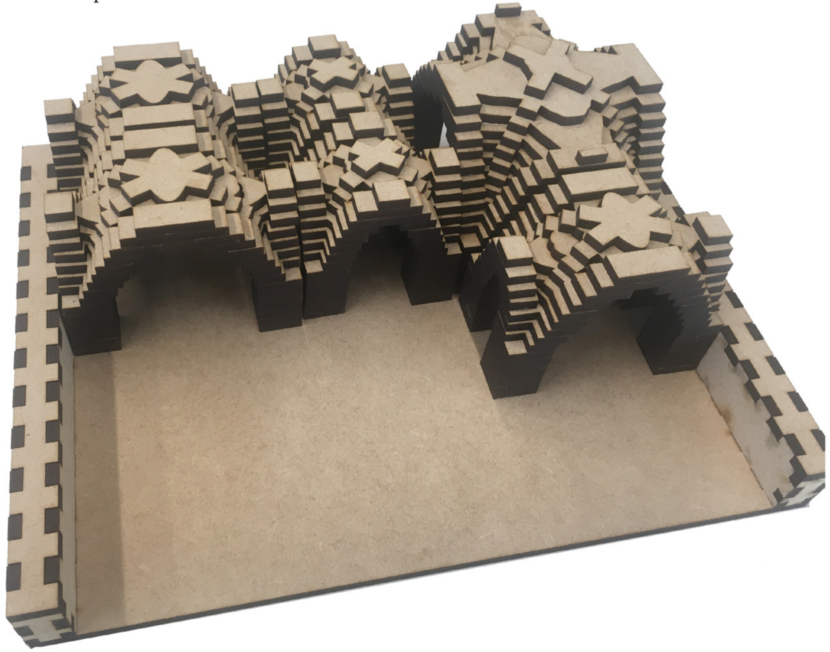
Phase 9: Coating the outside of the walls and structure
To waterproof the building

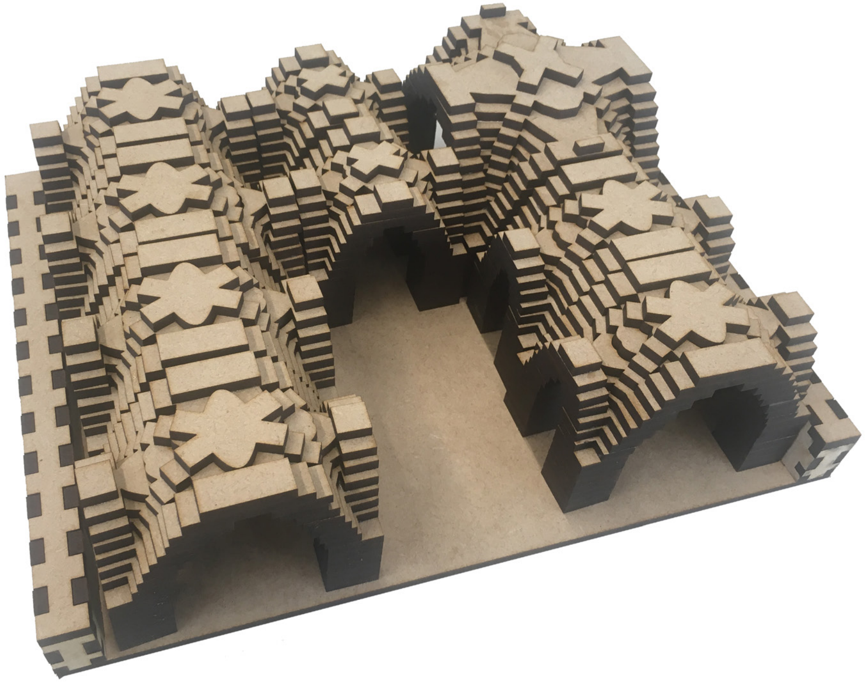
Physical model - Puzzle of the shops

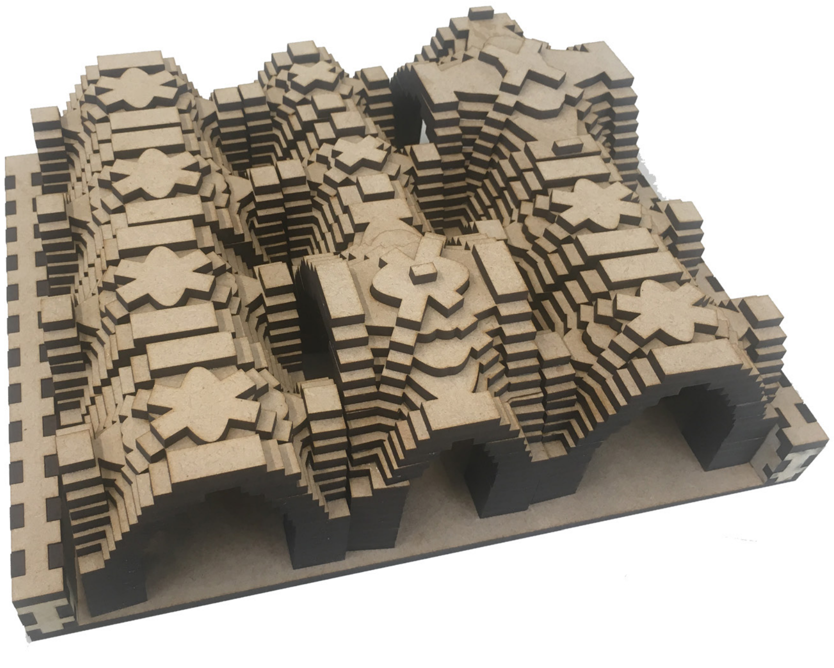




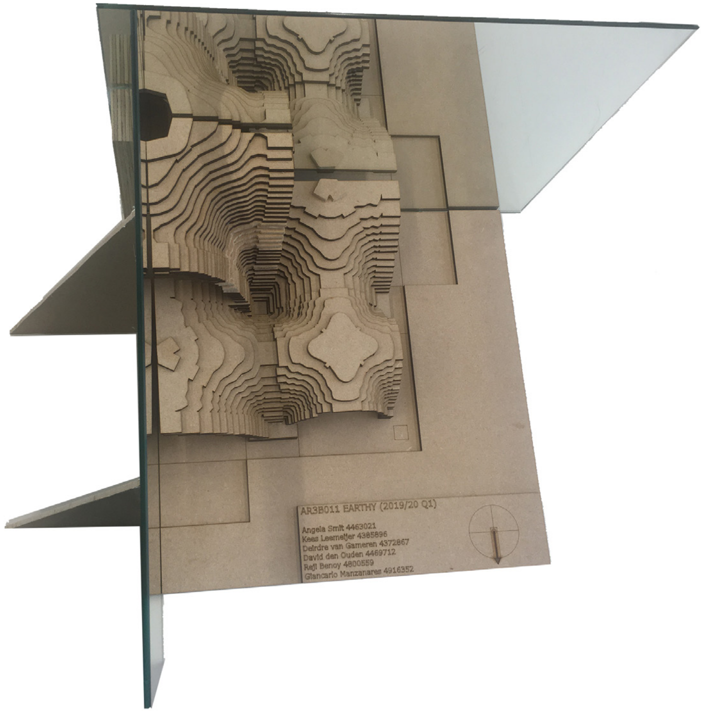


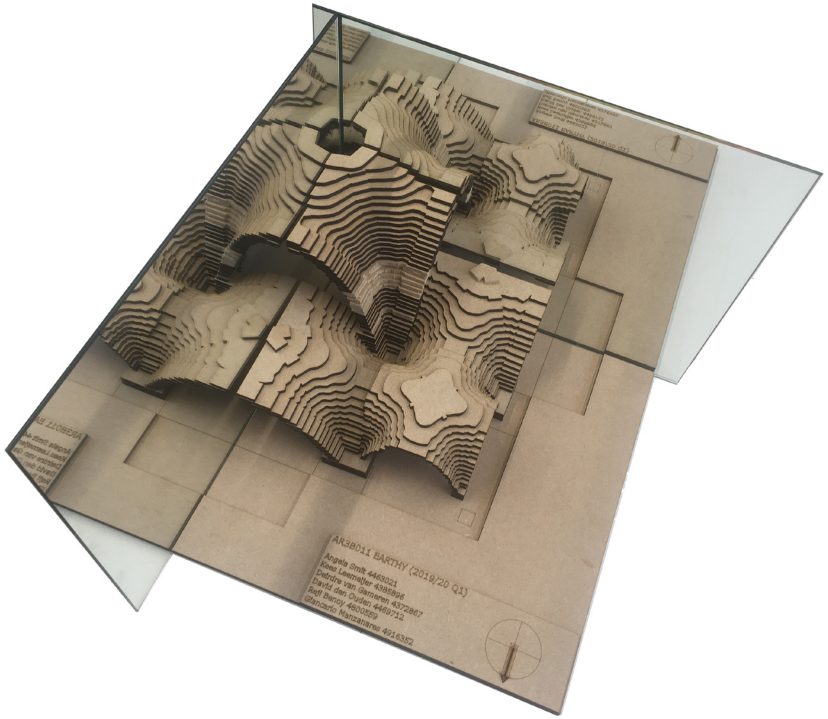


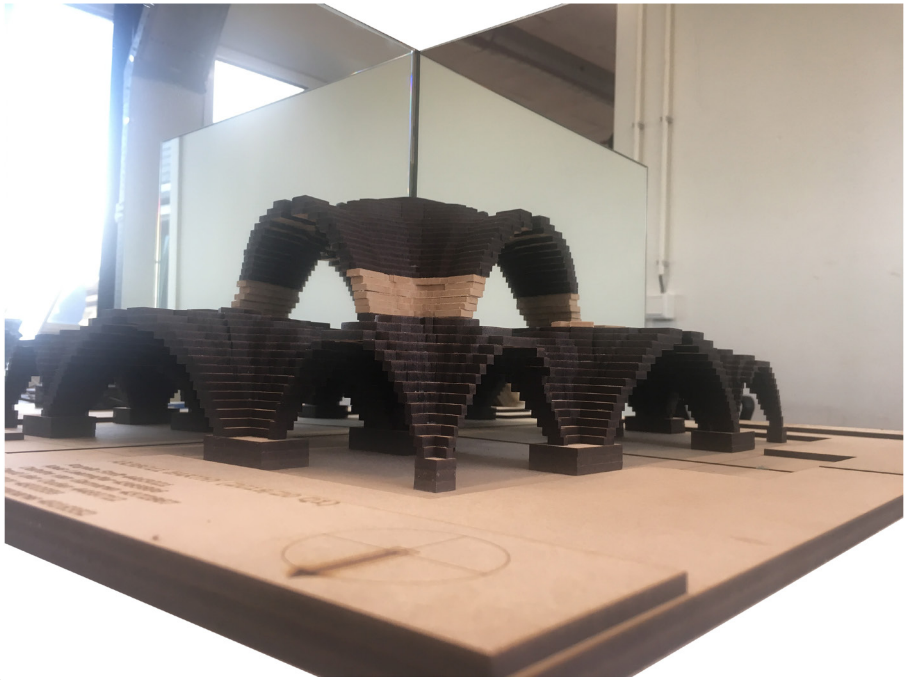


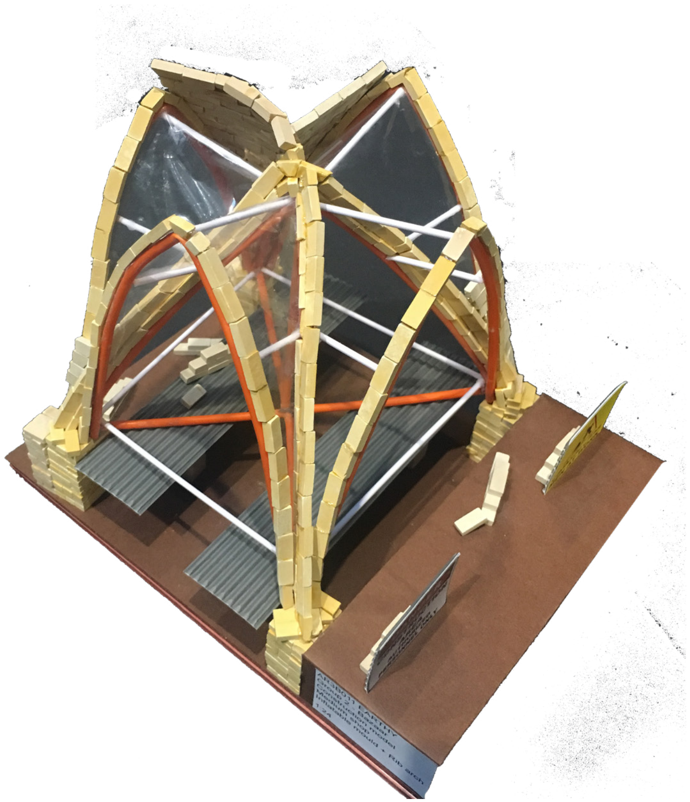


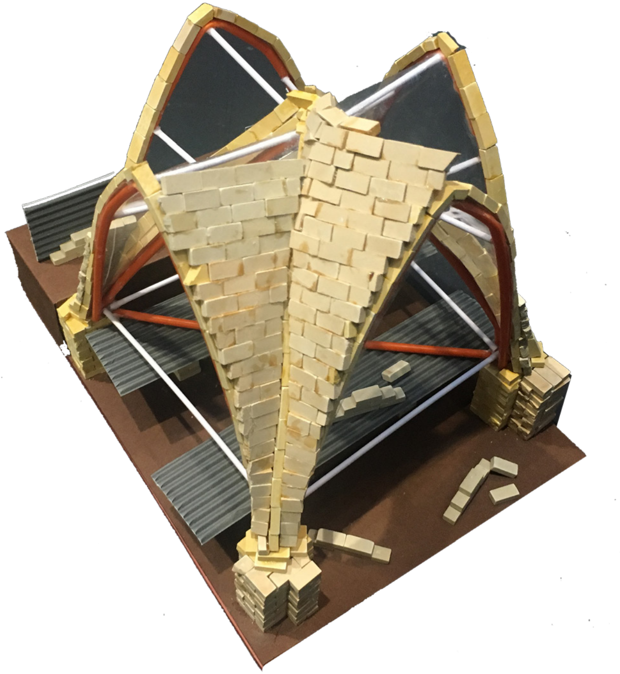
Physical model - Mirror model of the junction

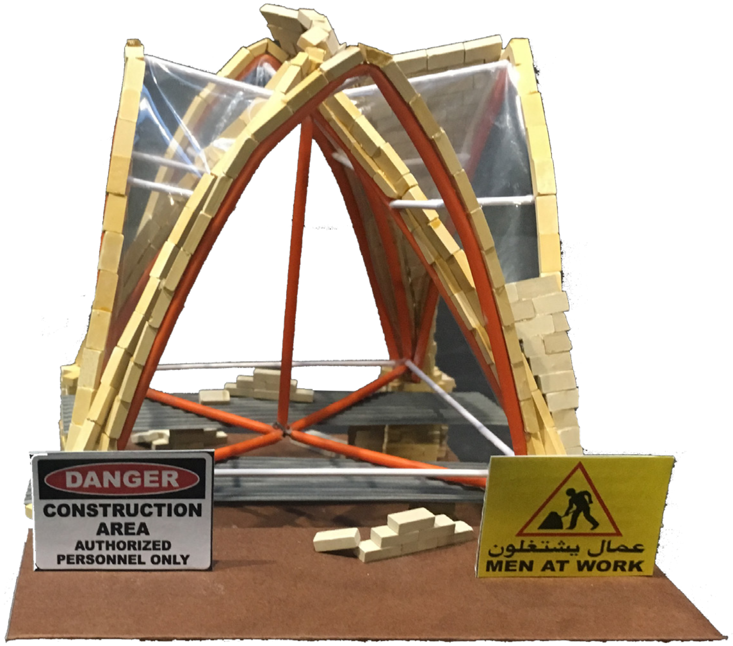












Physical model - Construction with inflatable mould

Conclusions

To conclude this project, we had a goal to create a modular system for all refugee camps as residents of these camps stay here for years. An urban building, a bazaar, is chosen to develop as a modular system as this an element what grows through the years based on the needs of the users. Therefore, five potential starting nodes based on the points of interest is introduced to create a social controlled area around the bazaar. Next, this starting node is a junction where the bazaar starts. Every potential shop owner can enter his requirements in the app to understand the potential locations of his shop in the bazaar. There are guidelines in the script of the app to give everybody the most optimal location in the bazaar. However, the wishes of the potential shop owner can always overrule these guidelines.

The junction contains three different domes as the shops have the same sizes, walkway can differ from the shop size and the main dome which is located in the middle. For the street, which will be dug in, three different shop sizes including a potential housing location on the biggest store are structurally analysed and meet all structural requirements. This also includes optional roofing for the walkway.

These structures can be constructed thanks to an inflatable mould. As this is a modular system, nine inflatable moulds are required to make an unlimited bazaar. This mould is owned by Unicef and local constructors are trained to use this mould. This mould can be reused many times, even in other refugee camps in the world. It is compact to transport and easy to use as support and guideline during construction.

Reflection

In the beginning of the project we decided to make a modular system instead of a design for camp Zaatari. Due to the fact that we did not have one fixed scenario we had some difficulties in the beginning of the project with configuring. We did not have a fixed programme/ plan to fall back on what left us with a lot of possibilities. Due to this, we spent more time than scheduled on this part until we found out how to approach a modular system, with the help of guidelines (not rules). To keep on track, we started with three self made scenarios of a bazaar and used this for the forming. However, simultaneously we worked on a script to show the modular method of how the bazaar can grow in every camp. Due to the wish of this modular method we had to create a design that is structurally independent in every step and can be changed to the wishes of the future owners, a puzzle.

For form finding, modeling the topology with variable spring stiffness could have led to an easier and more accurate translation to the final rib vault. Considering the time of the project (8 weeks) and the knowledge where we started with as a group we could not implement this within our design. Trying to explore the possibilities with variable spring stiffness would be a great starting point if we had the same assignment with the knowledge we have now. Resulting in a better relationship between the generated mesh and the eventual construction.

For structural, it was very difficult to implement a brick pattern in a double curved surface. Even with the advice of approach from the tutors, it was still impossible to implement this in the project in the available time. This is a part should be included for not only structural, but also architectural reasons. With rendering the models, the actual picture of the design is shown and can be way different than expected.

For the connection between junction and street, we did these two separately in this project. Form finding and structural analysis is performed with the same script, however, the final results were different. Therefore, the connection between the junction and street had to be performed manually. For the future, this should be included in an early phase of the project to avoid these issues.

For construction, the goal was really to have a new approach than the original way of building a dome with adobe. Therefore, we came up with an inflatable mould. All our research is based on small physical models, case studies and literature. However, we did not calculate the type of fabric and other properties of the mould. On this part, we really wanted to perform more research. However, due to time limitations we did not include it.

The focus of construction was mainly on the modular system of the street as this has to be repeated many times. For constructing the domes, the same principles can be applied. However, the scaffolding required a different system due to the height.

For the brick size, at the moment it is based on the weight of a brick as the builders still need to be able to lift it. Also, it is based on mentioned sizes in literature. For the future, this can be studied to understand the best size of a brick for the arches and other locations.

In general, we do believe communication was something that could be improved in the group as there were many misalignments through the weeks. Next to this, consults with the tutors was also intensive and not always beneficial for the project as it only made it more confusing. The confusion also caused a lot of time lost which could have been spent better. The consults could have been made more efficient if all the tutors focused one group at a time, or at least more than one tutor, since a lot of time was wasted in repeating explanations more than once on the consult days.

Figure 46: Different bonds in curved situation. (own picture)

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Appendix A: Context research

Climate conditions and Soil
The climate can be defined based on the Köppen Climate Classification System (Scijinks, n.d.). This is based on the annual averages of temperature over a period of time, 30 years or more. The tilt of the earth and the sun's radiations determines the climate. There are five major climate types.

A – Tropical. This is a hot and humid zone, with an average temperature higher than 18 degrees over the year and more than ~1500mm rain.
B – Dry. This is a dry zone where the moisture in the air is soon evaporated, with almost no rain during the year.
C – Temperate. This zone has warm and humid summers and mild winters with thunderstorms.
D – Continental. This zone has cold winters and warm to cool summers.
E – Polar. This zone has cold summers and winters. The temperature does not go higher than 10 degrees.

The Zataari camp is located in the Middle East in Jordan. When following the Köppen climate Classification System, Jordan has a type BSh climate. This is a 'hot semi-arid' climate, which means that there are long hot and dry summers and short warm to cool winters. Jordan lies in between the Arabian desert and the subtropical humidity of the eastern Mediterranean area. Temperatures vary in summer between 20-32 degrees with some hot days of more than 40 degrees, see figure 1. Due to the Shirocco, a hot and dry south wind, sandstorms occur. In winter, the average temperature is around 13 degrees. The rain season is between November and March around 60mm and almost nothing between June and August see figure 1. When it rains it is often concentrated in storms, causing flooding.

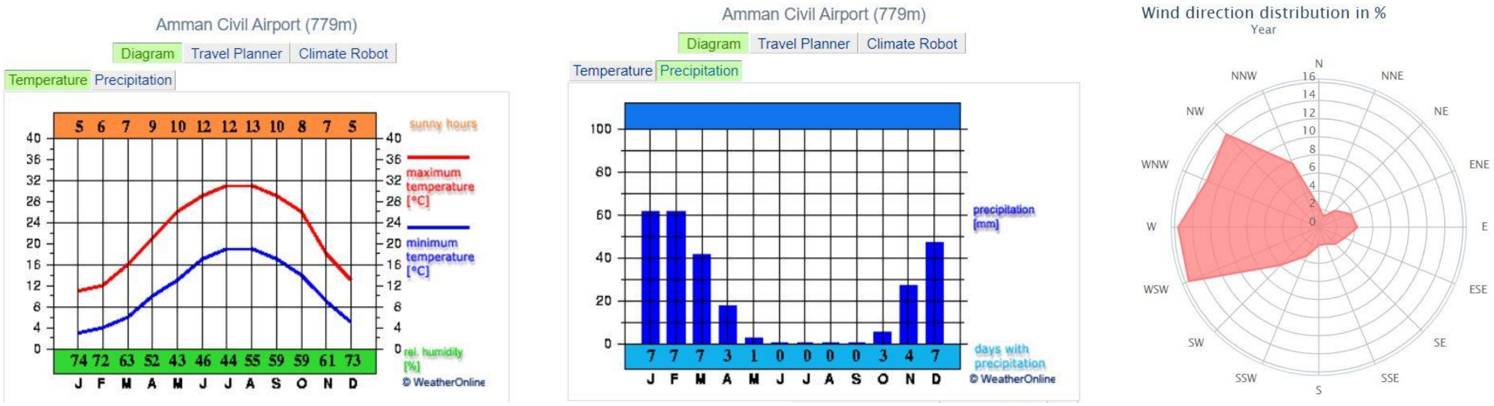

Figure 1: Temperature, rain and wind in North-Jordan. Retrieved from Weather Online (n.d.)

The average wind direction is West, see figure 2. In figure 3, the wind direction and wind speed can be seen for every month. The average wind speeds is 9kts. The wind speed slightly increases in summer what can cause a sandstorm.

Month of year	Jan 01	Feb 02	Mar 03	Apr 04	May 05	Jun 06	Jul 07	Aug 08	Sep 09	Oct 10	Nov 11	Dec 12	Year 1-12
Dominant wind direction													
Wind probability >= 4 Beaufort (%)	21	20	26	25	27	31	29	23	14	10	9	14	**20**
Average Wind speed (kts)	9	9	9	9	9	10	10	9	8	7	7	7	**8**

Figure 2: Wind direction Jordan per month. Retrieved from windfinder, n.d.)

Soil study

Zaatari camp is 600m above sea level and has no issue with groundwater. In the surroundings, only grass surfaces can be found. The composition of the soil at the Zaatari camp is shown in figure 4. Depending on the ratio of the clay, sand and silt, the depth can be determined. Silt consists mostly Orthents (old landforms) and haplic Cambisols (fertile soil). Next to this, rocks are required for the foundation and first 50cm height of the bazaar. This can be found at 2m depth (Soilgrids, n.d.). The maps of there the most concentrated clay, sand or silt is located are shown in figure 5 - 10.

Property	Value
Depth to bedrock (R horizon) up to 175 cm (BDRICM)	200 cm
Predicted probability of occurence (0-100%) of R horizon (BDRLOG)	12%
Absolute depth to bedrock (BDTICM)	948 cm
Drainage classes, based on FAO guidelines (DRAINFAO)	*<NA>*

Figure 5: Bedrock in depth. Retrieved from Soilgrids (n.d.)

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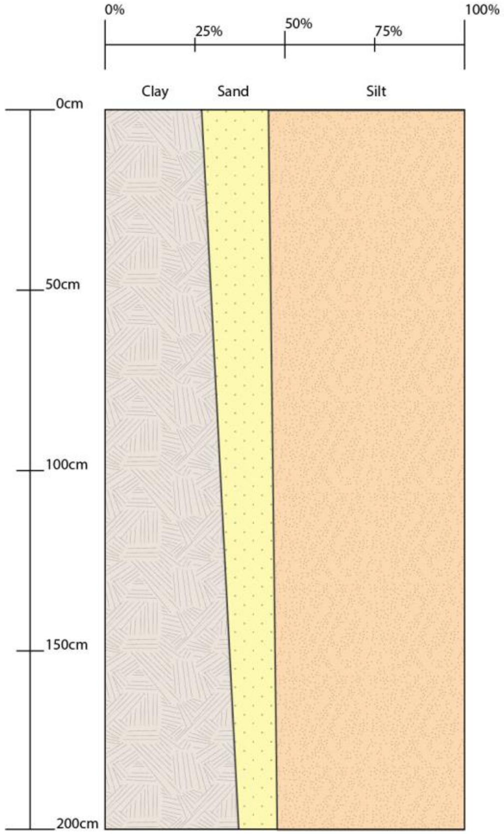


Figure 4: Composition of soil in percentage and depth. Information retrieved from Soilgrids (n.d.)

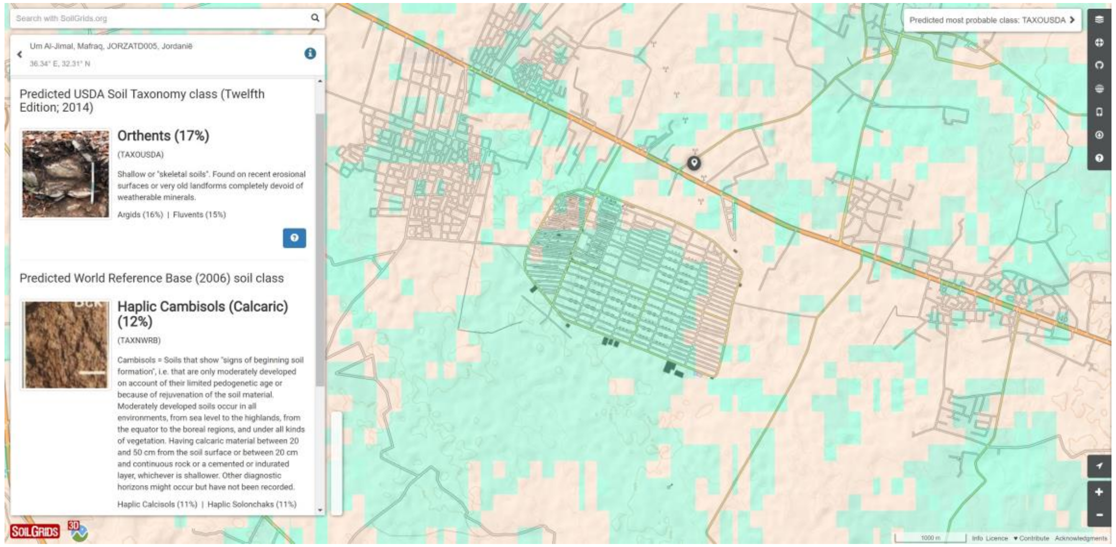


Figure 6: Type of soil. Retrieved from Soilgrids (n.d.)

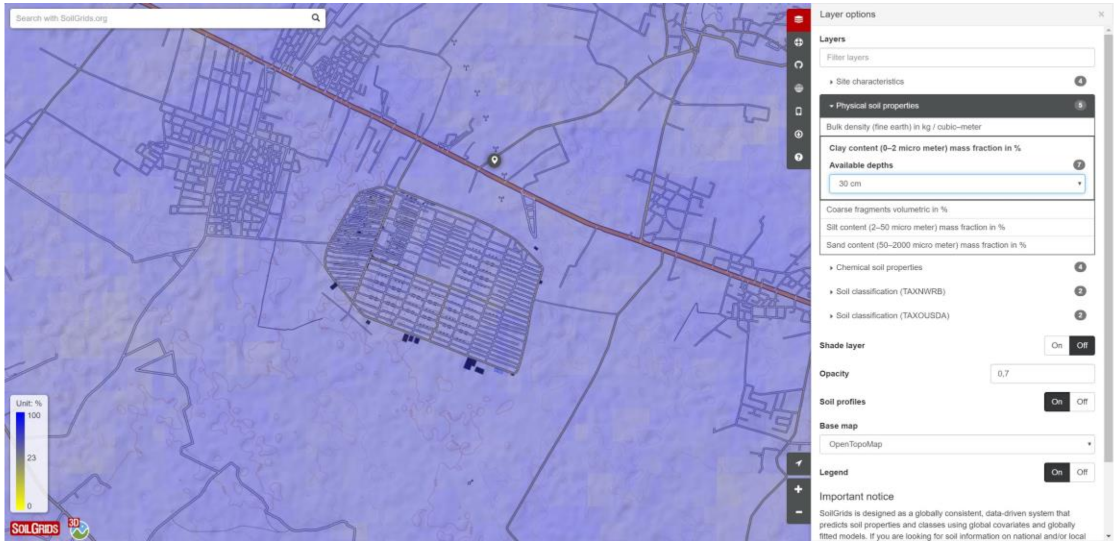


Figure 7: Clay probability at 30cm depth. Retrieved from Soilgrids (n.d.)

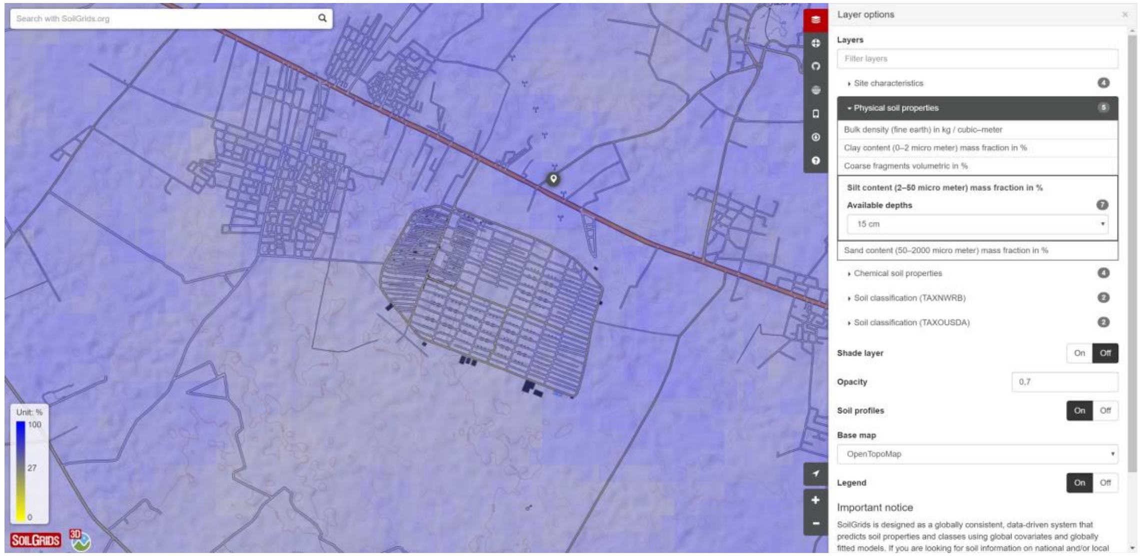


Figure 8: Silt probability at 15cm depth. Retrieved from Soilgrids (n.d.)

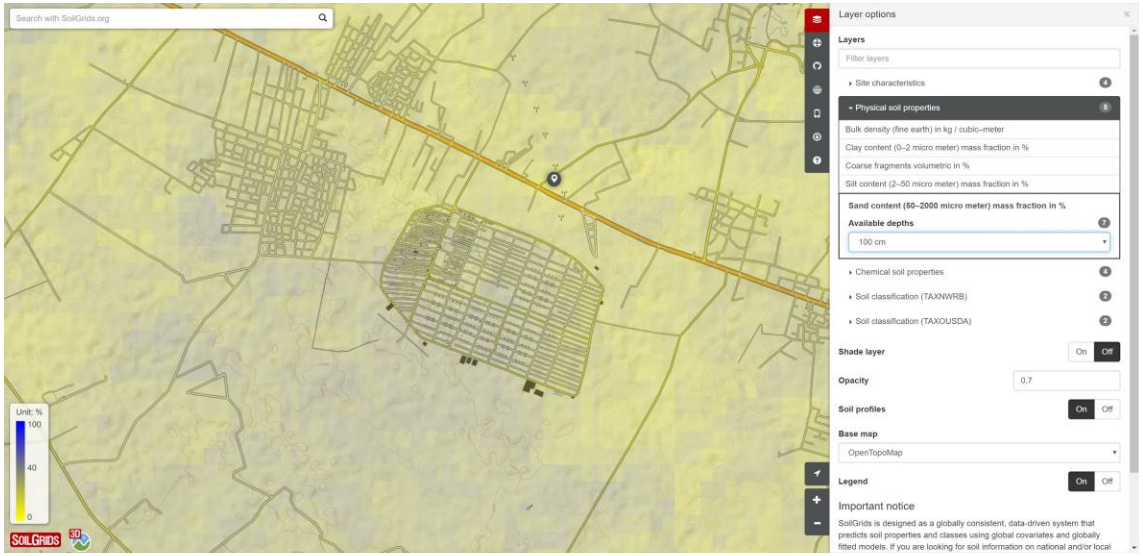


Figure 9: Sand probability at 100cm depth. Retrieved from Soilgrids (n.d.)

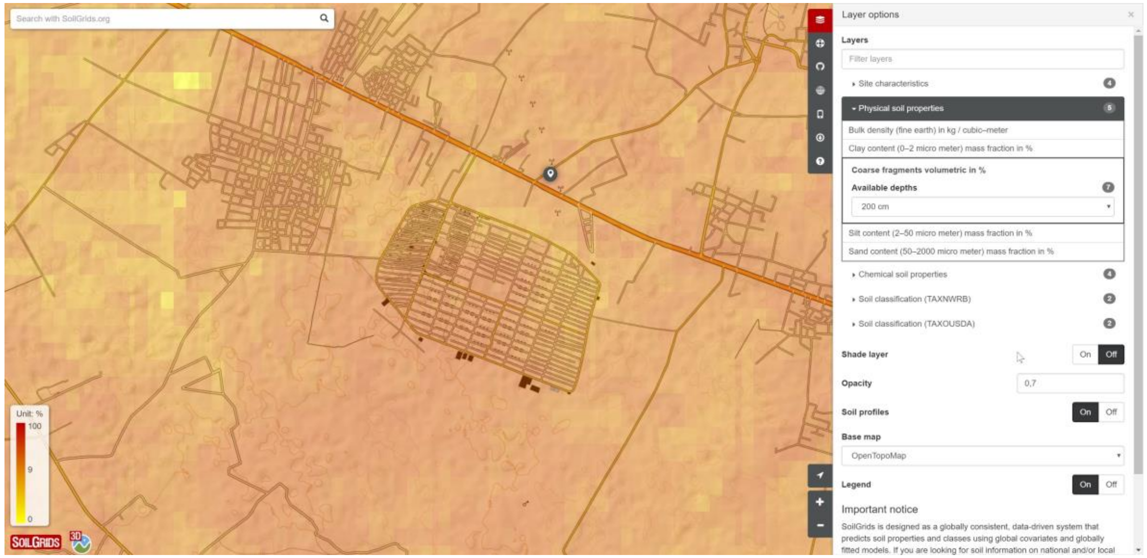


Figure 10: Clay probability at 200cm depth. Retrieved from Soilgrids (n.d.)

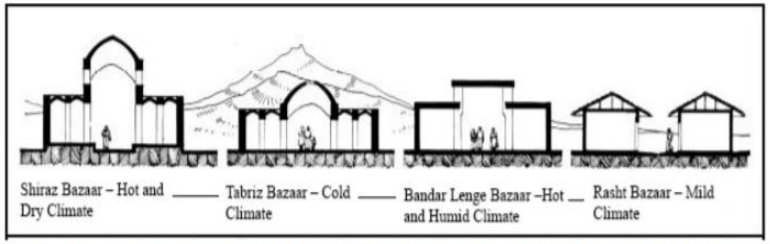


Fig. 1: Bazaar Structure in four Climates of Iran, source: Qobadiyan, V. "A Study on Iran's Traditional Monuments"

Appendix B: Architecture bazaar research

Analysis of Traditional Bazaars

Architecture and structures are rarely separated in Persian Architecture. They are built to be viewed in relation to each other (Pope, 1965). In the past, bazaars were built and maintained by the government, by public-spirited donors, or by the merchants themselves. One of the most beautiful bazaars is built in the beginning of the seventeenth century by Shah Abbas, the Qaysariya of Isfahan (figure 1). It has a monumental portal that opens on the maydan, faced with mosaic faience (Pope, 1965).

Figure 1: Qaysariya of Isfahan. Retrieved from Mehrnews (2017)

Functions in a bazaar

A bazaar is a place where multiple functions are clustered (figure 2). It is not only a place where people can buy their food and other products, but also a place to meet. In a bazaar four elements can always be found; Rasteh, Caesarea, Chaharsough and Timchech. **Rasteh** is the main element of the bazaar. There are major and minor rastehs (lanes) stretching from the gateway into the city covering several sections of the bazaar until it's arrival at the city's main square. There are stores located across both sides a rasteh. This can be (food) shops with sometimes factories at the back. The **Caesarea** is similar as the Rasteh. However, the Caesarea is for the sale of precious and delicate goods such as jewelry, silk, etc. These shops could also have a small factory at the back. When two main Rastehs intersect a junction is created, this is called the **Chaharsough**. Chaharsoughs are covered with tall domes hosting the daily presence of jarchis, nightly meetings of the sheriffs and sometimes punishing the criminals. It is a meeting space with a water fountain in the middle covered by a dome. A **Timcheh** can also be found in a bazaar. This is a small caravansary, an indoor space with chambers for tradesmen, usually built in two or three floors. This space was often covered with domes and special decorations. These days it is used for furniture sell and small factories as furniture and carpet sellers.

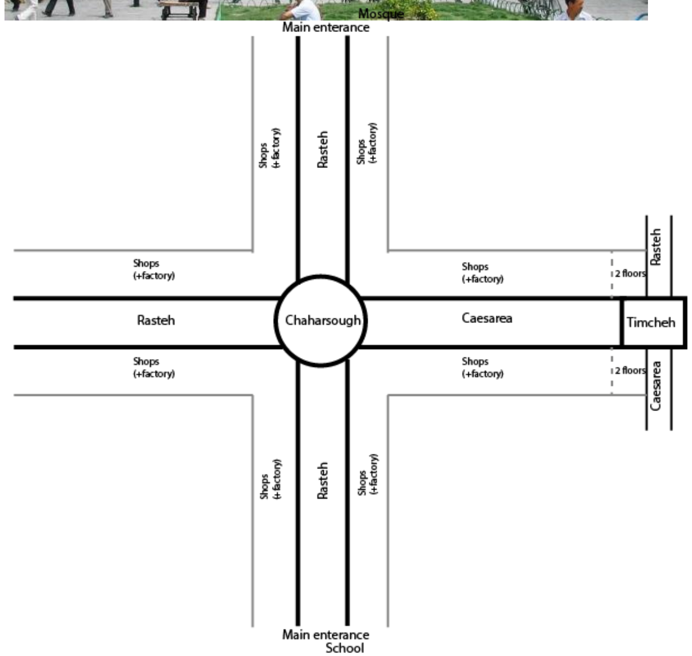


Figure 2: Layout of a bazaar.

Rastehs ____________________________ Caesarea______ Chaharsough__________ Timchech

Figure 3: Indication of architecture in a bazaar. Retrieved from unknown authors (n.d.)

Most bazaar are 24/7 open and the main entrance is at a mosque. Around the entrance of the bazaar pop-up shops appear (season related). Different types of shops and workshops can be found as Jewellers & pottery stores, Furniture & Carpets stores, Leather & Clothes stores, Tea & Herbs and of course restaurants. These restaurants and tea houses can be found in community space such as the Chaharsough (junction).

The following guidelines will be used for the program of the bazaar:

Chaharsough (junction):

- Water points/ faucets
- Community place
  - Tea houses/ restaurants
  - Events

Rasteh (road):

- Typology of stores are together
- More inside the bazaar food will be sold due to temperature difference. This is only applicable when the bazaar is bigger than the junction and a begin of the rasteh.

Rasteh/ Caesarea (road):

- Fabric/ silk are orientated near the carpet/ furniture
- Jewels and pottery are orientated near the fabric/silk

Timcheh (small square mostly multi level):

- Furniture/ carpets
- Big objects are sold

Analysis of Traditional Architecture

Iranian / Persian architecture dates back from 5.000BC. The architecture is based on an abundance of symbolic architecture. Pure forms such as circles and squares are used a lot and plans are often symmetrical with rectangular halls and courtyards, see figure 3.

Openings, arches and associated elements

There are two types of openings, doors and windows and arches. In Persian architecture, the openings on the outside of the façade are small. On the inner façade the openings are bigger, these openings overlook the courtyard. This is done for privacy and environmental reasons. In earth architecture the openings should be small, the largest opening that can be made is 1.9 x 0.9m (CORPUS Levant, 2004). Very small openings are used for ventilation, these differ from 20 to 40cm wide and 40cm high. A lintel is used above the openings, this can be straight or arched (CORPUS Levant, 2004).

Arches

Arches are frequently used in Persian architecture. They are often seen as entrances and passages in important and religious buildings. Arches can also be found in houses e,g, for the iwan. Arches can be used to overcome shorter spans (CORPUS Levant, 2004).

Vaults

Vaults are used for covering long halls and passages. Vaults are coming in the traditional architecture of souks. There are several types of vaults for example, the barrel vault (half cylindrical vaults) and the cross vault (consist of two consecutive crossing and orthographic vaults). Both types of vaults have the same building method and material use (stones)(CORPUS Levant, 2004).

Mud Cupolas

In the countryside of Syria, mud cupolas can be found. These are used in covering spaces of mud construction. The mud is used for rendering and binding (CORPUS Levant, 2004).

Stone Cupolas

Stone cupolas (figure 3) are roofs used in big spaces as, mosques, churches, baths and the bigger houses. These can be found in almost all Syrian cities and villages. These cupolas come in different shapes; semi spherical, onion shaped, ribbed shaped or egg shaped. This is dependent on the dimensions of the covered space and the ratio of the length to the width.

Figure 4: Openings, Arches, vaults, mud cupolas and stone cupolas architecture Syria. Retrieved from CORPUS Levant (2004).

Appendix C: Flow charts

Our overall workflow (figure 1) is structured by the course guidelines. The course guidelines consist of four steps describing the ‘Earthy’ design process. We tried to follow this structure as good as possible. Instead of creating a product we decided to create a method. As similar problems occur within other refugee camps, our solution might also be applicable there. Looking at the design process, this led to the following flowchart structured according to the four course points: Configuring, Forming, Structuring and Constructing. The programs which are used for realizing this project are shown in figure 2.

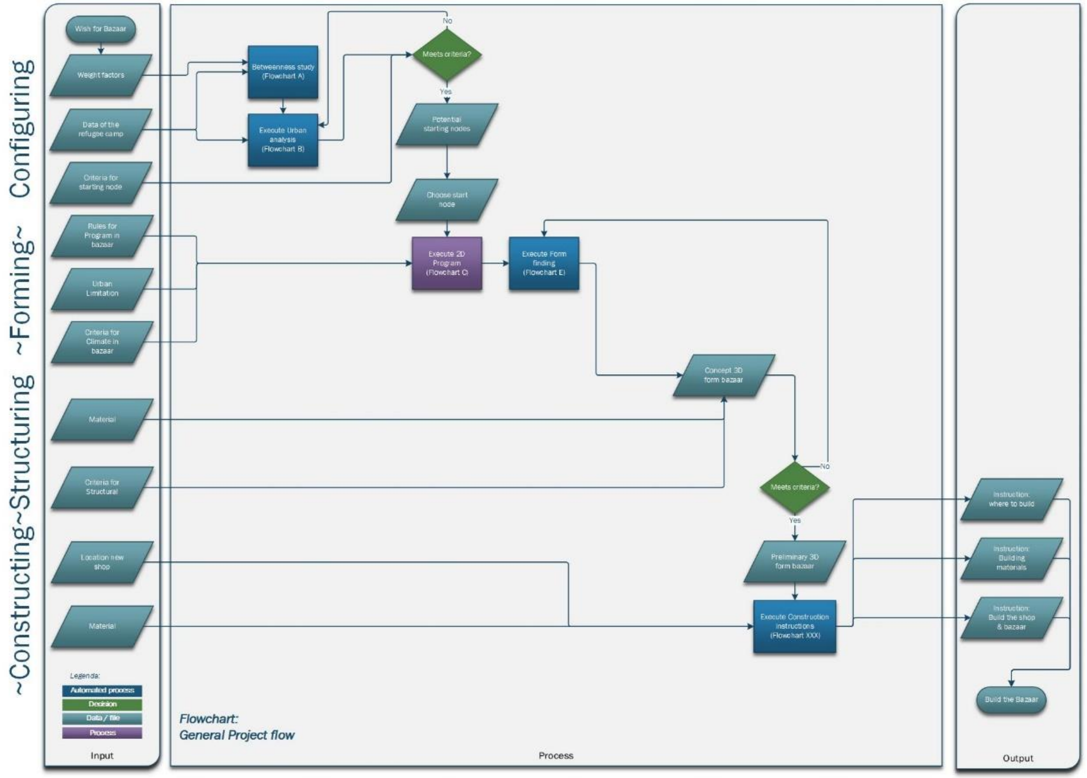


Figure 1: General flowchart.

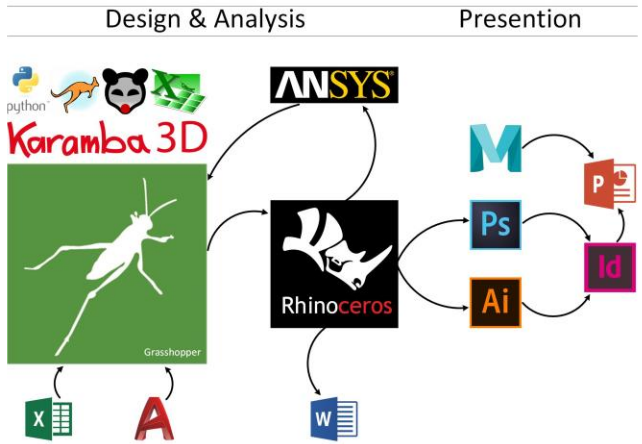


Figure 2: Program flowchart.

Flowchart A: Betweenness study

Flowchart A (figure 3) describes the process of testing other variables that might influence the choice of the location of the Bazaar. Examples are the execution of a closeness centrality study of the bazaars and the population, and testing the created rules to the results of the betweenness centrality study. The resulting locations - in the case of zaatari, 3 - will be hand selected given on the scoring results of the betweenness centrality study, the closeness centrality study and the implicit values estimated by the available urban designers.

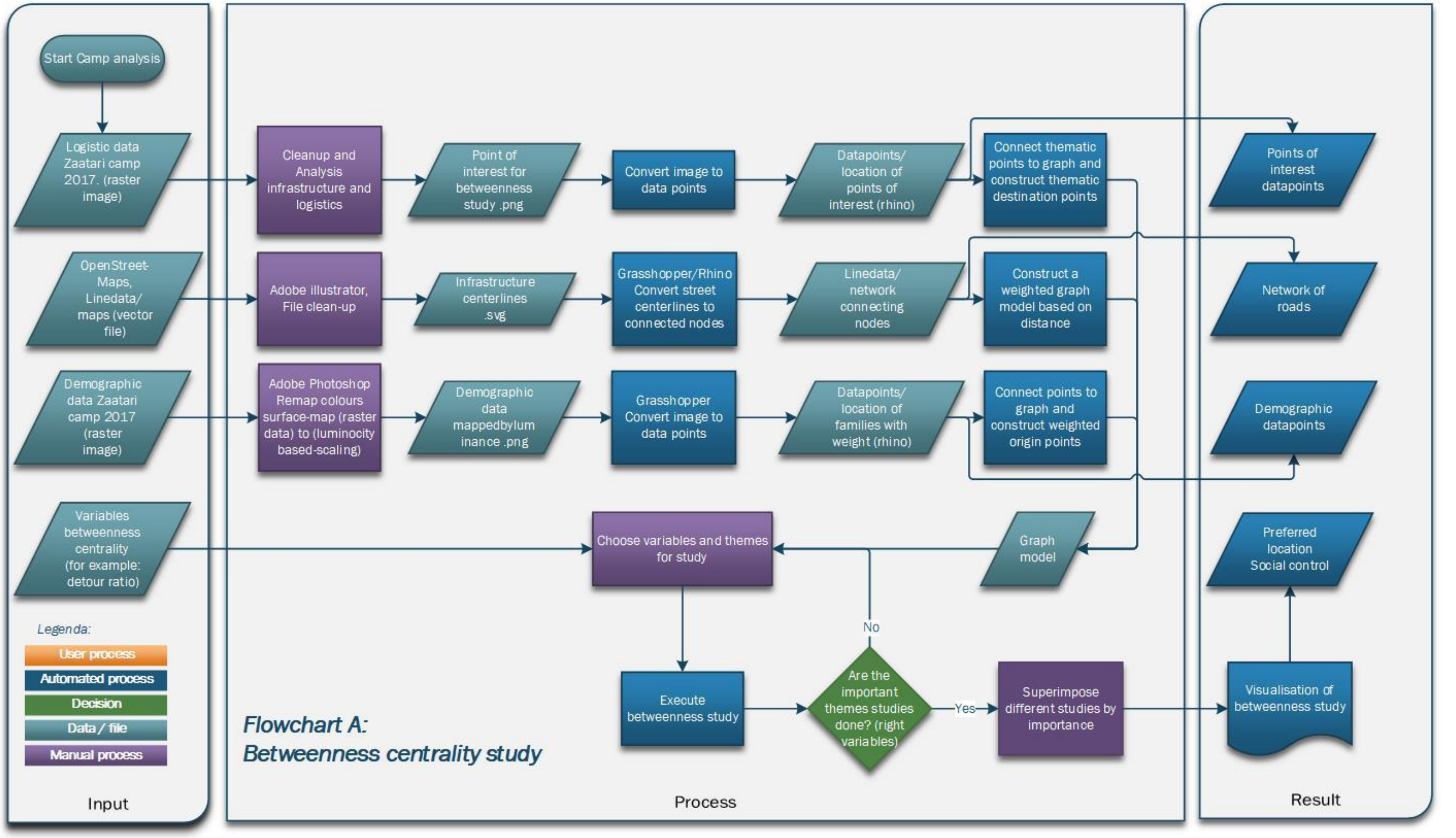


Figure 3: Betweenness study flowchart.

Flowchart B: Urban flowchart

For finding a location we focussed on a methodological approach. If a bazaar showcases to be an effective measure against certain problems in refugee camps it allows to apply the same method to other refugee camps. The data that we used to get to a location is satellite information, demographic information and logistical information map (often available of refugee camps to help aid). For the search of the optimal location the flowchart underneath was created. See figure 4 for the flowchart.

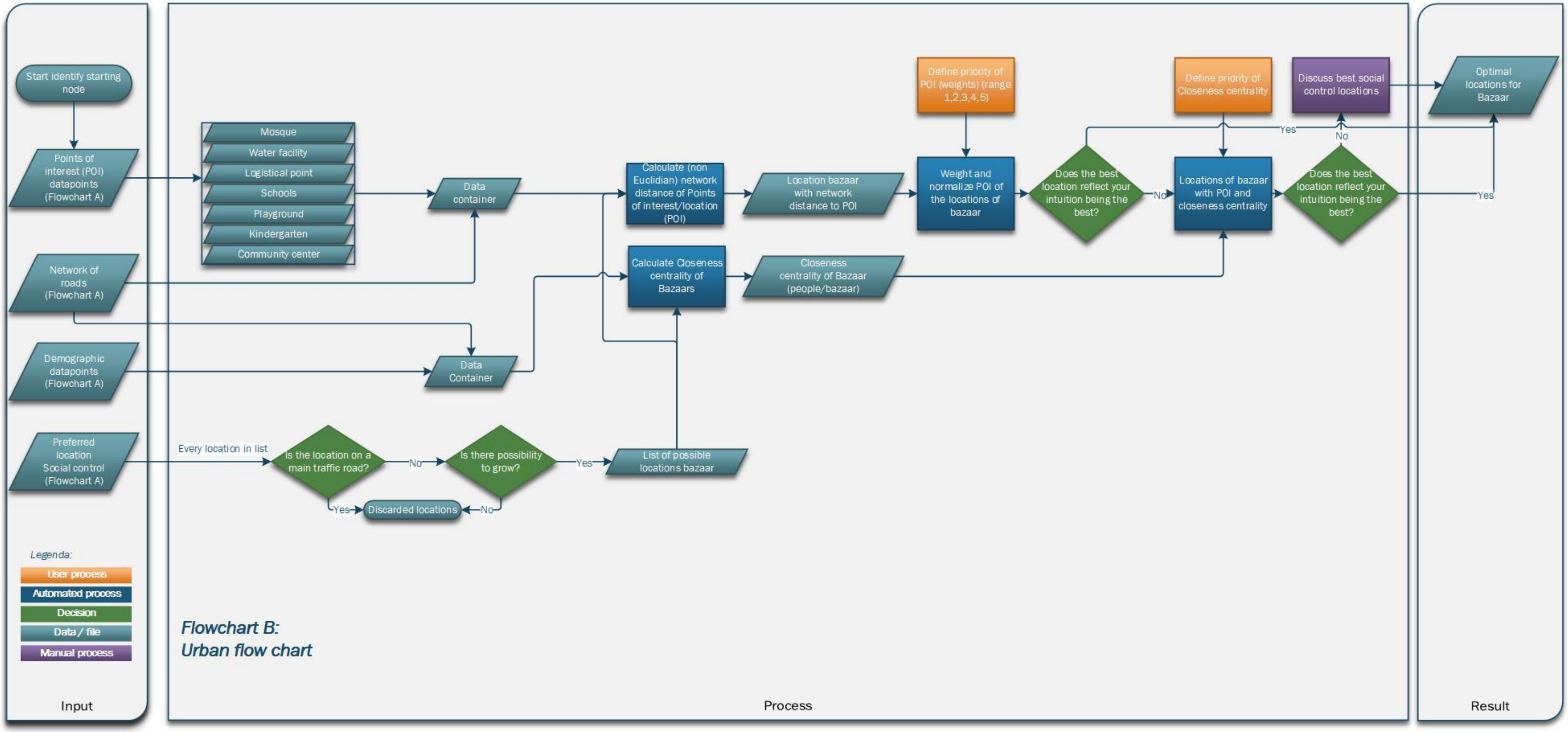


Figure 4: Urban (start junction node) flowchart.

Zaatari Camp
For the Zaatari camp, the following actions are taken. First, the focus is to find the starting point(s) of the bazaar by analysing the flows in the camp through use of the database available (e.g. the streets, houses, attractor points, demographic information). Once the starting point is decided through the output of the flow analysis and a group discussion, the team can move on by shaping the start of the bazaar.
This is important because the initial start of the bazaar should be in line with the vision we have in mind for the bazaar and also it should be attractive for the zaatari refugees. After this, two processes should be going parallel. The first one is the process of structuring the bazaar by doing structural analysis. Meanwhile, the app/program as described in the “Design goals” section, should be developed within grasshopper and python. More details of a process in the flowchart are referenced to another more detailed flowchart.After betweenness centrality study will result in a superimposed map, giving the best solutions (in reference to social control) for a given camp. In Zaatari, this resulted in 5 possible locations.

Flowchart C: 2D Lay-out

When the location - read as starting node - is found we need to better understand the local conditions and situation. Understanding the local urban lay-out, Climatic conditions, see figure 5. This resulted in 2 different aspects.

- Understanding the current situation, Urban climate, 2D layout Corridor and Junction
- Getting the available users within the refugee camp with their wishes.

This resulted in 4 different processes:

- Defining the spaces - based on local user input - and requirements of spaces.
- Understanding the spatial relationship between spaces within a bazaar (functions) and creating a vocabulaire. (excel database of relations).
- Finding optimal locations for stores, based on user input, their vocabulaire and relationships with other stores. (space-syntax/space grammar).
- Translating locations towards an 2D-layout and input for form finding, based on the defined ‘space grammar’.

Showcases the steps taken to understand the local conditions, requirements of thermal mass, boundaries for the bazaar, This also still includes the current manual process of creating a 2D layout.

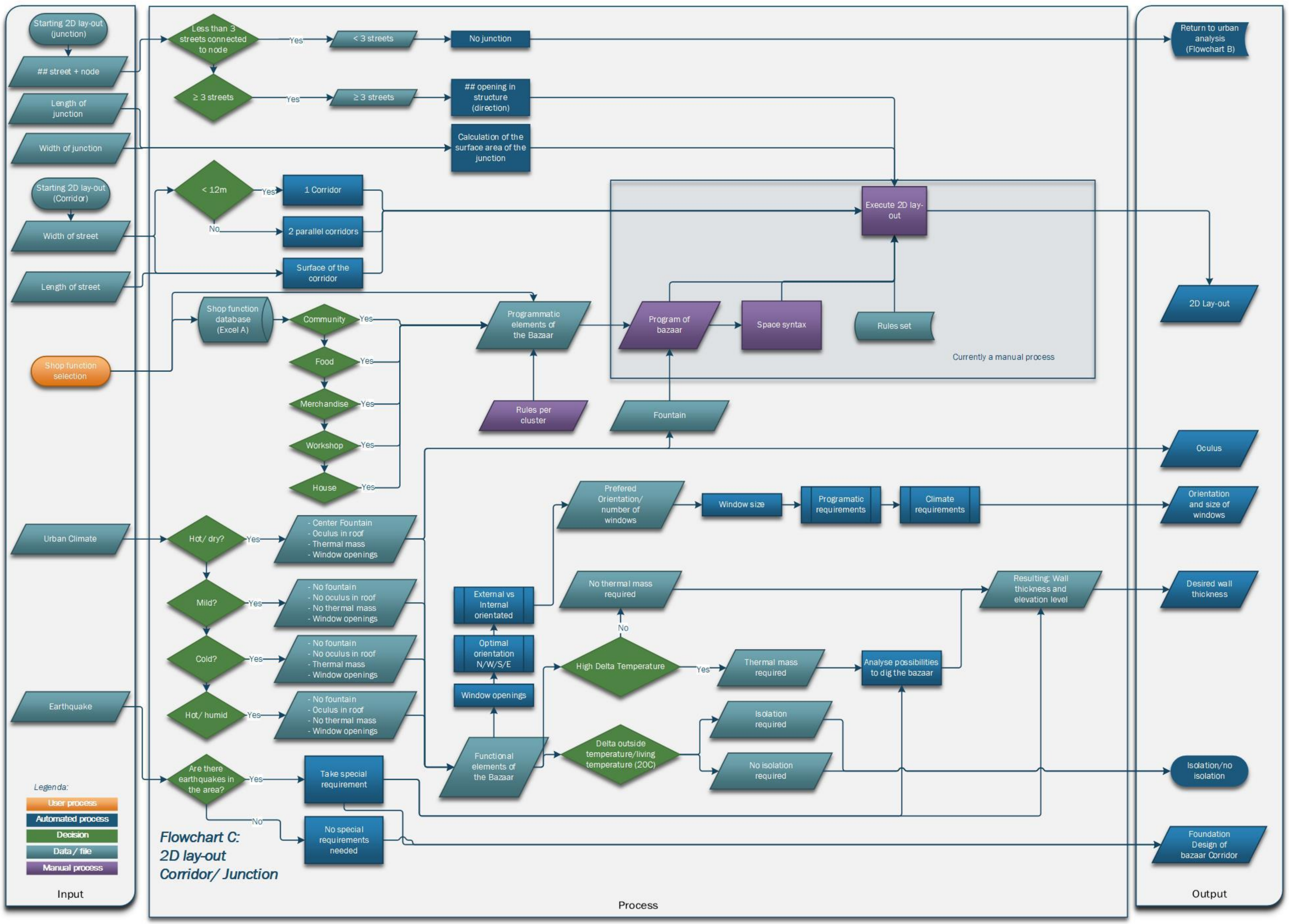


Figure 5: 2D lay-out flowchart.

Flowchart D: Space syntax

This flowchart shows the process of the user perspective. At which, he fills in his preferences and based on that gets added to the database of the bazaar. This is the first step of the automated ‘’space syntax, syntax/grammar, space grammar approach’’ process, see figure 6.

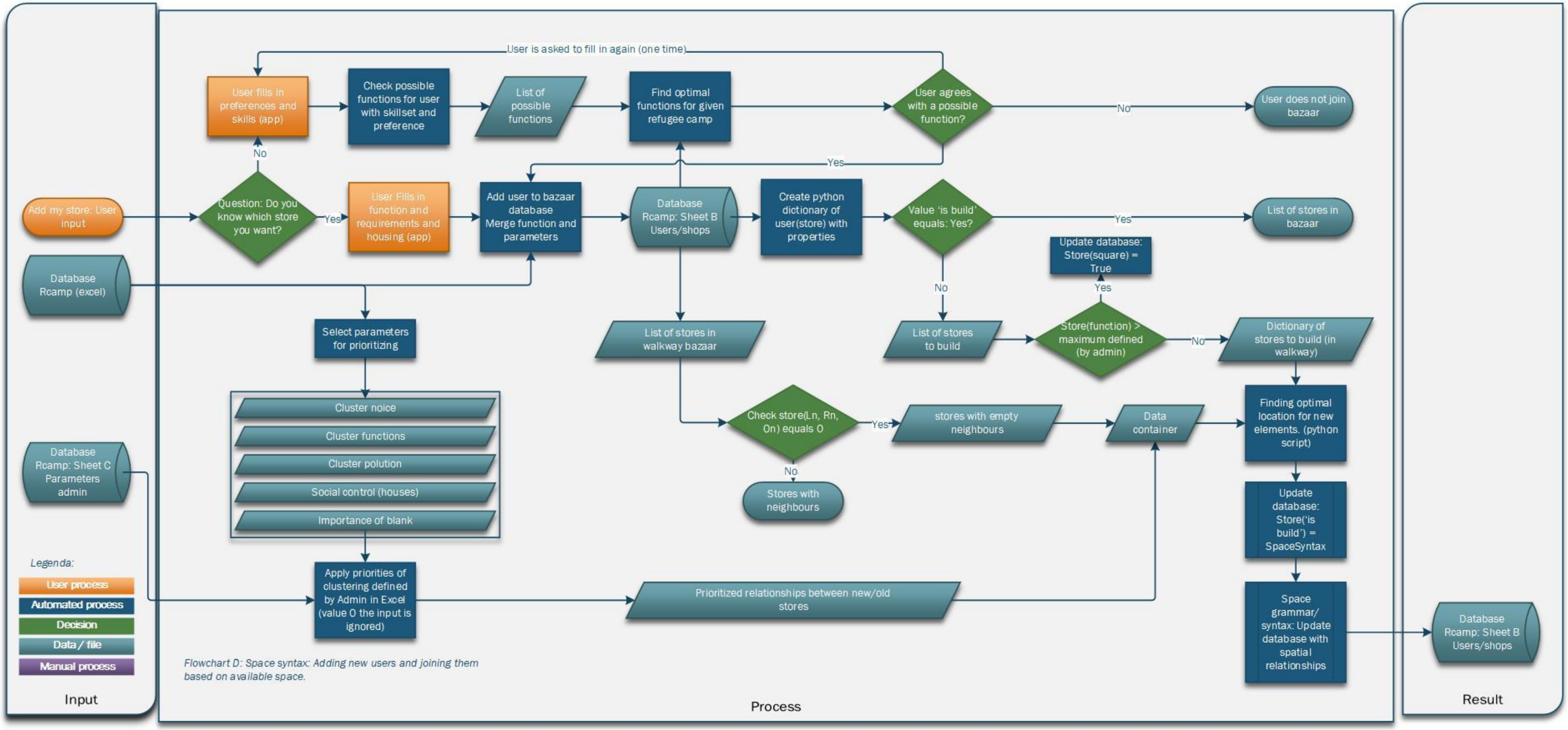


Figure 6: Space syntax flowchart.

Flowchart E: 3D Forming

In this flowchart (figure 7), the process of using the Grasshopper plug-in "Kangaroo" is described. First, the 2D lay-out is tessellated in different elements. This way, the surface can free-form in the most optimal form of gravity as the model should only be under compression.

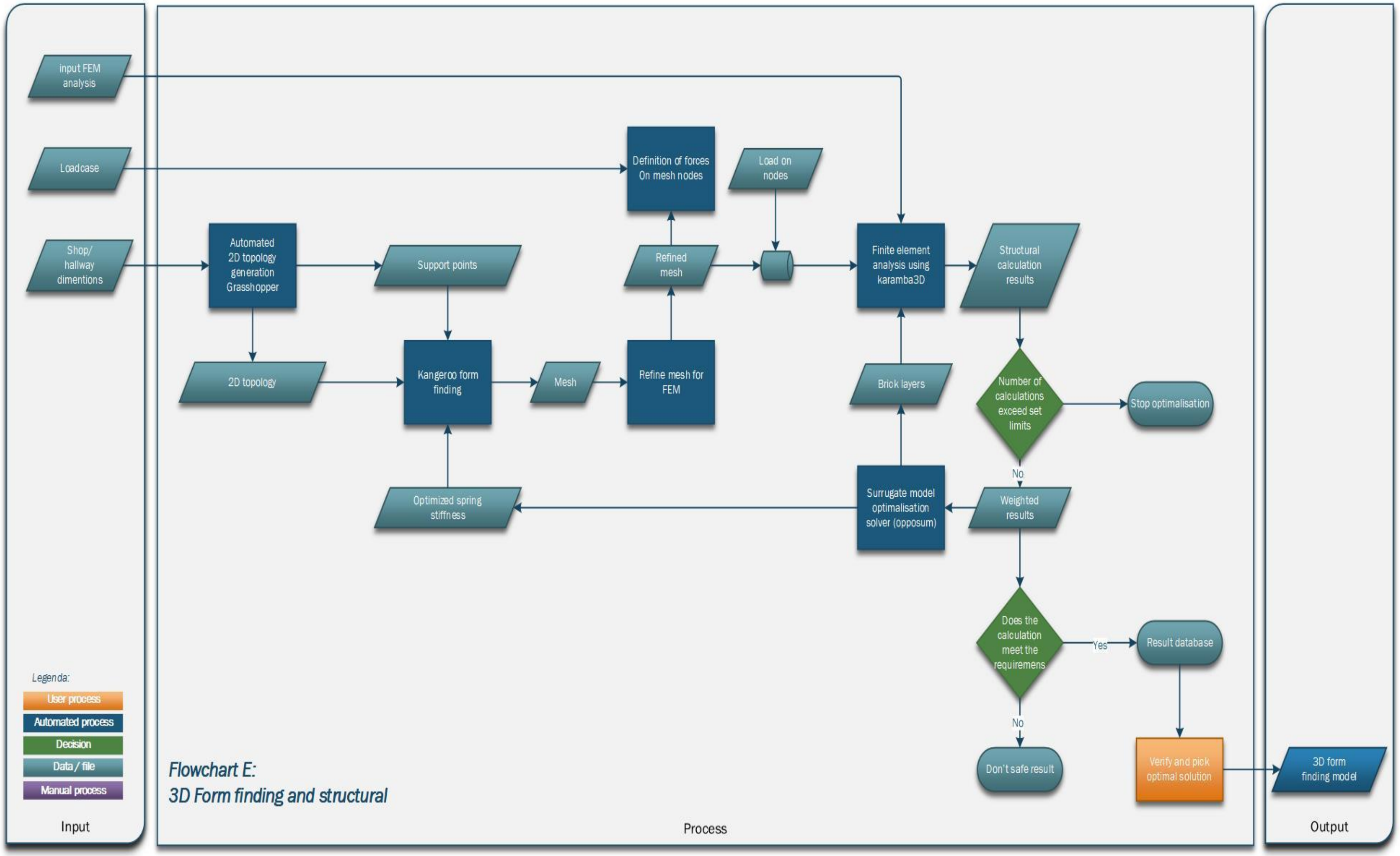


Figure 7: 3D forming flowchart.

Flowchart F: Structural analysis

There are two different ways of structural analysis performed. First, the mesh is analyzed in Karamba (Grasshopper plug-in). When the outcome of this result was according to expectations, the mesh was analyzed in Ansys, FEM program. When the model is approved in this system, the mesh is approved for further usage. If not, the process starts again from the beginning of 3D forming. See figure 8 for the flowchart.

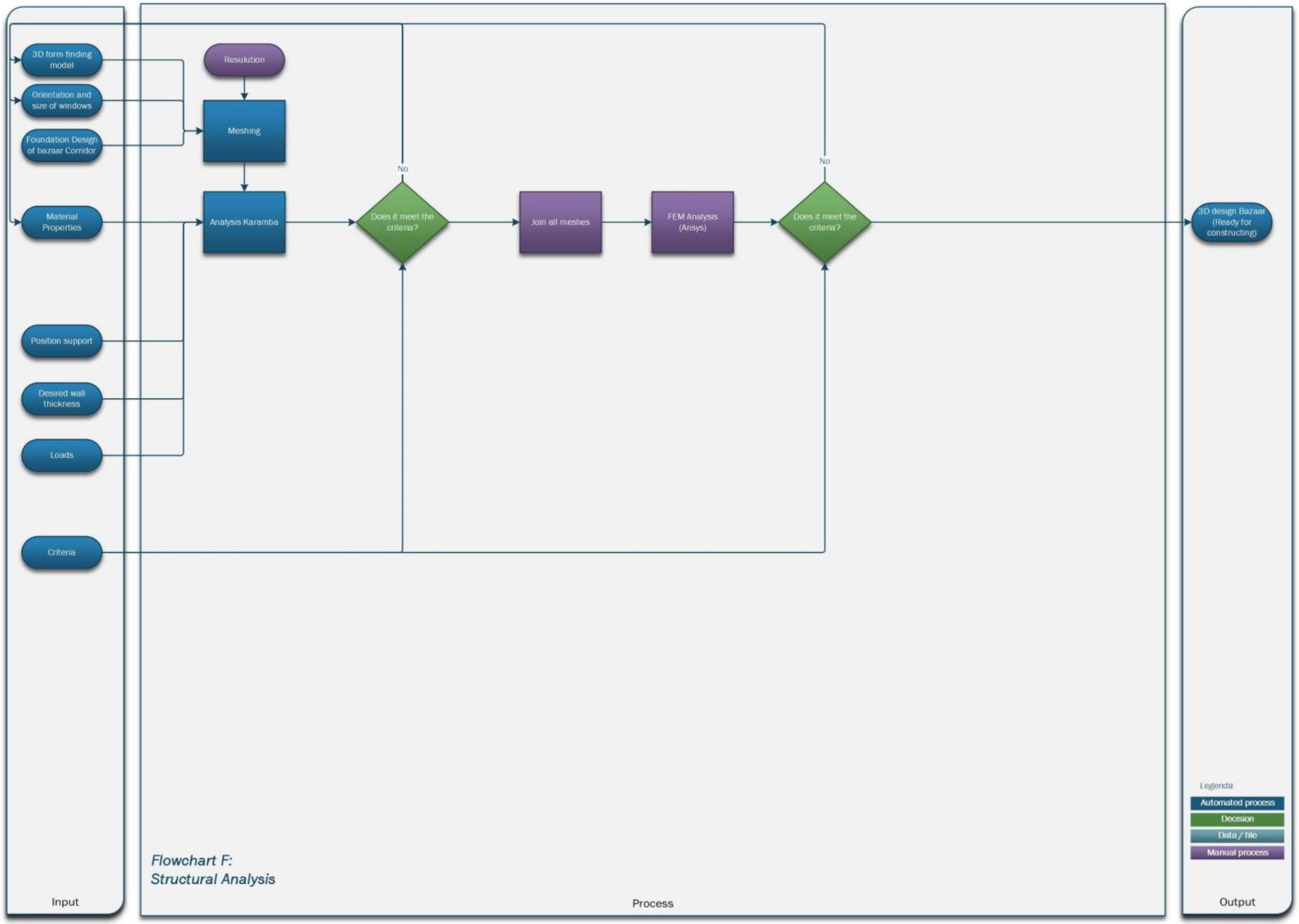


Figure 8: Structural flowchart.

Flowchart complete:

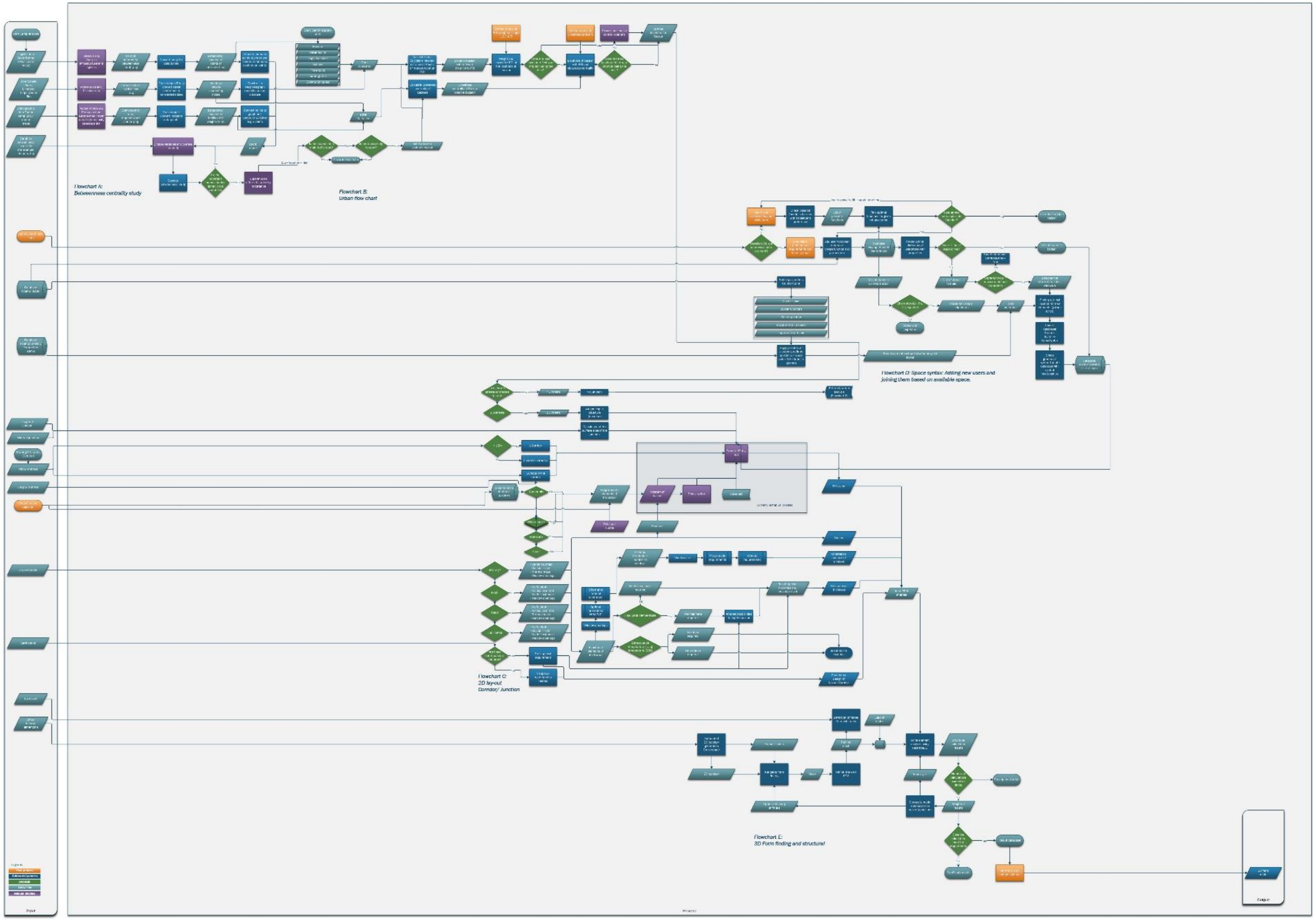


Figure 8: Complete Flowchart

Appendix D: Program of Requirements & Social Control

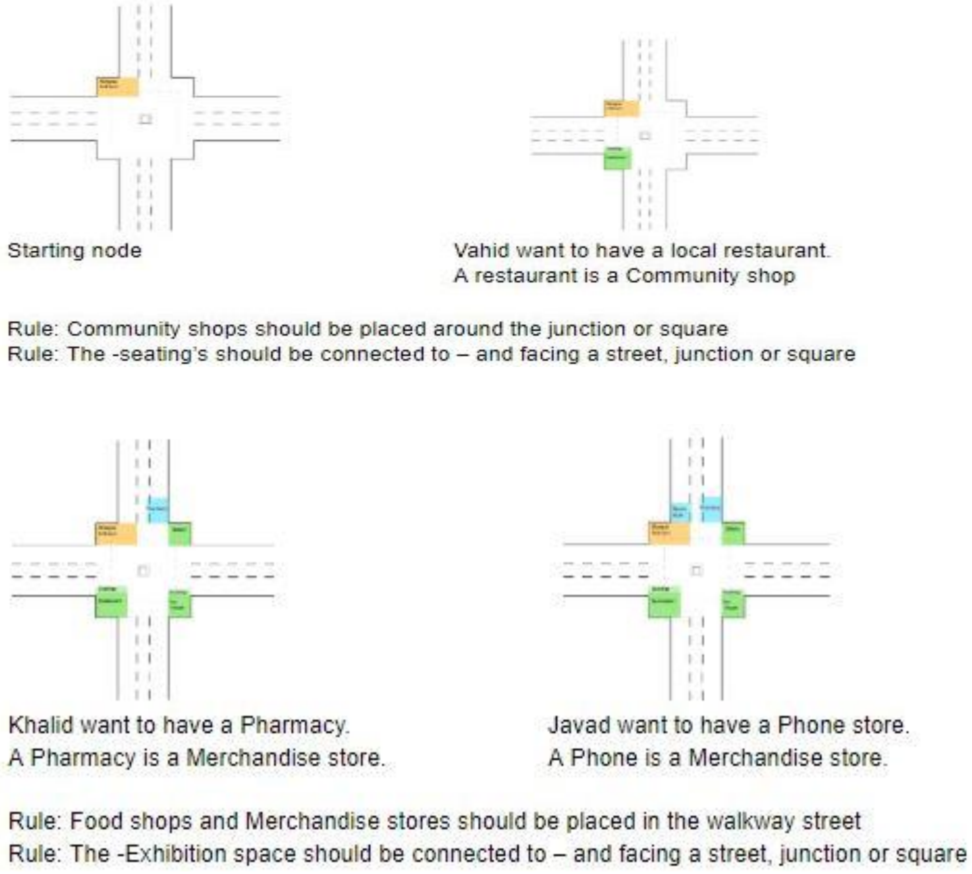
For setting a program of requirements (table 1), several topics are researched to understand the basics of a bazaar and what happens in a bazaar. All details of the research can be found in the appendix. In the below table, the program of requirements are written down which is also used as basis for the guideline book further in this project.

Cluster	Function	Similarities							
		Noise (generate)	**Water**	**Space m2**	**Space accessibility**	**Minimum height**	**Day light intensity**	**Publicing time**	**Connected to**
Community	Tea house	Medium	Medium	Medium (20m2)	Public	2.7	Medium	24/7	Walkway, junction, square
	Snack Shop	Medium	Medium	Medium (20m2)	Public	2.7	Medium	24/7	Walkway, junction, square
	Restaurant	High	Medium	Medium (20m2)	Public	2.7	Medium	from dawn after dusk	Walkway, junction, square
	School	High	Low	Big (20+ m2)	Semi-Public	2.7	high	from dawn after dusk	Walkway, square
	Mosque	Low	Medium	Big (20+ m2)	Public	5	high	24/7	Walkway, Junction
	Daycare	High	Low	Medium (20m2)	Semi-Public	2.7	medium	From dawn till dusk	Walkway, square
	Cinema/theater	Low	Low	Big (20+ m2)	Semi-Public	5	Zero	from dawn after dusk	Walkway, square
	Bathhouse	Low	High	Big (20+ m2)	Public	5	high	24/7	Walkway, square
	Fountain	Low	High	Small (10m2)	Public	5	high		Junction
Food	Herbs&Spices	Low	Low	Small (10m2)	Public	2.7	low	From dawn till dusk	Walkway, square
	Vegetable	Low	Low	Small (10m2)	Public	2.7	low	From dawn till dusk	Walkway, square
	Butcher/meat	Medium	Low	Medium (20m2)	Public	2.7	low	From dawn till dusk	Walkway, square
	Dry Fruit	Low	Low	Small (10m2)	Public	2.7	low	From dawn till dusk	Walkway, square
	Bakery	Low	Low	Small (10m2)	Public	2.7	low	From dawn till dusk	Walkway, square
Merchandise	General Fabrics	Low	Low	Medium (20m2)	Public	2.7	low	from dawn after dusk	Walkway, square
	Delicate Fabrics	Low	Low	Small (10m2)	Public	2.7	low	from dawn after dusk	Walkway, square
	Phone store	Low	Low	Small (10m2)	Public	2.7	low	from dawn after dusk	Walkway, square
	Pharma	Low	Low	Medium (20m2)	Public	2.7	low	from dawn after dusk	Walkway, square
	Bookstore	Low	Low	Medium (20m2)	Public	2.7	low	from dawn after dusk	Walkway, square
Workshop	Coppersmith	High	Medium	Medium (20m2)	Semi-Public	2.7	medium	from dawn after dusk	Walkway, square
	Shoe maker	High	Low	Medium (20m2)	Semi-Public	2.7	medium	from dawn after dusk	Walkway, square
	Tailor	High	Low	Medium (20m2)	Semi-Public	2.7	medium	from dawn after dusk	Walkway, square
	Pottery	High	Medium	Medium (20m2)	Semi-Public	2.7	medium	from dawn after dusk	Walkway, square
	Hairdresser	Medium	Medium	Medium (20m2)	Semi-Public	2.7	medium	from dawn after dusk	Walkway, square
	Blacksmith	High	Medium	Medium (20m2)	Semi-Public	2.7	medium	from dawn after dusk	Walkway, square
	Jewels	High	Low	Small (10m2)	Semi-Public	2.7	medium	from dawn after dusk	Walkway, square
	Bike store/ reperation	High	Low	Medium (20m2)	Semi-Public	2.7	medium	from dawn after dusk	Walkway, square
	Furnature	High	Low	Big (20+ m2)	Semi-Public	2.7	medium	from dawn after dusk	Square
Houses		Medium	Medium	Medium (20m2)	Private	2.7	medium	24/7	

Table 1: Program of Requirements for the clustered functions.

Example

A set of guidelines are created to give the administrators of the refugee camp a set of nudges in the right direction to from a bazaar that has a high qualitative value. These guidelines are by no means set in stone but when followed as much as possible, they are able to increase the quality of the bazaar. It is unrealistic to think that the bazaar will grow until proportions we don't want it to grow within the lifespan of a refugee camp. See figure 1 for the example.



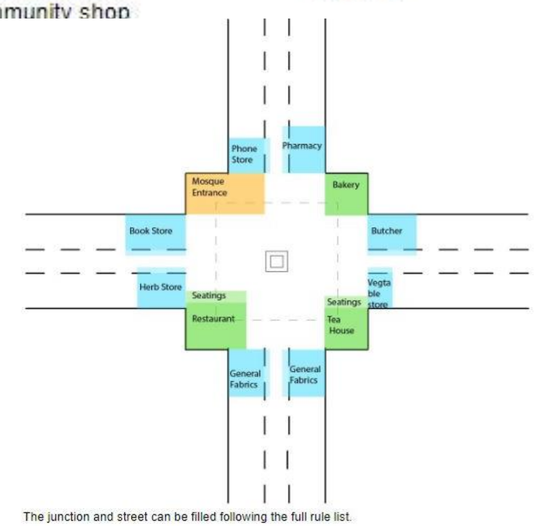


Figure 1:Step by step configuration of starting node (junction).

Figure 2: Final result of the node configuration.

Social control

Preventing crime by social control - Urban Research: graph theory to prevent crime

Crime is a problem in Zaatari. Informal power structures of organized crime, and semi-formal power structures of street leaders parallel the formal UNHCR system since 2013. Many street leaders are not against the use of exploitation, violence and theft to keep their position. Smuggling, theft, violence sexual- and gender based violence, and armed-forces recruiting have been observed in Zaatari (Ledwith, 2014).

When looking at crime bazaars might form a risk, Criminological research suggests that the location of where crimes happen are far from random (Weisburd, 2012). While bazaars might reduce the crime issues partly as it might create a wider sense of community, - which voluntarily limit the populations propensity to commit deviant acts (social control theory). The risk of theft within a bazaar is higher than the occurrence of theft on someone’s private property. Social control needs to be guaranteed.

Social control *is the control of the behavior of individuals and groups by society. Social control ensures that people adapt to behavior that is expected of them in the group. Behavior in groups is determined by social norms.*

When creating a bazaar, clustering of functions might result in timeframes without social control. To guarantee the maximum amount of social control a study is done in daily movements within refugee camps based on population and expected destinations within daily routines. In graph theory, betweenness centrality studies are used. This is a measure of centrality in a graph based on shortest paths.

Betweenness study

To find the best location of our bazaar (focussing on social security) we studied daily pedestrian traffic that is likely to happen. Hereby, we used the roads as network edges. We calculated expected trips between Origins (households) and Destinations (e.g. Mosques, water facilities, schools), using a betweenness centrality study. This is mathematically defined in formula 1.

Formula 1:

$$\text{Betweenness[i]}^{r,dr} = \sum_{j,k \in G-\{i\}, d[j,k] \leq r \cdot dr} \frac{n_{j,k}[i]}{n_{j,k}} \cdot W[j] \cdot \frac{1}{e^{\beta \cdot d[j,k]}}$$

Multiple variables can be defined while doing an betweenness study. When looking at our chosen variables the search radius, was always the closest distance to a POI (Points of interest), the detour ratio was based on surveys of pedestrian flow which state that people usually take a 10 to 20% maximum variation of the shortest route.

5.2 Results

We imported the street network from online street maps. Following this, we mapped to total population to the surface and connected these to the networks. This allowed them to travel to POI, see figure 3. Eventually, we weighed (Mosque factor 2, water point factor 0,5 and school factor 1) the results of the betweenness studies resulting in figure 4.

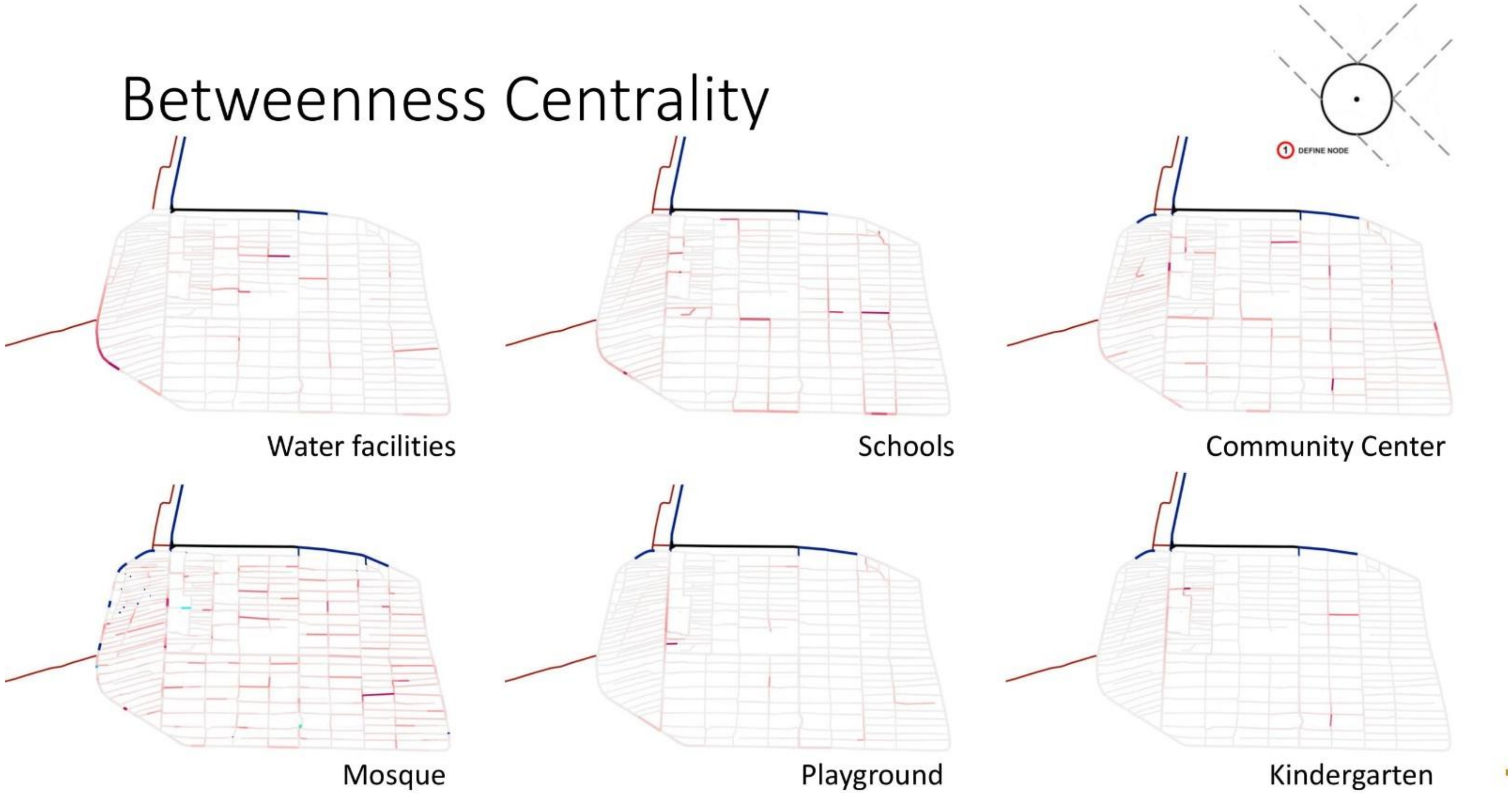


Figure 3: Results of pedestrian flow per function.

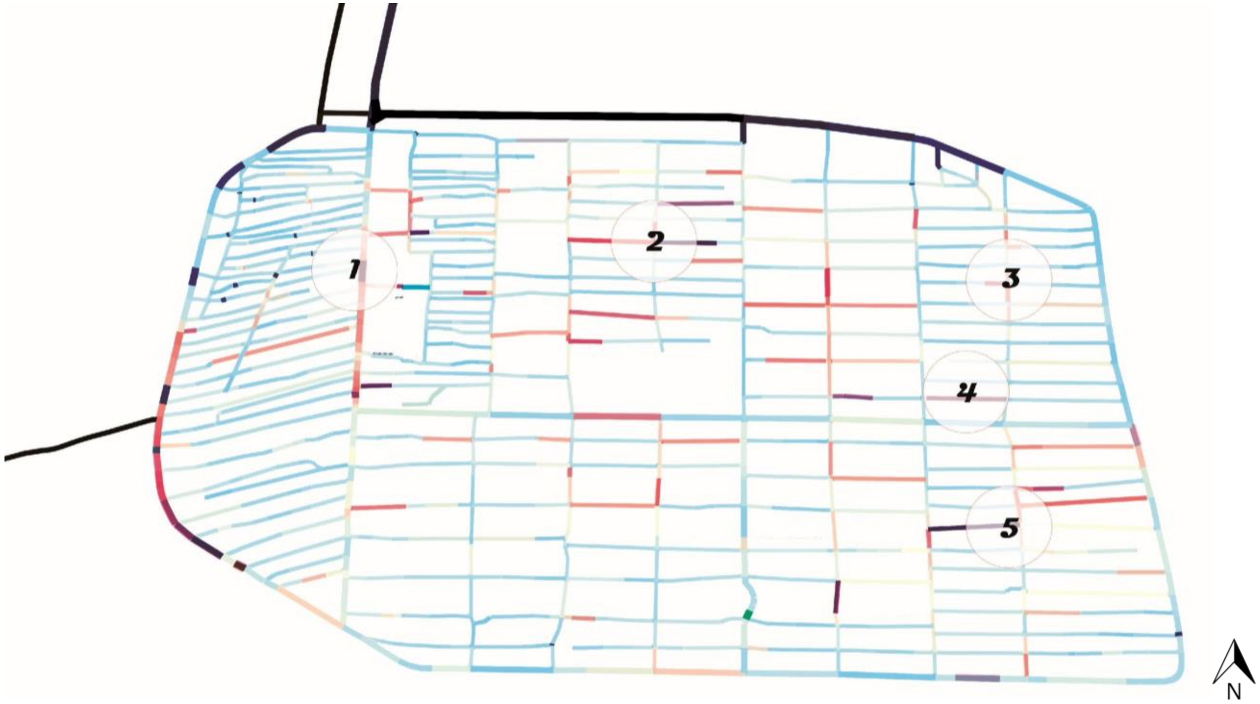


Figure 4: Decision drawing where to design an example bazaar.

A darker road (figure 4) means that this road is used more intensively. These intensively used roads are a good place to start a bazaar. The most intensively used roads are checked with the rules of our masterplan. 1) No cars, 2) High pedestrian density (the map), 3) Access to water, 4) Within 100m of a mosque and 5) Within 250m from a logistic point. The streets with a circle around it are the streets that meet all the requirements. As a group we decided to start our bazaar at location 2, because these is one of the streets which is most intensively used and closest to the most dense district (the district in the west are more dense than the district in the east).

Appendix E: Bubble diagram & REL chart

A bubble diagram is set up to understand the relationships between the shops and the logistics within the bazaar and the relationship between the walkway and the shop program. Therefore, different levels of detail for the bazaar logistic lay-out and four different clusters of programs in the bazaar are analyzed. The bubble diagram is set up with the help of 'Space Syntax' in Grasshopper, Rhino. Shops are clustered because:

- Lower costs thanks to shorter distances to transport goods
- They can share information, skills and ideas. Called 'knowledge spillover'.
- Customers know where to go in the bazaar for certain products.
- Production of noise is equal for nearby shops
- Make use of your neighbors' customers.
- Similar modules
- Good/service/Waste management

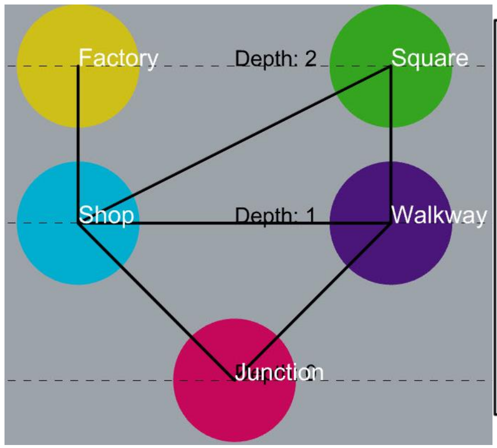
However, the con of clustering is:

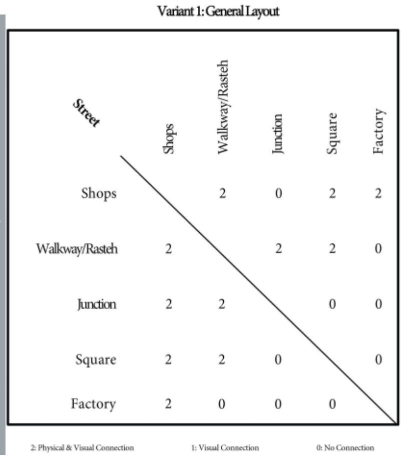
- Less diversity in shops per m2 – Longer distance
- Competition

Simplified bubble diagrams

Junction 1

All variants for the function in the bazaar have a viewpoint from the junction as it is an orientation point. All main functions are connected with the junction except for the factory as this is connected directly to the shop, see figure 1.





Variant 1: General Layout

Street	Shops	Walkway/Rasteh	Junction	Square	Factory
Shops		2	0	2	2
Walkway/Rasteh	2		2	2	0
Junction	2	2		0	0
Square	2	2	0		0
Factory	2	0	0	0	

2: Physical & Visual Connection   1: Visual Connection   0: No Connection

Figure 1: Simple junction 1 (bubble and REL diagram)

Junction 2

In variant 2, the shops are divided in cluster groups as this is seen in current bazaars. From here, all cluster streets are connected to the junction and a square with a cluster can be connected to a walkway. See figure 2 for the bubble diagram and REL chart.

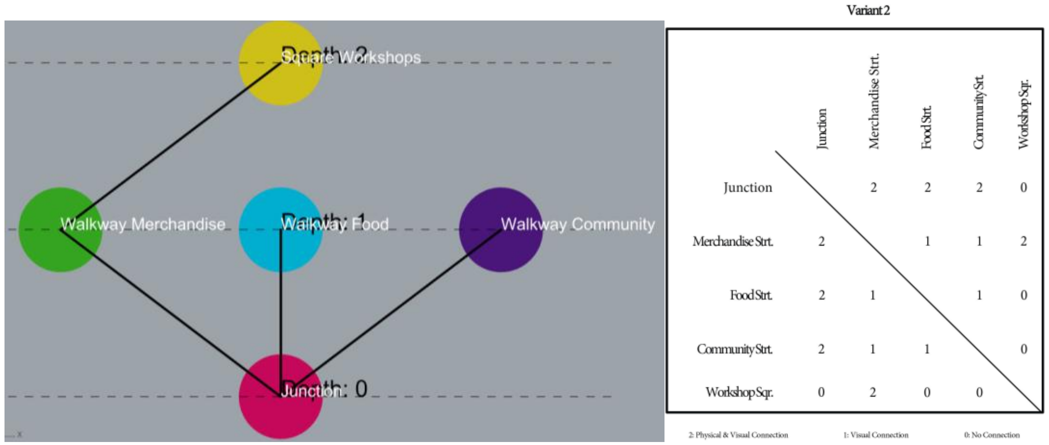
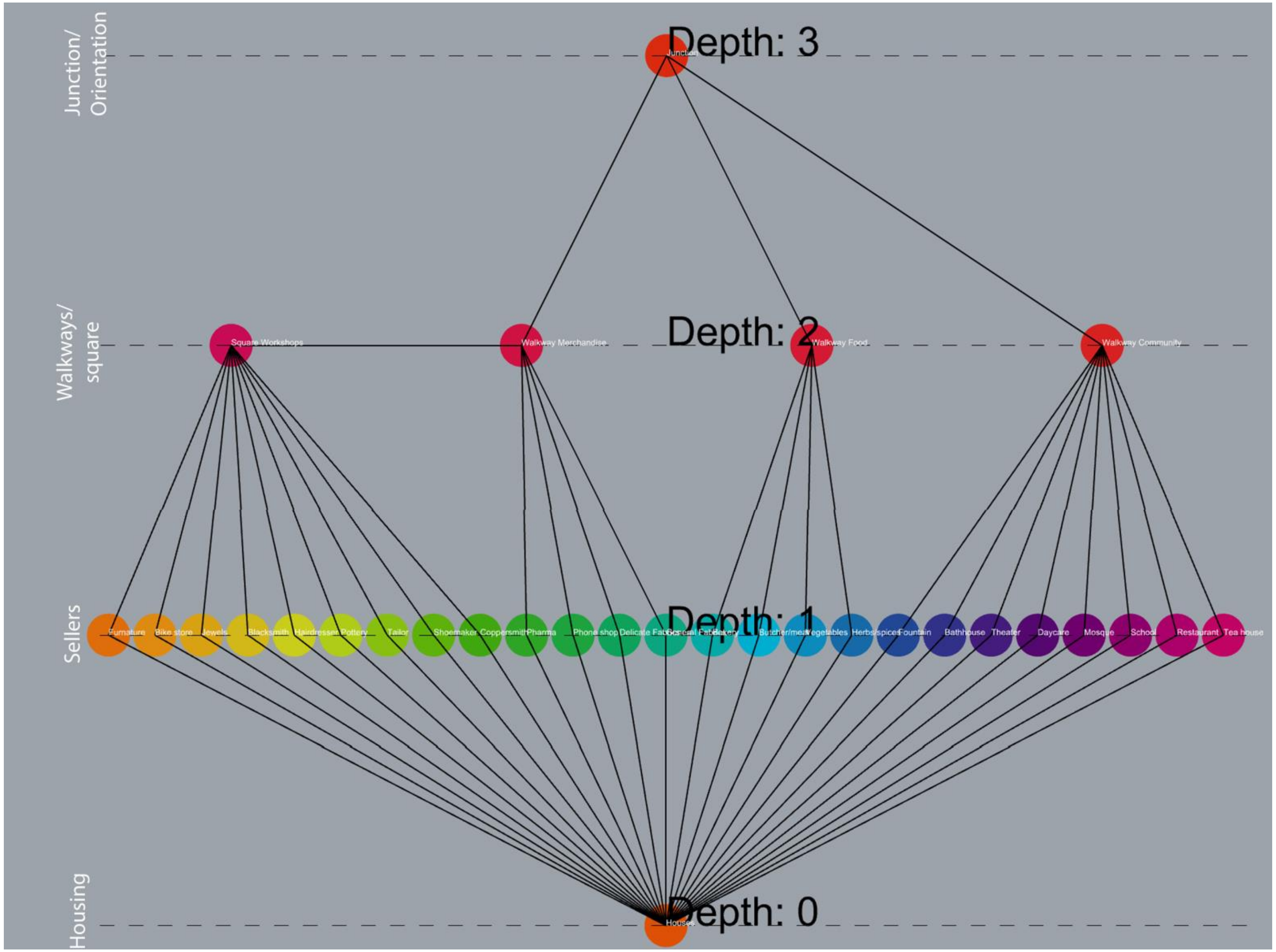


Figure 2: Simple junction 2 (bubble and REL diagram)

Junction 3

In version 3, the users can move from the junction to the cluster streets where the related shops are orientated. To keep a social controlled area, housing is oriented near the bazaar with possible access to it. See figure 3 for the bubble diagram and REL chart.



Junction/
Orientation
Depth: 3
Walkways/
square
Square Workshops
Walkway Merchandise
Depth: 2
Walkway Food
Walkway Community
Sellers
Depth: 1
Furniture
Bike store
Jewels
Blacksmith
Hairdresser
Pottery
Tailor
Shoemaker
Coppersmith
Pharma
Phone shop
Delicate
Vegetables
Herbs/spices
Fountain
Bathhouse
Theater
Daycare
Mosque
School
Restaurant
Tea house
Housing
Depth: 0

Variant 3

	Houses	Furniture	Bike store	Jewels	Blacksmith	Hairdresser	Pottery	Tailor	Shoemaker	Coppersmith	Pharmacy	Phoneshop	Delicate Fabric	General Fabric	Butcher/Meat	Vegetables	Bakery	Herbs/Spices	Fountain	Bath house	Theatre	Daycare	Mosque	School	Restaurant	Tea shop	Communtiy square	Merchandise strt.	Workshop strt.	Food strt.	Junction
Houses	•	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2							2	2	1	1	1	1	
Furniture	2	•	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Bike store	2	1	•	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Jewels	2	1	1	•	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Blacksmith	2	1	1	1	•	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Hairdresser	2	1	1	1	1	•	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Pottery	2	1	1	1	1	1	•	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Tailor	2	1	1	1	1	1	1	•	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Shoemaker	2	1	1	1	1	1	1	1	•	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Coppersmith	2	1	1	1	1	1	1	1	1	•	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Pharmacy	2	0	0	0	0	0	0	0	0	0	•	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Phoneshop	2	0	0	0	0	0	0	0	0	0	1	•	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Delicate Fabric	2	0	0	0	0	0	0	0	0	0	1	1	•	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
General Fabric	2	0	0	0	0	0	0	0	0	0	1	1	1	•	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Butcher/Meat	2	0	0	0	0	0	0	0	0	0	0	0	0	0	•	1	1	1	0	0	0	0	0	0	0	0	0	0	0	2	0
Vegetables	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	•	1	1	0	0	0	0	0	0	0	0	0	0	0	2	0
Bakery	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	•	1	0	0	0	0	0	0	0	0	0	0	0	2	0
Herbs/Spices	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	•	0	0	0	0	0	0	0	0	0	0	0	2	0
Fountain		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	•	1	1	1	1	1	1	1	0	0	0	0	0
Bath house		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	•	1	1	1	1	1	1	0	0	0	0	0
Theatre		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	•	1	1	1	1	1	0	0	0	0	0
Daycare		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	•	1	1	1	1	0	0	0	0	0
Mosque		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	•	1	1	1	0	0	0	0	0
School		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	•	1	1	0	0	0	0	0
Restaurant	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	•	1	0	0	0	0	0
Tea shop	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	•	0	0	0	0	0
Communtiy square	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	•	1	1	1	
Merchandise strt.	1	0	0	0	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	1	•	1	1	2
Workshop strt.	1	2	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	•	1	2
Food strt.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	1	1	1	•	2
Junction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		2	2	2	•

2: Physical & Visual Connection 1: Visual Connection 0: No Connection

Figure 3: Simple junction 3 (bubble and REL diagram)

Workshops

The workshops refers to the spaces inside the bazaar in which people from the refugee camp will produce different goods and offer services. In this configuration the workshops consist of a working space (workshop / factory) and an exhibition space, see figure 4. The exhibition spaces will be open spaces arranged on the sides of the walkway followed by the workshops which will be enclosed spaces which could also provide storage space for the goods displayed on the exhibition spaces in the closing hours. The workshop space ranges between a minimum of 10 m2 up to 20 m2. House containers could be attached to the workshop spaces on the outer part of the bazaar, providing the possibility to the owners of the different workshops to be directly connected to their working space.

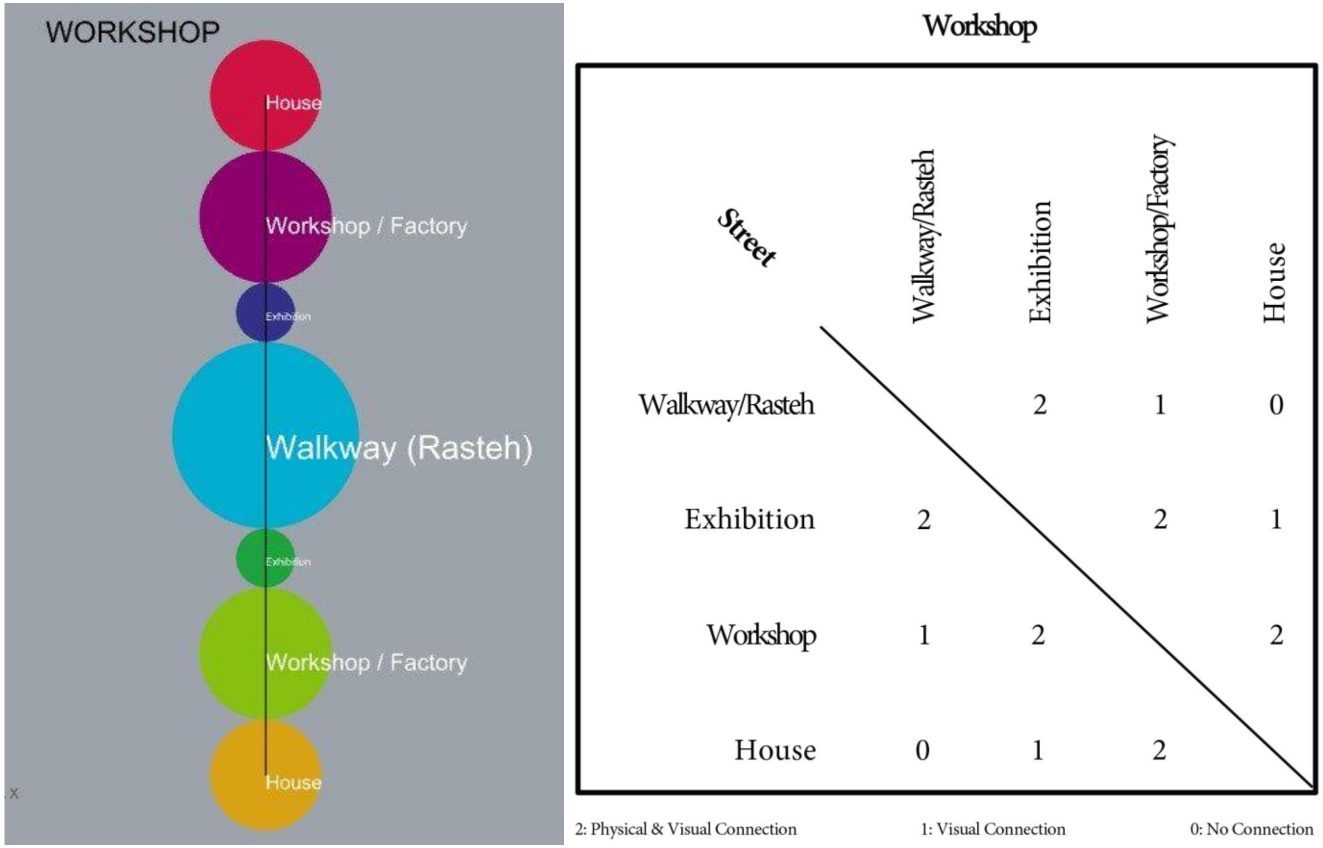


Figure 4: Simple Workshops (bubble and REL diagram)

Merchandise

This variant refers to a merchandise cluster of functions related to selling goods like pharmacies, general fabric stores, phone stores, etc. In this configuration the shops consist of a main shop in which different goods will be sold and several services provided (like phone repairs or haircuts among other services), and exhibition spaces which will be extensions of the main shops, with direct connection to people coming from the walkway. In this case people have access to both the main shop and the exhibition area. The shops will have areas ranging from 10 m2 to 20m2. In this case, the houses could also be attached to the different shops from the outer part of the bazaar. See figure 5 for the bubble diagram and REL chart.

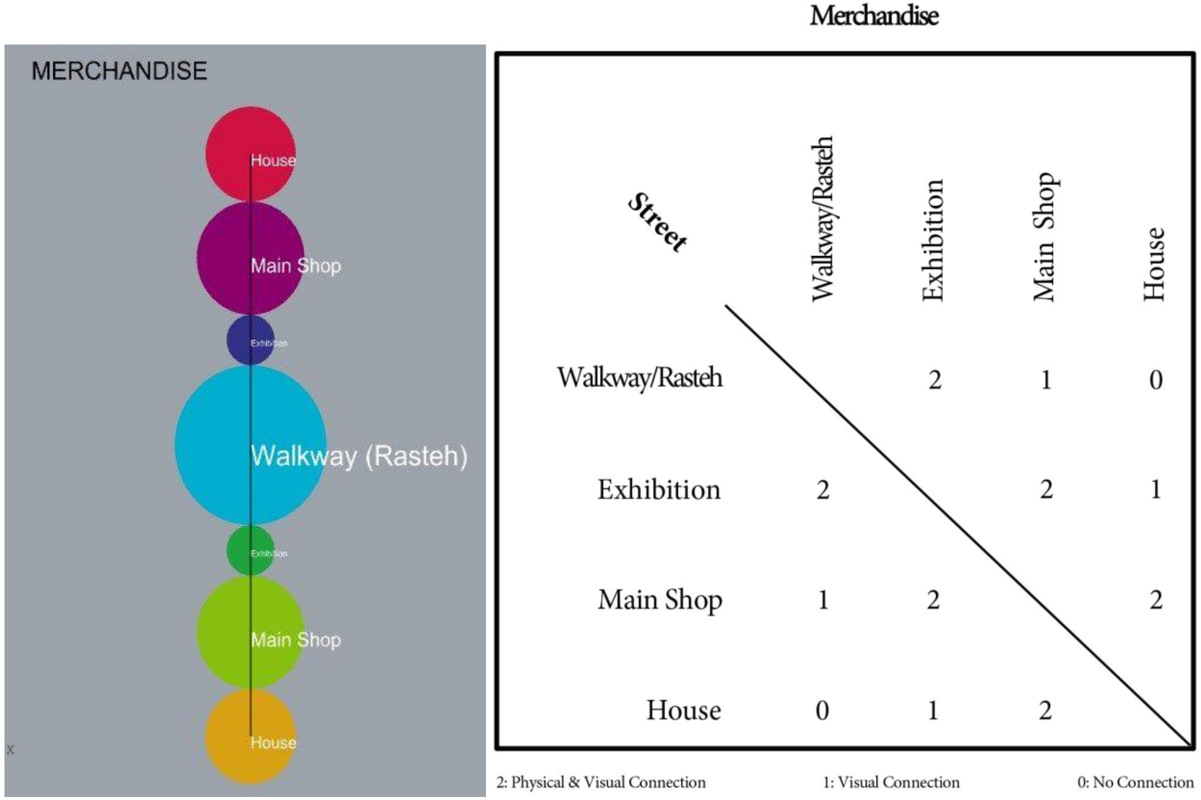
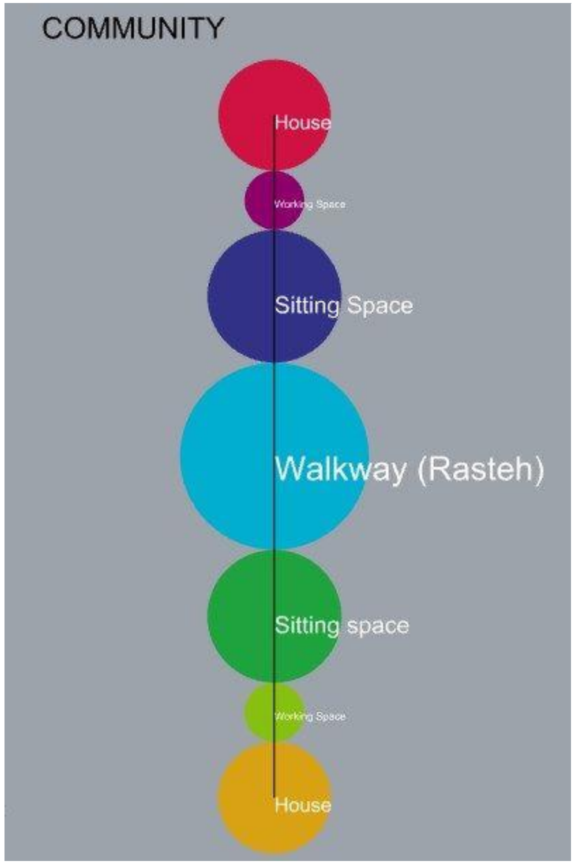


Figure 5: Simple Merchandise (bubble and REL diagram)

Community

This variant refers to a community cluster of functions related to meeting activities like restaurants, cafes, tea shops, etc. In this configuration the exhibition spaces disappear to leave room for chairs and tables for people to meet and/or eat. The working spaces refer to the places in which the food is prepared and these spaces require small areas therefore they decrease in size giving away more room to the sitting space, see figure 6.



Community

Street	Walkway/Rasteh	Sitting Space	Working Space	House
Walkway/Rasteh		2	2	0
Sitting Space	2		2	0
Working Space	1	2		2
House	0	1	2	

2: Physical & Visual Connection 1: Visual Connection 0: No Connection

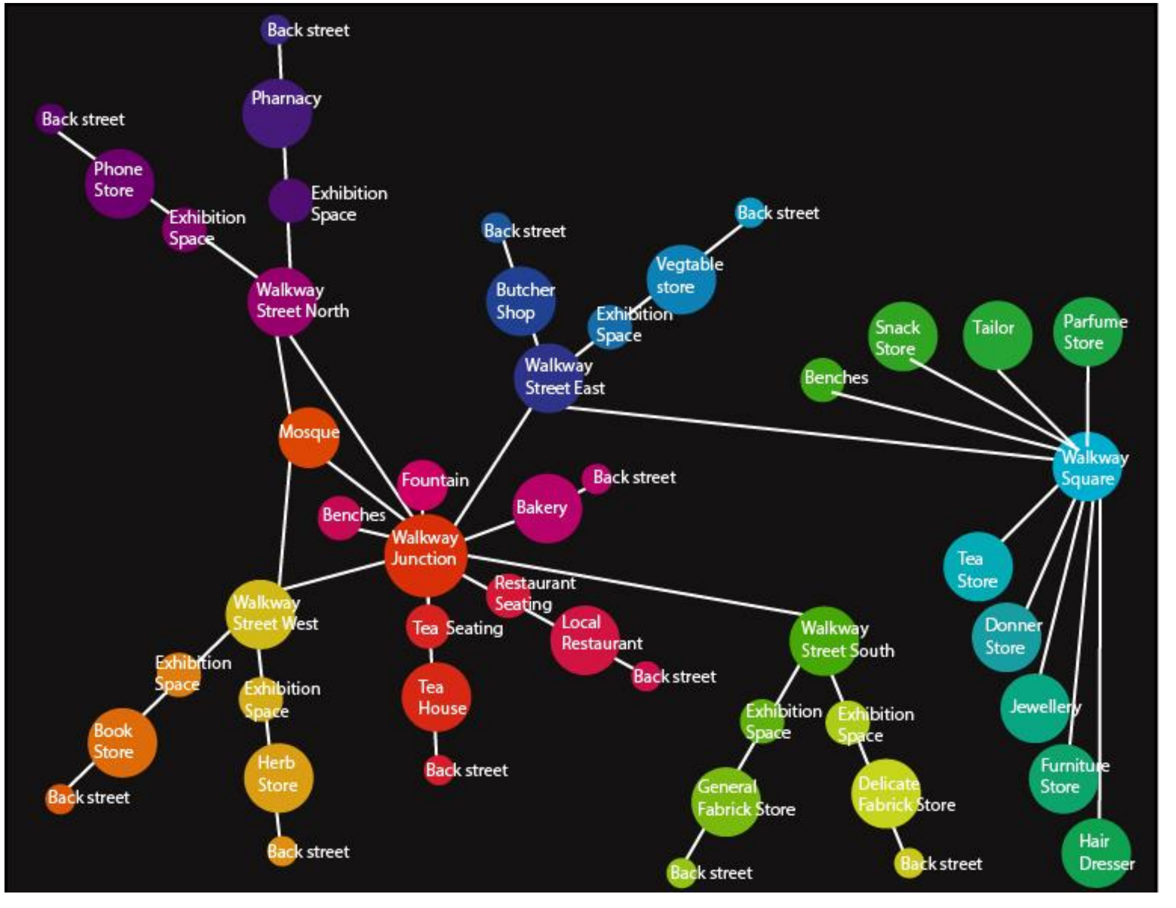
Figure 6: Simple Community (bubble and REL diagram)

Scenarios

Based on the simplified bubble diagrams, scenarios are made how the bazaar can start and further develop. The guidelines which are explained earlier are used.

Scenario 1

In this scenario, the junction is a combined location for community and food stores. The walkways are clustered per sector. Also, a square is added for the workshop related activities due to the noise production. For walkway areas, houses can be added above the shops for the social security. See figure 7 for the bubble diagram and REL chart.



SCENARIO 1			COMMUNITY							WALKWAY					MERCANDISE				FOOD			COMMUNITY			
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
			Mosque(or Entrance)	Fountain	Tea House Seating	Tea House	Restaurant Seating	Local Restaurant	Bakery	Walkway Junction	Walkway North Strt	Walkway East Strt	Walkway South Strt	Walkway West Strt	Exhibition Space Phn	Phone Store	Exhibition Space Phar	Pharmacy	Butcher/Meat	Exhibition Space Veg	Vegetable Store	Tea House Sqr	Doner Shop Sqr	Snack Shop	Public Seating Sqr
	0	Mosque(or Entrance)	•	1	1	1	1	1	1	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
COMMUNITY	1	Fountain	1	•	1	1	1	1	1	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
COMMUNITY	2	Tea House Seating	1	1	•	2	1	1	1	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
COMMUNITY	3	Tea House	1	1	2	•	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
COMMUNITY	4	Restaurant Seating	1	1	1	1	•	2	1	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
COMMUNITY	5	Local Restaurant	1	1	1	1	2	•	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
COMMUNITY	6	Bakery	1	1	1	1	1	1	•	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
	7	Walkway Junction	2	2	2	1	2	1	2	•	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0
WALKWAY	8	Walkway North Strt	1	1	1	1	1	1	1	2	•	0	1	0	2	1	2	1	0	0	0	0	0	0	0
WALKWAY	9	Walkway East Strt	1	1	1	1	1	1	1	2	0	•	0	1	0	0	0	0	2	2	1	0	0	0	0
WALKWAY	10	Walkway East Strt	1	1	1	1	1	1	1	2	1	0	•	0	0	0	0	0	0	0	0	0	0	0	0
WALKWAY	11	Walkway West Strt	1	1	1	1	1	1	1	2	0	1	0	•	0	0	0	0	0	0	0	0	0	0	0
MERCANDISE	12	Exhibition Space Phn	0	0	0	0	0	0	0	0	2	0	0	0	•	2	1	1	0	0	0	0	0	0	0
MERCANDISE	13	Phone Store	0	0	0	0	0	0	0	0	1	0	0	0	2	•	1	1	0	0	0	0	0	0	0
MERCANDISE	14	Exhibition Space Phar	0	0	0	0	0	0	0	0	2	0	0	0	1	1	•	2	0	0	0	0	0	0	0
MERCANDISE	15	Pharmacy	0	0	0	0	0	0	0	0	1	0	0	0	1	1	2	•	0	0	0	0	0	0	0
FOOD	16	Butcher/Meat	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	•	1	1	0	0	0	0
FOOD	17	Exhibition Space Veg	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	•	2	0	0	0	0
FOOD	18	Vegetable Store	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	2	•	0	0	0	0
COMMUNITY	19	Tea House Sqr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	•	1	1	1
COMMUNITY	20	Doner Shop Sqr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	•	1	1
COMMUNITY	21	Snack Shop	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	•	1
COMMUNITY	22	Public Seating Sqr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	•
	36	Walkway Square	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2
WORKSHOP	23	Jewellry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
WORKSHOP	24	Furniture Store	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
WORKSHOP	25	Hairdresser	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
WORKSHOP	26	Perfume Store	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
WORKSHOP	27	Tailor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
MERCANDISE	28	Exhibition Space GF	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
MERCANDISE	29	General Fabric Store	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
MERCANDISE	30	Exhibition Space DF	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
MERCANDISE	31	Delicate Fabric Store	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
MERCANDISE	32	Exhibition Space B S	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
MERCANDISE	33	Book Store	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
MERCANDISE	34	Exhibition Space Herb	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
MERCANDISE	35	Herb Store	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
BACKSTREET	37	Backstreet North 1	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
BACKSTREET	38	Backstreet North 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
BACKSTREET	39	Backstreet East 1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
BACKSTREET	40	Backstreet East 2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
BACKSTREET	41	Backstreet South 1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BACKSTREET	42	Backstreet South2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BACKSTREET	43	Backstreet West 1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BACKSTREET	44	Backstreet West 2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SCENARIO 1				WORKSHOP					MERCANDISE								BACKSTREET							
			23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
			Walkway Square	Jewellry	Furniture Store	Hairdresser	Perfume Store	Tailor	Exhibition Space GF	General Fabric Store	Exhibition Space DF	Delicate Fabric Store	Exhibition Space B.S	Book Store	Exhibition Space Herb	Herb Store	Backstreet North 1	Backstreet North 2	Backstreet East 1	Backstreet East 2	Backstreet South 1	Backstreet South2	Backstreet West 1	Backstreet West 2
	0	Mosque(or Entrance)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	0
COMMUNITY	1	Fountain	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMMUNITY	2	Tea House Seating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMMUNITY	3	Tea House	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
COMMUNITY	4	Restaurant Seating	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMMUNITY	5	Local Restaurant	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2
COMMUNITY	6	Bakery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
	7	Walkway Junction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WALKWAY	8	Walkway North Strt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WALKWAY	9	Walkway East Strt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WALKWAY	10	Walkway East Strt	0	0	0	0	0	0	2	1	2	1	2	1	0	0	0	0	0	0	0	0	0	0
WALKWAY	11	Walkway West Strt	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
MERCANDISE	12	Exhibition Space Phn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MERCANDISE	13	Phone Store	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
MERCANDISE	14	Exhibition Space Phar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MERCANDISE	15	Pharmacy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
FOOD	16	Butcher/Meat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
FOOD	17	Exhibition Space Veg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FOOD	18	Vegetable Store	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
COMMUNITY	19	Tea House Sqr	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMMUNITY	20	Doner Shop Sqr	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMMUNITY	21	Snack Shop	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMMUNITY	22	Public Seating Sqr	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	36	Walkway Square	•	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WORKSHOP	23	Jewellry	2	•	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WORKSHOP	24	Furniture Store	2	1	•	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WORKSHOP	25	Hairdresser	2	1	1	•	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WORKSHOP	26	Perfume Store	2	1	1	1	•	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WORKSHOP	27	Tailor	2	1	1	1	1	•	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MERCANDISE	28	Exhibition Space GF	0	0	0	0	0	0	•	2	1	1	1	1	1	1	0	0	0	0	0	0	0	0
MERCANDISE	29	General Fabric Store	0	0	0	0	0	0	2	•	1	1	1	1	1	1	0	0	0	0	2	0	0	0
MERCANDISE	30	Exhibition Space DF	0	0	0	0	0	0	1	1	•	2	1	1	1	1	0	0	0	0	0	0	0	0
MERCANDISE	31	Delicate Fabric Store	0	0	0	0	0	0	1	1	2	•	1	1	1	1	0	0	0	0	0	2	0	0
MERCANDISE	32	Exhibition Space B S	0	0	0	0	0	0	1	1	1	1	•	2	1	1	0	0	0	0	0	0	0	0
MERCANDISE	33	Book Store	0	0	0	0	0	0	1	1	1	1	2	•	1	1	0	0	0	0	0	0	2	0
MERCANDISE	34	Exhibition Space Herb	0	0	0	0	0	0	1	1	1	1	1	1	•	2	0	0	0	0	0	0	0	0
MERCANDISE	35	Herb Store	0	0	0	0	0	0	1	1	1	1	1	1	2	•	0	0	0	0	0	0	0	2
BACKSTREET	37	Backstreet North 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	•	0	0	0	0	0	0	0
BACKSTREET	38	Backstreet North 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	•	0	0	0	0	0	0
BACKSTREET	39	Backstreet East 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	•	0	0	0	0	0
BACKSTREET	40	Backstreet East 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	•	0	0	0	0
BACKSTREET	41	Backstreet South 1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	•	0	0	0
BACKSTREET	42	Backstreet South2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	•	0	0
BACKSTREET	43	Backstreet West 1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	•	0
BACKSTREET	44	Backstreet West 2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	•

Figure 7: Scenario 1 (bubble and REL diagram)

Scenario 2

In this scenario, the junction has no commercial purpose as there is no store located. It is only used for logistics in the bazaar and to the mosque. The walkways are clustered per sector. For walkway areas, houses can be added above the shops for the social security, see figure 8. REL chart is excluded as it is time consuming for this scale and scenario 1 is chosen to develop further in this design.

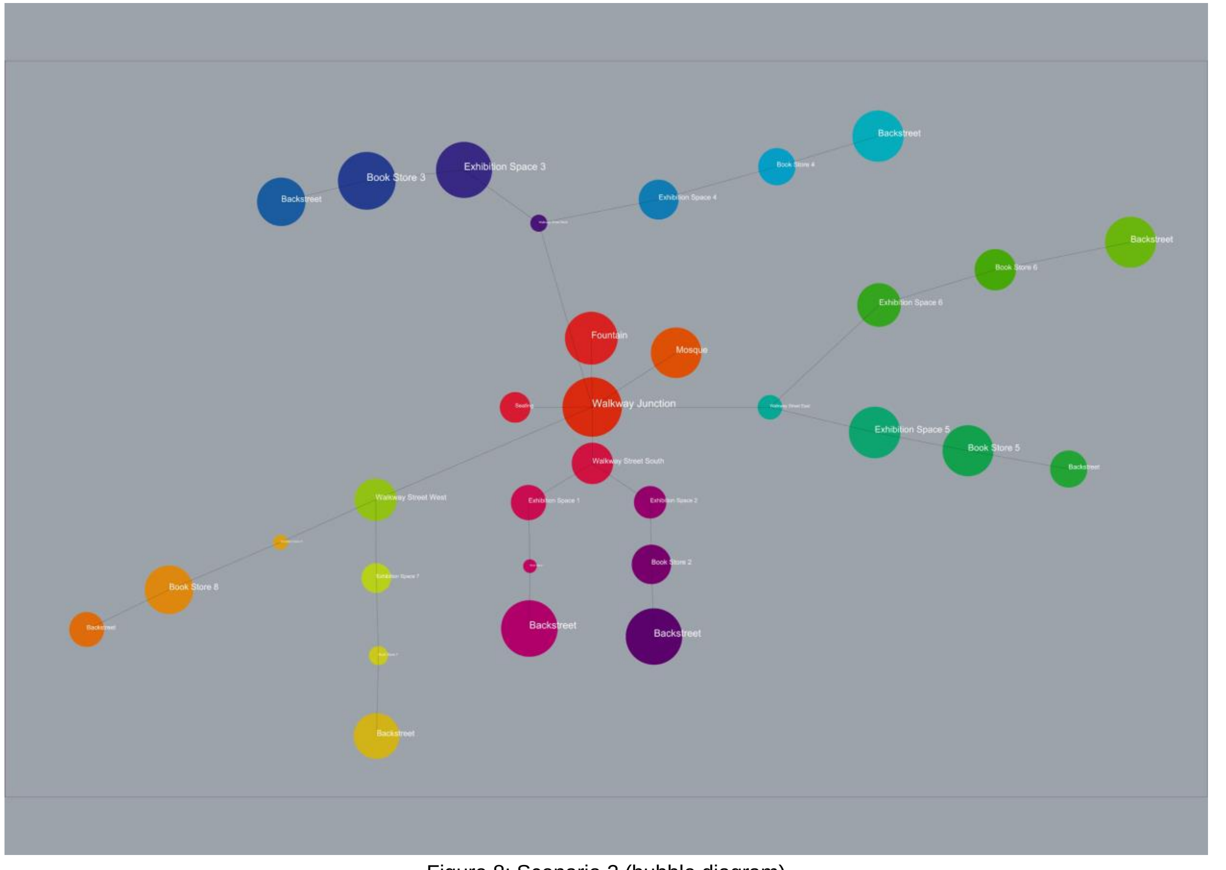


Figure 8: Scenario 2 (bubble diagram)

Scenario 3

In this scenario, the junction has only community stores as restaurants and teahouses. The walkways are clustered per sector. For walkway areas, houses can be added above the shops for the social security, see figure 9. REL chart is excluded as it is time consuming for this scale and scenario 1 is chosen to develop further in this design.

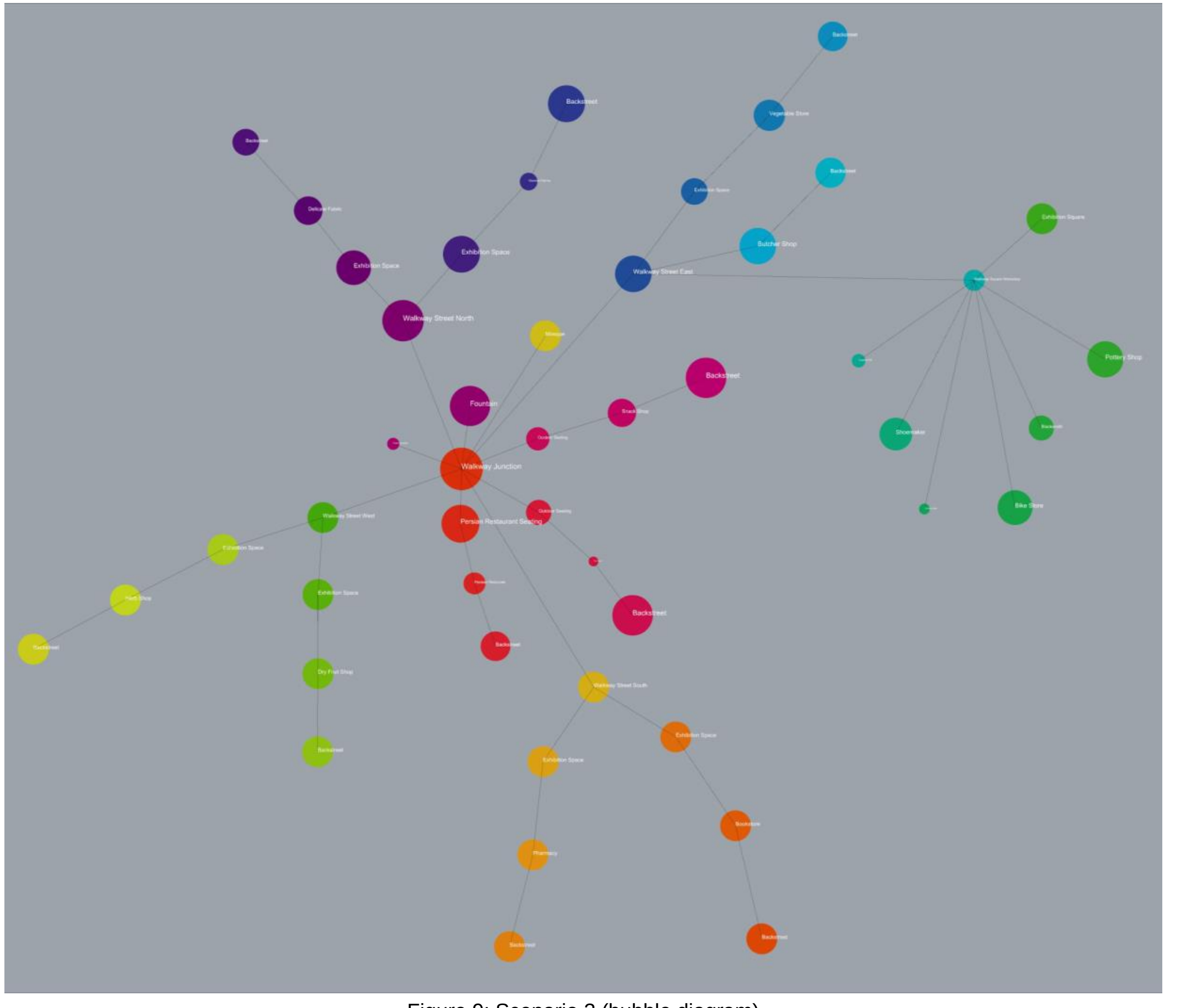


Figure 9: Scenario 3 (bubble diagram)

Appendix F: Position decisions

Zaatari camp decisions

Decision 1: Digging in VS not digging in (figure 1)

- Not digging: Building area directly available
- Digging: Using material immediately
- Digging: Using the digged space immediately
- Digging: Helps for constant climate conditions
- Digging: Helps for supporting the earth structure
- Not Digging: Transporting earth material costs time
- Digging: Leak of natural light
- Digging: Negative impact the airflow

Conclusion: Digging in

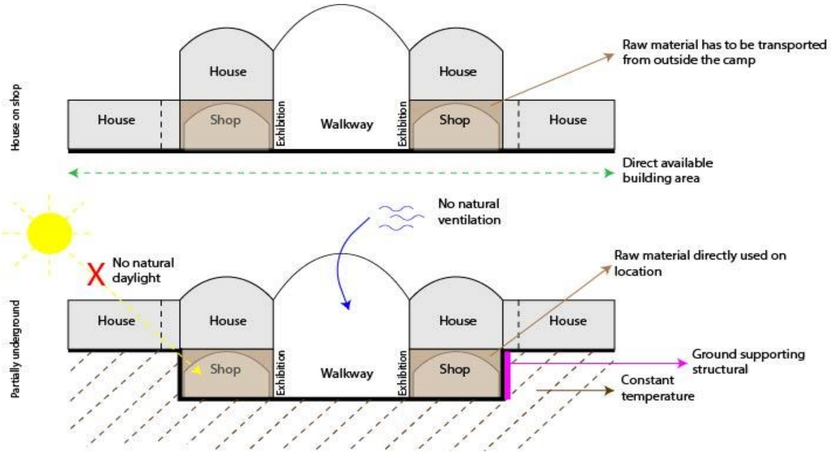


Figure 1: Decision 1: Digging in VS not digging in.

Decision 2: Digging in 3m VS Digging in 1-1.5m (figure 2)

- Digging in 3m: Better for the climate
- Digging in 3m: More material available
- Digging in 1-1,5m: Natural light
- Digging in 1-1,5m: Natural ventilation possible
- Digging in 1-1,5m: Visual connection with in and outside the bazaar

Conclusion: 1,5m digging in

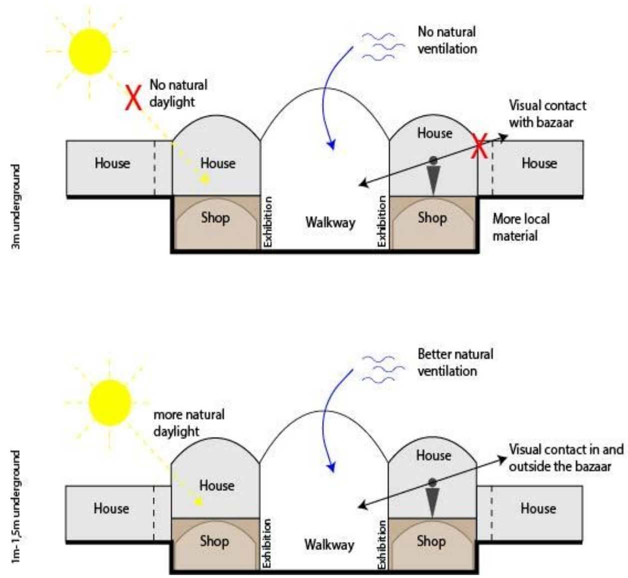


Figure 2: Decision 2: Digging in 3m VS Digging in 1-1.5m.

Decision 3: Housing connected vs Housing not connected (figure 3)

- Housing connected: Structural
- Housing not connected: Natural lighting
- Housing not connected: Natural ventilation
- Housing not connected: visual connection in and outside the bazaar
- Housing not connected: Supplied via the back + entrance house
- Housing not connected: Extra emergency exit
- Housing not connected: Less noise from neighbors

and

- Housing from earth: Original architecture
- Housing from earth: Everybody can build their own shop/house (no original house required)
- Re-use caravan: Lighter than earth material
- Re-use caravan: The object cannot be towed in place (manpower and knowledge)

and

- House located on top: social security in the bazaar
- House located on top: shop owner can live near his shop

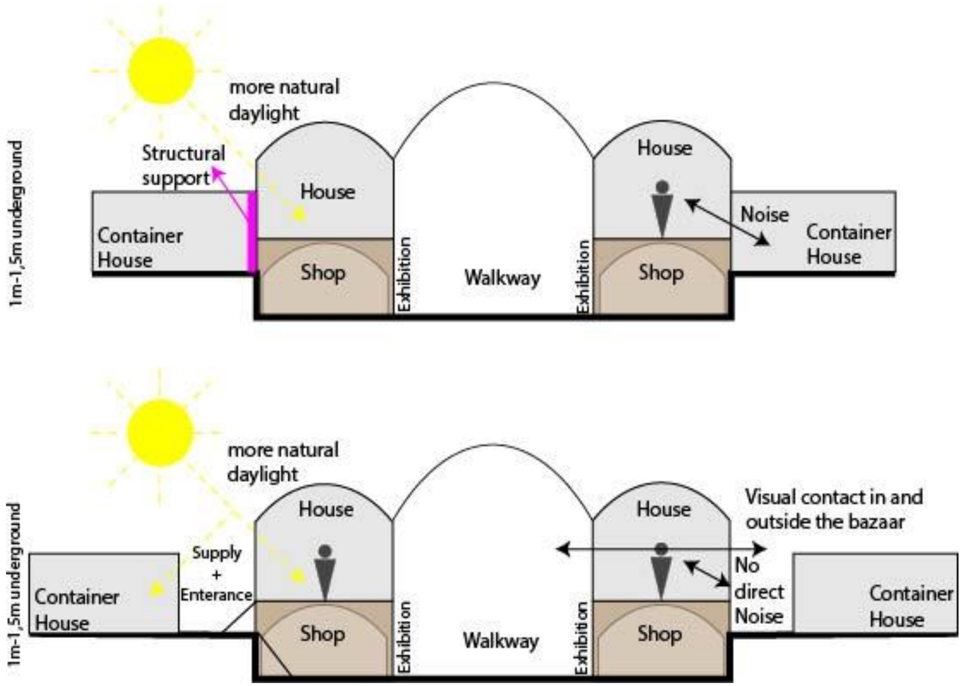


Figure 2: Decision 3: Housing connected vs Housing not connected.

Decision 4: Round Junction vs Square Junction

- Square junction: More efficient due to space usage
- Square junction: Suits in current urban lay-out
- Round Junction: Reflects the function of coming together

Overall conclusion: Houses will be made from earth and bazaar will not be connected with current located houses.

Appendix G-1: Pseudo codes & Python script & Possible outcomes

This appendix includes detailed information about the bazaarbuilding script, the first part includes the pseudocode, which was made in week 4, and is thus, outdated. However, it is still pretty much explains how to find the most optimal location. The second part goes in depth on the final python/grasshopper script and the third part is an appendix showing possible outcomes.

Pseudo codes

This paragraph describes the pseudo codes that have been developed so far to work out the computational forming of the 2D layout. This process will be done in three steps, which are discussed and worked out below.

Pseudocodes part 1 - Optimal Relation Database

This pseudo code describes the process of defining the best relation for a new shop compared to the existing shops. The code takes the database of the existing bazaar as input, as well as the requirements the user gives for his new shop. Also, admin input will help set the priorities of how the bazaar should be formed straight, see figure 1.

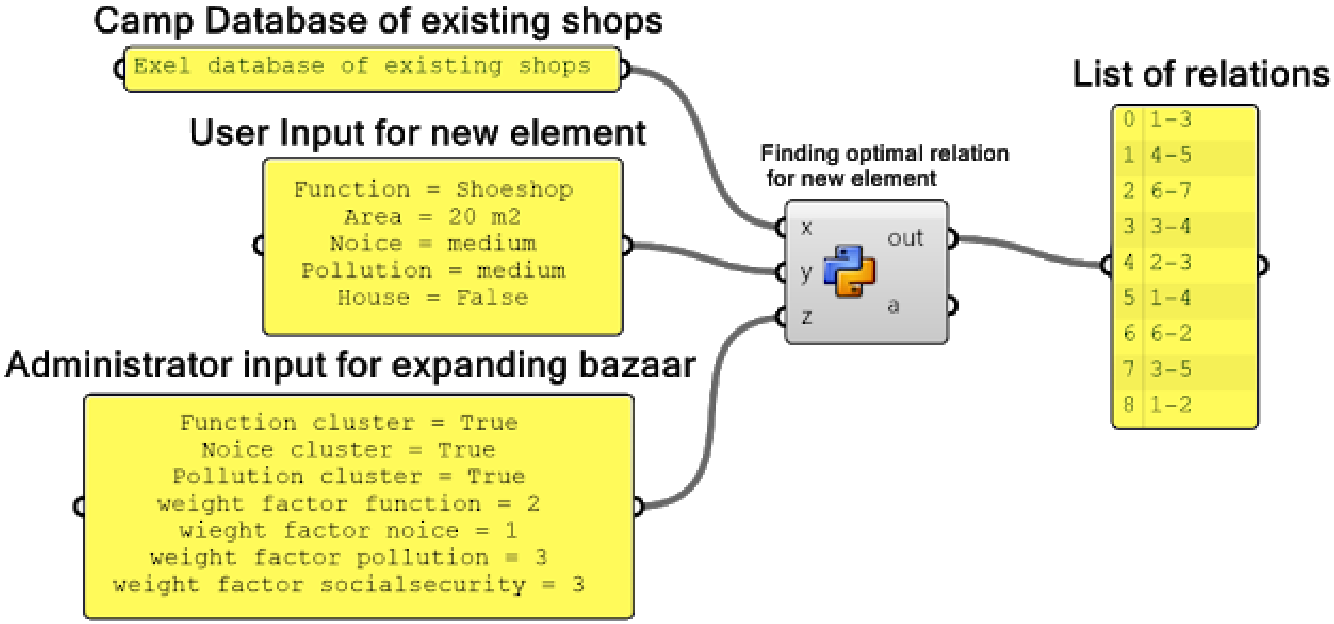


Figure 1: Pseudocodes part 1 - Optimal Relation Database

```
#########################
### Pseudocode part 1 ###
#########################

#Basic setting up project, import stuff

import math
import random

# import all the excel data using pyexcel or other plugins
# distribute the data from the existing nodes to the respective lists accordingly, could be dictionaries as well

noises_ = []
functions_ = []
pollutions_ = []
distances_nearest_house_ = []
relations_ = [{dictionaries}]

# make a list containing the qualifications of every existing node with the requested node

qualifications = []

# remap all the numbers (from the first 4) to a range of 1-100
# this will allow all numbers to be weighted the same
noise_r =
functions_r =
pollution_r =
distance_nearest_house_r =
relations_r =
```

```
# Add weight factors as admin input (or import them from grasshopper) by giving weightfactor = 0 the corresponding input is ignored
wn =
wf =
wp =
wd =

#add admin input for (or from grasshopper) the cluster or mixed variable
#if noise for example should be mixed the numbers will be inverted later
noisecluser = True
functioncluster = True
pollutioncluster = True

#import user input from grasshopper
user_noise =
user_pollution =
user_function =
user_house = True
#remap them aswell (except for house input)
user_noise_r =
user_pollution_r =
user_function_r =

#calculate the noise difference  between the user input and existing nodes
#first make a new list container
#also find the smallest difference, which might be useful later(nsd = noise smallest difference)
nsm = 200 #starting value is 200
noise_differences = []
for x in range(len(noise_r)):
	noise_difference = abs((user_noise-noises_r[x]))
	if noise_difference < nsm:
		nsm = noise_difference
```

```
#add the weight factor to the noise_difference
	noise_difference = noise_difference * wn
#check the noise of the neighbours of the current element
	neighbour_noise =
#add the noise of the neighbours as well for 25%
	noise_difference = noise_difference + neighbour_noise
#now append all the values to the noise_differences list
#check to see whether this category needs to be clustered or not
	if noisecluser = False:
		noise_difference = neg(noise_difference)
	noise_differences.append(noise_difference)

#since this is the first time checking the difference we can directly append to the qualifications list
qualifications.append(noise_difference)

#use the same procedure for the other 2 variables (pollution, function)
#only difference now is that instead of appending the values, they need to be added
for x in len(qualifications):
	qualifications[x]= qualifications[x] + function_difference

#Check to see whether the user wanted a house or not
if user_house:
	#if true use the same procedure as before except the numbers are inverted as a larger distance would favor a house more
	#(and the final relation is based on the lowest qualifications)
	#append the values
else:
	#also use the same procedure and don't invert the numbers
	#append the values

#Check the most optimal relation, which is the lowest number in the qualifications list
optimal_relation = qualifications.index(min(qualifications))
#now the optimal relation should have an open left or right neighbour slot
if shop(optimal_relation)[leftneighbour] == 0 or shop(optimal_relation)[rightneighbour] == 0:
```

```
        #if this is true the new value becomes the current shop
        if shop(optimal_relation)[leftneighbour] == 0 :
                shop(optimal_relation)[leftneighbour] = currentshop
                else:
                        shop(optimal_relation)[rightneighbour] = currentshop
#if it is not true the second best option has to be found, this process continues until a slot is filled

#write the variables of the new shop (all the user inputs) to the excel database
#add the most optimal relation (e.g.'2-4') to list with relations


#check whether squares need to be build
square_amount = 5
#separate the shops which are build from the shops that still have to be build
for shop in shops:
        if shop_build = False:
                notbuild.append(shop)
#check if there could be a square by counting the elements in the not build list
if len(notbuild) < square_amount:
        #if it’s smaller do nothing, else check if an amount of shops (square_amount) under the same category are connected
        #This can be done with a while loop, as long as the next neighbour is also the same category, continue
else:
        same_category = True
        count = 1
        while same_category:
                if:
                        count = count +1
                else:
                        same_category = False
#now check if the count is higher than or equal to the square_amount
        if count >= square_amount:
                #assign the property 'square' to the shops in question
                #write the properties to excel
```

#now the excel file can be read by the magnetizing floor plan generator plugin for grasshopper

Pseudocodes part 2 - Generate Basic Floorplan

This part of the pseudocode is about generating the basic shape of the bazaar, from the output generated in step 2 (list of relations between elements). This is done using a magnetizing plugin, which allows for the input of relations and room areas to generate different iterations of how the bazaars shape could be formed, see figure 2. This step is still a work in progress and might, in the end, require a lot of manual work.

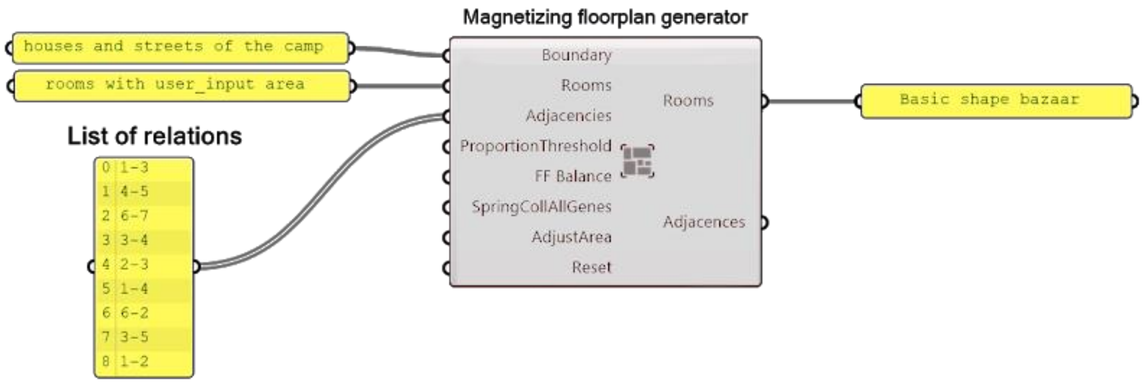


Figure 2: Pseudocodes part 2 - Optimal Relation Database

Pseudocodes part 3 - Transforming basic floorplan into form finding basis

This part of the pseudocode is about transforming the basic geometry into a more refined geometry which could be used for the form finding. This transformation is done using shape grammar. Shape grammar is a method which is able to define certain geometry (left hand shape) and transform this geometry using rules into a transformed geometry (right hand shape).

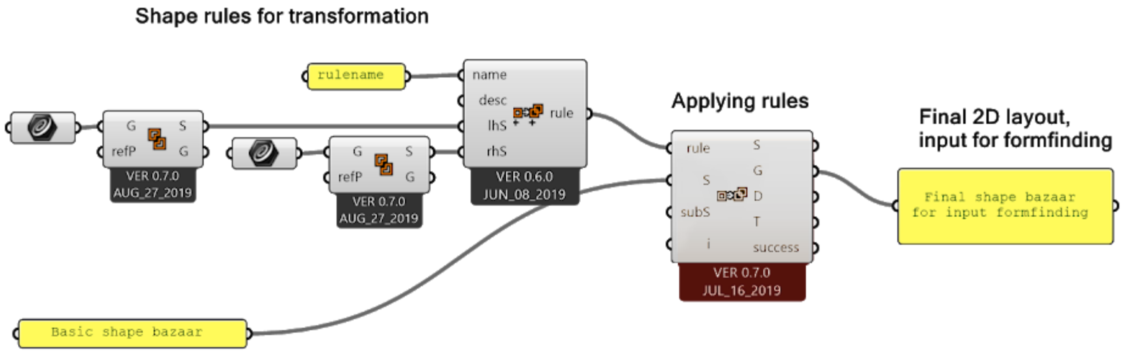


Figure 3: Pseudocodes part 3 - Transforming basic floorplan into form finding basis

Python script

This section describes in detail what the bazaar building script does. To put it very brief, the script allows the simulation of a bazaar with only a few starting nodes to grow and expand taking user input after user input and visualising this growth. The way the bazaar expands is thus dependant on the user input (different input will expand the bazaar differently), but also on the implementation of the guidelines for expanding (set by the group) and the weight the administrator (e.g. Camp director/ Unicef) gives the different guidelines.

The way this is done can roughly be divided into three different parts: Pre-python, python and post-python. Pre-python is mainly focused on providing all the information needed for the script to run properly. Some of these processes could also be performed in python, but since the knowledge on how to do them in grasshopper was already present it was chosen to do that part in grasshopper instead of in python.
The python part takes up the least space on the grasshopper canvas but has the most power, this part takes all necessary input and mathematically gives the most optimal locations for a new shop as output and adds the chosen location to the bazaar, after which another shop can be chosen. This process is simulated using random input for user input and running a for-loop in the main python component.
The post-python part is again something that might have been possible within python itself, but the knowledge for doing it in grasshopper was already present, thus it made more sense doing it in grasshopper. The post-python part handles the data so it can be visualised in the rhino viewport and it can be exported into , for example, excel.

Pre-python

The first step in the pre-python part is to take all the curves (drawn manually in Rhino) and import them into grasshopper. Then they can be divided using the width of one small shop, creating points. The script then identifies whether a point lies on a street, is a junction (this happens if a point is duplicate because two lines meet) is in a square (point in curves) or if the point is an end-point (end of a curve which is not duplicate). The points are split in their X, Y and Z coordinates and put in one single string separated by commas and fed into python. The reason they are put into one single string is because at this very early stage, we didn't know how to feed a grasshopper list to python.

Another important part of the pre-python phase, is the importing of the excel data, which contains the data necessary to get the bazaar started. This data is written using the rows as shops and the columns containing the data for: Shop number, function, noise, pollution, house Y/N, distance to the nearest house.

Also, the admin input (weight factors for various guidelines) is given as input in the pre-python phase. The admin input goes from -100 to 100, where a 0 implies the guideline is neglected, a negative number implies the guidelines is reversed and a positive number implies the guideline is implemented 'normally'. The admin weight factors are: noise, function, pollution, distance to the nearest house.

Lastly, in the pre-python phase is the slider that regulates the amount of iterations, this slider controls the number of times the for-loop is run and by changing the slider, the bazaar will visually grow.

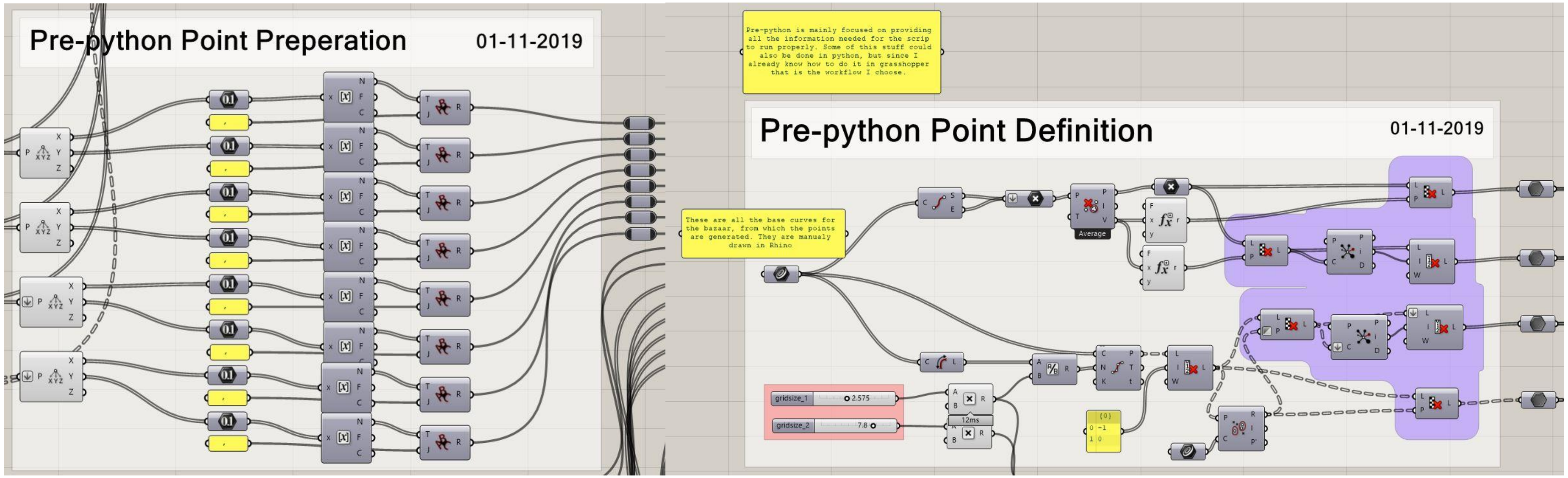


Figure 4: Pre-python: Point preperation and definition.

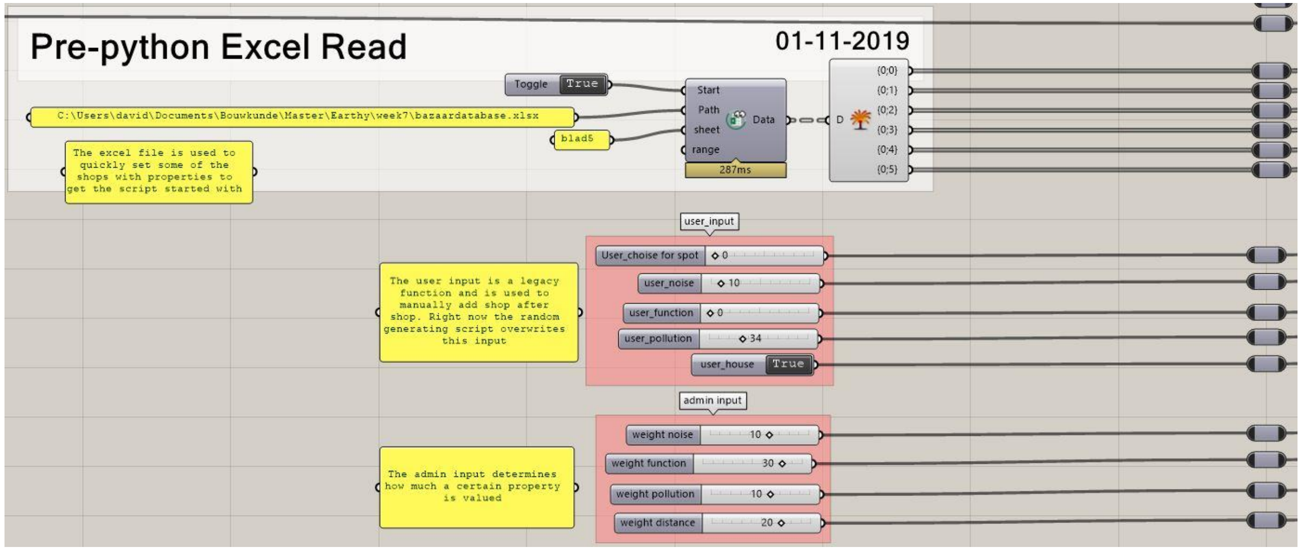


Figure 5: Pre-python: Excel reading and admin input (also user input but this is a legacy function).

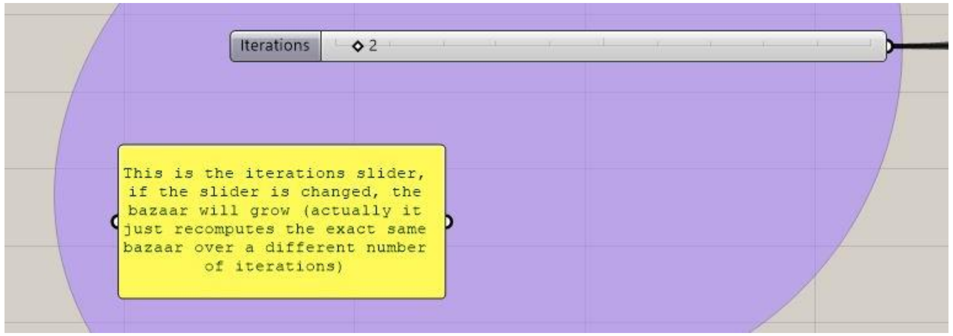


Figure 6:: Pre-python: Iterations slider.

Python

The second step is the python script, which consists of two parts, one part that generates the random input and the main script, which generates the bazaar. The following text is the code description of the main script.. The full python script can be found in appendix G-2.

Short description of the script:

This script takes points as input and makes shop objects using the class Shop
on all of those points. Then those shops are all empty except for the starting shops,

which are set to occupied and values for function, pollution, distance to the nearest house, and noise are added
with this as a starting position, a series of random input determine new shops that are added to the bazaar
these new shops will be appointed 5 top locations from which one is selected
these locations are found by computing the difference between the previously mentioned values of the new shop and all existing ones
keep in mind that only the difference between neighbouring available slots (empty slots next to occupied slot) and new shops are taken into account
Those differences are then multiplied by a factor determined by the admins (weigh factors)
And also they are multiplied by a factor which is computed using the distances between the 2 shops
One of the 5 locations is chosen and the new shop is set to occupied and the values are added
As a last step the distances for a shop to the nearest house are recomputed
In a newer version the user also has the option to choose a size, small medium or large
A large or medium shop will in essention 'just' fill multiple small slots

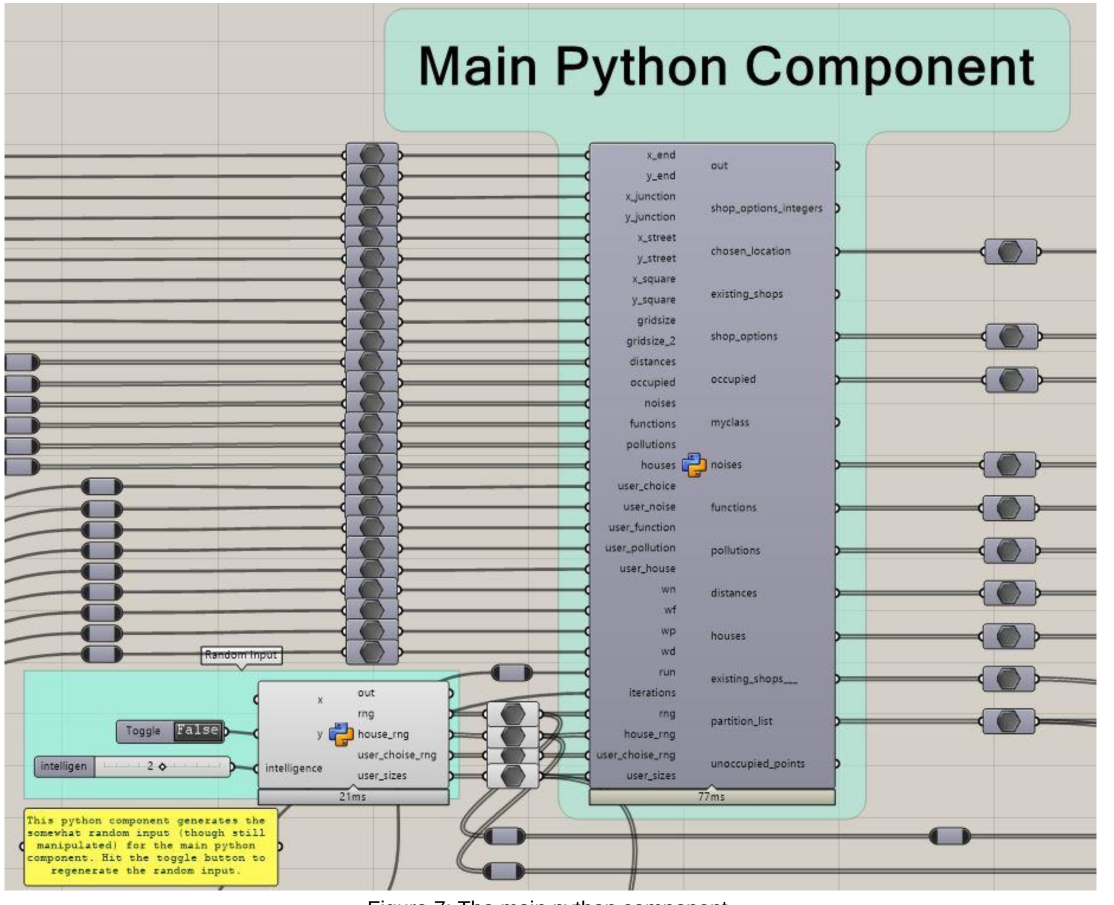


Figure 7: The main python component.

Post-Python

The post-python part focuses on presenting the results of the python script and visualising them. There are three main things to visualise, the shops themselves (rectangles), the information on the shops (function, type-category, house) and stats such as a pie chart showing additional information. Next to the visualisation data is handled and written into the same excel file the data was read from before. Lastly, a small script was found which captures the viewport for easy capturing of frames from which gifs could be made.

The visualisation of the shops is conducted by taking the individual small shops from the python component, together with a partition list. This partition list tells grasshopper which small shops to group into big shops. Then, once grouped, the outline can be found from the grouped shops to make one big or medium size shop. The small shops obviously remain untouched. In this way, the build shops, the new shop options and the chosen option are all visualised in this way.

The visualisation of the information on the shops also take the partition list as input. This is because we don't want the information duplicated for every point in the shop (big shops consist of 4 points for example) but just the first point. Also the function type list is used to provide different colors for every function type.

The visualisation of the pie-chart, extra information and a title is done using a grasshopper plugin called proving ground. This plugin draws information (including charts) directly to your rhino viewport using bounds of your viewport and a relative subdivision of those bounds.

Other than the visualization, the post-python part handles the writing of data into the same excel file that was used to read from before in the pre-python part. This is a legacy function, as it was originally used to add new shops manually, writing them to the excel file and then reading from that same excel file again, thus creating a loop. However, since the introduction of the automated generation of the bazaar, such a function was no longer needed. Should we in a later stage still decide to go back to this manual process, switching back is relatively easy.

Lastly, the post-python part is able to capture your rhino viewport, using a script that was found from: https://discourse.mcneel.com/t/capturing-rhino-layout-viewport-iterations-print-or-image-export/51387
This makes it very easy to capture every step in the process and afterwards make a gif from it.

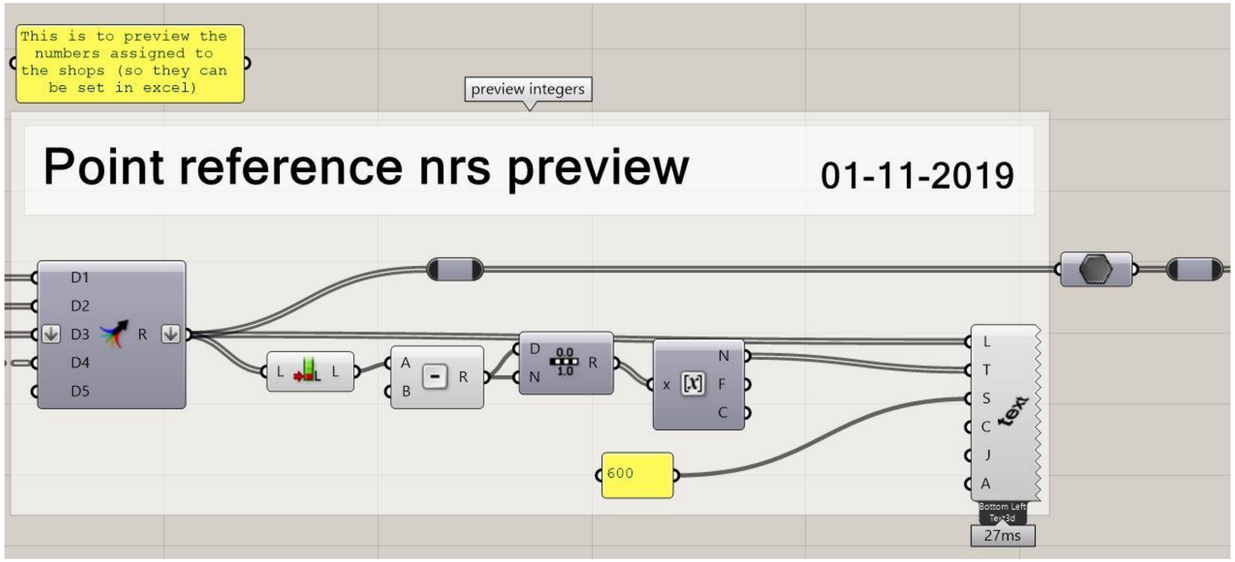


Figure 8: Point nrs preview.

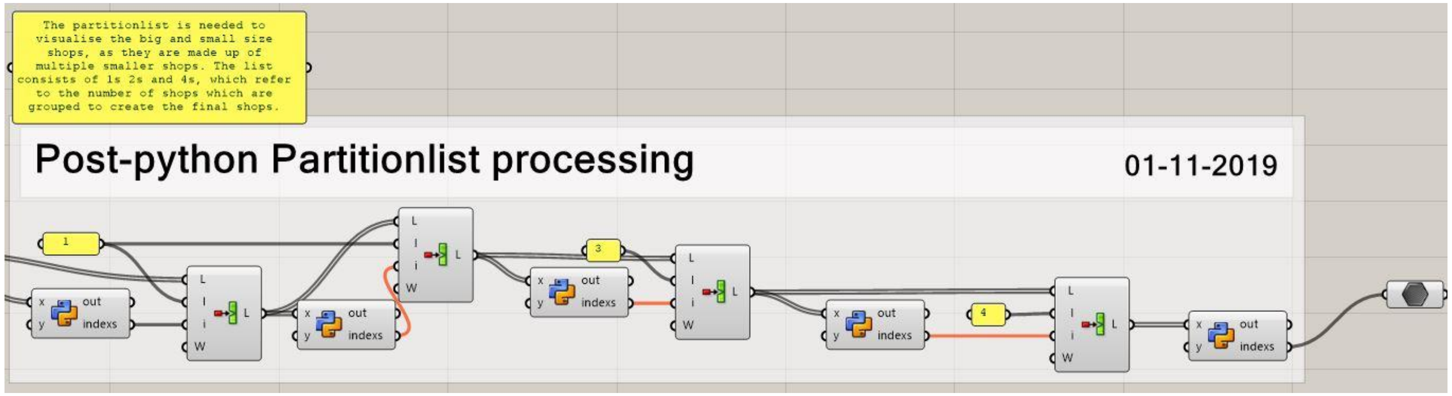


Figure 9: post-python partition list processing.

Figure 10: post-python excel write.

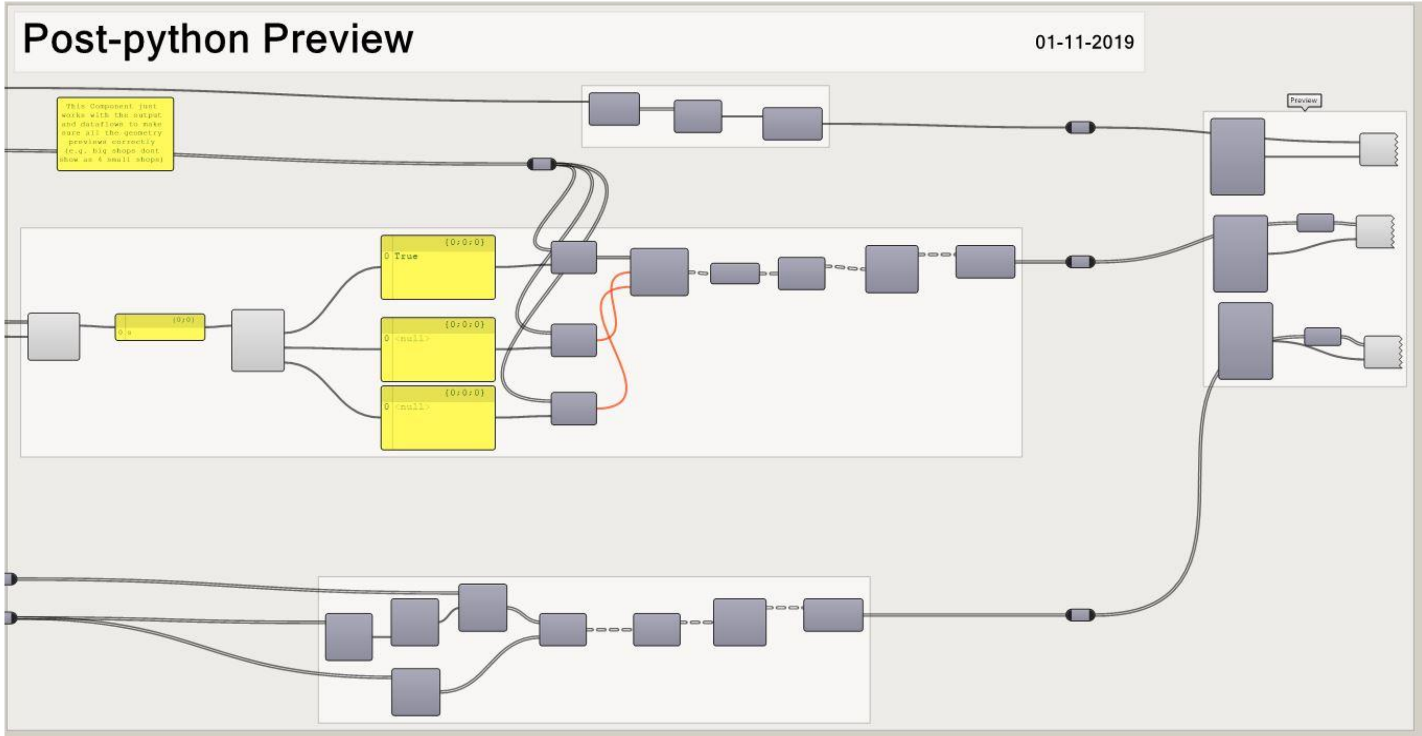


Figure 11: post-python preview the shops.

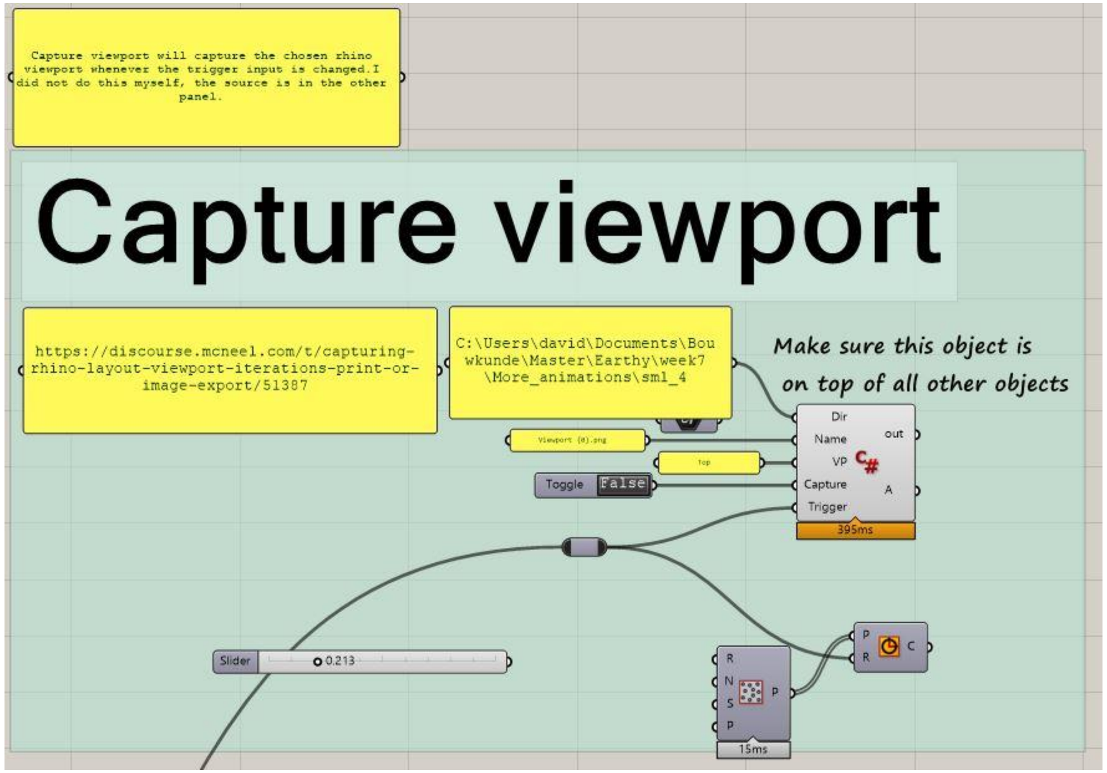


Figure 12: post-python capture viewport.

Capabilities of the script

This part describes what the script it capable of doing. Explaining this is incredibly hard to do without having a video playing in the background. For this reason, a YouTube channel was created: https://www.youtube.com/channel/UCcnWt3PzNn9uVaEwcG3JTjw?view_as=subscriber .
This channel contains all the gifs needed for explaining the capabilities of the script.

Firstly, the script is able to cluster the different shop types together. All shops are clustered under 4 main functions: Community shops, Food stores, Merchandise shops and workshops. In the following gifs, the script shows what happens when shops are added one after another keeping in mind only that similar shops should be clustered or should be mixed:

https://www.youtube.com/watch?v=T4aMi96csTk
https://www.youtube.com/watch?v=4B81WBI6M5Y

Secondly, the script is able to cluster houses, or better even, spread them. Spreading houses is important to ensure social security everywhere in the bazaar. This is extremely important because crime rates are high and we don't want to facilitate this. The following videos show the clustering and spreading of the houses (here portrayed as an 'H' but in other scripts portrayed as a '+' sign):

https://www.youtube.com/watch?v=ASMnQkHUvGg
https://www.youtube.com/watch?v=wxM0E8ReKoU

Thirdly, the script is able to cluster on pollution and noise. Every shoptype (community, food, merchandise, workshop) has different shops and they produce different pollution and noise levels. The specific shop (bakery, metalworker etc) is shown and a small grey number. Pollution and noise clustering looks at the pollution and noise levels of two shops and tries to place a new shop as close to shops that generate a similar level of pollution and noise, since this will give the least amount of nuisance.

https://www.youtube.com/watch?v=EZSZN71CWvQ
https://www.youtube.com/watch?v=VGv-Su2RAgw

Besides the above functions, the script is also able to: Take distance into account when computing any difference between two shops, take into account that community shops have priority to be in junctions, take into account that community shops and workshops have a priority to be placed in a square.

In all of the above gifs, the only input counted is the one from the respective function. In the next gifs, the admin input is set to be a mix of all of them in the following proportions:

- noise: 1
- function: 3
- pollution: 1
- social security: 2

The result of these settings can be found in the following gif:

https://www.youtube.com/watch?v=w2bgWDnUGKw

However, in this gif, the user always picks the most optimal choice. In this way, the guidelines are very well visible, but once the user is presented with more choices, the guidelines will start to fade:

https://www.youtube.com/watch?v=Ha5yTuymoCc
https://www.youtube.com/watch?v=jIbEymdZLoQ\

https://www.youtube.com/watch?v=sqCFAN3XdH8

In a later stage of the design, as previously discussed, the possibility to add different sizes shops were added, which resulted in the following possible scenarios (although more scenarios could have easily been generated):

https://www.youtube.com/watch?v=a81oicidSHw
https://www.youtube.com/watch?v=Fs9XW__E2-E
https://www.youtube.com/watch?v=GI_g5briYKs
https://www.youtube.com/watch?v=csdpcxVV7j0

After this, the script was done, and its output could then (theoretically) be linked to the form finding script. A gif was created to illustrate this process, but because of a lack of time, the actual linking of the two scripts was never done:

https://www.youtube.com/watch?v=y7WUJzq-yG0

Limitations of the script

Although a lot of time was spent into developing this script, there are still a few limitations the script has. First of all, there is the junctions. THe script is not able to connect the street with the junction perfectly, as in our real design, the junction is a lot bigger and deviates from the grid of the shopsize width. Secondly, no walkways are added and the script does not prioritise finishing both sides of the streets, as there was simply no time to implement this. Thirdly, due to the certain randomness the script organises the modules, they will (once form found) not match perfectly. This could be fixed in a later version but would take too much time at this instance. Lastly the script could be written a whole lot more efficiently.

Possible scenario's

These are the final generated scenarios when the different shopsizes were added. They are the same as in the above gifs, but provide 4 still images for closer observation.

Figure 11: A scenario of a built bazaar using 3 different shopsizes, the 1/3/1/2 admin settings and the user who choses from the top 3 spots.

Figure 12: A scenario of a built bazaar using 3 different shopsizes, the 1/3/1/2 admin settings and the user who choses from the top 3 spots.

Figure 13: A scenario of a built bazaar using 3 different shopsizes, the 1/3/1/2 admin settings and the user who choses from the top 3 spots.

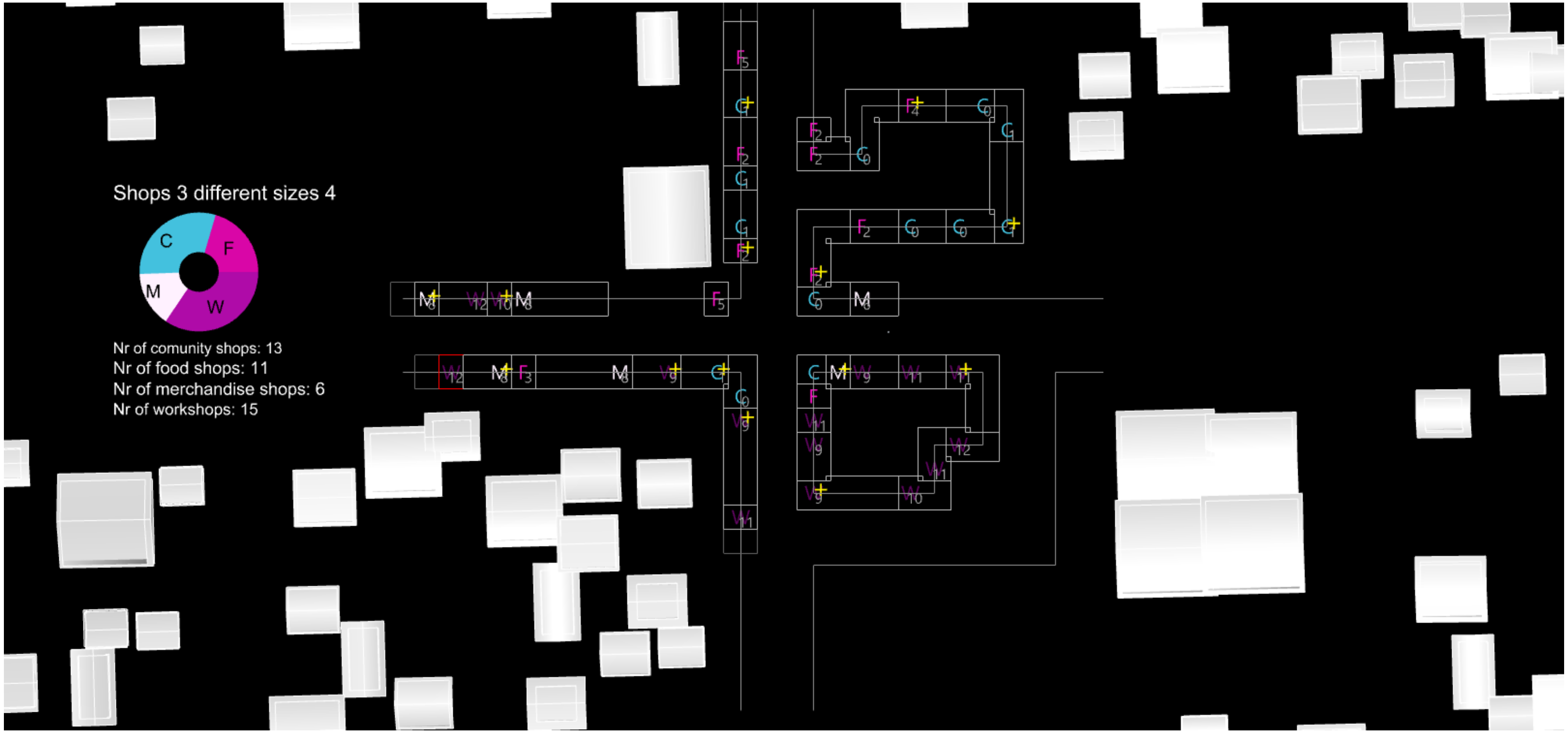


Figure 14: A scenario of a built bazaar using 3 different shopsizes, the 1/3/1/2 admin settings and the user who choses from the top 3 spots.

Appendix G-2: Python script Youtube

All GIFs and movies regarding Karamba, inflatable mould and configuration of all scenarios can be found in the below link on YouTube:

https://www.youtube.com/channel/UCcnWt3PzNn9uVaEwcG3JTjw/videos

Appendix G-3: Python script

NOTE: Some of the indentation seems to be missing or barely visible, please refer to the actual python code which will be on the gitlab.

```
__author__ = "David den Ouden"
__version__ = "01.11.2019 Final"

import rhinoscriptsyntax as rs
import math
import decimal
import random
import time
from math import sqrt

"""
Short description of the script:
    This script takes points as input and makes shop objects using the class Shop
    on all of those points. Then those shops are all empty except for the starting shops,
    which are set to occupied and values for function, pollution, distance to nearest house, and noise are added
    with this as a starting position, a series of random input determine new shops that are added to the bazaar
    these new shops will be appointed 5 top locations from which one is selected
    these locations are found by computing the difference between the previously mentioned values of the new shop and all existing
ones
```

```
	keep in mind that only the difference between neighbouring available slots (empty slots next to occupied slot) and new shops are
taken into account
	Those differences are then multiplied by a factor determined by the admins (weigh factors)
	And also they are multiplied by a factor which is computed using the distances between the 2 shops
	One of the 5 locations is chosen and the new shop is set to occupied adn the values are added
	As a last step the distances for a shop to the nearest house are recomputed

	In a newer version the user also has the option to choose a size, small medium or large
	A large or medium shop will in essention 'just' fill multiple small slots
"""

class Shop:
	"""This class will be used to make objects based on points, which are then;
	'shops' these shops have certain variables and can be either occupied or empty"""
	def __init__(self, x, y, type):
	self.x = x
	self.y = y
	self.type = type
	self.occupied = False
	self.house = False
	self.noise = None
	self.function = None
	self.pollution = None
	self.distance = None
```

```
def get_point(self):
"""represent the point the shop is located as a list [x,y,z]"""
self.point = [self.x, self.y, 0]
return self.point

def set_occupied(self):
"""make the shop actually real"""
self.occupied = True

def find_neighbour_points(self, gridsize, gridsize_2, point=None):
"""find all possible neighbour (using gridsizes) points
although some may be imaginary and return them as a list"""
if point:
point_1 = [(point[0]+gridsize),point[1],point[2]]
point_2 = [(point[0]-gridsize),point[1],point[2]]
point_3 = [point[0],(point[1]+gridsize),point[2]]
point_4 = [point[0],(point[1]-gridsize),point[2]]
point_5 = [(point[0]+gridsize_2),point[1],point[2]]
point_6 = [(point[0]-gridsize_2),point[1],point[2]]
point_7 = [point[0],(point[1]+gridsize_2),point[2]]
point_8 = [point[0],(point[1]-gridsize_2),point[2]]
possible_neighbours = []
possible_neighbours.append(point_1)
possible_neighbours.append(point_2)
possible_neighbours.append(point_3)
```

```
possible_neighbours.append(point_4)
possible_neighbours.append(point_5)
possible_neighbours.append(point_6)
possible_neighbours.append(point_7)
possible_neighbours.append(point_8)
return possible_neighbours
else:
 return None

def find_neighbour_points_4(self, gridsize, gridsize_2, point=None):
"""find all possible direct neighbours (using gridsizes)
points although some may be imaginary and return them as a list"""
if point:
      point_1 = [(point[0]+gridsize),point[1],point[2]]
point_2 = [(point[0]-gridsize),point[1],point[2]]
point_3 = [point[0],(point[1]+gridsize),point[2]]
point_4 = [point[0],(point[1]-gridsize),point[2]]
possible_neighbours = []
possible_neighbours.append(point_1)
possible_neighbours.append(point_2)
possible_neighbours.append(point_3)
possible_neighbours.append(point_4)
return possible_neighbours
else:
return None
```

```
    def draw_shop(self, point, shop = None, xaxis = None):
    """visualize the shop by drawing the rectangle;
    this should also depend on wether its a junction or another type of shop"""
z = (0,0,1)
    w = 2575
    if shop.type != "junction":
    if xaxis[1] == 1:
            point = (point[0]+1800, point[1]+w/2, 0)
            plane = rs.PlaneFromNormal(point, z, xaxis)
            w = -1 *w
            chosen_location = rs.AddRectangle( plane, w, 3600 )
    else:
            point[0] = point[0] -w/2
            point[1] = point[1] -1800
            plane = rs.PlaneFromNormal(point, z, xaxis)
            chosen_location = rs.AddRectangle( plane, w, 3600 )
    else:
    if xaxis == "dl":
            point = (point[0]-w/2, point[1]-w/2, 0)
            plane = rs.PlaneFromNormal(point, z)
            chosen_location = rs.AddRectangle( plane, 3087.5, 3087.5)
    elif xaxis == "ul":
            point = (point[0]-w/2, point[1]+w/2, 0)
            plane = rs.PlaneFromNormal(point, z)
```

```
        chosen_location = rs.AddRectangle( plane, 3087.5, -3087.5)
elif xaxis == "ur":
        point = (point[0]+w/2, point[1]+w/2, 0)
        plane = rs.PlaneFromNormal(point, z)
        chosen_location = rs.AddRectangle( plane, -3087.5, -3087.5)
    else:
        point = (point[0]+w/2, point[1]-w/2, 0)
        plane = rs.PlaneFromNormal(point, z)
        chosen_location = rs.AddRectangle( plane, -3087.5, 3087.5)
return chosen_location

def add_values(self,noise,function,pollution,distance):
"""add the values of an existing shop"""
self.noise = noise
self.function = function
self.pollution = pollution
self.distance = distance

def find_distances(self,points):
"""find the distances from a shop (wether empty or not) to a list of points"""
distances = []
for point in points:
distance = sqrt(abs(self.x - point[0])*abs(self.x - point[0])+ abs(self.y - point[1])*abs(self.y - point[1]))
distances.append(distance)
return distances
```

```
def set_house(self):
"""set an occupied shop to have a house on top"""
self.house = True

def find_xaxis(self,point, neighbourpoints, all_points, shop):
"""find the axis of the street the shop is on, this is different for a junction shop
as they need to be oriented in two directions"""
real_shops = []
neighbourpoints_r = []
for pnt in neighbourpoints[0:4]:
if pnt in all_points:
	real_shops.append(pnt)
if shop.type == "junction":
if point[0] - real_shops[0][0] > 0 or point[0] - real_shops[1][0] > 0:
	if point[1] - real_shops[0][1] > 0 or point[1] - real_shops[1][1] > 0:
	xaxis = "dl"
	else:
	xaxis = "ul"
else:
	if point[1] - real_shops[0][1] > 0 or point[1] - real_shops[1][1] > 0:
	xaxis = "dr"
	else:
	xaxis = "ur"
elif point[0] - real_shops[0][0] == 0:
```

```
        xaxis = (0,1,0)
        else:
        xaxis = (1,0,0)
        return xaxis

def find_integers_nbs(points, shops):
        """if you have a point of a shop, this method finds the integer(s) of the corresponding shops"""
        shop_index = []
        if points:
        for point in points:
        for index, shop in enumerate(shops):
                if point[0] == shop.x and point[1] == shop.y:
                shop_index.append(index)
                else:
                pass
        return shop_index
        else:
        return None

def remap(list, high=100):
        """remap all numbers in a list to a maximum value, the default is 100"""
        remapped_nrs = []
        for item in list:
        remapped = ((item-min(list))/(max(list)-min(list))) *high
        remapped = int(round(remapped))
```

```
        remapped_nrs.append(remapped)
        return remapped_nrs


#make nice python lists
x_end = (x_end.split(","))
y_end = (y_end.split(","))
x_junction = x_junction.split(",")
y_junction = y_junction.split(",")
x_street = x_street.split(",")
y_street = y_street.split(",")
x_square = x_square.split(",")
y_square = y_square.split(",")


#make every lists integers
x_end = list(map(int, x_end))
y_end = list(map(int, y_end))
x_junction = list(map(int, x_junction))
y_junction = list(map(int, y_junction))
x_street = list(map(int, x_street))
y_street = list(map(int, y_street))
x_square = list(map(int,x_square))
y_square = list(map(int,y_square))
occupied = list(map(int, occupied))
```

```
noises = list(map(int, noises))
functions = list(map(int, functions))
pollutions = list(map(int, pollutions))
distances = list(map(int, distances))

#remap some of the functions to a range of 0-100
noises_r = remap(noises)
functions_r = remap(functions)
pollutions_r = remap(pollutions)
distances_r = remap(distances)

#make shops from class Shop and append them to empty list
shops = []
for i in range(len(x_street)):
	shop= Shop(x_street[i],y_street[i],"street")
	shops.append(shop)
for i in range(len(x_end)):
	shop= Shop(x_end[i],y_end[i],"end")
	shops.append(shop)
for i in range(len(x_junction)):
	shop= Shop(x_junction[i],y_junction[i],"junction")
	shops.append(shop)
for i in range(len(x_square)):
	shop= Shop(x_square[i],y_square[i],"square")
	shops.append(shop)
```

```
#import the shops that are already occupied
#assign all the remapped values (noise,pollution,function, distance) for the shops that are occupied
#also assign a house if the shop has one
for index, i in enumerate(occupied):
    shops[i].set_occupied()
    shops[i].add_values(noises_r[index],functions_r[index],pollutions_r[index],distances_r[index])
    if houses[index] == 'yes':
    shops[i].set_house()
    else:
    pass

#find all possible points in lists of [x,y,z] to be used later
all_shop_points = []
for shop in shops:
    pnt = shop.get_point()
    all_shop_points.append(pnt)


#draw existing shops
existing_shops___ =[]
for shop in shops:
    if shop.occupied:
    point = shop.get_point()
    nbpnts = shop.find_neighbour_points(gridsize, gridsize_2, point)
```

```
        xaxis = shop.find_xaxis(point, nbpnts, all_shop_points, shop)
        rectangle = shop.draw_shop(point,shop, xaxis)
        existing_shops___.append(rectangle)
        else:
        pass

#multiply the weighfactors
#(for some reason the distance weight for social security outweighted all others)
wn = wn**2
wf = wf**2
wp = wp**2
wd = wd**0.25



#make a partition list and add the first 3 shops (which are already defined in the excel file)
partition_list = [1,1,1]

#now start a loop that generates the bazaar based on rng provided by a seperate python script
#this is to prevent the random numbers to be regenerated everytime the number of iterations is changed

############################################################
### HERE STARTS THE FOR LOOP THAT GENERATES AUTO ####
############################################################

if run:
```

```
for nr in range(iterations):
#checking the usershop size

user_size = user_sizes[nr]

#getting a random number to essentially choose from a catalogue
random_nr = rng[nr]
#teashop
if random_nr == 0:
user_noise = 40
user_pollution = 30
user_function = 0
user_choice = user_choise_rng[nr]
house = house_rng[nr]
if house == 0:
        user_house = 'yes'
else:
      user_house = 'no'
#restaurant
elif random_nr == 1 or random_nr == 13:
user_noise = 70
user_pollution = 40
user_function = 0
user_choice = user_choise_rng[nr]
house = house_rng[nr]
```

```
if house == 0:
        user_house = 'yes'
else:
        user_house = 'no'
#herb_store
elif random_nr == 2:
user_noise = 20
user_pollution = 20
user_function = 1
user_choice = user_choise_rng[nr]
house = house_rng[nr]
if house == 0:
        user_house = 'yes'
else:
        user_house = 'no'
#vegetable_store
elif random_nr == 3:
user_noise = 10
user_pollution = 30
user_function = 1
user_choice = user_choise_rng[nr]
house = house_rng[nr]
if house == 0:
        user_house = 'yes'
   else:
```

```
        user_house = 'no'
#bakery
elif random_nr == 4:
user_noise = 40
user_pollution = 30
user_function = 1
user_choice = user_choise_rng[nr]
house = house_rng[nr]
if house == 0:
        user_house = 'yes'
else:
        user_house = 'no'
#butcher
elif random_nr == 5:
user_noise = 50
user_pollution = 50
user_function = 1
user_choice = user_choise_rng[nr]
house = house_rng[nr]
if house == 0:
        user_house = 'yes'
else:
        user_house = 'no'
#fabrics
elif random_nr == 6:
```

```
user_noise = 20
user_pollution = 10
user_function = 2
user_choice = user_choise_rng[nr]
house = house_rng[nr]
if house == 0:
	user_house = 'yes'
else:
	user_house = 'no'
#pharmacy
elif random_nr == 7:
user_noise = 10
user_pollution = 40
user_function = 2
user_choice = user_choise_rng[nr]
house = house_rng[nr]
if house == 0:
	user_house = 'yes'
else:
	user_house = 'no'
#phonestore
elif random_nr == 8:
user_noise = 20
user_pollution = 0
user_function = 2
```

```
user_choice = user_choise_rng[nr]
house = house_rng[nr]
if house == 0:
        user_house = 'yes'
else:
      user_house = 'no'
#coppersmith
elif random_nr == 9:
user_noise = 80
user_pollution = 50
user_function = 3
user_choice = user_choise_rng[nr]
house = house_rng[nr]
  if house == 0:
        user_house = 'yes'
else:
        user_house = 'no'
#blacksmith
elif random_nr == 10:
user_noise = 100
user_pollution = 70
user_function = 3
user_choice = user_choise_rng[nr]
house = house_rng[nr]
if house == 0:
```

```
        user_house = 'yes'
else:
        user_house = 'no'
#furnature
elif random_nr == 11:
user_noise = 80
user_pollution = 100
user_function = 3
user_choice = user_choise_rng[nr]
house = house_rng[nr]
if house == 0:
        user_house = 'yes'
    else:
        user_house = 'no'
#pottery
elif random_nr == 12:
user_noise = 30
user_pollution = 60
user_function = 3
user_choice = user_choise_rng[nr]
house = house_rng[nr]
if house == 0:
        user_house = 'yes'
else:
        user_house = 'no'
```

```
#remap the 'user'input
user_noise_r = user_noise
user_pollution_r = user_pollution
user_function_r =  ((user_function-min(functions))/(max(functions)-min(functions))) *100



#find all shops that are not occupied
#check to see wether these open slots are actually adjecent to an already built shop = available
occupied_points = []
available_shops = []
unoccupied_points = []
possible_points_m = []
possible_points_m_p = []
possible_points_l = []
m_points = []
for o in occupied:
occupied_points.append(shops[o].get_point())
for ix,shop in enumerate(shops):
if shop.occupied == False:
        point = shop.get_point()
        unoccupied_points.append(point)
        #find the neighbouring points of these points and see if any belong to an already built shop
        if user_size == "s":
```

```
            nbs = shop.find_neighbour_points(gridsize,gridsize_2,point)
            check = False
            for neighbour in nbs:
            if neighbour in occupied_points:
                        check = True
            if check == True:
               available_shops.append(ix)
            #so now the hard part, if the shopsize is not small,
            #we should not append it to available shops directly but to a seperate list
            if user_size == "m" or user_size == "l":
            nbs = shop.find_neighbour_points(gridsize,gridsize_2,point)
            check = False
            for neighbour in nbs:
            if neighbour in occupied_points:
                        check =True
            if check == True:
            possible_points_m.append(ix)
            m_point = shop.get_point()
            possible_points_m_p.append(m_point)

#now we can run over the seperate list and check if they have an available neighbour
if user_size == "m" or user_size == "l":
for index in possible_points_m:
            pnt = shops[index].get_point()
            nbps = shops[index].find_neighbour_points_4(gridsize,gridsize_2,pnt)
```

```
check_m = False

for nb in nbps:
if nb in unoccupied_points:
check_m = True
possible_points_l.append(nb)
m_points.append(pnt)
if check_m == True:
        break
if user_size == "m":
if check_m == True:
available_shops.append(index)
"""
if user_size == "l":
if check_m == True:
m_points.append(pnt)
"""

#if the user size is large, the empty neighbour needs to have 2 more empty neighbours
#to create a sequence of 4 empty slots where at least one is adjecent to an occupied slot
#now it is also important to make sure that all these 4 slots are unique so its not a chain of 2 slots that are counted twice
if user_size == "l":
possible_shops_l = find_integers_nbs(possible_points_l, shops)
m_shops = find_integers_nbs(m_points,shops)
for middle,index,available in zip(m_points,possible_shops_l,m_shops):
```

```
        pnt = shops[index].get_point()
    nbps = shops[index].find_neighbour_points_4(gridsize,gridsize_2,pnt)
        middle_point = middle

        check_l = False
        for nb in nbps:
        if nb in unoccupied_points and nb != middle_point:
            check_l = True
        l_point = nb
        if check_l == True:
                break
        l_shop = find_integers_nbs([l_point],shops)
        nbps_2 = shops[l_shop[0]].find_neighbour_points_4(gridsize,gridsize_2,l_point)
        check_l2 = False
        for nb_2 in nbps_2:
        if nb_2 in unoccupied_points and nb_2 != pnt:
        check_l2 = True
        if user_size == "l":
        if check_l == True and check_l2 == True:
        available_shops.append(available)



#draw existing shops
   existing_shops =[]
```

```
for shop in shops:
if shop.occupied:
        available_points = []
        for indexx in available_shops:
        pnt = shops[indexx].get_point()
        available_points.append(pnt)
        point = shop.get_point()
        nbpnts = shop.find_neighbour_points(gridsize, gridsize_2, point)
        xaxis = shop.find_xaxis(point, nbpnts, all_shop_points, shop)
        rectangle = shop.draw_shop(point,shop, xaxis)
        existing_shops.append(rectangle)
else:
        pass

#now for every every element we should compute the distance to occupied slots as a list
#(in a future version i would like to check only the distanes within a certain range, but for now this isnt necassary)
#and then after immidiately check the most optimal spot based on the difference between noise function pollution and
#house distance and as a function of the previously computed distances between the new shop and all existing shops
slot_qualifications = []
flag = False
length_loop = len(available_shops)

for i in available_shops:
distances_occupied = shops[i].find_distances(occupied_points)
for index__,distance in enumerate(distances_occupied):
```

```
        if distance > 50000:
        distances_occupied[index__] =50000
d = remap(distances_occupied,10)
for index_,distance in enumerate(d):
        d[index_] = (10 -distance)/10
qualifications = []
   for j,x in enumerate(occupied):
        noise_difference = (abs(user_noise_r-shops[x].noise) * wn *d[j] )
        qualifications.append(noise_difference)
        function_difference = (abs(user_function_r-shops[x].function) *wf *d[j])
        qualifications.append(function_difference)
        pollution_difference = (abs(user_pollution_r-shops[x].pollution) * wp * d[j])
        qualifications.append(pollution_difference)
        if user_house == 'yes' and shops[x].house == False:
        qualifications.append((shops[x].distance * wd*-1 *d[j]))
        elif user_house == 'yes' and shops[x].house == True:
        qualifications.append((shops[x].distance * wd * d[j] ))
        elif user_house == 'no' and shops[x].house == True:
        qualifications.append((shops[x].distance * wd*-1 *d[j]))
        else:
        qualifications.append((shops[x].distance * wd * d[j] ))

qualifications = sum(map(float,qualifications))
#now apply a bonus factor if a community shop [0] is going to occupy a junction
#also apply a negative factor if any shop but community is going to occupy a junction
```

```
    if user_function == 0:
            if shops[i].type == 'junction':
            qualifications = qualifications * 0.75
    else:
            if shops[i].type == 'junction':
            qualifications = qualifications * 1.25
    #now apply a bonus factor if a community or workshop [0/3] is going to occupy a square
    #also apply a negative factor if any shop but community is going to occupy a square
    if user_function == 0 or user_function == 3:
            if shops[i].type == 'square':
            qualifications = qualifications * 0.75
    else:
       if shops[i].type == 'square':
            qualifications = qualifications * 1.25
    slot_qualifications.append(qualifications)

    #find the top 5 locations
    user_shop_integers = []
    user_shop_integer_1 = slot_qualifications.index(min(slot_qualifications))
    user_shop_integers.append(user_shop_integer_1)
  slot_qualifications[user_shop_integer_1] = 1000000000
    user_shop_integer_2 = slot_qualifications.index(min(slot_qualifications))
    user_shop_integers.append(user_shop_integer_2)
  slot_qualifications[user_shop_integer_2] = 1000000000
    user_shop_integer_3 = slot_qualifications.index(min(slot_qualifications))
```

```
    user_shop_integers.append(user_shop_integer_3)
slot_qualifications[user_shop_integer_3] = 1000000000
    user_shop_integer_4 = slot_qualifications.index(min(slot_qualifications))
    user_shop_integers.append(user_shop_integer_4)
slot_qualifications[user_shop_integer_4] = 1000000000
    user_shop_integer_5 = slot_qualifications.index(min(slot_qualifications))
    user_shop_integers.append(user_shop_integer_5)

    #visual feedback for the user to know which shop he is chosing
    #make all options visual
    shop_options = []
    shop_options_integers = []
    for k in user_shop_integers:
    rectangles = []
    shop_option_integer = available_shops[k]
    #if the user size isnt small 2 rectangles should be drawn
    if user_size == "m" or user_size == "l":
            mpoint = shops[shop_option_integer].get_point()
            mediumsizes = shops[shop_option_integer].find_neighbour_points_4(gridsize, gridsize_2, mpoint)
            m_real_points = []
            for m in mediumsizes:
            if m in unoccupied_points:
            m_real_points.append(m)
            m_real = find_integers_nbs(m_real_points, shops)
        if m_real:
```

```
        point_2 = shops[m_real[0]].get_point()
        nbpnts_2 = shops[m_real[0]].find_neighbour_points_4(gridsize, gridsize_2, point_2)
        xaxis_2 = shops[m_real[0]].find_xaxis(point_2, nbpnts_2, all_shop_points, shops[m_real[0]])
        rectangle_2 = shops[m_real[0]].draw_shop(point_2, shops[m_real[0]], xaxis_2)
        rectangles.append(rectangle_2)
        shop_options.append(rectangle_2)
#if the usersize is large 4 rectangles should be drawn
if user_size == "l":
        l_real_points = []
        l_point = shops[m_real[0]].get_point()
        m_point = shops[shop_option_integer].get_point()
        largesizes = shops[m_real[0]].find_neighbour_points_4(gridsize, gridsize_2, l_point)
        for l in largesizes:
        if l in unoccupied_points and l != mpoint:
        l_real_points.append(l)

        l_real = find_integers_nbs(l_real_points, shops)
        if l_real:
        point_3 = shops[l_real[0]].get_point()
        nbpnts_3 = shops[l_real[0]].find_neighbour_points_4(gridsize, gridsize_2, point_3)
        xaxis_3 = shops[l_real[0]].find_xaxis(point_3, nbpnts_3, all_shop_points, shops[l_real[0]])
        rectangle_3 = shops[l_real[0]].draw_shop(point_3, shops[l_real[0]], xaxis_3)
        rectangles.append(rectangle_3)
        shop_options.append(rectangle_3)
```

```
    l_real_points_2 = []
    for l2 in nbpnts_3:
    if l2 in unoccupied_points and l2 != l_point:
            l_real_points_2.append(l2)
    l_real_2 = find_integers_nbs(l_real_points_2,shops)
    if l_real_2:
    point_4 = shops[l_real_2[0]].get_point()
    nbpnts_4 = shops[l_real_2[0]].find_neighbour_points_4(gridsize, gridsize_2, point_4)
    xaxis_4 = shops[l_real_2[0]].find_xaxis(point_4, nbpnts_4, all_shop_points, shops[l_real_2[0]])
    rectangle_4 = shops[l_real_2[0]].draw_shop(point_4, shops[l_real_2[0]], xaxis_4)
    rectangles.append(rectangle_4)
    shop_options.append(rectangle_4)

point = shops[shop_option_integer].get_point()
nbpnts = shops[shop_option_integer].find_neighbour_points_4(gridsize, gridsize_2, point)
xaxis = shops[shop_option_integer].find_xaxis(point, nbpnts, all_shop_points, shops[shop_option_integer])
rectangle = shops[shop_option_integer].draw_shop(point, shops[shop_option_integer], xaxis)

rectangles.append(rectangle)
shop_options.append(rectangle)
shop_options_integers.append(shop_option_integer)



#let the user see his current choice (same as visualising all choises but then only for one of the 5)
```

```
#(iknow this could probably be done in the previous loop but ok)
user_integer =user_shop_integers[int(user_choice)]
user_shop = available_shops[user_integer]
chosen_location = []
if user_size == "m" or user_size == "l":
        mpoint = shops[user_shop].get_point()
        mediumsizes = shops[user_shop].find_neighbour_points_4(gridsize, gridsize_2, mpoint)
        m_real_points = []
 for m in mediumsizes:
        if m in unoccupied_points:
        m_real_points.append(m)
        m_real_u = find_integers_nbs(m_real_points, shops)
        if m_real_u:
        point_2 = shops[m_real_u[0]].get_point()
        nbpnts_2 = shops[m_real_u[0]].find_neighbour_points_4(gridsize, gridsize_2, point_2)
        xaxis_2 = shops[m_real_u[0]].find_xaxis(point_2, nbpnts_2, all_shop_points, shops[m_real_u[0]])
        rectangle_2 = shops[m_real_u[0]].draw_shop(point_2, shops[m_real_u[0]], xaxis_2)
        rectangles.append(rectangle_2)
        chosen_location.append(rectangle_2)
        existing_shops___.append(rectangle_2)

if user_size == "l":
l_real_points = []
l_point = shops[m_real_u[0]].get_point()
m_point = shops[user_shop].get_point()
```

```
        largesizes = shops[m_real_u[0]].find_neighbour_points_4(gridsize, gridsize_2, l_point)
    for l in largesizes:
            if l in unoccupied_points and l != mpoint:
            l_real_points.append(l)

    l_real_u = find_integers_nbs(l_real_points, shops)
    if l_real_u:
            point_3 = shops[l_real_u[0]].get_point()
            nbpnts_3 = shops[l_real_u[0]].find_neighbour_points_4(gridsize, gridsize_2, point_3)
            xaxis_3 = shops[l_real_u[0]].find_xaxis(point_3, nbpnts_3, all_shop_points, shops[l_real_u[0]])
            rectangle_3 = shops[l_real_u[0]].draw_shop(point_3, shops[l_real_u[0]], xaxis_3)

            rectangles.append(rectangle_3)
            chosen_location.append(rectangle_3)
            existing_shops___.append(rectangle_3)

            l_real_points_2 = []
            for l2 in nbpnts_3:
            if l2 in unoccupied_points and l2 != l_point:
            l_real_points_2.append(l2)
            l_real_u2 = find_integers_nbs(l_real_points_2,shops)
            if l_real_2:
            point_4 = shops[l_real_u2[0]].get_point()
            nbpnts_4 = shops[l_real_u2[0]].find_neighbour_points_4(gridsize, gridsize_2, point_4)
            xaxis_4 = shops[l_real_u2[0]].find_xaxis(point_4, nbpnts_4, all_shop_points, shops[l_real_u2[0]])
```

```
        rectangle_4 = shops[l_real_u2[0]].draw_shop(point_4, shops[l_real_u2[0]], xaxis_4)
        rectangles.append(rectangle_4)
        chosen_location.append(rectangle_4)
        existing_shops___.append(rectangle_4)

point = shops[user_shop].get_point()
nbpnts = shops[user_shop].find_neighbour_points_4(gridsize, gridsize_2, point)
xaxis = shops[user_shop].find_xaxis(point, nbpnts, all_shop_points, shops[user_shop])
rectangle = shops[user_shop].draw_shop(point, shops[user_shop], xaxis)
chosen_location.append(rectangle)
existing_shops___.append(rectangle)



#This is an important step for the past processing, the partition list will help see which shops
#should be considered as one shop (as large and medium shops are build from multiple small ones)
if user_size == "m":
partition_list.append("2")
elif user_size == "l":
partition_list.append("4")
else:
partition_list.append("1")



#set the chosen shop to occupied
#if the user size is medium or large, set multiple shops to occupied
```

```
shops[user_shop].set_occupied()
occupied.append(user_shop)
if user_size == "m" or user_size == "l":
shops[m_real_u[0]].set_occupied()
  occupied.append(m_real_u[0])
if user_size == "l" :
shops[l_real_u[0]].set_occupied()
occupied.append(l_real_u[0])
shops[l_real_u2[0]].set_occupied()
occupied.append(l_real_u2[0])

#set the chosen shop to house if there is a house
#if the user size is medium or large, set multiple houses
if user_house == 'yes':
shops[user_shop].set_house()
if user_size == "m" or user_size == "l":
        shops[m_real_u[0]].set_house()
if user_size == "l":
         shops[l_real_u[0]].set_house()
         shops[l_real_u2[0]].set_house()
else:
pass

#although this is a legacy function, I might still need this in the future
#append user values to excellist ouput
```

```
#if shopsize is medium or large, append it multiple times
noises.append(user_noise)
functions.append(user_function)
pollutions.append(user_pollution)
if user_size == "m" or user_size == "l":
noises.append(user_noise)
functions.append(user_function)
pollutions.append(user_pollution)
if user_size == "l":
noises.append(user_noise)
functions.append(user_function)
pollutions.append(user_pollution)
noises.append(user_noise)
functions.append(user_function)
pollutions.append(user_pollution)

#find a method to recalculate the housing distances and change the houses
distances = []
houses = []
pnts = []
for l in occupied:
if shops[l].house == True:
        pnt = shops[l].get_point()
         pnts.append(pnt)
for indx,value in enumerate(occupied):
```

```
dstncs = shops[value].find_distances(pnts)
distances.append(min(dstncs))
if shops[value].house == True:
        houses.append('yes')
else:
        houses.append('no')

#add values to chosen shop
#again, if the size is m or l, add values to multiple shops
shops[user_shop].add_values(user_noise_r,user_function_r,user_pollution_r,distances[-1])
if user_size == "m" or user_size == "l":
shops[m_real_u[0]].add_values(user_noise_r,user_function_r,user_pollution_r,distances[-1])
if user_size == "l":
shops[l_real_u[0]].add_values(user_noise_r,user_function_r,user_pollution_r,distances[-1])
shops[l_real_u2[0]].add_values(user_noise_r,user_function_r,user_pollution_r,distances[-1])
distances = list(map(int, distances))
```

Appendix H: 2D Lay-out

In this paragraph, three manual scenario's are made visual in a 3D representation.

Scenario 1

In this scenario (figure 1), the junction is a combined location for community stores. The walkways are clustered per sector. Also, a square is added for workshops and community, which produce low noise. Walkway areas, houses can be added above the shops for the social security.

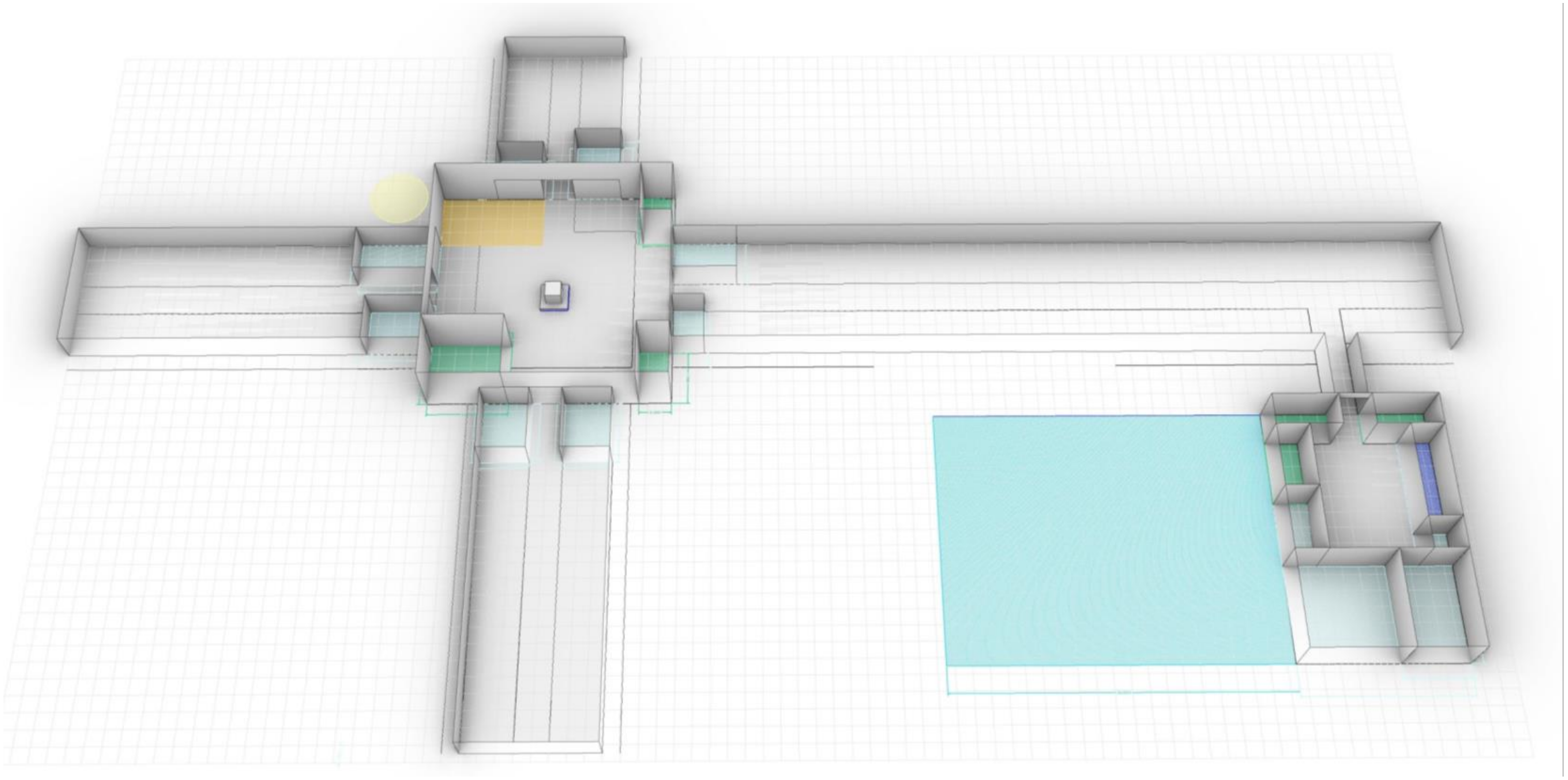


Figure 1: Floor plan - scenario 1

Scenario 2

In this scenario (figure 2), the guidelines are tested; 'what will happen if there are only merchandise stores and they follow the guidelines?' The junction will remain empty and the merchandise stores will come in the street. This can be seen in the picture below. For walkway areas, houses can be added above the shops for the social security.

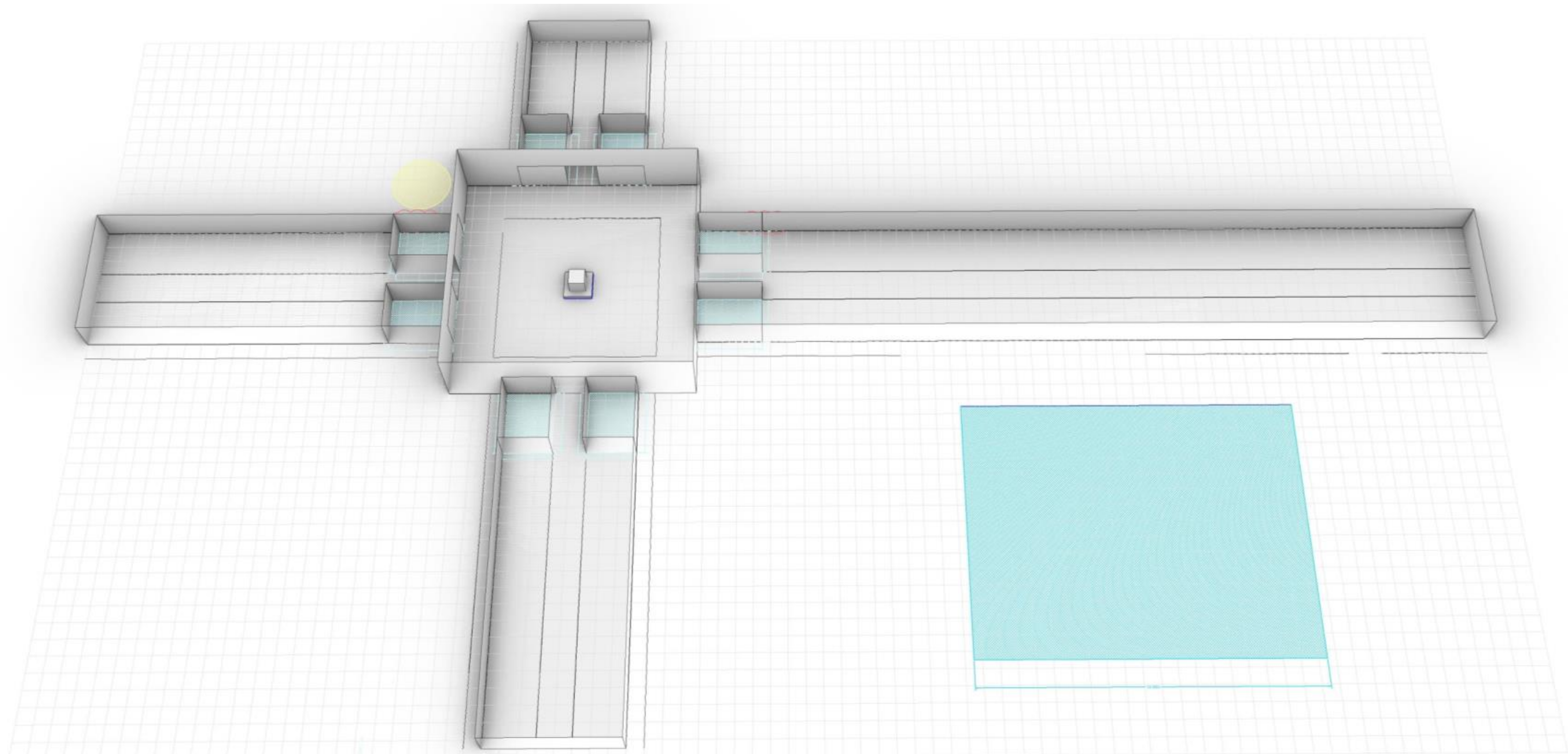


Figure 2: Floor plan - scenario 2

Scenario 3

In this scenario (figure 3), the junction has only community stores as restaurants and teahouses. The walkways are clustered per sector. For walkway areas, houses can be added above the shops for the social security. Also, a square is added for workshops only, this is done for clustering noise.

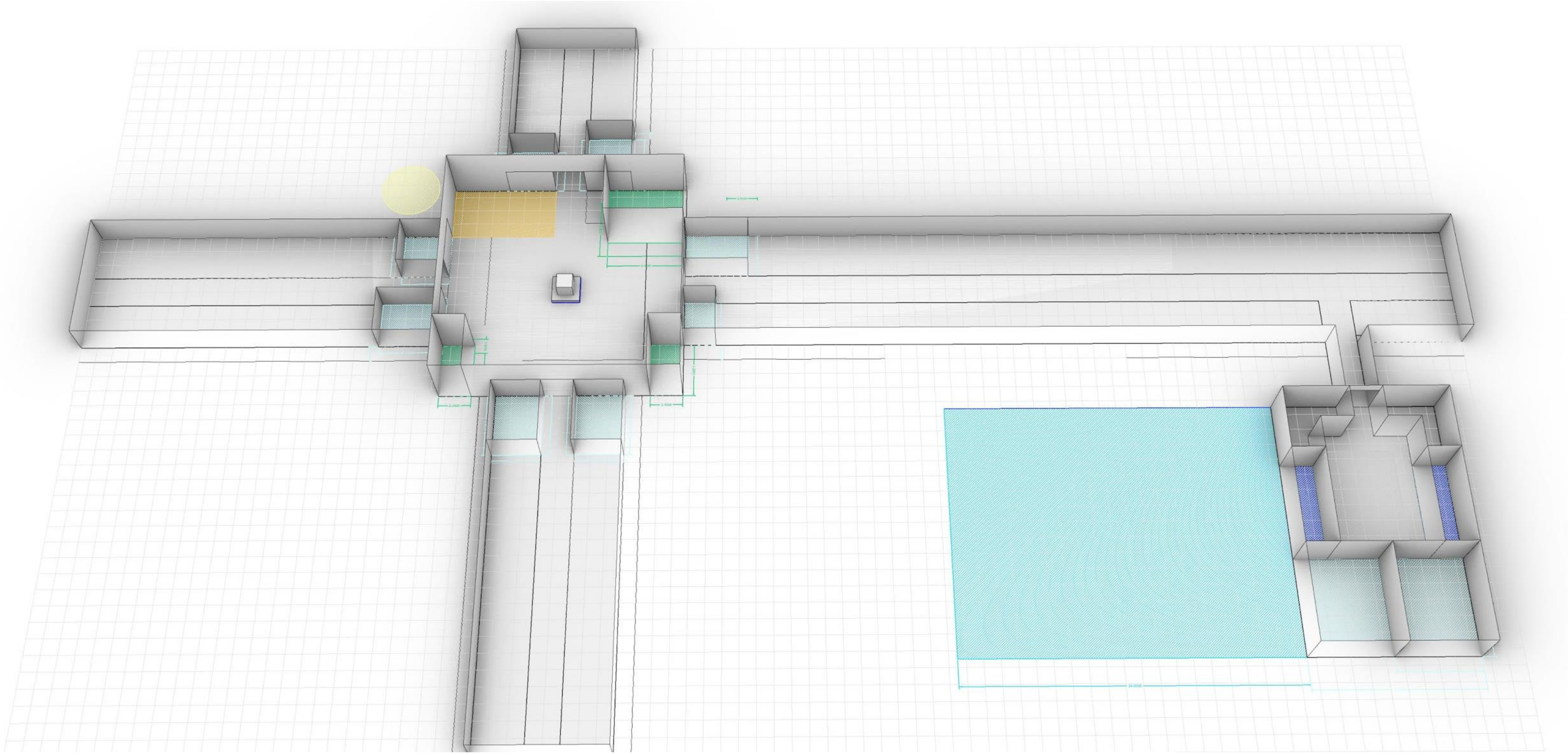


Figure 3: Floor plan - scenario 3

Appendix I: Form finding

Form finding is a forward process in which parameters are explicitly/directly controlled to find an ‘optimal’ geometry of a structure which is in static equilibrium with a design loading, different form finding methods exist:

Stiffness matrix	Natural Shape finding
Geometric stiffness	Force Density Method Surface Stress Density Method Trust Network Analysis
Dynamic equilibrium	Dynamic Relaxation Particle-Spring system

Table 1: Form finding methods

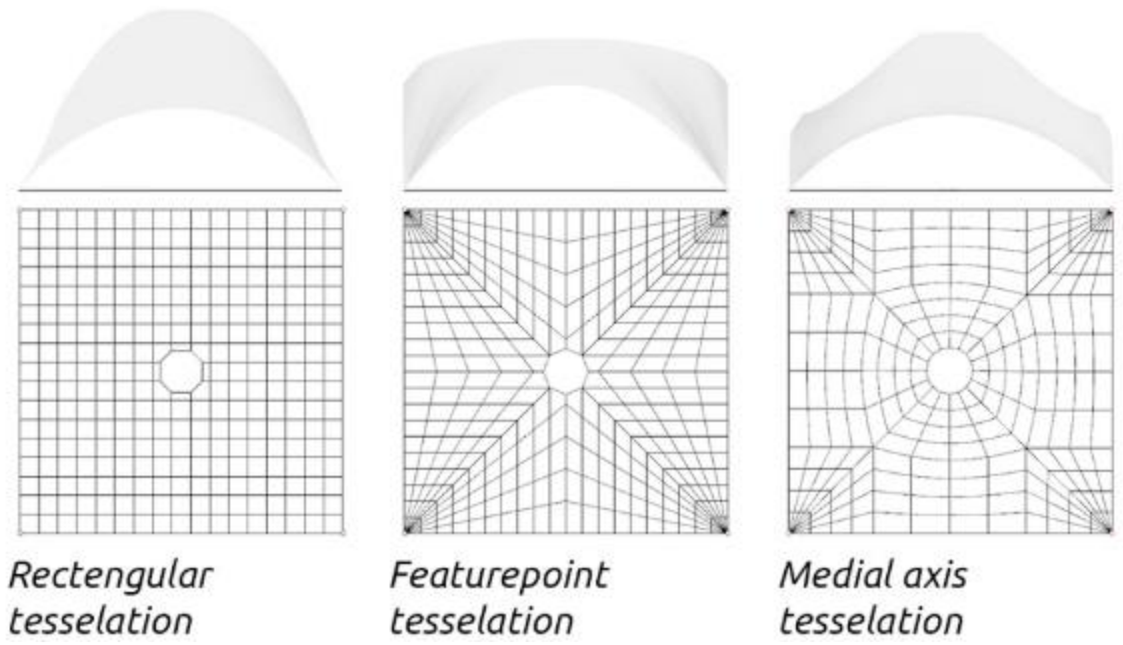
To find the final shape we used the dynamic equilibrium method. (Dynamic Relaxation). The basis dynamic relaxation is to follow step by step, the dynamic behaviour of a structure from the time when it is initially loaded. At a certain time the structure reaches a steady equilibrium state. The damping within a structure happens 'close-coupled' within the structural members. The masses of the structure are assumed to be concentrated at the node points. A further in-depth can be found at the structural appendix. An in-depth on the topology (input) and material optimisation follows later in paragraph ‘Form finding topology to 3D mesh’ and ‘’.

Figure 2: comparison of boundary edges between the Sicli building and The Kresge auditorium. (1)

To apply dynamic relaxation we used a tool made by daniel Piker named Kangaroo. This allowed us to combine it with finite element analysis and the rhino/grasshopper interface. The visual aspect of the form finding was a great addition, and allowed us to understand that shells derive their stiffness from double curvature. When optimizing for deflection you could see the naked edges slightly turned up, providing stiffness. This example is best explained by a reference to existing architecture. Comparing Sicli Company Building, 1970, Geneva with the Kresge Auditorium. Where the Sicli building has a thin edge and the Auditorium required a thick beam to re-enforce the outer edge (Bertin and Trevor, 2013).

Form finding topology to 3D mesh

The topology, which serves as input to the dynamic equilibrium method, defines your outcome. For our formfinding we started with rectangular modular units which allow to be connected. Firstly, the set of guidelines let to constraining the outer boundaries with an un-optimized mesh. Afterwards, we realised we can influence the shape by designing our topology accordingly. The relationship with different types of topology and outcome is shown in figure 1:



First, we started with a regular quad mesh tessellation resulting in a shortest path of force equally distributed across the geometry what you could see is that the outer boundaries were pulled inwards. For a line supported shape this would be the 'optimal mesh'. Due to the fact that we had the outer points as support points and we wanted to keep the naked edge in the same x/y position. We ended up with the featurepoint tessellation, resulting in a rib-like shape. This is mainly like this due to the fact that the shortest path of force from the nodes (intersection of lines) is almost always within the diagonals leading towards the corner points. Another topology we tested is the Medial axis tessellation where the force tends to accumulate in a reinforced ring. Another possibility is to vary the spring stiffness within the form-finding process, but this was relatively hard within the chosen design software.

Figure 1: Three different topologies with their resulting form.

Figure 2 explains the finding of our final form from the input. Basically, we start with a boundary edge, create medial points on the boundary edge from the support points, then create medial axis. Then divide these to create spring lines towards the support points. Then we divided the boundary edge to connect them with the diagonal and medial axis resulting in our final tessellation. Another option was to use the circles to intersect the diagonales resulting into a more quad mesh representing the principle directions. However, as the method we created required more computational power, increasing the time of optimizing our spring stiffness we finally opted to go for a rectangular spacing. This is resulted in our final used topology.

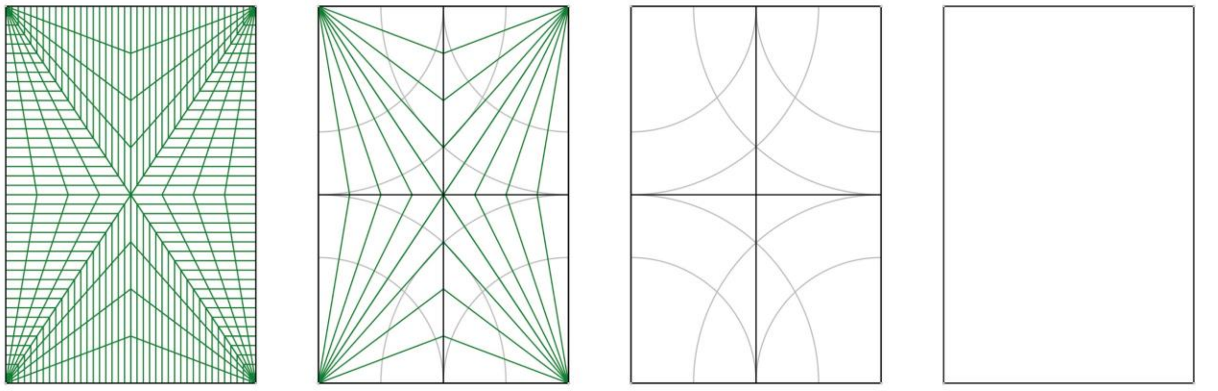


Figure 2: Topology design, From right to left: 1. Input shape with 4 corner supports, 2. Finding medial axis support points, 3. Generating closest lines to supports 4. Final mesh design meeting the three aspects.

Another advantage of opting for the method with the rectangular spacing (non quad-mesh) is that more stress would accumulate in the diagonal edges. Resulting in a shape which is easier to make structurally sound as more stress accumulates in the ribs. When you look at recent research you find several examples. One good example is the funicular floor designed by the block research group, within this process they used form-finding, typology and constructability within the design of funicular structural elements (figure 3).

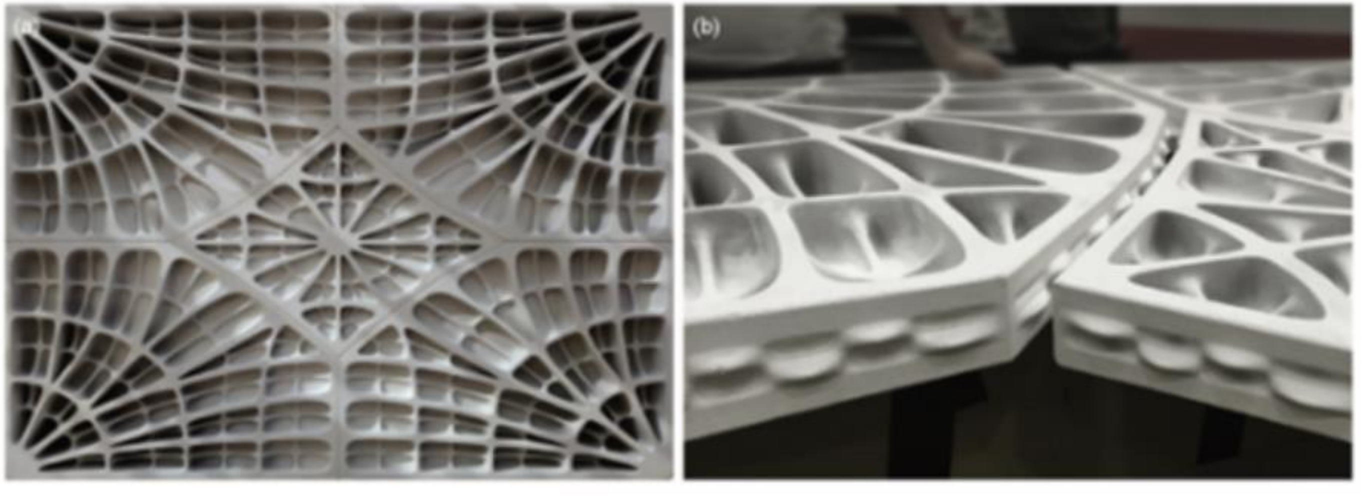


Figure 3: Funicular floor system. Retrieved from Block and Van Mele (2019)

Within the design process of the funicular floor you can clearly see the impact of the used fabrication method on the final topology and floor (maximum sizing of the used sand printer to create the mould). Ending up in the creation of five different elements connected by a dry concrete connection. Or as the paper states: No mechanical connection was used between neighbouring components. As a substitute, the compression dominant structural form of the prototypes allowed for an easy interface design utilizing solely male–feminine interlocking options to ensure alignment (Block and Van Mele, 2019).

Optimizing spring stiffness

An understanding of the relationship between material properties, constructability, dynamic relaxation, and the used spring stiffness came within the design process. Tension within our first forms resulted in the realisation that we had to optimize our spring stiffness in a way that all modular units fitted the material- and structural limits. More about how we did this can be found in paragraph “”

What could we have done differently (topology design)

Better understanding of the constructability constraints and the material properties of clay could have led to a more optimal form. A better understanding of the relationship between material thickness and resulting spring stiffness could have let to a shape which was easier to translate into a constructible dome. While we know that the final constructed product will meet our structural constraints we could have made it closer to the actual product. Modeling the topology with variable spring stiffness could have led to an easier and more accurate translation to the final rib vault. Considering the time of the project (8 weeks) and the knowledge where we started with as a group we could not implement this within our design. Trying to explore the possibilities with variable string stiffness would be a great starting point if we had the same assignment with the knowledge we have now. Resulting in a better relationship between the generated Mesh and the eventual construction.

Sidenote: Making walls thicker is to our advantage for climatic reasons so finding this optimal form would be more ‘optimal’ based on material use and structural requirements.

Appendix J-1 3D Forming

Our final model is based on the found topology named in appendix I, paragraph ‘Form finding topology to 3D mesh’. This one due to his capability to be performed modular and the flexibility it gives to the end user by allowing it to be on four support points. Why making it more complex by four support points is a question we asked ourselves, but the benefits outweigh the disadvantages:

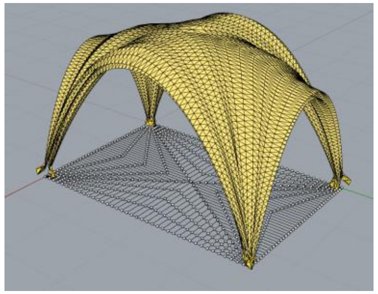
pros:

- Allows use to use the same support structure / structure for different modules (by separating walls and roof structurally)
- Makes it easier to integrate double levels as it allows for separation of structural systems of the first and second floor
- Gives flexibility to the user as walls are non-load bearing
- Gives flexibility to future use, for example store expansion or future uses.

cons:

- Adobe on four support points is structurally more challenging
- Constructability might be harder then wall supported roofs.

By studying the constructability of vault types, we realised that 4-point supported vaults are constructible, What we did realised in the first forms we found, when dynamically relaxing the shape, is that we did not meet the required tension in the second principle direction. Therefore we had to look for a way to improve the outcome of our form finding. otherwise we had to look into other options. We eventually looked into optimizing the spring stiffness and the thickness.



Optimising spring stiffness

On the left you see the outcome of the 3D forming based on the In the dynamic relaxation process the string stiffness is defined by the material and its thickness. (figure 1) It is really hard to calculate the spring stiffness, so we wrote a script which used the results of the finite element analysis to optimize the spring stiffness and material thickness. (figure 2) Hereby we set a constrained the thickness of the structure to the height of the bricks. The script would approximate the 'perfect' spring stiffness for our given modular unit. It was based on a surrogate model optimization solver, More about this script can be found in appendix T 'computational form finding script'.

Figure 1: 3d form outcome

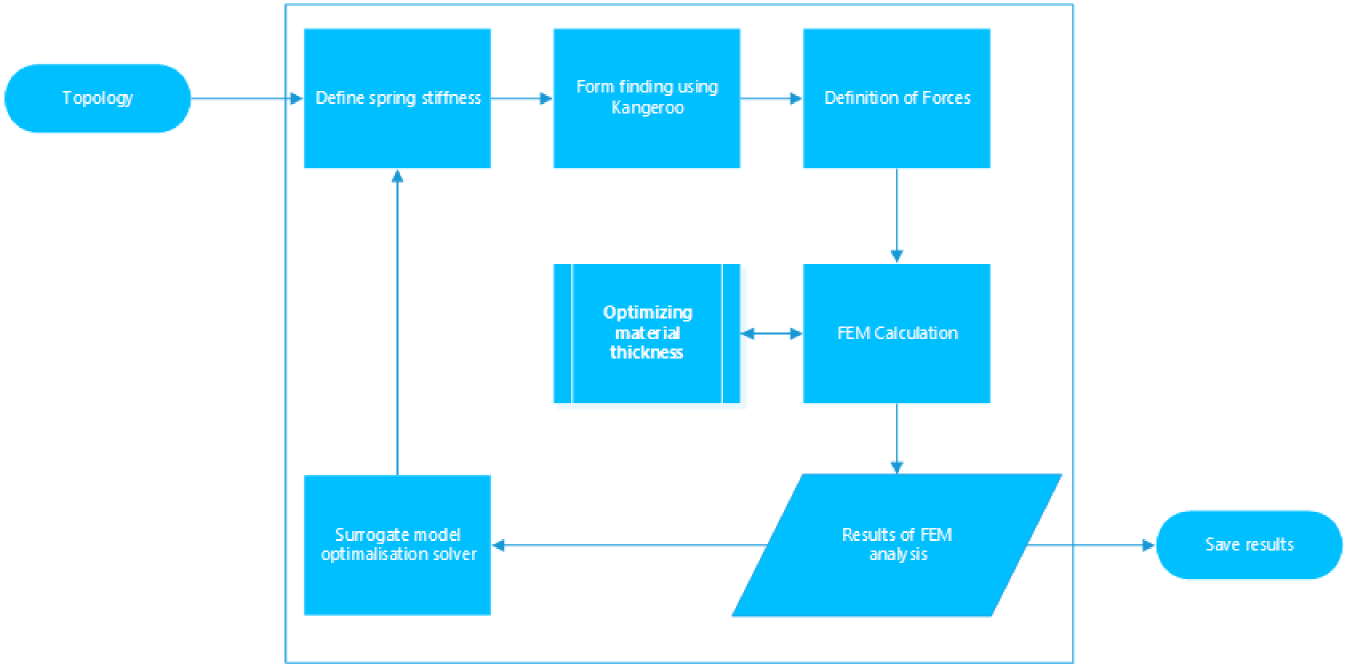
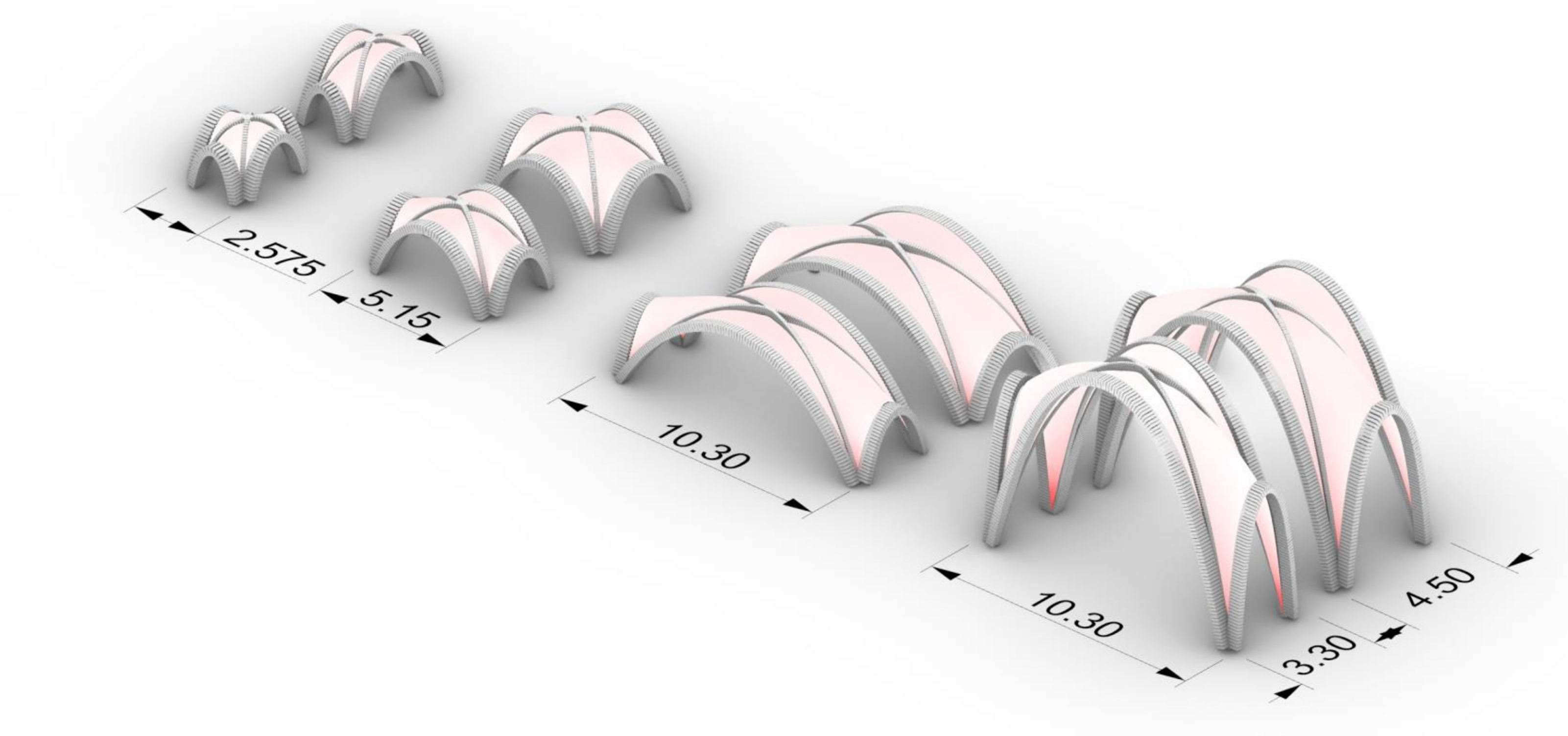


Figure 2: Surrogate based optimalisation of the spring stiffness and material thickness. (saving the best results

The modularity (read as connectability) resulted in working structures for the given floorplans from the configuring part. Walls can be filled in to user preferences allowing freedom to the end user. This separation allows for easier implementation of user preferences within the construction of their store.

Modular units and connectability



Design a grid-based schematic layout of the method

All the modular units (small, medium and large shops) are based on a grid of 2.575 meters. The dimensions of every shop will be shown next:

- Small Shop: 2.575 m x 4.5 m
- Medium Shop: 5.15 m x 4.5 m
- Large shop: 10.3 m x 3.3 m

For structural reasons all the rib vault modules (shops) have an offset of 45 cm to the outside of the structure, which included as part of the grid, as shown in figure 3.

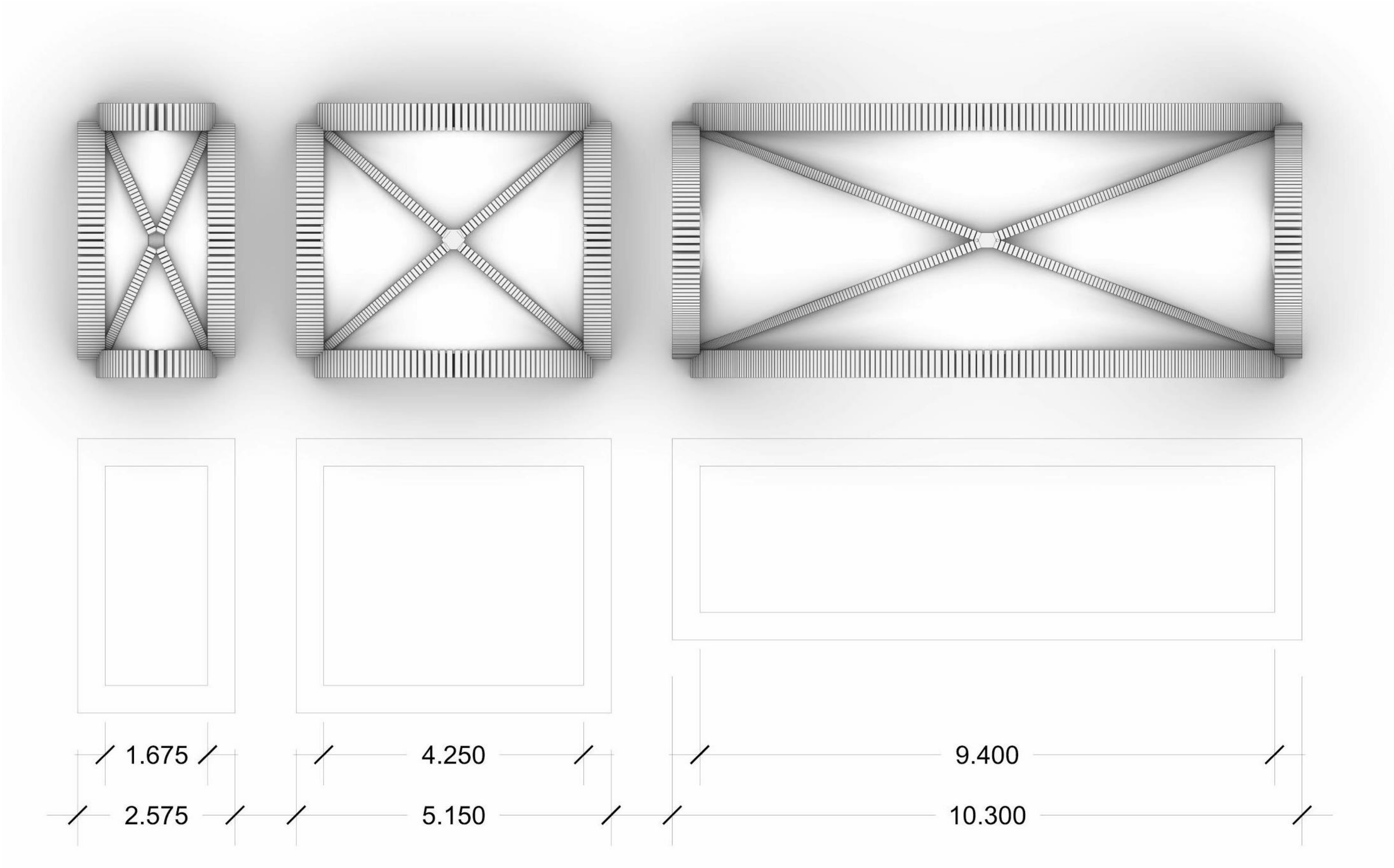


Figure 3: Different shop sizes based on a module of 2.575 including the structural offset.

Relationships Between Shops and Walkways

Large Corridor + Small Shops

One possible outcome in the walkways of the bazaar is the connection between small shops in both ends of the corridors and large walkways, which follow the same length as a large shop. This connection can be observed in figures 4 and 5. The connection between these two different sized volumes gives the possibility to ventilate and illuminate the space in the larger structure as shown in figure 5.

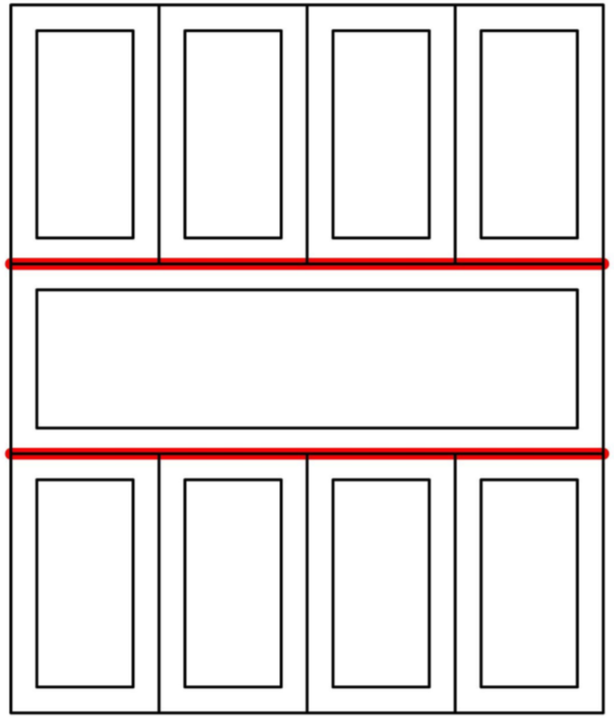


Figure 4: Plan view of the large to small shop relationship.

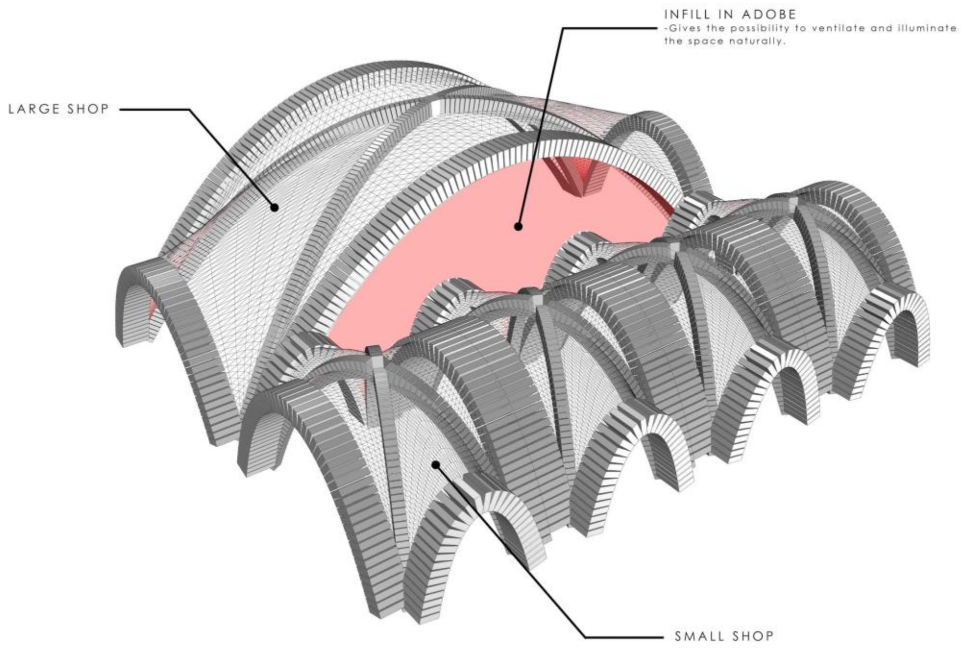


Figure 5: Perspective view of the possible outcome between large and small shop volumes.

Large Corridor + Medium Shop

In this outcome the possibility between large corridor and medium shops are shown. Similarly, to the previous outcome, this outcome gives the possibility to illuminate an ventilate the larger volume naturally due to the empty space that is created when the two different volumes are connected, as seen in figure 7. In figure 6, it can be understood that all the shops are based on a modular grid since it can be observed that two small shops together make a medium shop, and two medium shops make a big shop in length.

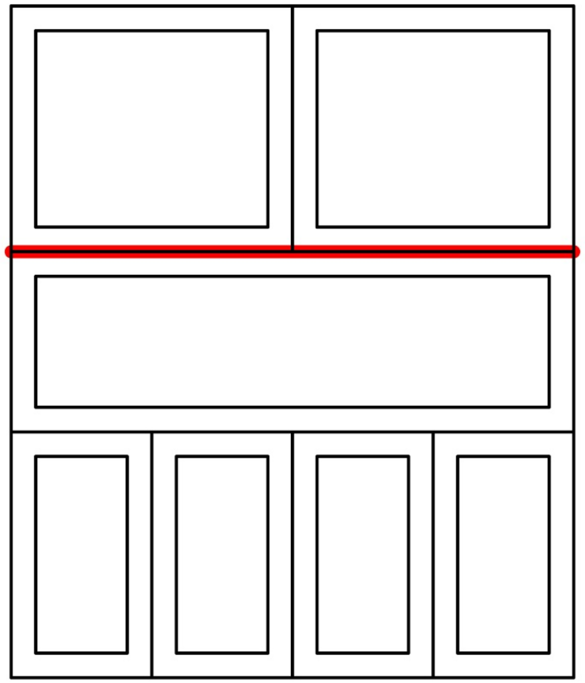


Figure 6: Plan view of the large corridor to medium shop relationship.

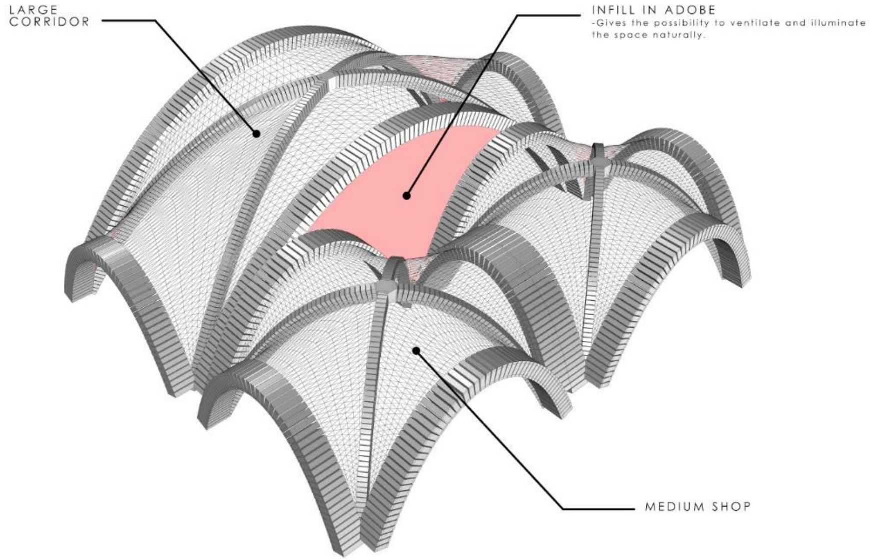


Figure 7: Perspective view of the possible outcome between large corridor and medium shop volumes.

Small Shop + Medium Corridor

This outcome shows the relationship between the medium corridor modules with the small shops. The medium corridors will only be used in the case that a medium shop module is facing either another medium sized module or two small shop modules on the other side of the corridor, as illustrated in figure 8. The same possibility of natural ventilation and illumination is created in the empty space generated in between the connection of a medium corridor and small shops, as shown in figure 9.

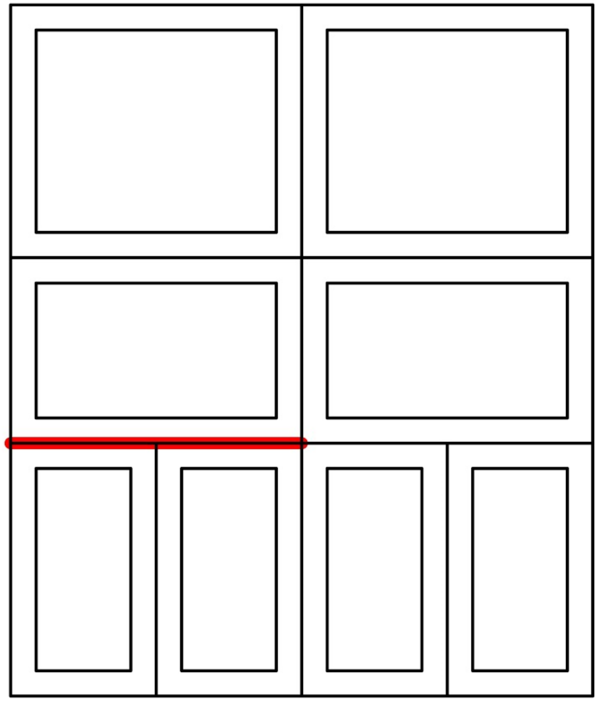


Figure 8: Plan view of the medium corridor to medium and small shop relationship.

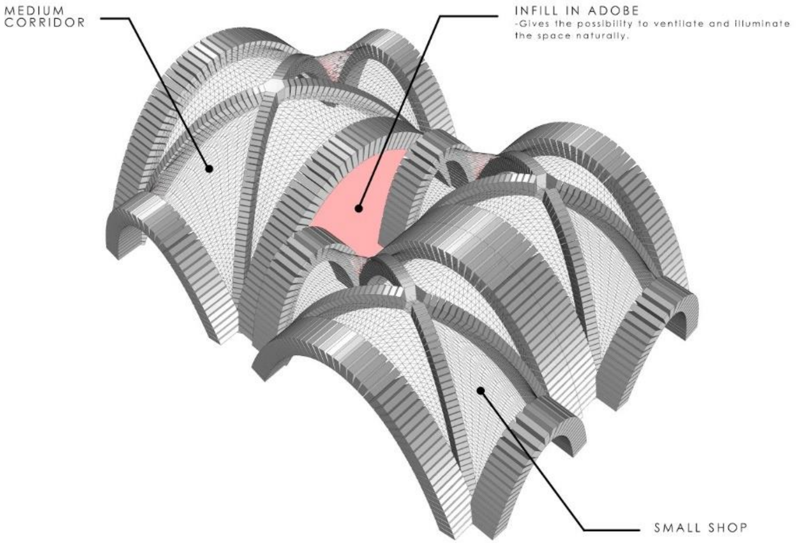
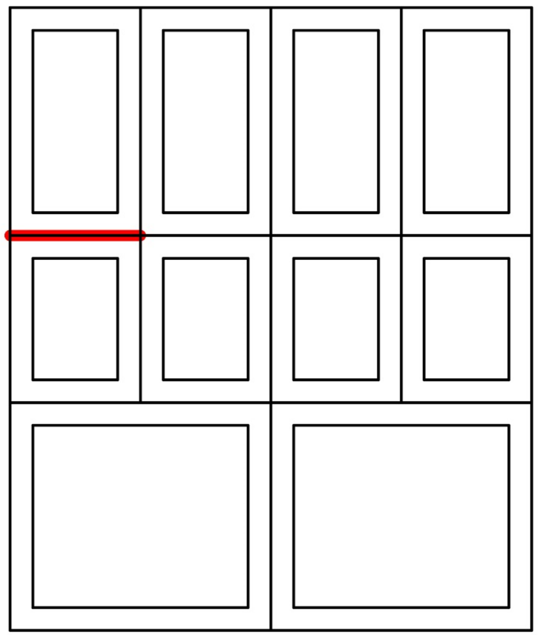


Figure 9: Perspective view of the possible outcome between medium corridor and small shop modules.

<u>Small Shop + Small Corridor</u>

This outcome shows the relationship between a small corridor and a small shop. The small corridors will be used in a scenario in which a shop owner builds up a small shop with no other shops next to it by the time this shop is built. The downside of a small corridor is that it does not allow for natural ventilation or light to come into the structure as the previous corridor modules, but this is compensated by the time a medium or a large corridor is added to the system.



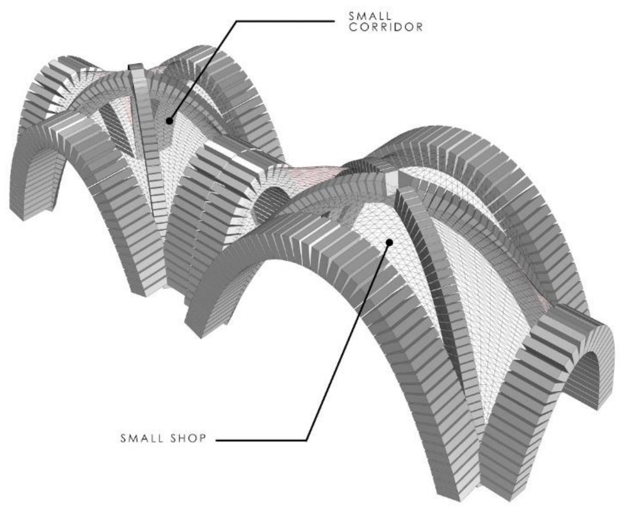


Figure 10: Plan view of the small corridor to small shop relationship.

Figure 11: Perspective view of the possible outcome between small corridor and small shop modules.

Appendix J-2: 3D Forming (old approach)

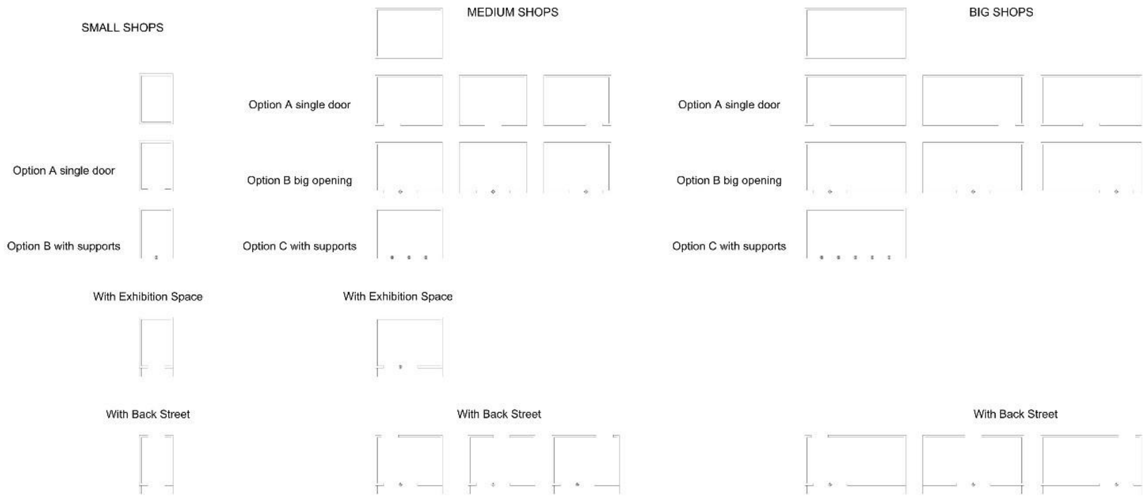


Figure 1:Initial shop layouts used for form finding

Initial Form finding.

To begin with, the shops of different sizes figure 1 were form found with script based on the principle of Particle Spring System. The script involves a custom generated mesh based on the size of shops(plan) which denotes particles and springs. The desired height/form was achieved by controlling the internal and external spring stiffness along with adjusting the force applied to the springs, that are expected to behave as per Hooke's law. Some particles were set as supports and anchors based on the architectural space. As a force is applied the connecting springs starts to oscillate until it reaches equilibrium. The script has been made in a way that every particle is given a force depending on the area it has to carry. Different forms were developed based on our floor plan and ideology. The forms were developed based on modular system of fixed sizes and as per the size of different shops and street which are self-standing or supported by the adjacent ones. The shops were assumed to be separated by non-loadbearing partition walls. Initial design and structural decisions were taken into consideration after group discussions.

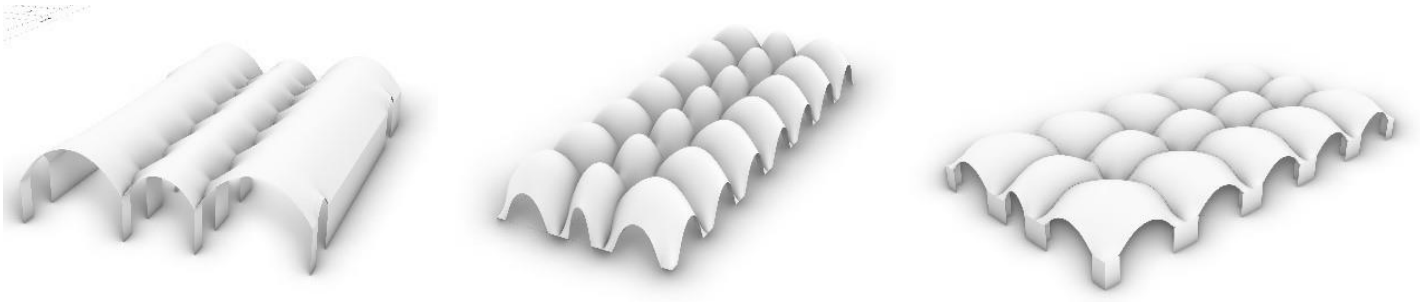


Figure 2: Barrel Vault, Dome supported from the ground and supported with walls (shop modules of 3.6x3.6)

In this paragraph, the shape of the bazaar is explored by utilizing the dynamic relaxation technique. Different scenarios responding to the internal configuration of the bazaar are proposed in order to start giving a specific shape to the building.

This first approach can be later optimized in order to have a more relaxed shape of the building which is also more structurally efficient.

Variant 1: Equal distribution roof grid
In this variant, the anchors of the form finding are based on a 2,4 by 2,4 grid as the factor is 1,2m. This shows modular construction where all shop spaces are equal and have no diversity in program, see figure 1.

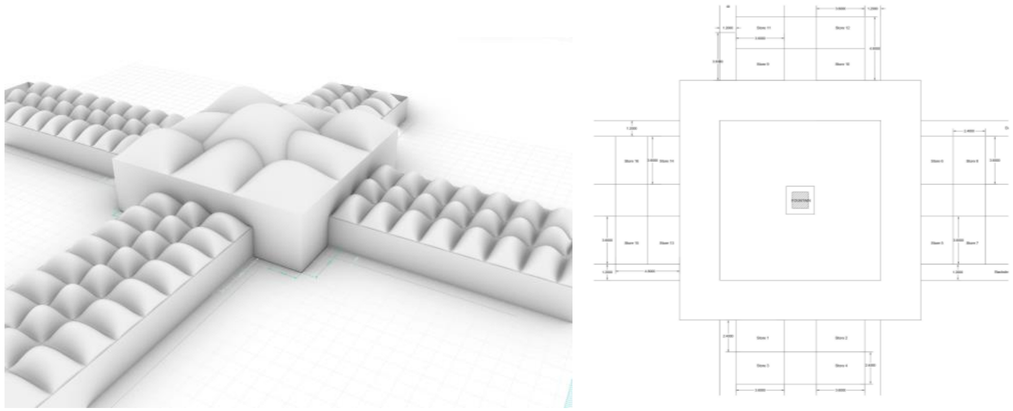


Figure 3: Variant 1: Equal distribution roof grid

Variant 2: Equal Distribution Roof Large grid

In this variant, the anchors of the form finding are based on a 3,6 by 3,6 grid as the factor is 1,2m. This shows all shop spaces are equal and have no diversity in program, see figure 2.

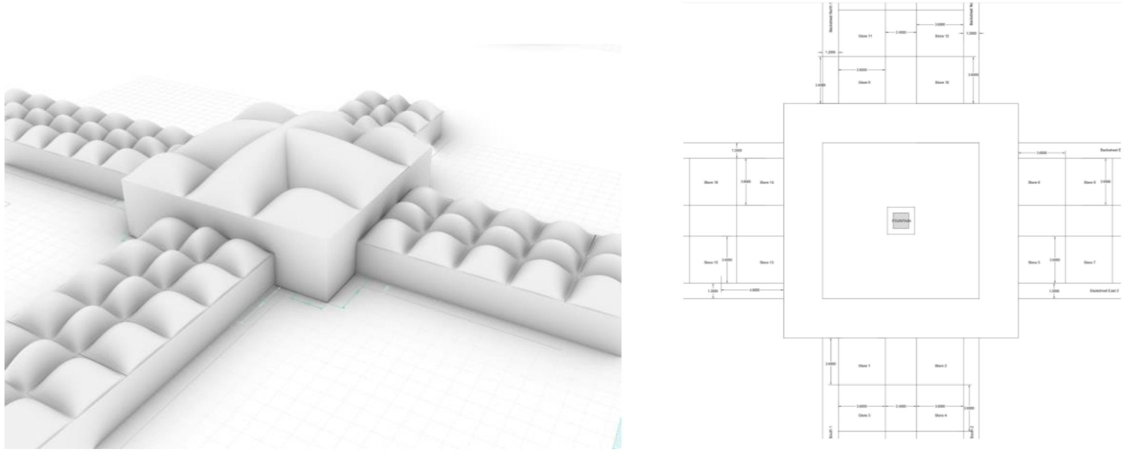


Figure 4: Variant 2: Equal Distribution Roof Large grid.

Variant 3: Growth difference sizes

In this variant, the anchors of the form finding are based on a 1,2 by 3,6 grid for the shops and 2,4 by 3,6 grid in the corridors as the factor is 1,2m. This shows different sizes of shops, but also shows issues in building it modulair as the forces are not in equilibrium, see figure 3.

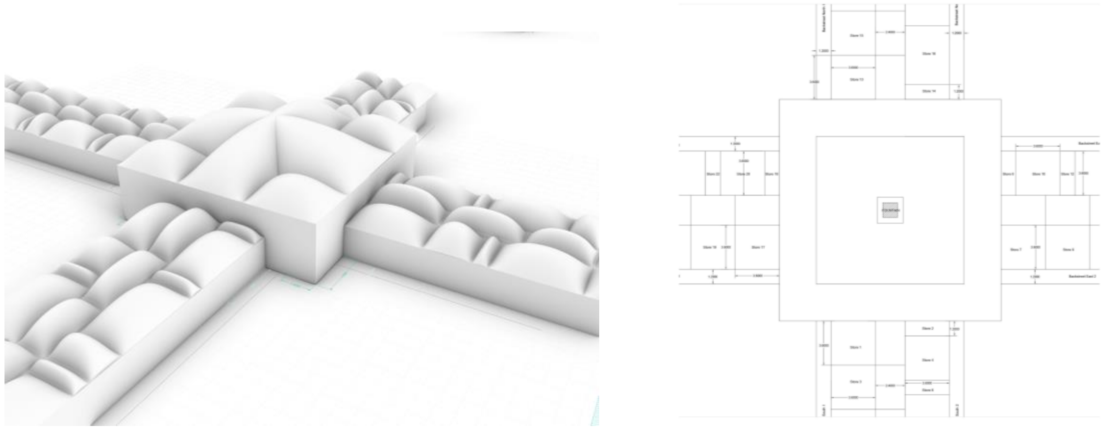


Figure 5: Variant 3: Growth difference sizes

Challenges variant 1-3

The different arches shows a challenge in making sure there is an equilibrium as the column is not following the trustline, see figure 4.

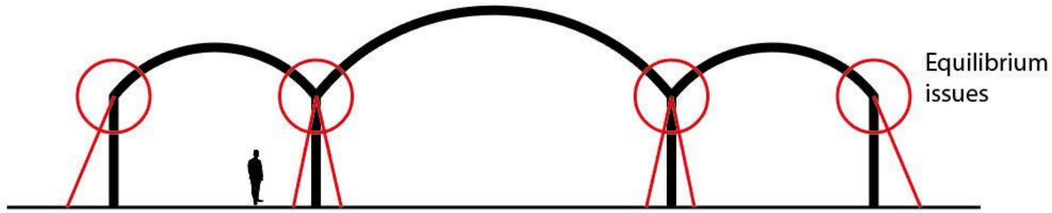


Figure 4: Structural challenges.

Variant 4: Single Vault

In this variant, the shops and corridor are under a single vault roof, which can be built in a modular way. One main advantage of this variant is that it gives uniformity to the walkways of the bazaar and makes the construction easier and faster, see figure 5.

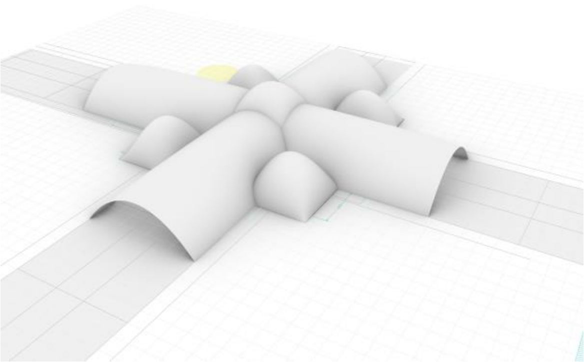


Figure 6: Variant 4: Single Vault

Variant 5: Triple Vault

In this variant the shops are under a smaller and different vault roof than the corridors. There is a structural advantage on this variant, and it is that the vaults have shorter spans than the previous variant. making them more stable, see figure 6.

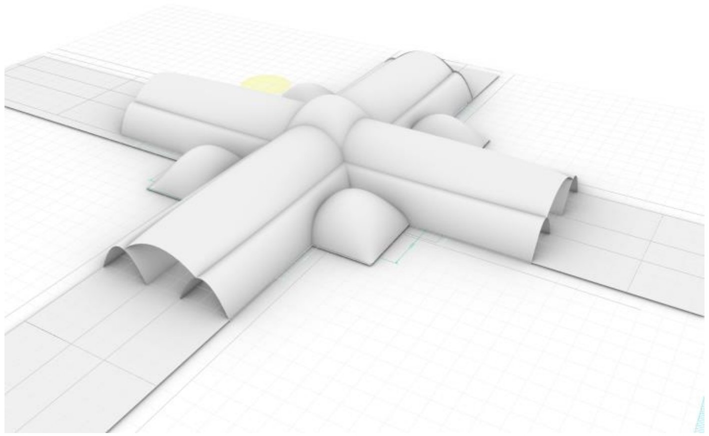


Figure 7: Variant 5: Triple Vault

Challenges variant 4-5

The highest part of the dome should be as light as possible due to the dead weight forces to the foundation. Also, when houses are added above the shops, the height should be considered as the space below the arch should be useful. Therefore, the option for digging the bazaar in is suggested, see figure 7.

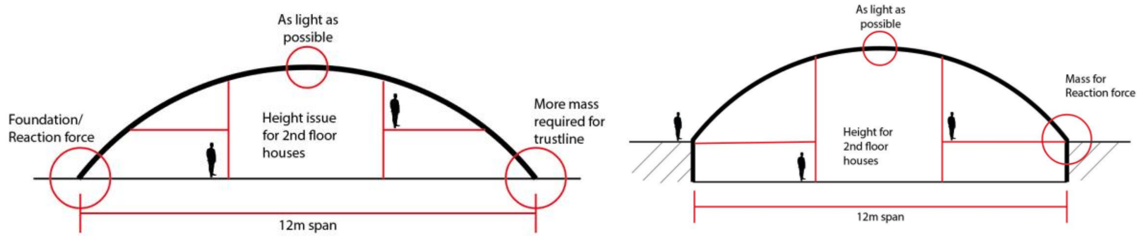


Figure 8: Structural challenges

Appendix K: Typology Vaults

Elements of vaults

Vaults are built with several elements. Figure 1 shows all the important elements and their description.

1. Keystone: The central stone at the summit of an arch, locking the whole together.
2. Voussoir: A wedge-shaped or tapered stone used to construct an arch.
3. Extrados: The upper or outer curve of an arch.
4. Impost: The top course of a pillar that supports an arch.
5. Intrados: The lower or inner curve of an arch.
6. Rise: Move from a lower position to a higher one.
7. Clear span: An arch or part of a bridge between piers or supports.
8. Abutment: A structure built to support the lateral pressure of an arch or span.

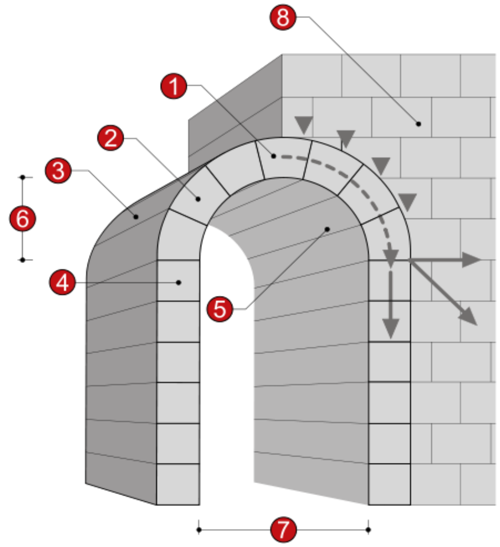


Figure 1: Vault's elements. Retrieved from Swoboda (n.d.)

Different types of vaults can be found around the world. They can also be found in any time from ancient Egypt to the Gothic period in Europe. The most common vaults are explained below (Mission (n.d.) & Mallikarjun (2017)).

Barrel vaults

A barrel vault is one of the simplest forms of vaults, see figure 2. The vault is formed by an extrusion of a single curve over a certain distance. It has a semi-circular shape. Sun-dried bricks were used in Egypt around 3500 BC to make vaults with spans of two meter. Long span barrel vaults are vaults where the barrel is larger than its width. For short span barrel vaults the span is shorter than its width, see figure 3.

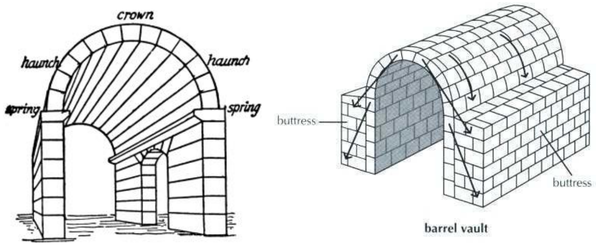


Figure 2: Barrel vaults. Retrieved from unknown (n.d.)

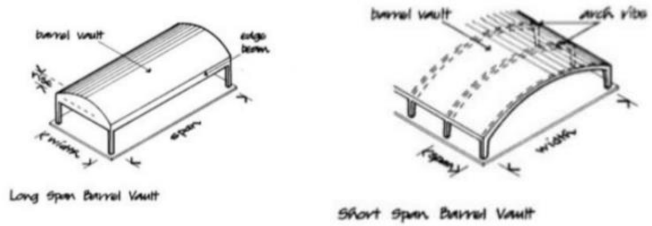


Figure 3: Long barrel vault. Retrieved from Mallikarjun (2017).

Groin vault

When two barrel vaults intersect at a certain angle a groin vault is created, see figure 4. Groin refers to the edge of two intersecting vaults. Groin vault can have a round and pointed arches. To make a groin vault, special skills are required in cutting stone for a neat arris. It is also difficult to construct neatly because of the geometry.

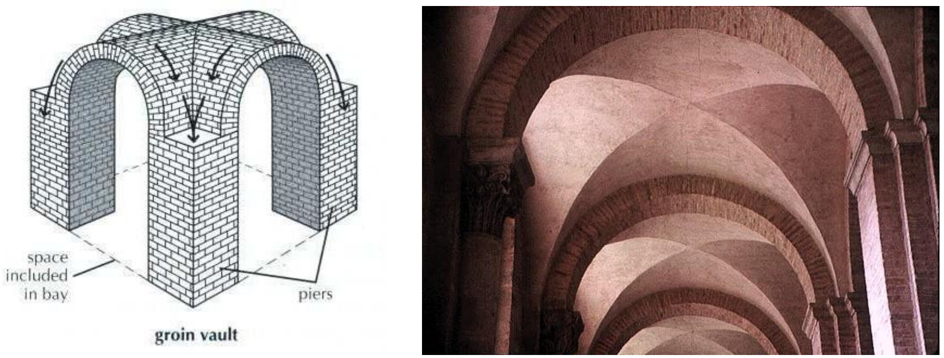


Figure 4: Groin vault. Retrieved from unknown (n.d.)

Rib vault

When two or three pointed barrel vaults intersect a rib vault is created, see figure 5. A pointed barrel vaults transfer a load more directly what leads into smaller buttresses. There are two types; The quadripartite rib vault, when two masonry ribs divide into four sections and the sexpartite rib vault when it divides into six sections. Ribs vault are good to use for roofing.

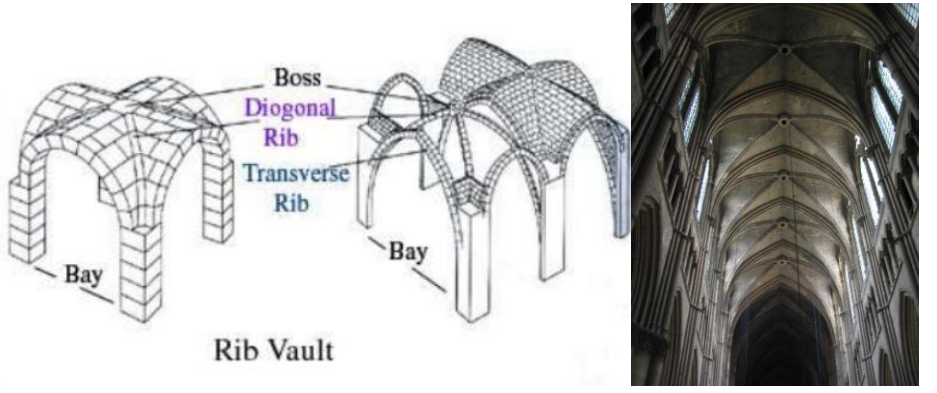


Figure 5: Rib vault. Retrieved from Mallikarjun (2017).

Fan Vault

With a fan vault all the ribs have the same curve and spaced equidistantly around an axis, see figure 6. There is a flat central space between the conoids.

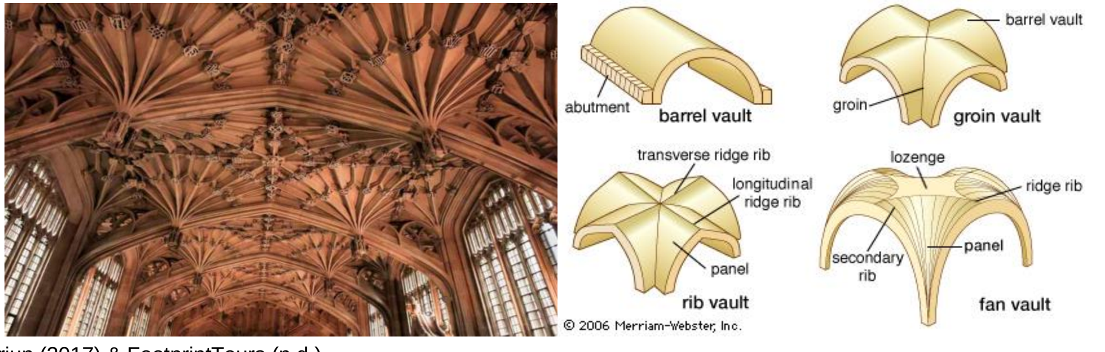


Figure 6: Fan vault. Retrieved from Mallikarjun (2017) & FootprintTours (n.d.).

Cloister Vault / Domical

This vault is made of four concave surfaces meeting in the centre point, see figure 7. The cloister vault can be formed when two barrel vaults intersect.

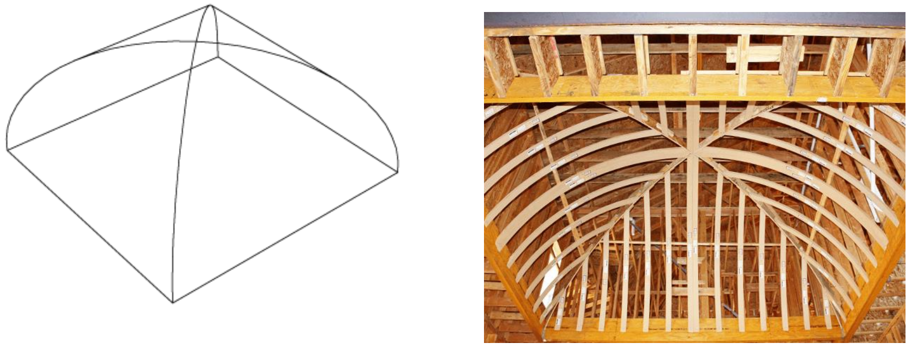


Figure 7: Cloister vault. Retrieved from Mallikarjun (2017) & ArchwaysCeiling (n.d.).

Rampant Vault

With a rampant vault the two abutments are located on an inclined plane, see figure 8. This means that the impost on one side is higher than the other side.

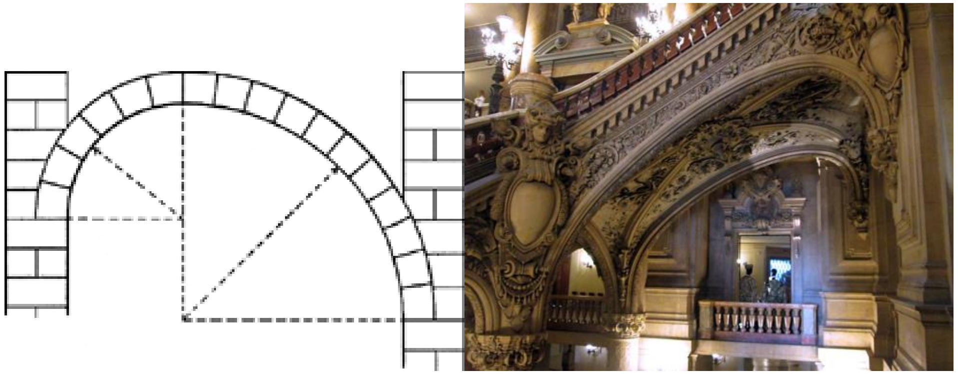


Figure 8: Rampant vault. Retrieved from Mallikarjun (2017)

Catalan Vault / Timbrel vault / Tile vault

Plain bricks are used to form the low arch of a catalan vault, see figure 9. A wood form is used to create a gentle curve together with a fast set mortar. Making a catalan vault requires less material and can be built more quickly. For the construction no or minimal formwork is needed.

Figure 9: Catalan vault. Retrieved from Mallikarjun (2017)

Nubian Vault

The Nubian Vaults are made by layering inclined bricks on vertical surfaces as seen in figure 10.
This system requires minimum scaffolding since it only requires the scaffold to build the vertical elements (arches), then the rest of the bricks are laid down inclined against these elements until the vault is closed as seen in figure 11.

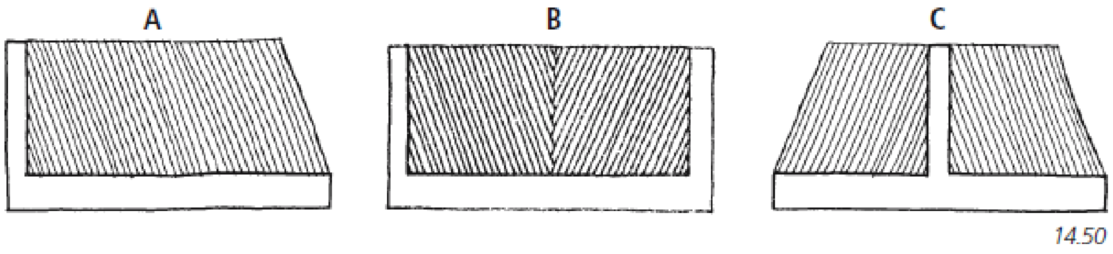


Figure 10: Brick Layering. Retrieved from Minke (2006).

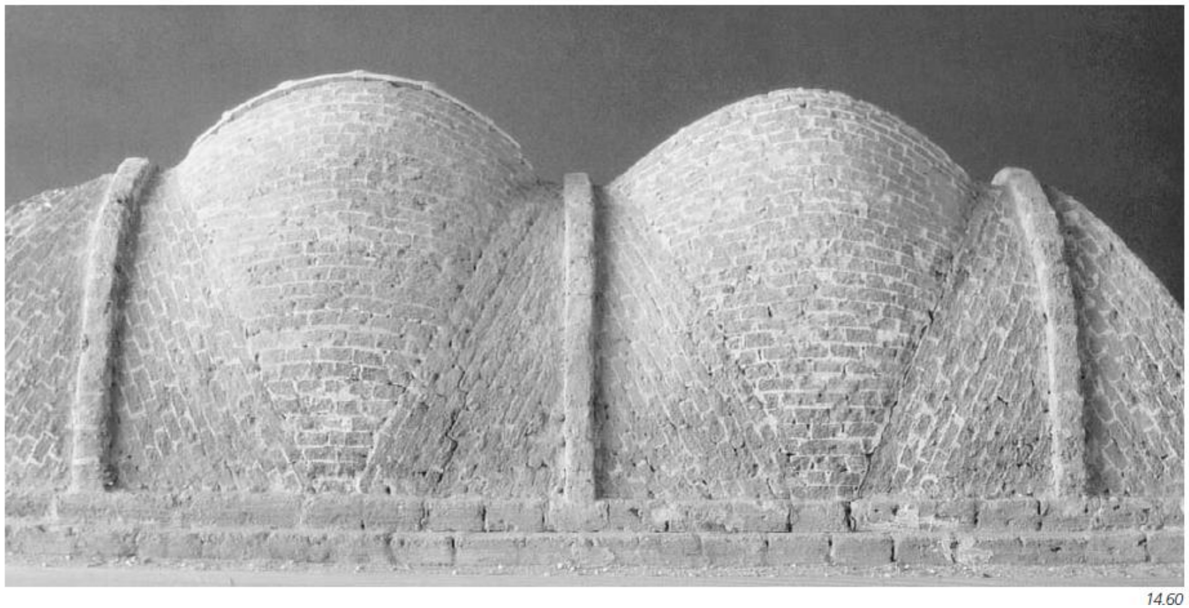


Figure 11: Nubian Vault. Retrieved from Minke (2006).

Self made structures

We tested 4 different structures and made them by our self with small bricks. The first one we constructed was the false vault. During this construction we found out that at a certain point an extra structure is needed. Without this additional structure the construction would fall down. See figure 12 for the pictures during the process and final result.

Figure 12: False vault

The second construction we tested was the pointed rib vault (one direction). During this construction we found out that we needed an extra support structure, as with the false vault. A first comparison can be made between the false vault and the pointed rib vault. The rib vault is more stable and transfers the load better than the false vault. The false vault already deforms when a little bit of pressure is put on. This does not happen with the rib vault. See figure 13 for the pictures during the process and final result.

Figure 13: Rib vault

The third construction we tested is the nubian vault. This construction is used a lot in the middle east. Formwork was needed to create the first arch. After this the brick pattern could be placed without any extra construction. See figure 14 for the pictures during the process and final result.

Figure 14: Nubian vault

The fourth construction we tested was a dome. To build this we used the idea of the inflatable structure. A balloon is used to test this, in the camp this will be done with pvc. In this case the (inflatable) mould is structural as for the form. The dome is a rigid structure, even with an oculus in the middle. See figure 15 for the pictures during the process and final result.

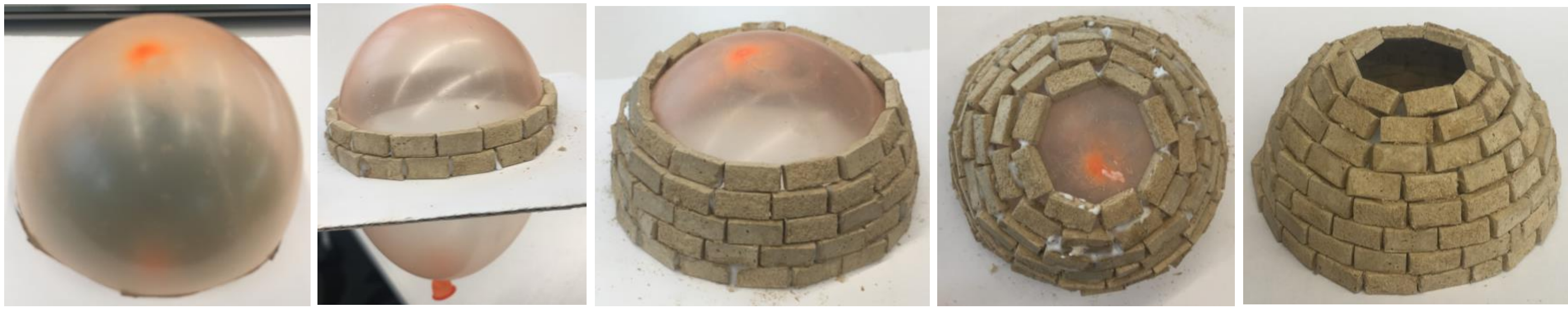


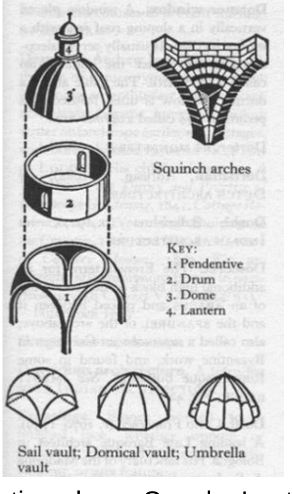
Figure 15: Inflatable structure, Dome

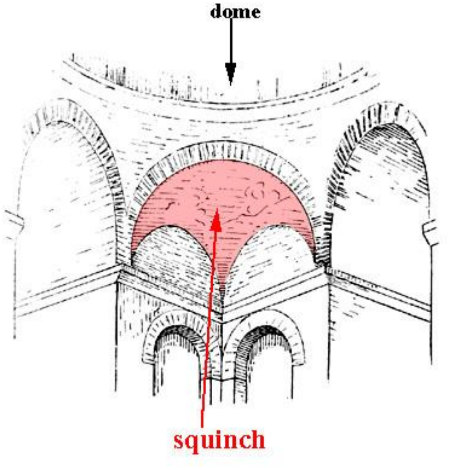
Appendix L: Typology Domes

Elements of Domes

Domes are built with several elements. Figure 1 shows all the important elements and their description. All below description is based on Designingbuildings (2018) and Elements of Dome (2017).

Pendentive: A curved triangle of vaulting formed by the intersection of a dome with its supporting arches.
Tholobate/Drum: A circular vertical wall supporting a dome.
Cupola: A rounded dome forming or adorning a roof or ceiling.
Lantern: A square, curved, or polygonal structure on the top of a dome or a room, with the sides glazed or open so as to admit light.
Coffer: A decorative sunken panel in a ceiling.
Oculus: A round or eye-like opening or design.
Rotunda: A round building or room, especially one with a dome (floorplan).
Squinch: A straight or arched structure across an interior angle of a square tower to carry a superstructure such as a dome.





Pendentive, drum, Cupola, Lantern   Coffer, Oculus   Squinch

Figure 1: Dome elements. Retrieved from ArchitecturalTravel (2012), Unknown (2017) and unknown (n.d.)

Corbel Dome

The corbel dome also known as the beehive dome and false dome are part of the Paleolithic constructions, see figure 2. These domes are made by the superposition of smaller rings of mud bricks or stone.

Figure 2: Corbel dome. Retrieved from Löbbecke (2016) and Hedderman (2006).

Cloister Domes

See cloister vaults. These domes keep their polygonal shape in horizontal section

Crossed-arch dome

The crossed-arch dome is related to the ribbed vault, see figure 3. However, the ribs do not meet in the middle but are intertwined and form polygons.

Figure 3: Crossed arch dome. Retrieved from unknown (n.d.)

Geodesic Dome
A structural framework is needed for this sphere like structure, see figure 4. Because of this, the geodesic dome is not applicable in this situation.

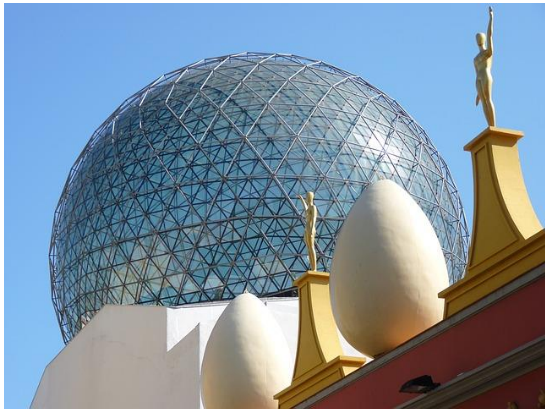


Figure 4: Geodesic Dome. Retrieved from Designing BuildingsWiki (2018)

Monolithic dome
This dome structure is casted in one piece, and due to this not constructed with bricks, see figure 5. This is why the Monolithic dome is not applicable in this situation.

Figure 5: Monolithic dome. Retrieved from Ulrich (2018)

Onion Dome
These domes have an ogee (s-curve) profile and their width is smaller than their height, see figure 6. This is typically Russian architecture and normally not constructed with bricks. This is why this dome is not applicable in this situation.

Figure 6: Onion dome. Retrieved from DesigningBuildingsWiki (2018)

Rotational dome/ hemispherical domes
When a circular arch is rotated around its axis a hemispherical dome is formed, see figure 7.

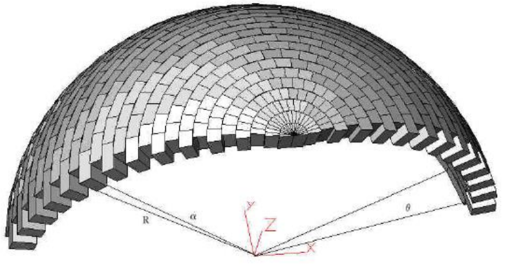


Figure 7: Rotational dome. Retrieved from D’Ayala & Casapulla (2001).

Inflated domes

A lightweight fabric is used as double membrane skin, air is pressed inside this double membrane to make the desired shape. This works like a bicycle tire.

Figure 8: Inflated Domes. Retrieved from Architen Landrell (n.d.)

Overview of shapes for domes

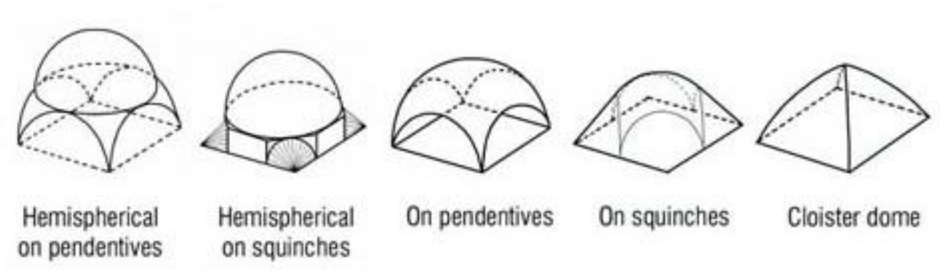


Figure 9: Overview dome shapes. Retrieved from Maekawa (n.d.).

Appendix M: Material study

Summary

For the course ‘AR3B011-Earthy’, group 2 is designing a method to apply a bazaar in every refugee camp in the Middle East. For thousands of years earth materials like adobe are used as building materials in hot or dry climates. As the properties of earth bricks are changing depending on the ingredients, an experiment is executed to understand the strength and production method of earth bricks. With this method, the properties which are conducted from a true experiment will be used as input for structural calculations. The following main research question will be investigated in this study: “What are the differences between an earth brick and bricks which contain reinforcement materials?”

For this study, literature research is studied and a true experiment is executed. Literature is used to understand earth bricks and what the expected outcome of the test will be. The results of the experiment will be used for the structural analysis.

In this study, five different types of earth bricks are tested: adobe only, adobe with straw, adobe with wood chip, adobe with sorghum and adobe with feathers. When looking at the test results, stray and feather reinforced adobe are the most shape remaining. The compressive stress of an adobe with straw ranges between 2.02 MPa - 2.99 MPa and for adobe with feathers 0.83 MPa -2.92 MPa. Therefore, these two types of earth bricks will be used for structural analysis as material availability is limited.

1 Introduction

For thousands of years earth materials like adobe are used as building materials in hot/dry climates. As the properties of earth bricks are changing depending on the ingredients, an experiment is executed to understand the strength and production method of earth bricks. The results of the measurements that were conducted on October 2nd, 2019 in the material test laboratory at the Faculty of Mechanical, Maritime and Material Engineering (3ME) of the Delft University of Technology. These measurements were conducted in the framework of the master Building Technology in the course ‘AR3B011-Earthy’. In this course, group 2 is designing a method to apply a bazaar in every refugee camp. Therefore, the properties which are calculated will be used as input for structural calculations. The following main research question will be investigated in this study: *What are the differences between an earth brick and bricks which contain reinforcement materials?*

The main aim of this paper is to find out what the influence is of the composition of clay, fine sand and coarse sand and the added reinforcement materials sorghum, wood chip, straw and pigeon feathers on self made adobe bricks by finding out their properties. This study contributes to a wider research into self made adobe bricks. To achieve this, 5 types of adobe bricks with different compositions were tested. The results of the series of measurements are reported in this document.

The approach of this study is based on literature and a true experiment which is executed to generate data. In this report, the methodology chapter will discuss the problem statement, research objective, method and design, research instruments and data collection techniques, execution plan, validity and reliability of the experiment and measures which are taken to ensure the scientific rigor. The results of the measurements will discuss the properties of the tested specimens, execution of the experiment and results. Finally, the results of the test and this paper will be concluded in the conclusion.

2 Methodology

In this chapter, the problem statement, research objective, general research design and execution plan will be discussed.

2.1 Problem statement

A steadily growing number of people are moving into refugee camps. At the moment, almost 80.000 Syrian refugees live in camp Zaatari, North Jordan. The emphasis of refugee camps is on establishing temporary solutions. In reality, these camps exist for many years. In the area of Zaatari, the original main building material is earth. To understand the strength of self made earth bricks, this experiment is performed. In the course 'AR3B011-Earthy', group 2 is designing a method to apply to build a bazaar in every refugee camp. This includes roof structures with large spans. Therefore, the strength has to be known to understand the limitations of the span construction.

2.2 Research objective

The main objective of this experiment is to define the influence of the composition on the strength of the self made adobe bricks. Not only the results of group 2 will be used for understanding the properties, but also the results of other groups which are part of the course 'AR3B011-Earthy'. These results can be compared afterwards to determine which composition had the best properties. The chosen brick composition will be used as input for the structural design.

Based on the research objectives, the following main research question is formulated: *What are the differences between an earth brick and bricks which contain reinforcement materials?*

2.3 Research method

A laboratory experiment was conducted to find an answer to the research question. A laboratory experiment is an experimental method where the effects of independent variables on dependent variables are tested in a controlled environment, ensuring that relationships between certain factors and characteristics can be determined (Thompson, 2017). Also, literature is included in this study to select other ingredients in the brick mixed to increase the strength.

For this experiment, five types of specimens are tested:

- 1) Standard earth bricks (fine sand(30%), coarse sand (40%) and clay(30%));
- 2) Standard earth brick with wood chip (1% of the standard earth brick weight);
- 3) Standard earth brick with straw (1% of the standard earth brick weight);
- 4) Standard earth brick with Sorghum powder (400 grams added to the standard earth brick composition) and;
- 5) Standard earth brick with pigeon feathers (100 grams added to the standard earth brick composition).

2.4 General research design

This study is a quantitative research including true experiment with independent samples and repeated lab measurements. Data of the deformation and force applied on different specimens is collected and used for this research. The research was conducted at the material test laboratory at the Faculty of Mechanical, Maritime and Material Engineering (3ME) of the Delft University of Technology. Before performing the test, the specimens were closely investigated to identify the deformations and defects. The measurements were documented along with the defects and deformities. The dimensions of the samples were measured with a RVS ruler (brand AMI) and collected in Microsoft Excel.

The specimens were tested on strength, only compression force was applied to the bricks, see figure 1 for the set-up of the test. First, the bottom plate is a regular pine wood plate of 18mm. The specimen is placed on the plate below the steel plate which will compress the specimen. The compression plate had a diameter of 100mm.

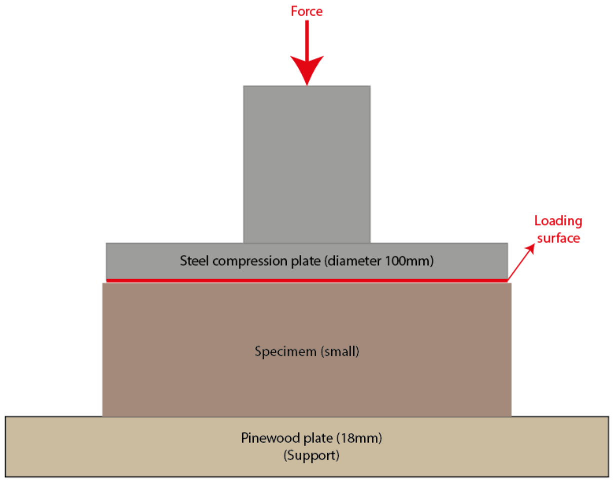


Figure 1: Schematic visualisation of the compression test.

2.5 Research instruments and data collection techniques

The specimens are measured one day before testing. The measurements are dimensions and weight of each specimen, see 'Extra information A' at the end of this appendix. Defects of the specimens were written down at the 3ME test location as the specimens are transported from the faculty of Architecturing in Delft to 3ME in Delft. The following equipment is used for the laboratory experiment (compression test):

- RVS ruler (brand AMI);
- Zwick z100 compression testing machine;
- Microsoft Excel for collecting data;
- A small scale (brand Soehnle).

For making the bricks:

- a large scale (unknown brand);
- Concrete mixer (brand Festool);
- Buckets and shovels;
- Plastic containers as moulds (120x120x50 and 120x170x130).

2.6 Execution plan

The execution of this experiment is divided in two parts: 1) making the specimens and 2) testing the specimens.
For making the specimens, the following steps were followed:

1. Perform literature research to figure out which two additional raw materials can be added to find out the properties of the specimen.
2. Receiving all raw materials for making the bricks.
3. Weighing the raw materials (with a scale) and mix these in a bucket.
    a. The basic mixture is made of 3kg of clay, 3kg of fine sand, 4 kg of coarse sand and 1 liter of water.
4. Adding water to it and mix the mixture with the electrical Festool mixer for five minutes.
5. Additional:
    a. When wood chip or straw is added to the process, first the mixture is weighted and 1% of the total weight is the amount of the additional material which is added. This is mixed by hand for 5 minutes.
    b. Sorghum powder (400 grams) or pigeon feathers (100 grams) are added to a batch which had the weight of 11kg. This is mixed by hand for 5 minutes.
6. Add minimum water to the edges of the plastic containers to reduce issues while removing the specimen from the container.
7. Mixture is divided in the plastic containers (figure 2).
8. Mixture is compressed and equally divided with a wooden plate for 5 minutes (figure 3).
9. Mixture is removed from the mould and placed on a plastic sheet.
10. Place a sticky note next to the specimen to know which specimens contains which mixture.
11. The wet specimens have to dry for 1 week near the South windows at the “Maquette hal” at the Faculty of Architecture in Delft.
12. On day 6, the dimensions (RVS ruler) and weight (small scale) of the specimens were written down.
13. On day 7, the specimens were transported from the Faculty of Architecture in Delft to 3ME in Delft.

Figure 2: Big (left) and small (right) plastic moulds.

Figure 3: Equally divide mixture in container

For testing the specimens, the following steps were followed:

1. Specimens are unloaded and placed on the table in the order of testing.
2. Specimens were checked for defects or remarks. This is noted down in Excel.
3. Place the specimen on the wooden plate directly and centralized under the compression mechanism.
4. Photograph every specimen before the test.
5. Perform the test with the Zwick z100 machine.
6. Film 1 specimen type during the test.
7. Photograph every specimen after the test.
8. Note down the first findings during testing the samples.
9. Note down the maximum force per specimen.
10. Clean the wooden plate.
11. Start from point 3 for the new specimen.
12. Collect and analyze all results for finding the compression strength.
13. Discuss the results in the report.

2.7 Validity, reliability and limitations of the experiment

The internal validity of this study is based on the definition of the research and the steps per process which are executed. The results are combined with the results of the other groups which are part of the course 'AR3B011-Earthy'.

The errors in the process from making the specimens, measuring the specimens, testing the specimens, reporting and analyzing the specimens can impact the reliability of this study. The conditions which can impact the reliability of this study are:

- Instrument error; use different equipment devices, deviations.
- Quantisation error; the number of digits of the equipment devices is different.
- Method error; measuring other length, height or wall thickness of the specimen, variable placing specimen below the compression plate.
- Read-out error; read different numbers from the ruler, scale or test machine.
- Adjustment error; variable temperature in the experimental room during the drying process. Also, three different base mixtures had to be made as the buckets were too small for one big batch.

The big scale which was used for weighing the raw materials has the purpose to indicate human' weight. Therefore, the weighting procedure can contain a instrument, quantisation and read-out error. Next to this, test results of other groups are included in the result calculation. This brings inconsistencies in making batches procedures as this was not monitored. Also, the test method might deviate from this test set-up. As described, this test included a compression plate with a diameter of 100mm. Other groups might have used other surfaces and shapes to test the compression. This also refers back to a method error.

When producing the specimens, it was challenging to remove the specimen from the moulds. Therefore, the strength of the specimens can be influenced by this process.

Due to time limitations, the specimens only had one week to dry. Therefore, a difference between the big and small specimens can appear as the smaller bricks might be more dry than the bigger specimens. This can influence the strength. Also, the Dutch climate (even indoor climate) is different than were the earth bricks will be produced e.g. Middle East.

2.8 Materials tested

Six different variants in mixture and sizes are made. The average data is shown in table 1.

Specimen	Average size (mm)			Average volume (mm^3)	Average weight (grams)	Density (kg/m3)
	length	Width	Height			
1) Adobe only (big)	159	122	67	1.295.652	1.944	1500,1
2) Adobe only (small)	112	109	40	487.214	837	1717,5
3) Adobe + straw	114	112	41	517.687	755	1459,1
4) Adobe + Wood chip	124	117	51	733.775	1.016	1384,6
5) Adobe + Sorghum	122	117	44	634.233	923	1454,9
6) Adobe + Feathers	117	112	41	542.151	827	1524,7

Table 1: Own specimens data

Standard specimen

The standard earth specimens contain:

- Fine sand (30%);
- Coarse sand (40%) and;
- Clay(30%).

Five specimens were made with the big container mould (specimen 1A-1E) and five specimens were made with the small container mould (Specimen 2A-2E). In figure 4, two specimens are shown. The basic mixture is made of 3kg of clay, 3kg of fine sand, 4 kg of coarse sand and 1 liter of water. The raw materials were supplied by TU Delft. In total we mixed two of these mixtures together to make one consistent mix. The specimens were made from the first out of three batches which are made to make all specimens for this study. No reinforcements were added to this mixture to understand the basics of the earth bricks. Some specimens were compressed very well and had no visible cracks. Some of the specimens were more brittle in appearance.

According to Sasui (2017), the compressive strength of earth bricks is between 0,45 MPa and 1,21 MPa. However, Illampas, Ioannou and Charmpis (2014) state that the compressive strength is between 0,6 and 8,3 MPa.

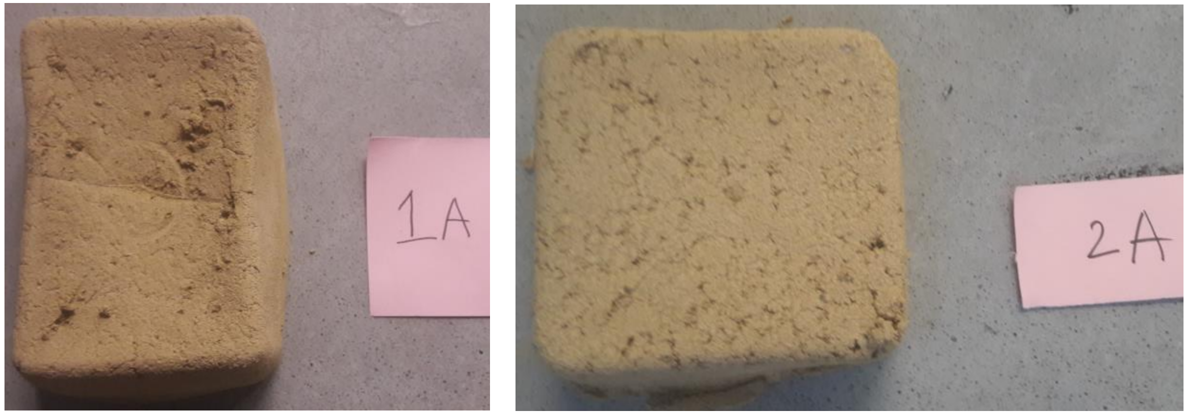


Figure 4: Big standard earth specimen 1A (left) and small standard earth specimen 2A (right).

Straw specimen

The straw specimens contain:

- Standard earth brick mixture (batch 1);
- 1% straw based on the standard earth mixture weight.

The standard earth mixture was part of the first batch which was produced. The straw is supplied by TU Delft. Only three specimens (specimen 3A-3C, figure 5) were made with the small container and left over was used for a very small specimen (specimen 3D). However, the exceptional small specimen was not tested due to time limitation. These specimens seem to be less brittle and appear to be more compressed because these specimens are the least heavy of all specimen types.

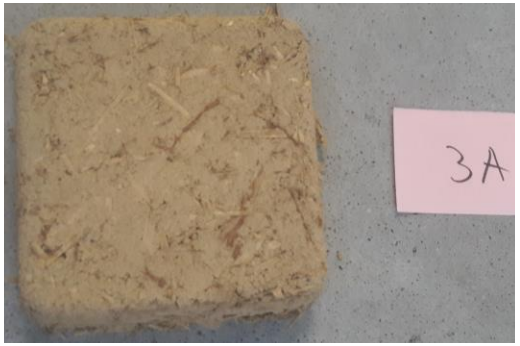


Figure 5: Small straw specimen 3A.

Wood chip specimen

The wood chip specimens contain:

- Standard earth brick mixture (batch 2);
- 1% wood chip based on the standard earth mixture weight.
-

Only two small specimens are made with wood chip, see figure 6. The wood chip is supplied by TU Delft. The standard earth mixture is from batch 2 out of 3. Therefore, the composition of the specimens can deviate from the standard and straw specimens. As with the straw specimens, these specimens appear to be less brittle and more compressed, but is heavier than the straw specimens. This might be caused by the density of the wood chips itself.

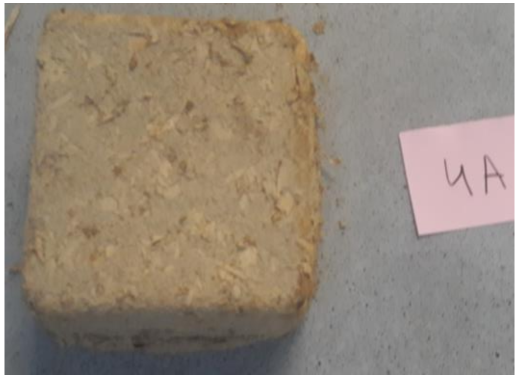


Figure 6: Small wood chip specimen 4A.

Sorghum specimen

The Sorghum specimens contain:

- Standard earth brick mixture (batch 2);
- 400 grams of white sorghum powder (brand Holland & Barrett).

According to Salih, Imbabi and Osofero (2018) sugarcane improves the strength of an earth brick. Sugar is an ingredient which can be used for food purposes. Therefore, an ingredient which is important for feeding the camp is excluded. Therefore, an alternative is sorghum. Sorghum is a sticky ingredient which can also be used for food purposes, but also for waterproof houses. It grows quickly in dry climates(sorghumcheckoff, n.d.) and is therefore suitable for Jordan.

Seven small specimens are made with the sorghum specimen, see figure 7. The sorghum powder is supplied by group 2 and is bought at the Holland & Barrett shop. The mixture is mixed with the sorghum powder. No visual difference between the standard mixture specimens and the sorghum specimens except it looks more compressed and less brittle. This can be caused by the sorghum powder, a mixture of the standard earth and/ or mixing time.

Figure 7: Small sorghum specimen 5A.

Feather specimen

The feather specimens contain:

- Standard earth brick mixture (batch 3);
- 100 grams of pigeon feathers.

According to Salih, Imbabi and Osofero (2018) chicken feather improves the strength of an earth brick. Therefore, feathers are chosen to be tested in this study.

Eight small specimens are made and one big specimens as this was a left over, see figure 8. The pigeon feathers were collected from a local pigeon keeper who keeps the birds for food purpose. The feathers were cut in pieces of approximately 30mm as the complete feather did not fit in the plastic container. Also, for mixing the feather with the earth mixture, it made it more difficult. In appearance, the specimens were the same as the standard earth mixture, but the feathers were visible on the surface. Also, it seems to be less brittle than the small standard earth specimens.

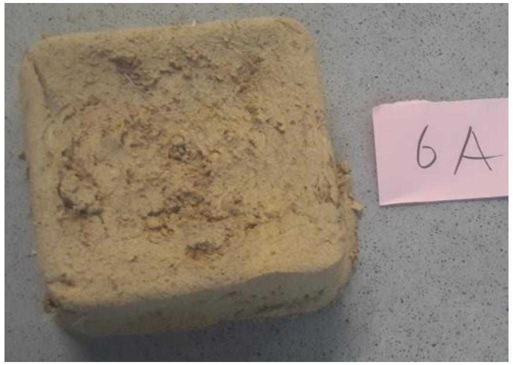


Figure 8: Small feather specimen 6A.

2.9 Measures taken to ensure scientific rigor

The process of this study is written down in detail including pictures. In the appendix, all the pictures of the tests can be found which includes showing the visible defects of the specimens. However, all specimens are made by hand. When repeating this process for validation, the end results might be different.

3 Results of the measurements

In this chapter, the properties of the tested specimens, execution of the experiment and results including calculations will be discussed. Also, the imprecision and reliability of the research will be discussed.

3.1 Properties of the tested specimens

All details of our and other groups specimens can be found in ‘Extra information B’ at the end of this appendix. In this overview, the dimensions, weight and ingredients are shown.

3.2 Execution of the experiment

The compression test of the specimens were performed by using the Zwick z10 machine at the Faculty of Mechanical, Maritime and Material Engineering (3ME) of the Delft University of Technology. This machine was limited till 100.000 N and will stop automatically.

First, all specimens were unloaded and ranked when every specimen should be tested, see figure 10. Also, the specimens were checked for visible defects as big cracks or missing parts. In this case, two specimens (3D & 5G) were not taken into account for this test.

A specimen was placed below the compression plate and visually centralized as much as possible, see figure 9. The test was executed and the results was noted down in Excel and the specimen was photographed. Per specimen type, the test was filmed to understand the behaviour of the material when it is under compression.

Figure 9: Compression test

Figure 10: Specimens at 3ME testing lab.

3.3 Results

In this paragraph, the physical fail results and the calculations of the compressive stress and elasticity modulus will be discussed. Where possible, this will be cross checked with literature.

Physical fail results

In figures 11 - 15, the physical results of each specimen type are shown. In ‘Extra information A’ at the end of this appendix, all the results of the specimens of group 2 are shown. Other specimens pictures were not available as these were made by other groups. The physical results show that specimens with adobe only, wood chip and sorghum complete fail as these specimens completely lost their original shape. Specimens with straw and feathers only lost their original shape around the edges, the rest of the specimens remains as original.



Figure 11: Result adobe only (2D). Figure 12: Result straw (3A). Figure 13: Results wood chip (4B).


Figure 14: Result sorghum (5A). Figure 15: Result Feathers (6C).

Accuracy

The more specimens are used for calculating the compressive stress and elasticity modulus, the more accurate the results will be. Therefore, not only the results of group 2 are used, but also the results of comparable specimens of the other groups are used. With these results, a normal distribution and statistical estimation of the imprecision with 95% are made. When the number of specimens are below 20, the factor that expresses the confidence which we state that the imprecision is correct (t) is used. See formule 1 which is used for all imprecision calculations and see formule 2-3 for the input formulas.

Formula 1:

$$\delta x = \frac{ts}{\sqrt{n}}$$

Formule 2:

$$\text{Mean} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Formule 3:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}$$

Where;
t = imprecision correction

s = sample st. dev.
n = number of specimens
x = result per specimen

Compressive Stress

Adobe constructions are mostly build on compression. Therefore, the compressive stress has to be calculated to understand which specimens is best suited for the design assignment of a bazaar. Formula 4 is used to calculate the compressive stress.

Formula 4:

$$Comp.Stress = \frac{F}{A}\left[\frac{N}{mm^2}\right]$$

Where;
F = Force in Newton
A = Surface of specimen in mm2

With the results of all specimens per type, a histogram was made. For adobe only, the histogram shows two normal distributions, see figure 16. This was caused by different sizes of blocks which were made by the groups. Therefore, first a limit range was determined with a box plot, see figure 17. The box plot shows the range of the common data and exceptional data. However, there was still no normal distribution shown in the histogram. Therefore, the specimens were divided into groups based on the compression surface. A normal distribution was shown per group and this is used for determining the strength of the specimens. For the other specimens types, this was no issue. All shows a normal distribution in the histogram. All histograms and calculation overviews can be found in 'Extra information B' at the end of this appendix.

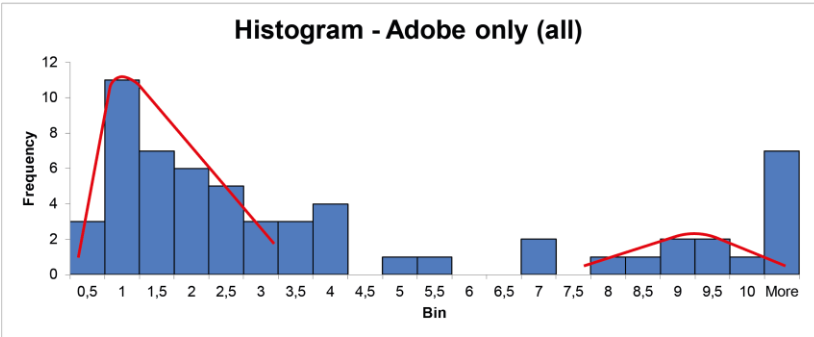


Figure 16: Histogram all adobe only.

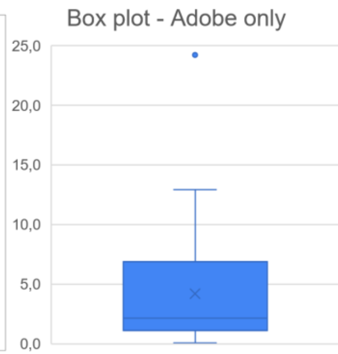


Figure 17: Box plot adobe only.

The calculated compressive stress is shown in table 2. For adobe only specimens, the results of the surface range are according to the statement of Illampas, Ioannou and Charmpis (2014) as they mentioned a compressive strength between 0,6 and 8,3 MPa for earth bricks with the same ratio of ingredients. To determine which type of material can be used as input for the design assignment, the physical outcome was selected. For the safety factor, according to Stewart and Lawrence (2007) a brick wall in compression van have a safety factor around 1.2. Due to many imprecisions of this test, a safety factor of 2 is chosen. The minimum compressive stress including safety factor will be used. Only the straw and feather specimen showed a most remaining shape. Therefore, these two types will be used as input for the structural calculation. The location of the type brick can be determined by the compressive stress as materials are limited in the camp.

Compressive stress [N/mm2]											
	Adobe only							Straw	Wood chip	Soghum	Feathers
	All	Limited range	Limited 0-5000 mm^2	Limited 5000-7500 mm^2	Limited 7.500-10.000 mm^2	Limited 10.000-15.000 mm^2	Limited 15.000+ mm^2	All	All	All	All
Min	0,06	1,07	1,49	1,39	3,70	0,84	0,06	2,28	1,22	0,97	0,93
Max	24,23	6,93	24,23	12,94	11,26	8,83	3,35	10,48	7,55	1,61	7,95
Average	4,19	2,75	10,51	4,00	7,31	2,87	1,03	5,00	3,50	1,13	3,75
Median	2,13	2,13	9,01	2,62	6,79	1,47	0,76	3,81	2,84	1,04	3,25
st. dev	4,46	1,50	8,33	3,46	3,39	3,02	0,86	2,32	1,83	0,24	2,49
Correction factor	1,96	1,96	2,78	2,13	2,23	2,16	2,16	1,96	2,12	2,57	2,37
n	60,00	32,00	5,00	16,00	11,00	14,00	14,00	22,00	17,00	6,00	8,00
Correction	1,13	0,52	10,35	1,84	2,28	1,74	0,50	0,97	0,94	0,25	2,09
Min Stress	3,07	2,23	0,16	2,16	5,04	1,13	0,53	4,03	2,56	0,87	1,66
Max Stress	5,32	3,27	20,86	5,84	9,59	4,61	1,53	5,97	4,44	1,38	5,84
Safety factor	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00
Min Stress incl. factor	1,53	1,12	0,08	1,08	2,52	0,56	0,27	2,02	1,28	0,44	0,83
Max Stress incl. factor	2,66	1,63	10,43	2,92	4,80	2,30	0,77	2,99	2,22	0,69	2,92
Physical test result	Complete destroyed							Shape mostly remained	Complete destroyed	Complete destroyed	Shape mostly remained

Table 2: Results compressive stress per specimen type.

Elasticity modulus

Even when the whole design is based on compression force only, external factors can create tension in the structure e.g. wind. As the domes of the bazaar could be higher than the rest of the camp's buildings and caravans, wind has to be taken into account. According to Blondet and Vargas (1986), adobe bricks have a elasticity modulus of 170 MPa. Martins and Varum (2006) tested adobe bricks and concluded that elasticity modulus is between 117 MPa and 273 MPa. For calculating the elasticity modulus, formula 5 is used. Less specimens were used for this calculations than with compressive stress due to software problems during testing. The deflection of the specimens were not always recorded. The strain of the specimen is not based on the total deflection, but on the linear deflection of the specimen. In figure 18 an example is shown how the strain is determined per specimen. The first part of the deflection is the adjustment of the compression plate to the specimen. The middle part is the deflection of the specimen itself. The last part is when the specimen already failed.

Formula 5:

$$E = \frac{\sigma}{\varepsilon}\left[\frac{N}{mm^2}\right]$$

Where;
ε = Strain in mm
σ = Compressive stress in N/mm2

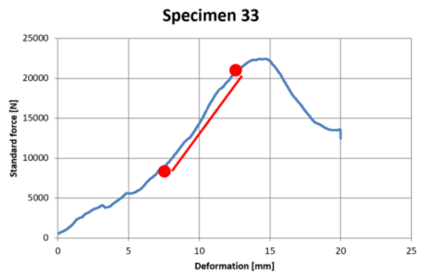


Figure 18: Determine the strain per specimen.

All histograms per type of specimens show a normal distribution. Therefore, no special ranges were made. In table 3, the results are summed. As straw and feathers are used as input for the structural design of the bazaar, the elasticity modulus will be used as an input.

Young's Modulus [N/mm2]					
	Adobe only	Straw	Wood chip	Soghum	Feathers
	All	All	All	All	All
Min	6,62	15,44	13,72	9,23	11,54
Max	647,00	174,63	141,12	16,85	55,70
Average	68,13	63,64	54,05	14,36	30,40
Median	25,22	55,94	50,74	15,99	24,37
st. dev	115,08	41,27	36,74	3,14	15,69
Correction factor	1,96	1,96	2,20	2,78	2,37
n	42,00	22,00	12,00	5,00	8,00
Correction	34,80	17,24	23,33	3,90	13,15
Min E-modulus	33,33	46,40	30,72	10,46	17,25
Max E-modulus	102,94	80,89	77,38	18,26	43,55
Physical test result	Complete destroyed	Shape mostly remained	Complete destroyed	Complete destroyed	Shape mostly remained

Table 3: Results elasticity Modulus per specimen type.

3.4 Imprecision and reliability of the research

As it is not known how the other groups selected their specimens for testing, the results can deviate. Also, The compression strength is not always the maximal strength which can be applied to the specimen. The specimen can be unequal so it breaks directly after the first moment of compression. Next to this, compression was applied on the specimen while is physically already failed(e.g. due to unequal bottom which caused major cracks. It is unknown if the other groups took this into account when they shared their results. Also, the number of specimens impact the final results of this study. For the feathers and sorghum variants, only seven specimens are tested in comparison with 22 straw specimens. The specimen sizes differs between 60 and 7 per type. Therefore, the comparison of the properties per type is less reliable. Finally, the mixture of the specimens can be made different by every group as factors like weight of the ingredients and mixture time can deviate. Also, the drying time and how the brick was positioned and treated during to process. Some groups turned the bricks during the drying process and some did not. According to Sasui (2017), the bricks should dry for 28 days in the shadow to increase the strength of the brick, while the tested specimens only had 1 week to dry due to time limitation.

To conclude, the compressive stress and elasticity modulus for adobe is near the scientific studies, but it is made with Dutch ingredients instead of the Jordan ingredients. As we chose for adobe + straw and adobe + feathers, these type of bricks can even be stronger in Jordan. For filling up domes which has no structural purpose, adobe only bricks can be used. For now, we use the outcome of our tests.

4. Discussion, limitations and conclusion of the research

Discussion and limitations in combination with the conclusion will be discussed in this chapter.

4.1. Discussion and limitations

This study is based on literature research and a true experiment. However, limited literature is used as it was only to understand the limitations and treatment of earth bricks.

Next to this, this research contains limited specimens which were produced by different groups. This means different batches were produced and drying process deviates from each other. Also, the specimen sizes was different per group which not only impacts the compressive strength, but also the behavior of the specimen in the drying process.

4.2 Conclusion

The research question of this study is as follows: *What are the differences between an earth brick and bricks which contains reinforcement materials?* The strength of an adobe only specimen was between 0,16 MPa and 9,59 MPa. This deviates from other study's outcome. The tested adobe only specimens were completely destroyed, so the use of this type of adobe is not an option. Also for adobe with wood chip and adobe with sorghum, the specimens lost their original shape completely. The compressive stress of adobe with straw was between 2.02 MPa and 2.99 MPa and for adobe with feathers between 0.83 MPa and 2.92 MPa. These two variants remained mostly in shape after testing.

To answer the research question: the difference of a plane earth brick and earth bricks with adhesive materials depends on the type of adhesive. Only straw and feathers made a difference in result as the shape was mostly intact after testing. Therefore, these two types of bricks will be used for further structural research for the course 'AR3B011-Earthy', designing a method of a bazaar in a refugee camp in the Middle East.

For future research, the behavior of the two chosen earth bricks can be further explored as only compressive stress and elasticity Modulus are based on compression. Also Tension and impact testing can be performed to understand the behavior of the bricks when it is under tensile force.

Extra information A: Specimens

Data specimens

Specimen	1L water	% sand (coarse)	% sand (fine)	% clay	% Straw	% Wood chip	Sorghum (grams)	Pigeon feathers (grams)	Batch	Weight (grams)	Length (mm)	Width (mm)	Height (mm)	Moulds	F_{max} (N)	dL at F_{max} (mm)	Area (mm2)	Compressive Stress (n/mm2)	Comment
1A	Yes	40	30	30	No	No	No	No	1	2.099	164	121	71	Big	8.320	11,8	19844	0,42	
1B	Yes	40	30	30	No	No	No	No	1	1.732	159	124	63	Big	15.681	11,8	19716	0,80	
1C	Yes	40	30	30	No	No	No	No	1	2.004	155	124	67	Big	10.478	11,2	19220	0,55	
1D	Yes	40	30	30	No	No	No	No	1	1.796	159	114	64	Big	12.006	13,1	18126	0,66	
1E	Yes	40	30	30	No	No	No	No	1	2.087	159	128	68	Big	8.844	12,4	20352	0,43	Unequal in bottom
2A	Yes	40	30	30	No	No	No	No	1	904	113	113	43	Small	19.500	-	12769	1,53	Unequal in bottom
2B	Yes	40	30	30	No	No	No	No	1	820	109	111	40	Small	93.036	25,0	12099	7,69	
2C	Yes	40	30	30	No	No	No	No	1	752	109	108	36	Small	101.161	24,3	11772	8,59	
2D	Yes	40	30	30	No	No	No	No	1	908	116	109	42	Small	20.700	-	12644	1,64	Unequal in bottom
2E	Yes	40	30	30	No	No	No	No	1	800	111	102	40	Small	99.968	24,1	11322	8,83	
3A	Yes	40	30	30	1	No	No	No	1	725	115	111	40	Small	100.549	15,0	12765	7,88	
3B	Yes	40	30	30	1	No	No	No	1	780	116	114	41	Small	100.385	19,8	13224	7,59	
3C	Yes	40	30	30	1	No	No	No	1	761	111	110	41	Small	100.294	20,9	12210	8,21	
3D	Yes	40	30	30	1	No	No	No	1	373	119	88	30	Except. small	-	-	10472		
4A	Yes	40	30	30	No	1	No	No	2	988	125	118	50	Small	38.374	20,0	14750	2,60	
4B	Yes	40	30	30	No	1	No	No	2	1.044	122	115	52	Small	65.934	25,0	14030	4,70	
5A	Yes	40	30	30	No	No	400	No	2	854	119	117	45	Small	22.449	14,6	13923	1,61	
5B	Yes	40	30	30	No	No	400	No	2	953	121	113	48	Small	14.198	10,4	13673	1,04	
5C	Yes	40	30	30	No	No	400	No	2	1.052	124	118	50	Small	14.135	13,0	14632	0,97	
5D	Yes	40	30	30	No	No	400	No	2	859	124	117	42	Small	15.700	-	14508	1,08	
5E	Yes	40	30	30	No	No	400	No	2	965	120	118	46	Small	14.385	17,5	14160	1,02	
5F	Yes	40	30	30	No	No	400	No	2	849	121	120	38	Small	15.158	11,3	14520	1,04	Partirly breaking
5G	Yes	40	30	30	No	No	400	No	2	927	123	118	42	Small	-	-	14514		Partirly breaking
6A	Yes	40	30	30	No	No	No	100	3	883	118	115	44	Small	22.502	15,0	13570	1,66	
6B	Yes	40	30	30	No	No	No	100	3	795	118	109	35	Small	11.900	-	12862	0,93	
6C	Yes	40	30	30	No	No	No	100	3	888	119	116	42	Small	27.988	15,0	13804	2,03	
6D	Yes	40	30	30	No	No	No	100	3	840	116	114	41	Small	28.210	15,0	13224	2,13	
6E	Yes	40	30	30	No	No	No	100	3	905	119	111	46	Small	57.591	20,0	13209	4,36	
6F	Yes	40	30	30	No	No	No	100	3	715	116	109	39	Small	100.492	18,3	12644	7,95	
6G	Yes	40	30	30	No	No	No	100	3	811	118	115	44	Small	86.520	20,0	13570	6,38	
6H	Yes	40	30	30	No	No	No	100	3	776	113	106	40	Small	54.940	20,0	11978	4,59	
6I	Yes	40	30	30	No	No	No	100	3	1.682	159	122	63	Big	19.300	-	19398	0,99	

Standard specimen (left:Dry specimens at BK, middle: before test, right: after test)

1A:   

1B:



1C:



1D:

1E: 

2A: 

2B: 

2C:

2D:

2E:

Straw specimen (left:Dry specimens at BK, middle: before test, right: after test)

3A:   

3B:   

3C:   

3D: Not tested

Wood chip specimen (left:Dry specimens at BK, middle: before test, right: after test)

4A:   

4B:   

Sorghum specimen (left:Dry specimens at BK, middle: before test, right: after test)

5A:   

5B:   

5C 

5D: 

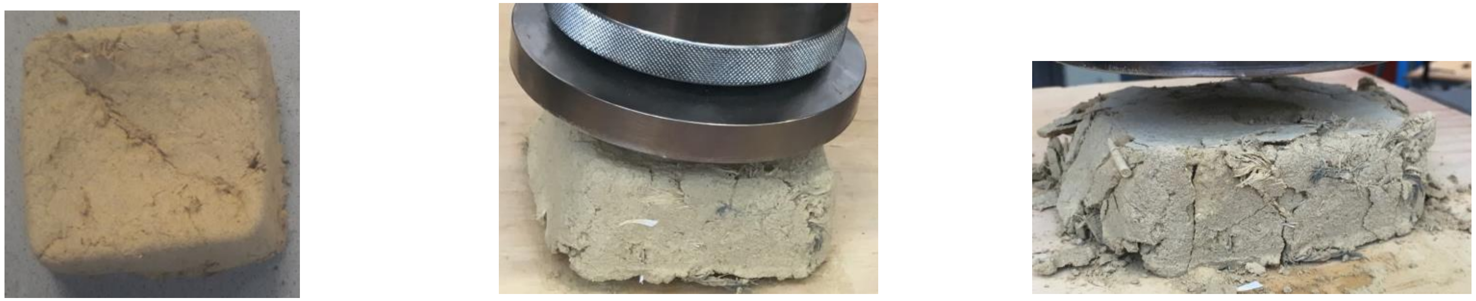
5E: 

5F:   

5G:  Not tested

Feather specimen (left:Dry specimens at BK, middle: before test, right: after test)

6A:   

6B: 

6C: 

6D: 

6E: 

6F:   

6G:   

6H:   

6I:

Extra information B: Calculations and Histogram Compressive stress

Data adobe only specimens:

Code	Dimensional Properties (mm) L	W	H	Fmax (N)	dL at Fmax (mm)	Area (mm2)	Compressive stress [N/mm2]
2	165	105	65	1.104	0,09	17325	0,1
1A	164	121	71	8.320	11,76	19844	0,4
1E	159	128	68	8.845	12,41	20352	0,4
1C	155	124	67	10.478	11,19	19220	0,5
5	165	105	65	11.457	9,67	17325	0,7
1D	159	114	64	12.006	13,09	18126	0,7
3	165	105	65	12.436	9,60	17325	0,7
1B	159	124	63	15.681	11,81	19716	0,8
A1	175	85	40	12.458	11,32	14875	0,8
A3	175	85	40	13.028	11,29	14875	0,9
4	165	105	65	15.587	8,49	17325	0,9
A2	175	85	40	13.624	9,26	14875	0,9
1	165	105	65	16.123	8,98	17325	0,9
A1	160	100	60	14.900	NA	16000	0,9
A4	175	85	40	15.951	14,95	14875	1,1
A5	175	85	40	19.770	8,56	14875	1,3
1	100	100	60	13.310	9,13	10000	1,3
S1s	95	70	30	9.216	7,91	6650	1,4
A6	175	85	40	21.832	10,02	14875	1,5
5	100	100	60	14.792	8,95	10000	1,5
7	60	60	50	5.352	12,54	3600	1,5
A3	95	70	30	10.380	4,91	6650	1,6
4	100	100	60	16.457	14,33	10000	1,6
A4	100	75	30	13.673	9,43	7500	1,8
3	100	100	60	19.247	12,70	10000	1,9
A9	170	90	40	29.867	9,68	15300	2,0
A6	100	75	30	14.996	11,96	7500	2,0
A8	170	90	40	31.979	7,55	15300	2,1
A3	100	75	30	15.700	NA	7500	2,1
A4	95	70	30	14.003	5,90	6650	2,1
2	100	100	60	21.595	9,90	10000	2,2
A2	95	70	30	16.087	NA	6650	2,4
S5s	95	70	30	16.900	NA	6650	2,5
S3s	95	70	30	17.900	NA	6650	2,7
A5	95	70	30	18.571	NA	6650	2,8
S4s	95	70	30	20.200	NA	6650	3,0
S2s	95	70	30	21.900	NA	6650	3,3
A7	170	90	40	51.283	19,53	15300	3,4
A9	105	75	30	29.158	NA	7875	3,7
A11	105	75	30	30.335	NA	7875	3,9
7	110	80	30	35.100	NA	8800	4,0
10	110	80	30	35.139	NA	8800	4,0
9	110	80	30	39.892	NA	8800	4,5
A1	100	75	30	38.700	NA	7500	5,2
8	110	80	30	59.763	NA	8800	6,8
A5	100	75	30	52.000	NA	7500	6,9
2B	109	111	40	93.036	24,98	12099	7,7
9	60	60	50	30.596	3,82	3600	8,5
2C	109	108	36	101.161	24,30	11772	8,6
2E	111	102	40	99.968	24,05	11322	8,8
10	60	60	50	32.418	6,39	3600	9,0
6	60	60	50	33.602	2,73	3600	9,3
A7	105	75	30	78.228	14,97	7875	9,9
A12	105	75	30	79.126	14,98	7875	10,0
A10	105	75	30	87.904	14,99	7875	11,2
6	110	80	30	98.454	14,98	8800	11,2
A2	100	75	30	83.998	11,97	7500	11,2
A8	105	75	30	88.700	NA	7875	11,3
A6	95	70	30	86.044	NA	6650	12,9
8	60	60	50	87.217	3,74	3600	24,2

Data straw specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm2)	Compressive stress [N/mm2]
	L	W	H				
S2	175	85	40	33.958	14,79	14875	2,3
12	135	90	40	29.811	8,86	12150	2,5
S1	175	85	40	36.593	14,94	14875	2,5
16	135	90	40	38.757	14,94	12150	3,2
S4	175	85	40	51.785	14,93	14875	3,5
S6	105	75	30	27.459	9,97	7875	3,5
S1	170	90	40	53.933	24,96	15300	3,5
15	135	90	40	43.370	13,16	12150	3,6
S3	175	85	40	56.106	14,94	14875	3,8
S5	175	85	40	56.502	14,94	14875	3,8
14	135	90	40	46.270	14,94	12150	3,8
11	135	90	40	46.286	14,94	12150	3,8
S2	170	90	40	69.109	18,18	15300	4,5
S4	170	90	40	72.196	23,67	15300	4,7
13	135	90	40	63.062	14,95	12150	5,2
S2	100	75	30	47.607	11,97	7500	6,3
S3	170	90	40	100.499	16,27	15300	6,6
3B	116	114	41	100.385	19,83	13224	7,6
3A	115	111	40	100.550	14,95	12765	7,9
3C	111	110	41	100.294	20,94	12210	8,2
S3	100	75	30	66.656	11,96	7500	8,9
S1	100	75	30	78.582	11,98	7500	10,5

Data wood chip specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm2)	Compressive stress [N/mm2]
	L	W	H				
WD3	90	90	40	9843	7,28	8100	1,22
WD1	170	90	40	24253	6,72	15300	1,59
20	135	90	40	26409	9,44	12150	2,17
19	135	90	40	27851	14,94	12150	2,29
SW1s	95	70	30	15900		6650	2,39
Sw3s	95	70	30	16700		6650	2,51
4A	125	118	50	38374	19,96	14750	2,60
17	135	90	40	32480	9,24	12150	2,67
WD2	170	90	40	43393	16,73	15300	2,84
18	135	90	40	35831	9,97	12150	2,95
21	135	90	40	35841	14,69	12150	2,95
Sw2s	95	70	30	22700		6650	3,41
4B	122	115	52	65934	24,97	14030	4,70
WD2	100	75	30	38300	-	7500	5,11
W1	105	75	30	43293	11,96	7875	5,50
WD3	100	75	30	52496	11,98	7500	7,00
WD1	100	75	30	56650	11,97	7500	7,55

Data sorghum specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm2)	Compressive stress [N/mm2]
	L	W	H				
5A	119	117	45	22.449	14,6	13923	1,61
5B	121	113	48	14.198	10,4	13673	1,04
5C	124	118	50	14.135	13,0	14632	0,97
5D	124	117	42	15.700	-	14508	1,08
5E	120	118	46	14.385	17,5	14160	1,02
5F	121	120	38	15.158	11,3	14520	1,04

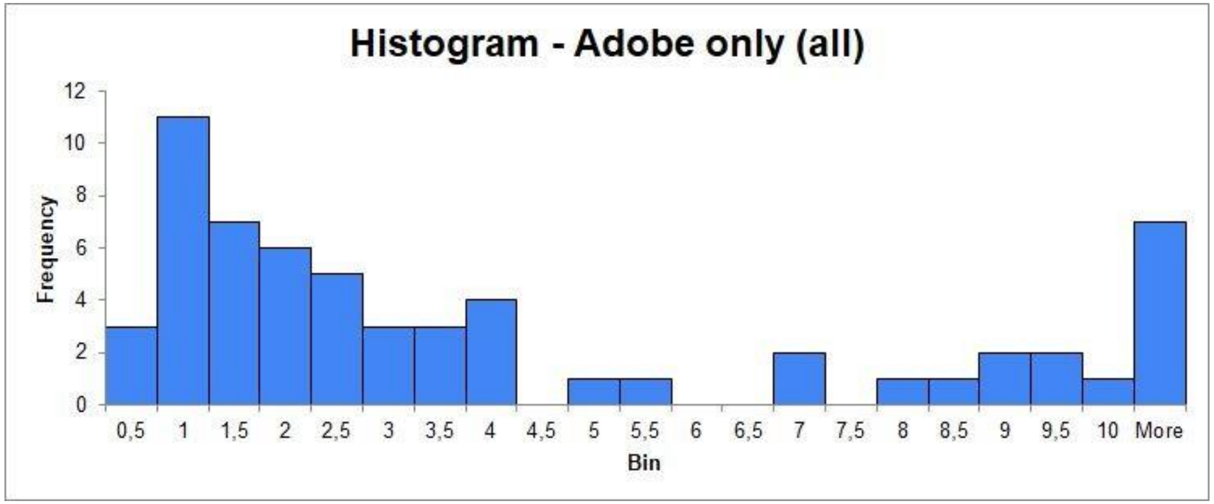
Data feathers specimens:

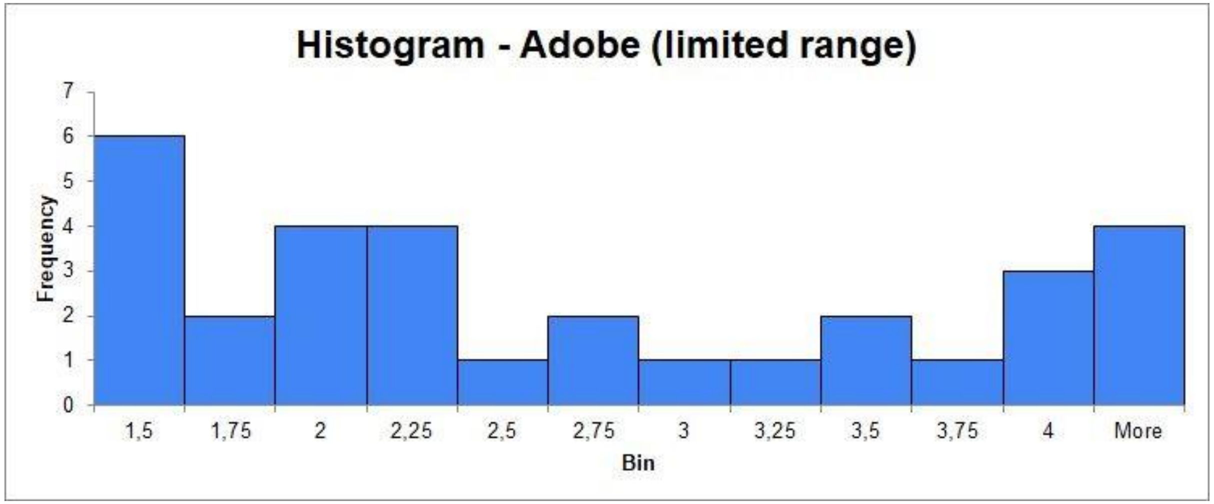
Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm2)	Compressive stress [N/mm2]
	L	W	H				
6A	118	115	44	22.502	15,0	13570	1,66
6B	118	109	35	11.900	15,0	12862	0,93
6C	119	116	42	27.988	15,0	13804	2,03
6D	116	114	41	28.210	15,0	13224	2,13
6E	119	111	46	57.591	20,0	13209	4,36
6F	116	109	39	100.492	18,3	12644	7,95
6G	118	115	44	86.520	20,0	13570	6,38
6H	113	106	40	54.940	20,0	11978	4,59
6I	159	122	63	19.300		19398	0,99

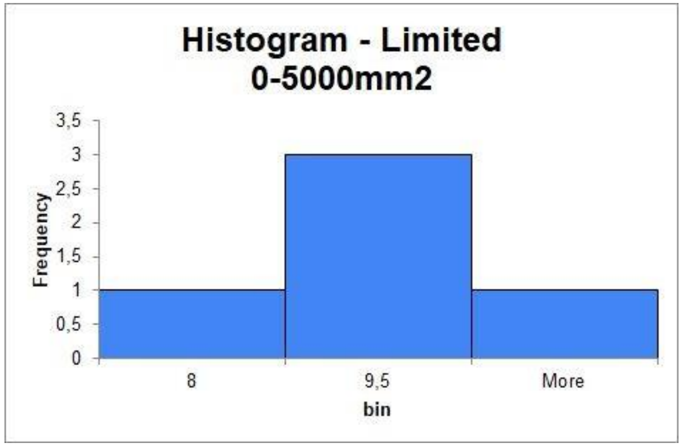
Accuracy calculation - Statistical estimation of the imprecision:

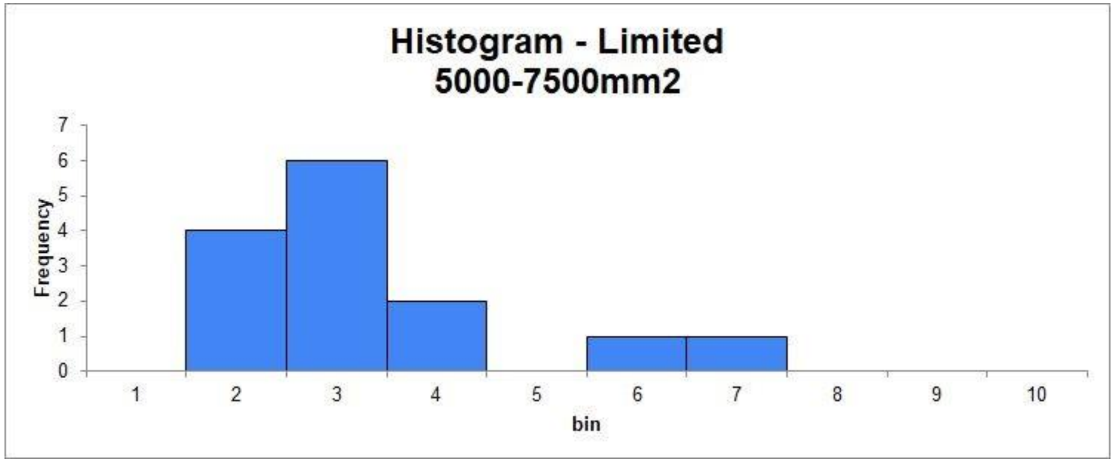
Compressive stress [N/mm2]											
	Adobe only							Straw	Wood chip	Soghum	Feathers
	All	Limited range	Limited 0-5000mm²	Limited 5000-7500mm²	Limited 7.500-10.000mm²	Limited 10.000-15.000mm²	Limited 15.000+ mm²	All	All	All	All
Min	0,06	1,07	1,49	1,39	3,70	0,84	0,06	2,28	1,22	0,97	0,93
Max	24,23	6,93	24,23	12,94	11,26	8,83	3,35	10,48	7,55	1,61	7,95
Average	4,19	2,75	10,51	4,00	7,31	2,87	1,03	5,00	3,50	1,13	3,75
Median	2,13	2,13	9,01	2,62	6,79	1,47	0,76	3,81	2,84	1,04	3,25
st. dev	4,46	1,50	8,33	3,46	3,39	3,02	0,86	2,32	1,83	0,24	2,49
Correction factor	1,96	1,96	2,78	2,13	2,23	2,16	2,16	1,96	2,12	2,57	2,37
n	60,00	32,00	5,00	16,00	11,00	14,00	14,00	22,00	17,00	6,00	8,00
Correction	1,13	0,52	10,35	1,84	2,28	1,74	0,50	0,97	0,94	0,25	2,09
Min Stress	3,07	2,23	0,16	2,16	5,04	1,13	0,53	4,03	2,56	0,87	1,66
Max Stress	5,32	3,27	20,86	5,84	9,59	4,61	1,53	5,97	4,44	1,38	5,84
Safety factor	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00
Min Stress incl. factor	1,53	1,12	0,08	1,08	2,52	0,56	0,27	2,02	1,28	0,44	0,83
Max Stress incl. factor	2,66	1,63	10,43	2,92	4,80	2,30	0,77	2,99	2,22	0,69	2,92
Physical test result	Complete destroyed							Shape mostly remained	Complete destroyed	Complete destroyed	Shape mostly remained

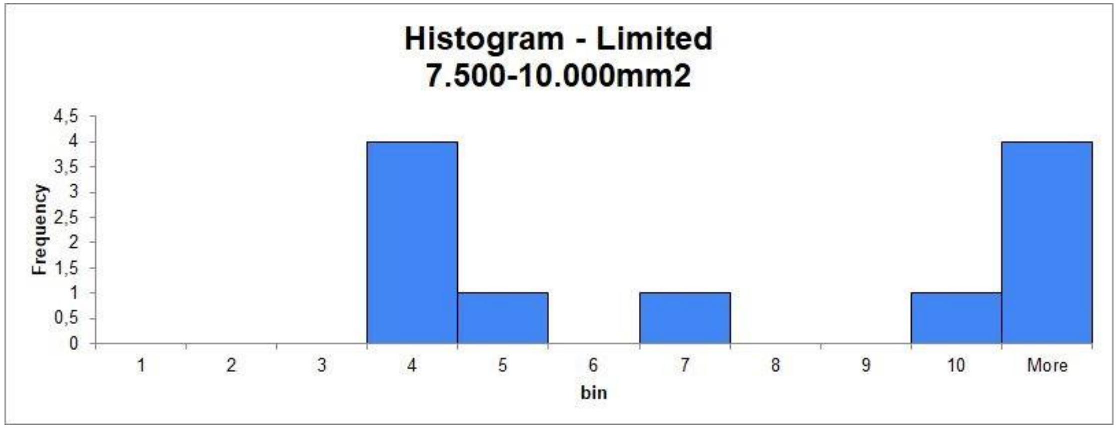
Histogram:

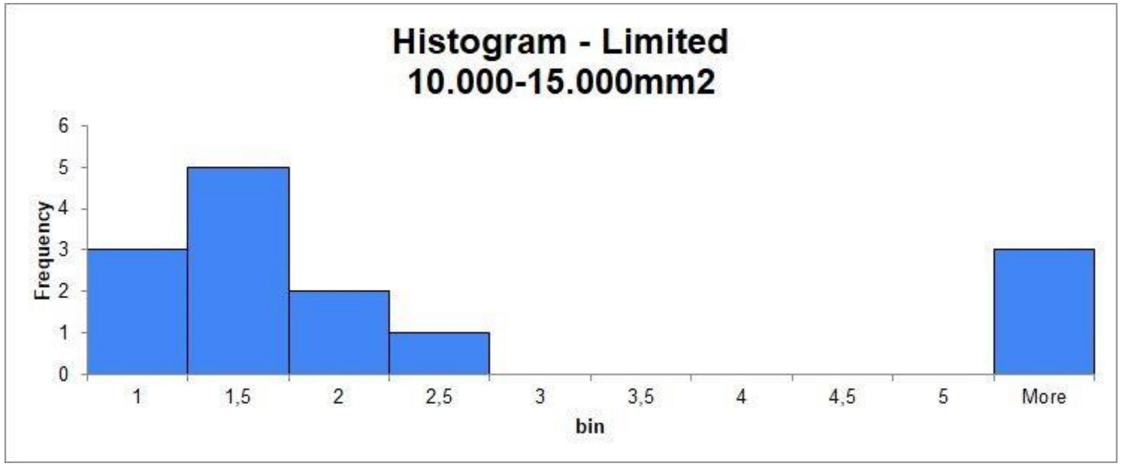

Histogram - Adobe only (all)
12
10
8
6
4
2
0
Frequency
0,5 1 1,5 2 2,5 3 3,5 4 4,5 5 5,5 6 6,5 7 7,5 8 8,5 9 9,5 10 More
Bin

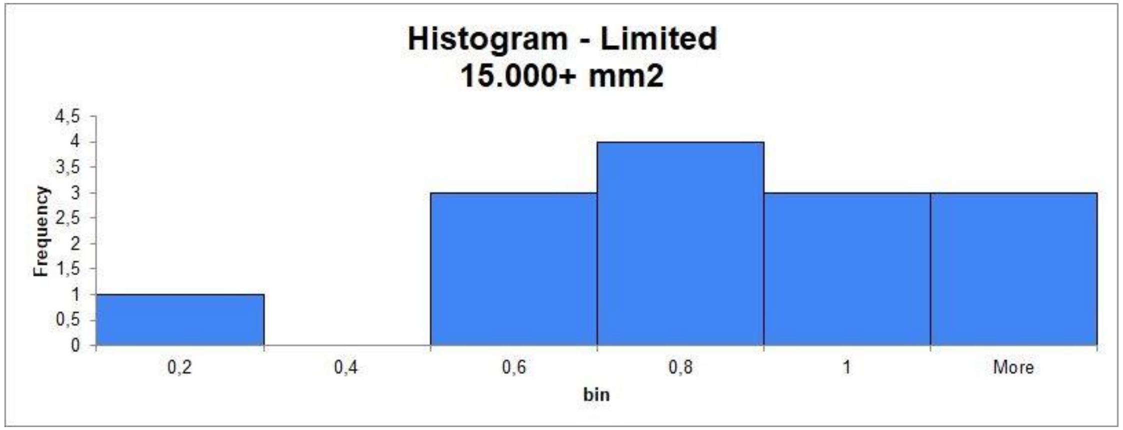

Histogram - Adobe (limited range)
7
6
5
4
3
2
1
0
Frequency
1,5 1,75 2 2,25 2,5 2,75 3 3,25 3,5 3,75 4 More
Bin


Histogram - Limited
0-5000mm2
3,5
3
2,5
2
1,5
1
0,5
0
Frequency
8
9,5
More
bin


Histogram - Limited
5000-7500mm2
7
6
5
4
3
2
1
0
Frequency
1
2
3
4
5
6
7
8
9
10
bin


Histogram - Limited
7.500-10.000mm2
Frequency
bin
1 2 3 4 5 6 7 8 9 10 More


Histogram - Limited
10.000-15.000mm2
Frequency
bin
1 1,5 2 2,5 3 3,5 4 4,5 5 More


Histogram - Limited
15.000+ mm2
Frequency
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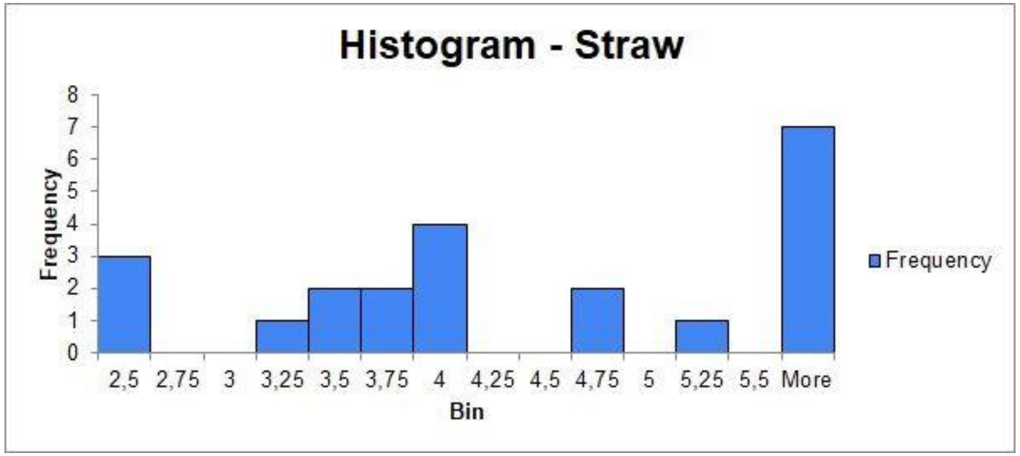
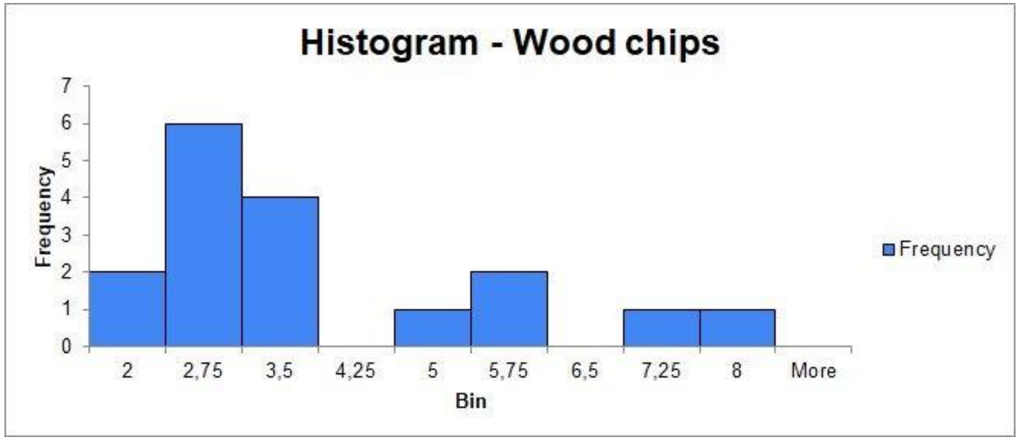
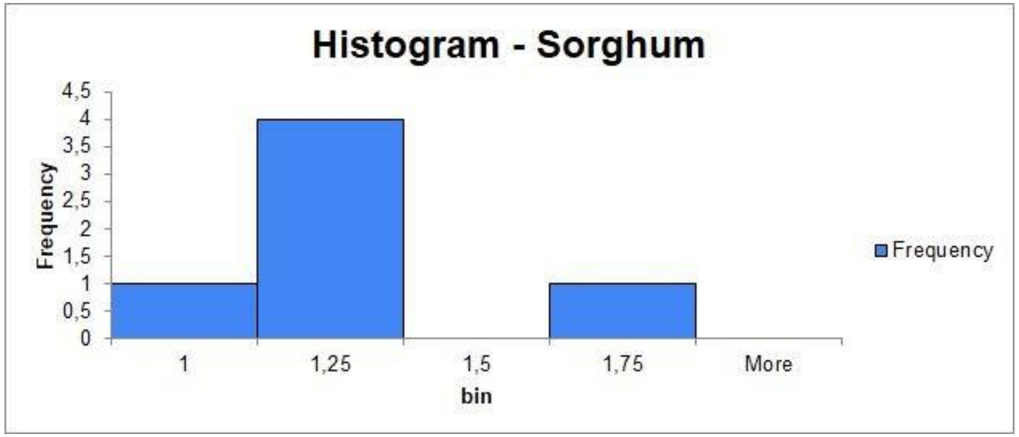
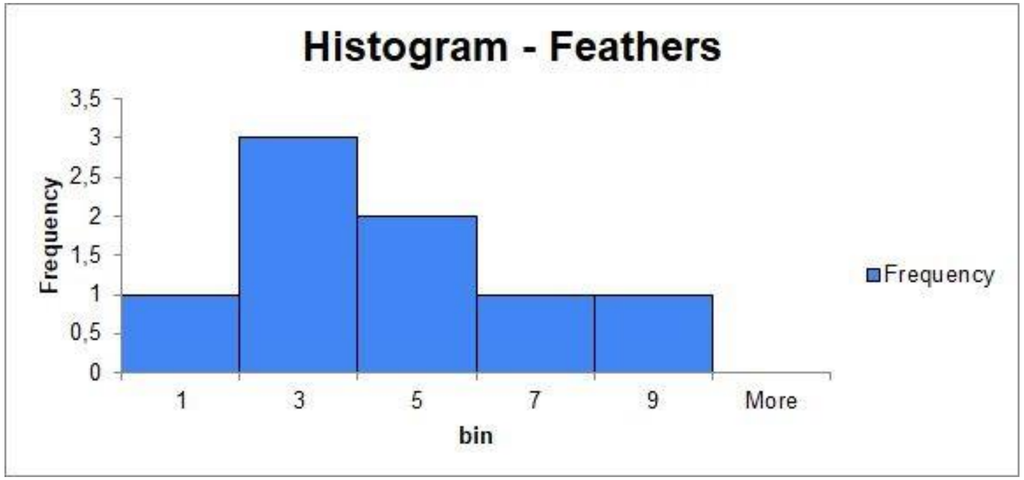
4
3,5
3
2,5
2
1,5
1
0,5
0
0,2
0,4
0,6
0,8
1
More
bin


Histogram - Straw
Frequency
8
7
6
5
4
3
2
1
0
2,5
2,75
3
3,25
3,5
3,75
4
4,25
4,5
4,75
5
5,25
5,5
More
Bin
Frequency


Histogram - Wood chips
Frequency
Bin
2
2,75
3,5
4,25
5
5,75
6,5
7,25
8
More
0
1
2
3
4
5
6
7
Frequency


Histogram - Sorghum
Frequency
bin
1
1,25
1,5
1,75
More
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
Frequency


Histogram - Feathers
Frequency
3,5
3
2,5
2
1,5
1
0,5
0
1
3
5
7
9
More
bin
Frequency

Extra information C: Calculations and Histogram elasticity Modulus

Data adobe only specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm^2)	Compressive stress [N/mm^2]	Moment of Inertia (mm^4)	Strain (mm)	Young's modulus (N/mm^2)
	L	W	H							
2	165	105	65	1.104	0,09	17325	0,1	2.402.969	0,09	70,81
1A	164	121	71	8.320	11,76	19844	0,4	3.608.936	6,00	6,99
1E	159	128	68	8.845	12,41	20352	0,4	3.353.941	6,00	7,24
1C	155	124	67	10.478	11,19	19220	0,5	3.107.884	5,00	10,90
5	165	105	65	11.457	9,67	17325	0,7	2.402.969	4,00	16,53
1D	159	114	64	12.006	13,09	18126	0,7	2.490.368	10,00	6,62
3	165	105	65	12.436	9,60	17325	0,7	2.402.969	6,00	11,96
1B	159	124	63	15.681	11,81	19716	0,8	2.583.819	10,00	7,95
A1	175	85	40	12.458	11,32	14875	0,8	453.333	10,00	8,37
A3	175	85	40	13.028	11,29	14875	0,9	453.333	5,00	17,52
4	165	105	65	15.587	8,49	17325	0,9	2.402.969	5,00	17,99
A2	175	85	40	13.624	9,26	14875	0,9	453.333	9,26	9,89
1	165	105	65	16.123	8,98	17325	0,9	2.402.969	8,98	10,36
A4	175	85	40	15.951	14,95	14875	1,1	453.333	6,00	17,87
A5	175	85	40	19.770	8,56	14875	1,3	453.333	8,56	15,53
1	100	100	60	13.310	9,13	10000	1,3	1.800.000	4,10	32,46
S1s	95	70	30	9.216	7,91	6650	1,4	157.500	7,91	17,52
A6	175	85	40	21.832	10,02	14875	1,5	453.333	10,02	14,65
5	100	100	60	14.792	8,95	10000	1,5	1.800.000	6,50	22,76
7	60	60	50	5.352	12,54	3600	1,5	625.000	8,00	18,58
A3	95	70	30	10.380	4,91	6650	1,6	157.500	3,91	39,92
4	100	100	60	16.457	14,33	10000	1,6	1.800.000	9,00	18,29
A4	100	75	30	13.673	9,43	7500	1,8	168.750	6,00	30,38
3	100	100	60	19.247	12,70	10000	1,9	1.800.000	10,00	19,25
A9	170	90	40	29.867	9,68	15300	2,0	480.000	6,68	29,22
A6	100	75	30	14.996	11,96	7500	2,0	168.750	6,00	33,33
A8	170	90	40	31.979	7,55	15300	2,1	480.000	7,55	27,68
A4	95	70	30	14.003	5,90	6650	2,1	157.500	4,90	42,97
2	100	100	60	21.595	9,90	10000	2,2	1.800.000	9,90	21,82
A7	170	90	40	51.283	19,53	15300	3,4	480.000	11,00	30,47
2B	109	111	40	93.036	24,98	12099	7,7	592.000	15,00	51,26
9	60	60	50	30.596	3,82	3600	8,5	625.000	3,82	222,70
2C	109	108	36	101.161	24,30	11772	8,6	419.904	7,00	122,76
2E	111	102	40	99.968	24,05	11322	8,8	544.000	10,00	88,30
10	60	60	50	32.418	6,39	3600	9,0	625.000	6,39	141,01
6	60	60	50	33.602	2,73	3600	9,3	625.000	2,73	342,35
A7	105	75	30	78.228	14,97	7875	9,9	168.750	9,00	110,38
A12	105	75	30	79.126	14,98	7875	10,0	168.750	9,00	111,64
A10	105	75	30	87.904	14,99	7875	11,2	168.750	9,00	124,03
6	110	80	30	98.454	14,98	8800	11,2	180.000	9,00	124,31
A2	100	75	30	83.998	11,97	7500	11,2	168.750	8,00	140,00
8	60	60	50	87.217	3,74	3600	24,2	625.000	3,74	647,00

Data straw specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm^2)	Compressive stress [N/mm^2]	Moment of Inertia (mm^4)	Strain (mm)	Young's modulus (N/mm^2)
	L	W	H							
S2	175	85	40	33.958	14,79	14875	2,3	453.333	14,79	15,44
12	135	90	40	29.811	8,86	12150	2,5	480.000	6,86	35,77
S1	175	85	40	36.593	14,94	14875	2,5	453.333	14,94	16,47
16	135	90	40	38.757	14,94	12150	3,2	480.000	10,94	29,16
S4	175	85	40	51.785	14,93	14875	3,5	453.333	14,93	23,32
S6	105	75	30	27.459	9,97	7875	3,5	168.750	5,97	58,41
S1	170	90	40	53.933	24,96	15300	3,5	480.000	10,96	32,16
15	135	90	40	43.370	13,16	12150	3,6	480.000	6,16	57,95
S3	175	85	40	56.106	14,94	14875	3,8	453.333	10,94	34,48
S5	175	85	40	56.502	14,94	14875	3,8	453.333	14,94	25,42
14	135	90	40	46.270	14,94	12150	3,8	480.000	7,94	47,96
11	135	90	40	46.286	14,94	12150	3,8	480.000	4,94	77,12
S2	170	90	40	69.109	18,18	15300	4,5	480.000	5,50	82,13
S4	170	90	40	72.196	23,67	15300	4,7	480.000	8,75	53,93
13	135	90	40	63.062	14,95	12150	5,2	480.000	4,95	104,85
S2	100	75	30	47.607	11,97	7500	6,3	168.750	6,00	105,79
S3	170	90	40	100.499	16,27	15300	6,6	480.000	12,27	53,53
3B	116	114	41	100.385	19,83	13224	7,6	654.750	9,93	76,45
3A	115	111	40	100.550	14,95	12765	7,9	592.000	10,95	71,94
3C	111	110	41	100.294	20,94	12210	8,2	631.776	10,94	75,08
S3	100	75	30	66.656	11,96	7500	8,9	168.750	6,00	148,12
S1	100	75	30	78.582	11,98	7500	10,5	168.750	6,00	174,63

Data wood chip specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm^2)	Compressive stress [N/mm^2]	Moment of Inertia (mm^4)	Strain (mm)	Young's modulus (N/mm^2)
	L	W	H							
WD3	90	90	40	9843	7,28	8100	1,22	480.000	5,27	23,06
WD1	170	90	40	24253	6,72	15300	1,59	480.000	6,72	23,59
20	135	90	40	26409	9,44	12150	2,17	480.000	3,44	63,18
4A	125	118	50	38374	19,96	14750	2,60	1.229.167	18,96	13,72
17	135	90	40	32480	9,24	12150	2,67	480.000	7,24	36,92
WD2	170	90	40	43393	16,73	15300	2,84	480.000	6,73	42,14
18	135	90	40	35831	9,97	12150	2,95	480.000	4,97	59,34
21	135	90	40	35841	14,69	12150	2,95	480.000	4,69	62,90
4B	122	115	52	65934	24,97	14030	4,70	1.347.493	24,97	18,82
W1	105	75	30	43293	11,96	7875	5,50	168.750	7,96	69,06
WD3	100	75	30	52496	11,98	7500	7,00	168.750	4,96	141,12
WD1	100	75	30	56650	11,97	7500	7,55	168.750	7,97	94,77

Data sorghum specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm^2)	Compressive stress [N/mm^2]	Moment of Inertia (mm^4)	Strain (mm)	Young's modulus (N/mm^2)
	L	W	H							
5A	119	117	45	22.449	14,6	13923	1,61	888.469	9,57	16,85
5B	121	113	48	14.198	10,4	13673	1,04	1.041.408	6,40	16,22
5C	124	118	50	14.135	13,0	14632	0,97	1.229.167	6,04	15,99
5E	120	118	46	14.385	17,5	14160	1,02	957.137	7,53	13,49
5F	121	120	38	15.158	11,3	14520	1,04	548.720	11,30	9,23

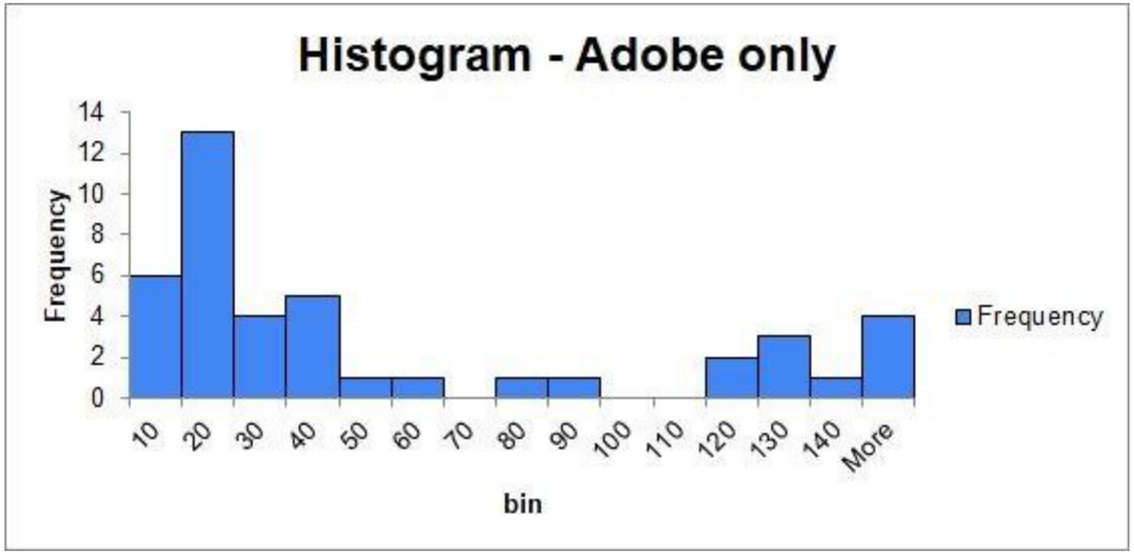
Data feathers specimens:

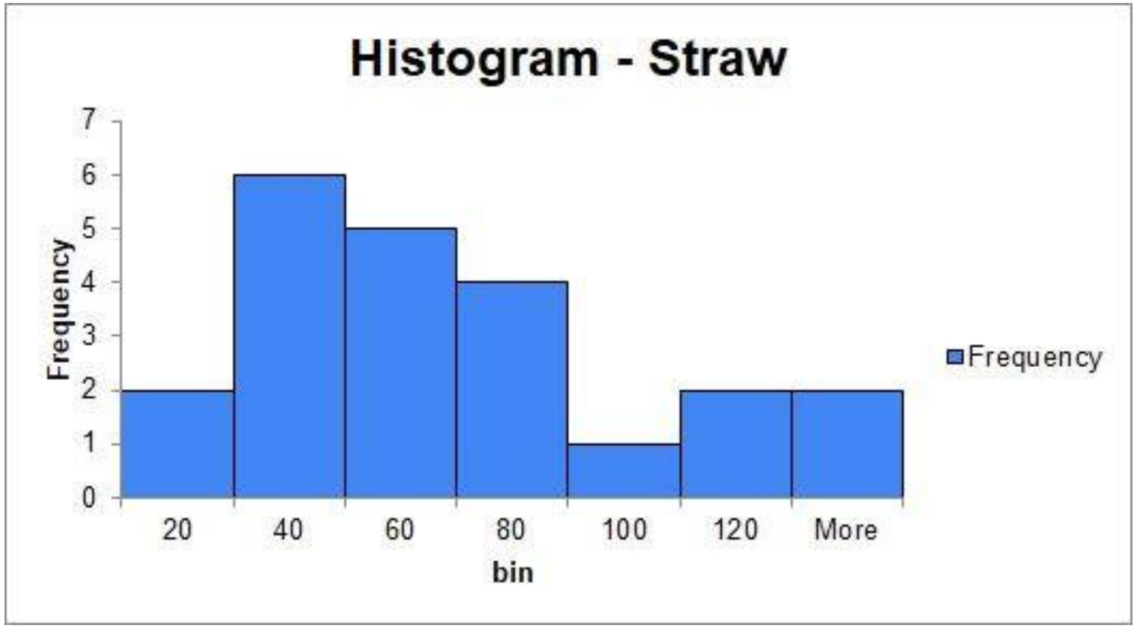
Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm^2)	Compressive stress [N/mm^2]	Moment of Inertia (mm^4)	Strain (mm)	Young's modulus (N/mm^2)
	L	W	H							
6A	118	115	44	22.502	15,0	13570	1,66	816.347	9,06	18,30
6B	118	109	35	11.900	15,0	12862	0,93	389.448	8,02	11,54
6C	119	116	42	27.988	15,0	13804	2,03	716.184	9,96	20,36
6D	116	114	41	28.210	15,0	13224	2,13	654.750	9,95	21,44
6E	119	111	46	57.591	20,0	13209	4,36	900.358	15,97	27,30
6F	116	109	39	100.492	18,3	12644	7,95	538.814	14,27	55,70
6G	118	115	44	86.520	20,0	13570	6,38	816.347	14,97	42,59
6H	113	106	40	54.940	20,0	11978	4,59	565.333	9,98	45,96

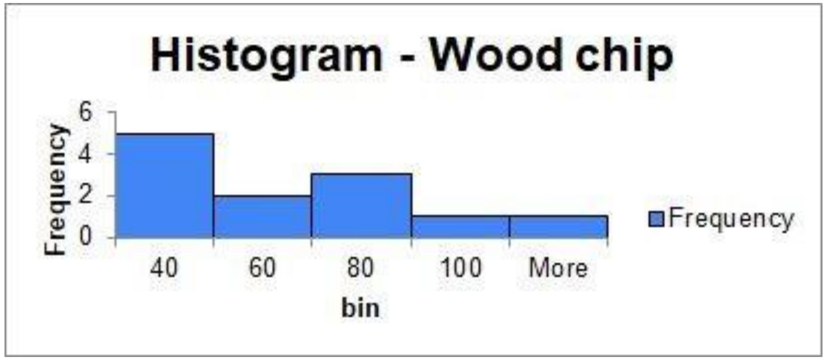
Accuracy calculation - Statistical estimation of the imprecision:

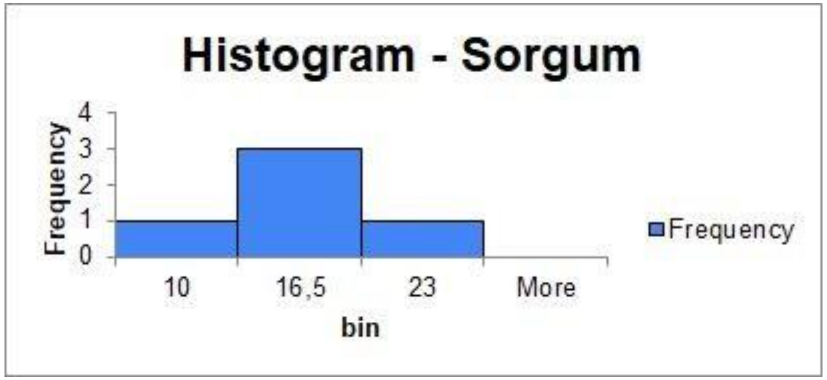
Young's Modulus [N/mm2]					
	Adobe only	Straw	Wood chip	Soghum	Feathers
	All	All	All	All	All
Min	6,62	15,44	13,72	9,23	11,54
Max	647,00	174,63	141,12	16,85	55,70
Average	68,13	63,64	54,05	14,36	30,40
Median	25,22	55,94	50,74	15,99	24,37
st. dev	115,08	41,27	36,74	3,14	15,69
Correction factor	1,96	1,96	2,20	2,78	2,37
n	42,00	22,00	12,00	5,00	8,00
Correction	34,80	17,24	23,33	3,90	13,15
Min E-modulus	33,33	46,40	30,72	10,46	17,25
Max E-modulus	102,94	80,89	77,38	18,26	43,55
Physical test result	Complete destroyed	Shape mostly remained	Complete destroyed	Complete destroyed	Shape mostly remained

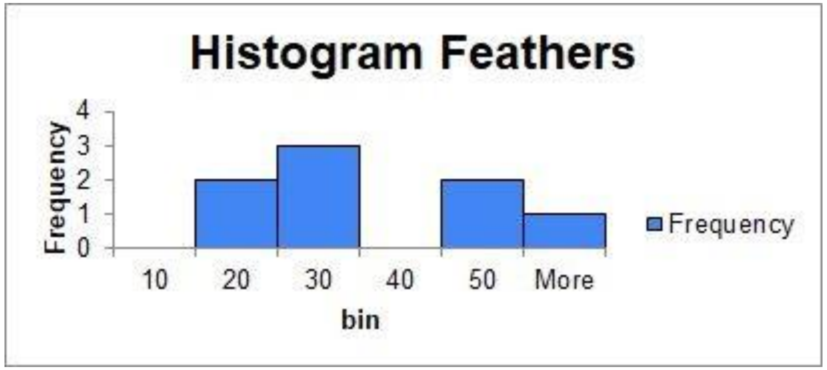
Histogram:


Histogram - Adobe only
14
12
10
8
6
4
2
0
Frequency
10
20
30
40
50
60
70
80
90
100
110
120
130
140
More
bin
Frequency


Histogram - Straw
7
6
5
4
3
2
1
0
Frequency
20
40
60
80
100
120
More
bin
Frequency


Histogram - Wood chip
Frequency
6
4
2
0
40
60
80
100
More
bin
Frequency


Histogram - Sorgum
Frequency
4
3
2
1
0
10
16,5
23
More
bin
Frequency


Histogram Feathers
Frequency
4
3
2
1
0
10
20
30
40
50
More
bin
Frequency

Appendix N: Brick bonds

Making of bricks:

The bricks can have different sizes and compositions depending on the context and design. The bricks are mainly produced in tools called “ladders”, see figure 1. These moulds are made from hardwood. Before the composition of the bricks can be put in the mould, sand is applied to prevent sticking to the mould.

Figure 1: Ladder mould for bricks. Retrieved from Handmadebrick (n.d.).

Structural brick bonds

Inspired by the vault brickwork of Guastavino, a study is performed to understand the possibilities and side notes of bonds. According to Stenvert (2012) Flemish, Cross, Chain, English and Header bonds are structural bonds which can resist load-bearing force. Many decoration bonds can be made, but this can only be performed with workers with high skill level and when there is an actual structural caring wall/ ceiling behind it. Different colors can be applied in the bricks to play with the original bonds to give it more decoration.

Interlocking bricks are out of scope for this project as this tension can occur in these kinds of structures (domes and vaults) and more study is required to understand how to design a brick with less as possible tension (Mulder, 2016). Also, the bricks must be made by low skills people. Therefore, the process should not be more complicated than already creating a building

Flemish bond

The Flemish bond is easy to perform in bricklaying, see figure 1. The on every row, the number of headers and stretchers are the same. The header should be in the center of the stretcher (Hodge,1971). Therefore, the beds and perpends are not limited in dimension. It is also possible to create a

‘Brazilian’ bond based on the Flemish bond. The Brazilian bond is a bond which leaves out the headers of the bond (Mulder, 2016). This results in a small window and ventilation openings in a brick structure. The Flemish bond has potential for the domes, vaults and walls for the bazaar.

Figure 1: Flemish bond. Retrieved from Stenvert (2012).

Cross bond

The cross bond (figure 2) is the most used bond in North-Europe as this can be performed quickly and headers can be left out to create construction ventilation. For Jordan, the left-out headers can be used for small window or ventilation purpose. As with the Flemish bond, this bond is one of the strongest bonds (Mulder, 2016). The cross bond has potential for the domes, vaults and walls for the bazaar.

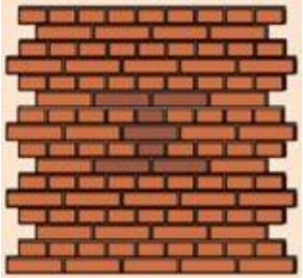


Figure 2: Cross bond. Retrieved from Stenvert (2012)

Chain bond

In the chain bond, the pattern is each time header, stretcher, header, stretcher etc. Therefore, this pattern shows a chain, see figure 3. This is a simple pattern and easy to bricklaying. However, the higher the wall with this bond, the weaker it gets. Therefore, thicker walls are required (Mulder, 2016). Therefore, this method is less suitable for the bazaar.

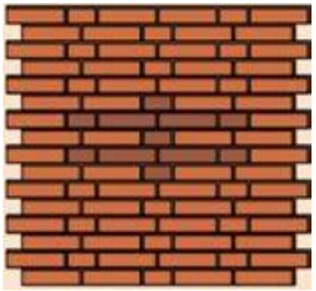


Figure 3: Chain bond. Retrieved from Stenvert (2012).

English bond

The English bond has a very simple appearance however, it requires high skill level. This pattern shows continues vertical line in the wall, see figure 4. When the bricklaying is performed incorrectly, the bricks do not have much overlap, forces can cause cracks in the wall. Only with strong mortal this can be solved (Mulder, 2016). When the bricklaying is performed as it should be, this is one of the strongest bonds (Hodge,1971). Due to the high skill level, English bond is less suitable for the bazaar in Zaatari.

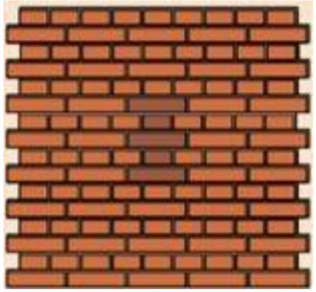


Figure 4: English bond. Retrieved from Stenvert (2012).

Header bond

The header bond is very easy to lay, but difficult to keep it straight for a long wall, see figure 5. Therefore, experienced bricklayers can perform this method. Also, the stability of the wall gets less as with the chain bond (Mulder, 2016). Therefore, this pattern is not feasible for Zaatari.

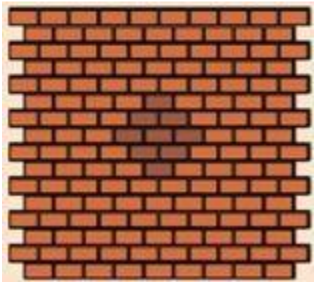


Figure 5: Head bond. Retrieved from Stenvert (2012).

Non-structural brick bonds

For filling the structural elements, a non load-bearing bond can be chosen e.g. single herring-bone bond and basket-weave bond, see figure 6. These bonds are able to cover double curved surfaces (Buffaloah, n.d.).

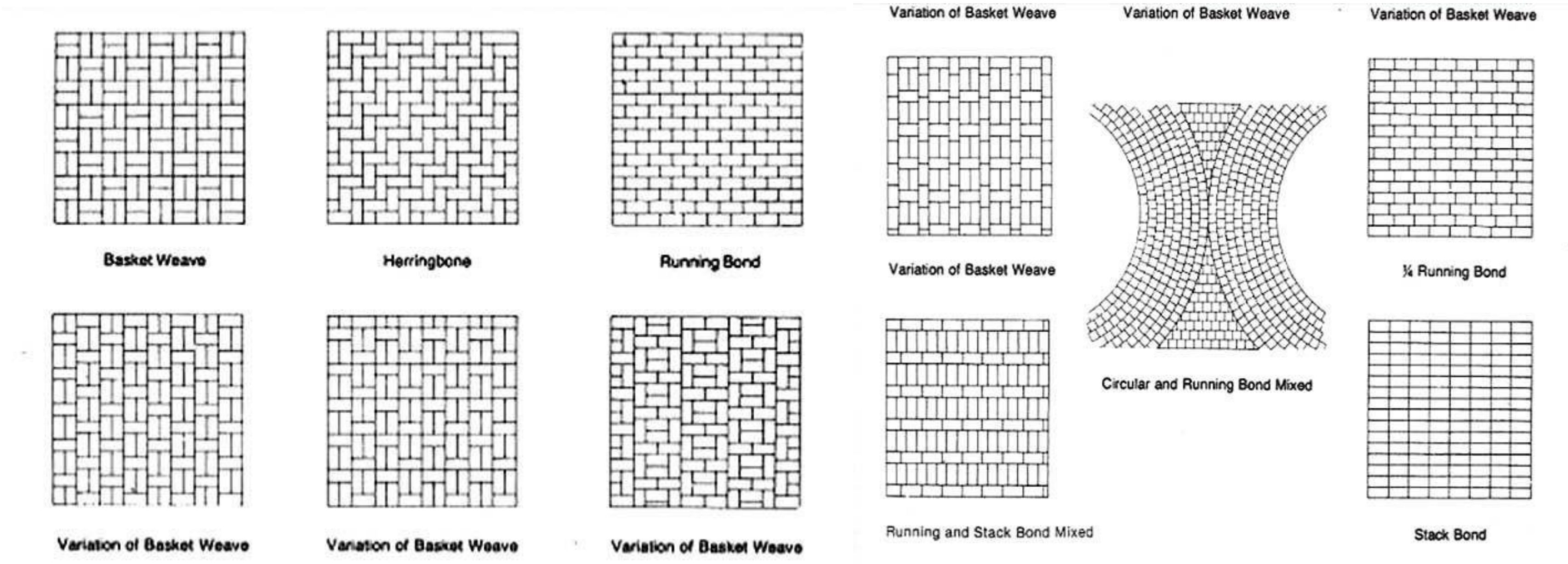


Figure 6: non load-bearing bonds which can cover double curve. Retrieved from Buffaloah (n.d.).

Column

There are many ways to bricklaying a column, see figure 7. However, the bond does impact the load-bearing force. Next to this, the shape of the column has to meet the function. In an intensive used space, round columns are more used than rectangular columns. Next to these two standard shapes, many variants can be made e.g. increasing the width of the radius of the round column in the middle, or by twisting the rectangular column. These methods can create a different experiment of the space without adding extra brick types (Weijde, 1950). Depending on the size of the column, there are different methods of stacking bricks. The most important element of stacking a brick is to make sure the bricks overlap each other, see figure 8.

Figure 7: Left - round column (Constructor, n.d.), middle - rectangular column (unknown, n.d.), right - twisted rectangular column (Reynolds, 2012)

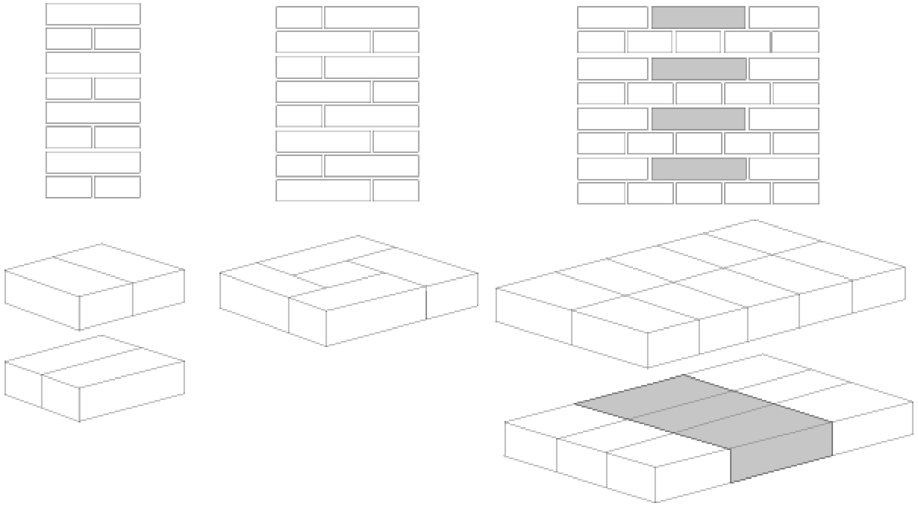


Figure 8: Different methods of stacking bricks for a column (depending on size)

Brick arches

Temporarily supports are original from wood and supports the brick arch during construction as the mortar still needs to dry. Next to this, the supports are also the guidelines of the geometry. On the back of the arch ribs, another row of bricks are applied. Not only for structural reasons, but also for supports of the filling bricks between the arches, see figure 9.

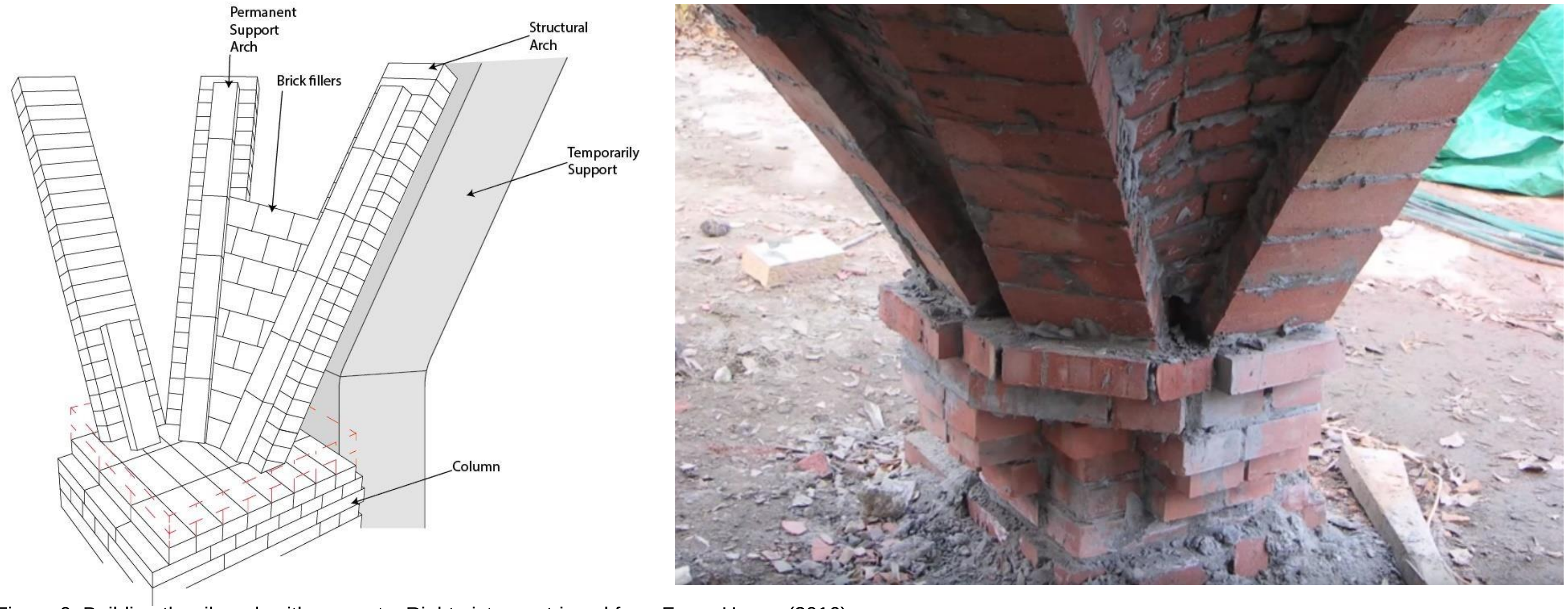


Figure 9: Building the rib arch with supports. Right picture retrieved from ForumHouse (2016).

Fillings between the arches

Several bonds can be applied between arches, but the most common bonds are stretchers and herringbone (Rajabzadeh & Sassone, 2016) . The application is shown in figure 10. In the end, all bonds have required hand cut bricks are this has to finish the surface, see figure 11.

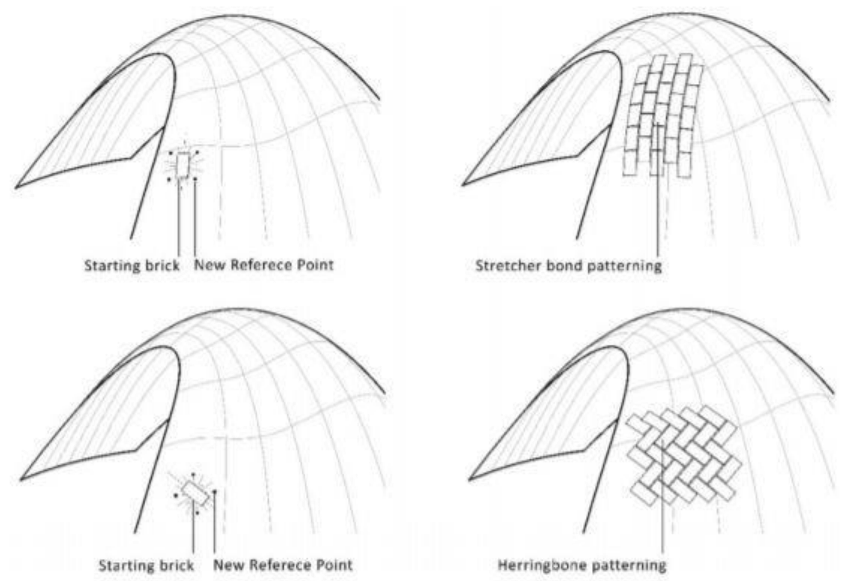


Figure 10: Brick pattern free form surface. Right picture retrieved from Rajabzadeh & Sassone (2016).

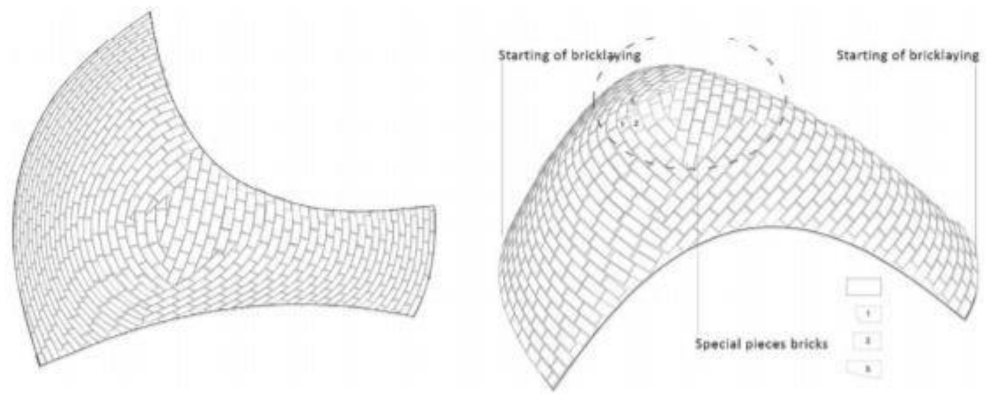


Figure 11: Finishing free form surface with bricks. Right picture retrieved from Rajabzadeh & Sassone (2016).

Appendix O: Constructing rib vaults/ domes & window opening

Dome and vaults

The rib dome and rib vault is chosen to realize the span of the bazaar. Domes for the junctions, shops and houses and vaults for the walkways. The traditional method to build a rib dome and/or vault is by creating a wooden support. This is shown in figure 1. First the ribs, and then the space between the ribs are filled with tiles. Also, it is important the the lay the edges of the bricks as close as possible in the inner circle. However, wood is limited in refugee camp like Zaatari to use it as support. Therefore, alternatives have to be found. One way is re-using waste in the camp. At the moment, cardboard is available in Zaatari and can be used as support. Another temporary support can be made by stacking bricks without mortar. A temporary support is created and the bricks can be reused in the next part of the structure. Finally, an inflatable mould is possible.

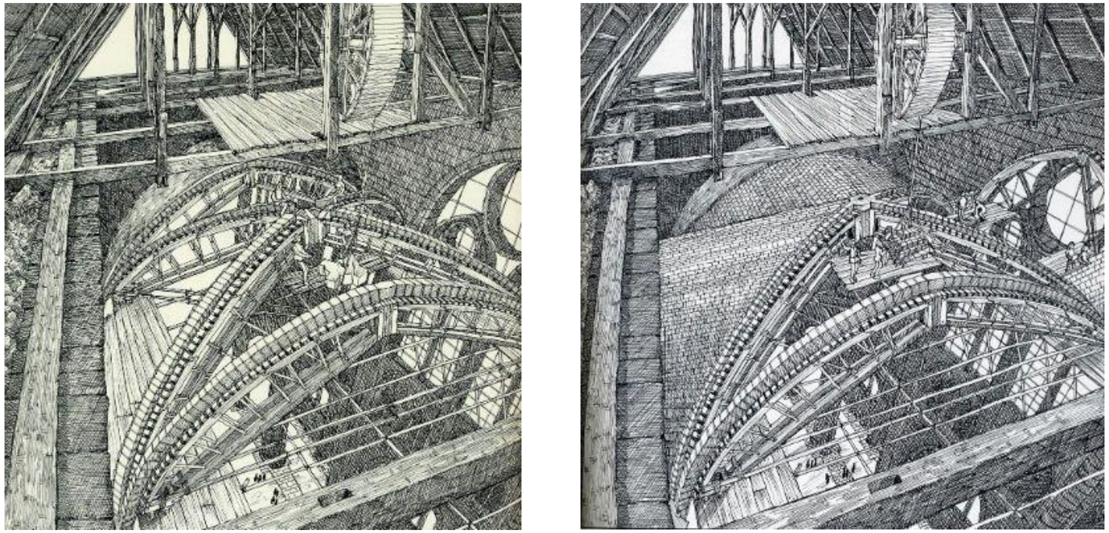


Figure 1: Construction of a rib vault. Retrieved from Henrickus (n.d.).

Next to the solid formworks a radial arm (figure 2) can be used to construct hemispherical domes. First the bricks with a shallow angle are placed as base of the dome. After this inclination of the bricks grows. The radial arm rotates around the centre point and helps the constructor finding the right place and angle of the bricks. A disadvantage of the radial arm is that it is a time consuming process because one arm is used to lay all the bricks.

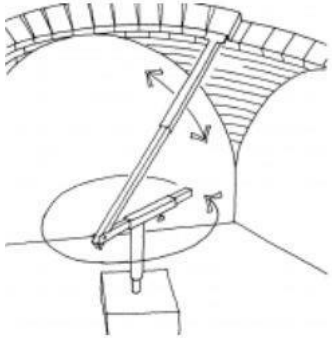


Figure 2: Radial Arm. Retrieved from The Dome (n.d.)

Wall opening

To create an opening in a wall, the forces of the wall should be transferred. This is needed to avoid tension in the adobe bricks. The traditional ways in The Netherlands is by adding an arch. Different kinds of arches are possible as shown in figure 3. Depending on the architecture of the building, types of bricks and level of skill of the workers an arch type can be selected. A lancet arch is most common in South-Syrian, the origin house of the refugees in Zaatari camp. Next to this, the bazaar will be contain domes and vaults which are based on rib vaults. Therefore, the lancet arch is chosen.

The lancet arch can be made in two different ways. First, a birth line can be made as shown in figure 3. The birth of the arch contains a regular brick, but a brick in an angle is also possible. This method requires high skill from the workers. A second method is by creating a negative framework, see figure 4. This framework is placed where the opening is planning. The framework is a guideline and a support for the bricks. This formwork follows the intrados of the curve. Formworks can be made for example from wood, metal and cardboard. In case of the Zaatari camp wood or cardboard can be used because these materials are available. The formwork should be made in such a way that it can be reused immediately. A modular design is recommended, otherwise a lot of different types of formwork is need to constructed the bazaar.

This method is easy for low skills workers and feasible for Jordan.

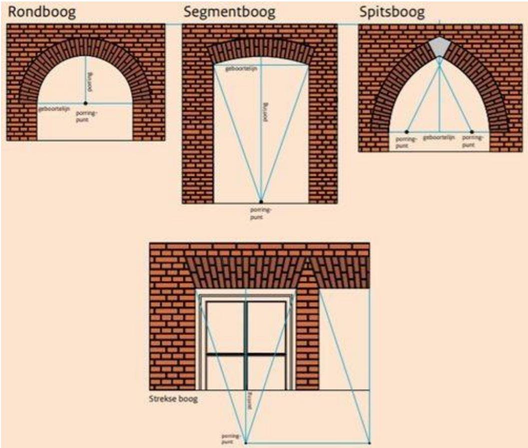


Figure 3: Arches as wall opening. Retrieved from Stenvert (2012).

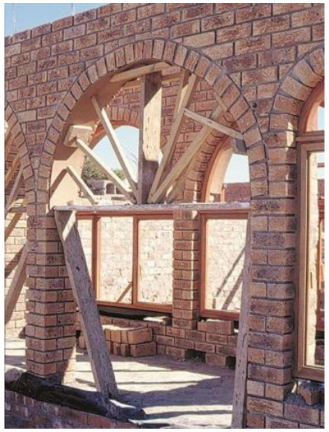


Figure 4: Framework for window opening. Retrieved from Joffroy (1994)

Tent as mould

Another option to use as mould is a tent structure, figure 5. The simplest tents are in principle made of two components; the poles and the skin. The poles are there for structural purpose and the skin is to protect the inside from the outside such as rain. In case of a rib structure tent's could be used as moulds because the forms of the rib can be simulated by combining the aluminium poles, canvas and nylon ropes. There is a lot of tensile force on the tent therefore the need of the aluminium poles and nylon ropes. Next to this ropes there should be some kind of foundation where these poles and ropes can be connected to. This could be a problem in the Zaatari camp because of the earthy underground.

Figure 5: Disassemble tent. Retrieved from Architen Landrell (2014).

Inflatable structures

Inflatable structures are already used in architecture and in the toy industry. An inflatable building is made of two membremes with pressurized air in between. The true structure is made by the walls with the air. Typically a membrane has a thickness of less than 1mm. This means that not a lot volume is needed as formwork/ structural support. This makes it easy to transport the membrane. Figure 6 shows an inflatable building in Dubai and figure 7. shows an inflatable room for on example congresses.

Figure 6: Spirit of Dubai. Retrieved from QuickSpace (n.d.)

Figure 7: Inflated room for congresses. Retrieved from QuickSpace (n.d.).

Inflatable structures are also used a lot as playing tool for children, as inflatable jumping castles, maze for laser tag, bubble football etcetera, see figure 8-10.

Figure 8: Inflatable jumping castle. Retrieved from SXT events (n.d.).
Figure 9: Maze for laser tag. Retrieved from Bounce (n.d.)
Figure 10: Bubble football. Retrieved from DHgate (n.d.).

Inflatable moulds concrete domes

Since two years inflatable moulds are also used for making concrete domes, see figure 12. This technique is called Pneumatic forming of hardened concrete. An inflatable mould is supported with post-tension tendons to create a concrete shell. How does it work: First multiple concrete slabs are cast on a flat underground. When the concrete is hardened the balloon is inflated. The concrete slabs are encircled with post tension tendons which prevent the slabs from sliding. There is a company called beton ballon who already deliver housing build in this way.

Figure 11: Inflatable concrete. Retrieved from Interesting Engineering (2017).
Figure 12: Inflatable concrete. Retrieved from Beton Ballon (2015).

Inflatable Moulds - Inflating

The inflatable jumping castles require a blower with a constant power of 1100 Watt. This can be connected to a 'normal' european socket of 220-230 Volt. There are no extra connecting pieces needed, this is included in the design of the castle, see figure 13. There are several electricity poles in the camp Zaatari. All twelve districts have access to safe electricity due to the solar power plant.

Figure 13: Air pressure pump. Retrieved from Attractieverhuurshop (2015).

Some inflatable moulds do not need constant power from a blower. These moulds are filled once and then closed off. An example of this is an inflatable rubber culvert mold, or a bicycle tire, see figure 14.

Figure 14: One time on pressure structures: Mold (left), cyclist inner tire (right). Retrieved from Zaoqiang (n.d.) and Curbside Cycle (n.d.).

In case of using the inflatable structure as mould and structural base for the bricks the option with the blower is chosen. This is because without a blower the air slowly moves out of the mould what influence the form. This is something that can not be allowed, the form of the mould should stay intact. The weight of the brick forces the canvas to move down, the air from the blower counters this and pushes the weight back.

Inflatable mould and their materials

There are many potential materials which are water- and windproof (MediaMatic (n.d). Examples are:

- Bisonyl which is used for truck sails and commercial sails;
- Chikara which is double coated and can stretch many times. Therefore, this material is durable when it is blown up multiple times;
- Contender is a very light material which is used for paragliding, but is sensible to tearing as it can only stretch one way.
- Dacron is a material which is mostly used in kites. It is strong and flexible, but can stretch less, so lower durability.
- Icarex is a material which is very lightweight, can stretch a lot, very well in water and windproof. It is UV resistance and easy to repair. However, economically it is more expensive than other materials.

There are many more materials which are suitable for the inflatable mould as long is durable in usage, can stretch in more than 1 direction, is water/wind proof and is easy to repair.

Bricks and inflatable mould

Bricks are stacked on each other in compression. Due to this the bricks do not start to slide off as with concrete. In principle the bricks lean on each other and follow the form of the mould in the beginnen. In a later stadium the bricks have to lean on the mould (top part). When there is no extra structure or air force up the balloon will deform. There are several solutions for this.

1. Take the deflection into account for the desired shape
2. Create a rigid substructure on those places so the shape can not deform.
3. Make sure the mould can not deform due to walls

Chambers in inflatable mould

The inflatable mould should be build from multiple chambers. This can be seen in air balloons and leading edge kites, see figure 15 and 16. In case of the bazaar this means the rib structure is the first layer. This layer needs more air pressure inside because the bricks will lay on top of this. The ribs can be compared with the leading edge, this is a very stiff air compartment which can not be bent by hand, see figure 18. A secondary structure should be added connected to this first chamber, in the kite this is called the struts. This structure makes sure the mould can not deform in any direction, see figure 18. Then the last part is the space in between the ribs. This space does not carry the bricks but is just there to follow the shape, see figure 18. Due to this there can be less air pressure in these chambers. This structure has its own chamber so it does not influence the rib structure. All the chambers are connected to each other due to the 'floor'. This is needed for stability and to keep the mould in place. On the sides are special ropes and tent peg to secure the mould to the already build walls, see figure 17.

Figure 15: Kite system. Retrieved from Kitefeel (n.d.).

Figure 16: Special shape ballon. Retrieved from GIC (2017).

Figure 17: Connection to the ground.. Retrieved from Axitraxi (n.d.)

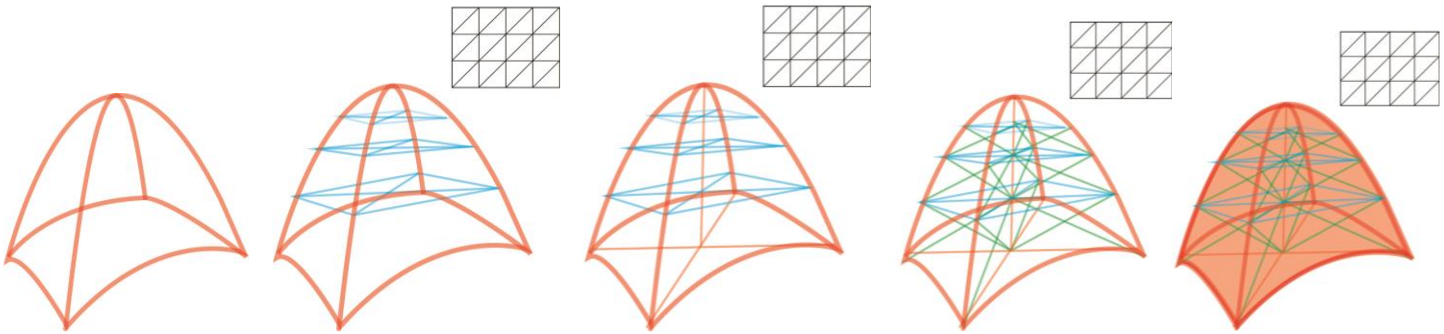


Figure 18: Design of the mould.

The mould makes it possible that the construction of the building can start simultaneously from all corners. Together with the substructure this means that the mould would not deform in horizontal direction. The primary structure, can be seen as a bicycle tire of leading edge, is very stiff. Together with the substructure this makes sure that the inflatable mould does not deform in vertical direction, see figure 19.

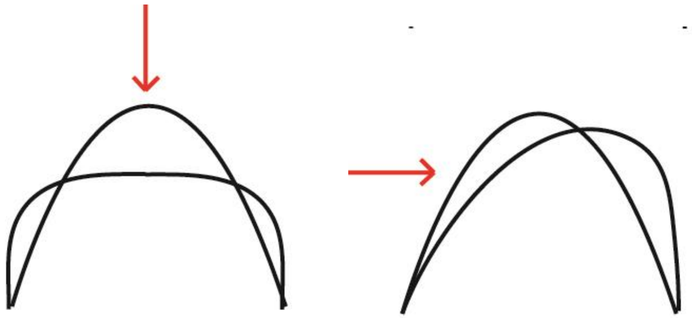


Figure 19: Reaction of inflatable structure which is unwanted.

Who owns the mould and how to repair

The mould is property of unicef. They take care of the mould and provide them to the camps. The future shop owner is not the person who uses the mould and build the shop. There is a special group of builders who are educated in how two build the structures of the bazaar and how to use the mould. This special group of builders is educated in the camp and are the only ones who are aloud to borrow the mould from unicef. When some builders leave the camp because they found their new living place new builders from the school can take their place. When a mould has a tear in the canvas it can be easily fixed. There are two ways. The first option is by using a blowdryer which heats the material. The second option is by using special PVC-glue and a small piece of extra PVC. This is like repairing the tire of a bike. The repairing can be done by the builder themself, they repairing equipment is delivered by unicef.

Benefits of inflatable mould

The inflatable mould is easy in transport because of it small volume. By using an inflatable mould the formwork and structural support could be tackled at once. By providing an inflatable mould the construction part of the bazaar is made a lot easier. The people in the camp do not have to make their own mould from example cardboard. This means they can not make a mistake in the form what is beneficial for the construction. The form of the mould is made in such a way to optimize the structural performance. Another benefit of the inflatable mould is that it is a 3D object. There is almost no room for mistakes from the builders. They follow the form, see figure 18.

Appendix P: Structural analysis - Street Karamba

The structural concept is made of connecting modular units ranging from 1.675m x 2.4m till 9.4m x 3.6m. In this chapter the FEM results from each module will be discussed.

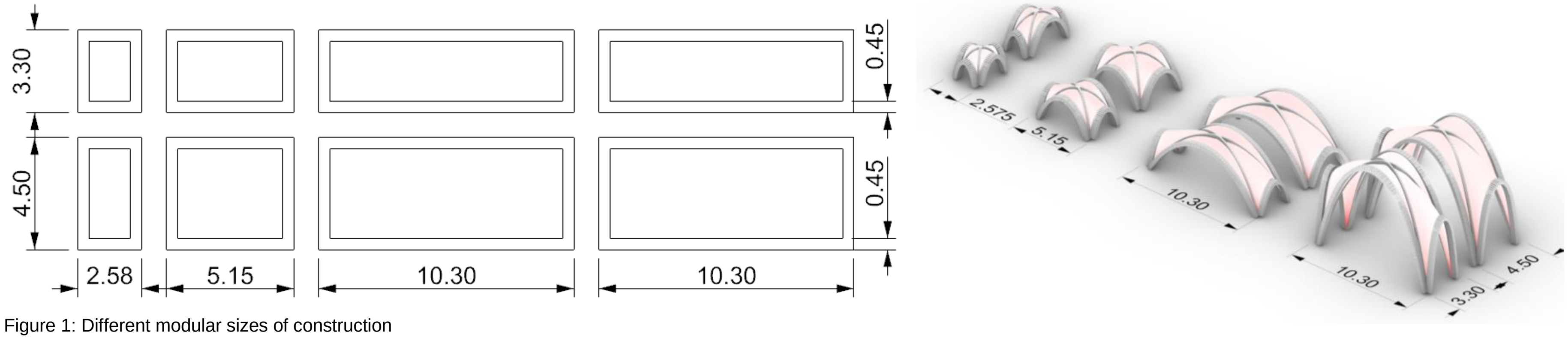


Figure 1: Different modular sizes of construction

Below you see the flow of forces illustrated of one of our modular units. (figure 2) Every unit is designed structurally sound on itself, The impact of wind-load was not verified by FEM, but was taken into account within the design process. we also expect the modular units to support each-other when they are placed next to one another. - wind load is only exposed on one of the modular units, and being brought to the ground by three. (for the high dome of 10.3m x 4.5m the wind load is expected to be the main problem. Here the flooring of first level could be designed to support in horizontal direction)

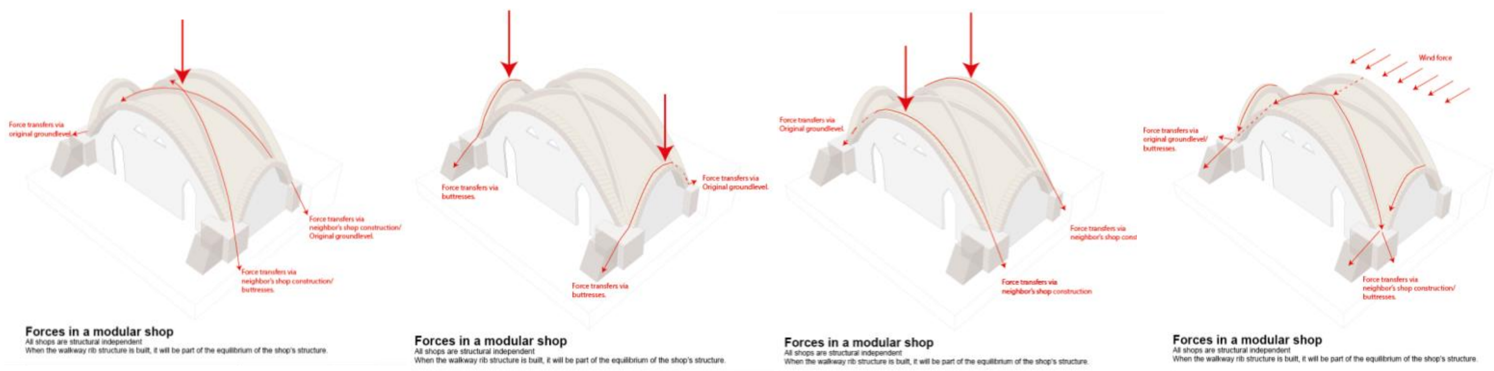


Figure 2: Flow of forces in a modular unit.

Limit states and material properties

Three different limit states were tested within our fem analysis of the modular units:

- *The tension/compression in principle direction 1*
- *The tension/compression in principle direction 2*
- *The deflection of the structure*

For the maximum deflection of the structure we took 1/200 times the span. For the maximum compression 3 *N/mm2 and* tension 0.3 *N/mm2* (1/10th of compression, value confirmed by Dirk) were used. When we look at the other material properties used in the FEM analysis we used the following values:

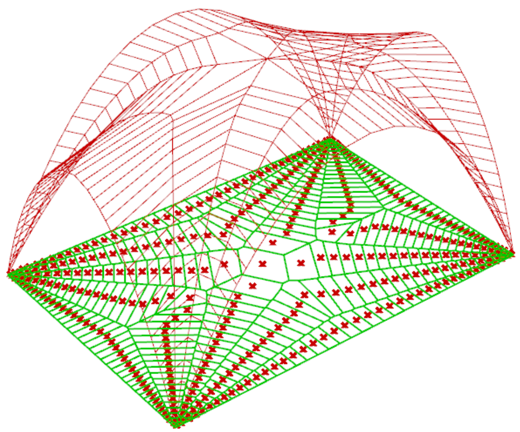
Youngs modulus 211 N/mm2 (E mean, based on)
Poisson ratio 0,3 [-]
shear modulus = Youngs modulus /(2(1+Poison ratio))*
Specific Weight 1452kg/m3
Compressive strength 3 N/mm2 (value confirmed/given by Dirk)

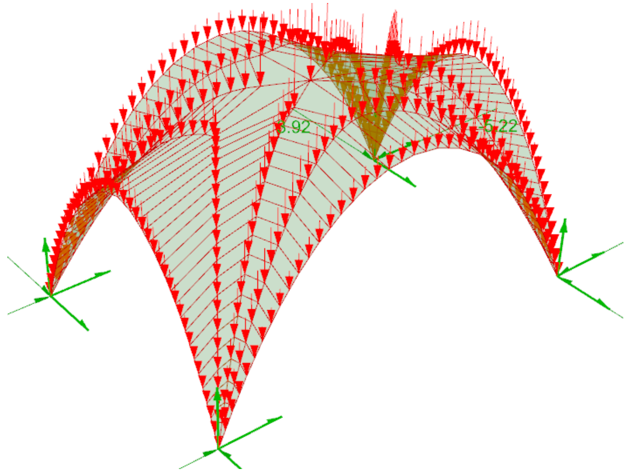
The above values have been set in Karamba3D this is an integrated FEM tool within grasshopper rhino. It allowed us to integrate finite element analysis within our design process, and creating optimisation loops, optimizing the spring stiffness to match our material and thickness.

Besides the FEM analysis we wanted to check if the resulting vector of the forces is within the column underneath the vaults. We applied a structural offset of 45cm between the vaults as seen in figure 1. This was to decrease the chance that the vector of the force was outside the structure. Especially for the domes with a big span and a relatively small height this was expected to be a problem. In the end of the chapter this is tested.

Applied forces

Three Different loads were applied: *Self weight, added mass (added mass for drainage purposes, thermal mass, and redirecting the force line) and imposed loads.* We took safety factors of 1.5 considering all loads. The self weight was integrated using the build in gravity tool in Karamba3d, For the imposed loads we took the surface area of a projected voranoid of the nodes on the XY plane and multiplied this by an expected load of 1.5kn/m2 (2.25 with safety factor) (figure 3)





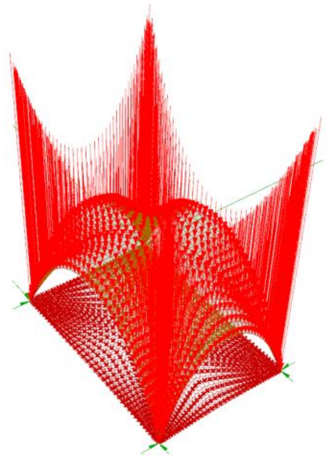


Figure 3: projected paranoid of structural nodes, which is used to calculate exposed loads on the structure. (simplified mesh for clarity)

Figure 4: showcase of applied load (without voranoid)

In the case of added mass we measured the difference in height between the highest point of the unit and the structural node, (figure 4) multiplying this by the surface area of the projected voranoid will give the added mass. Main reasons making sure the force line stays within the structure. (figure 5) (note: also redirects it downwards in the columns/edges)

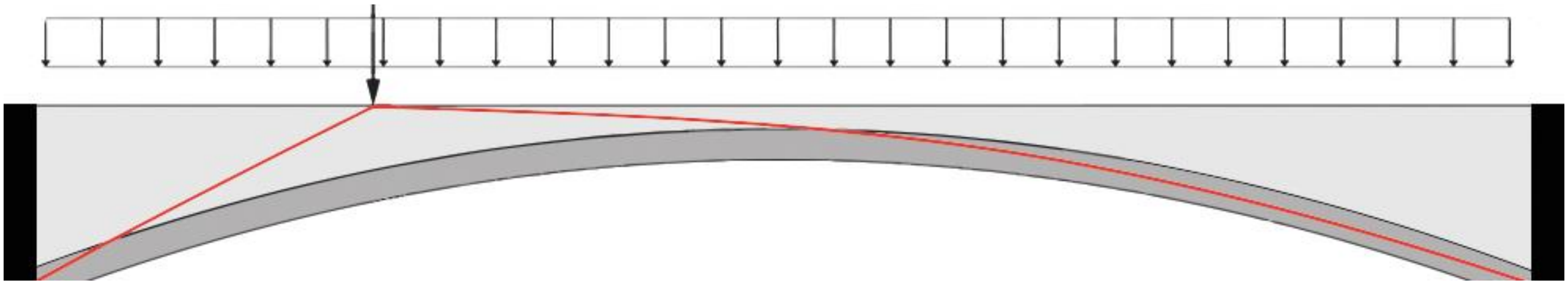


Figure 5: showcase of the added value of extra applied material

Modular vault 1.675m x 2.4m

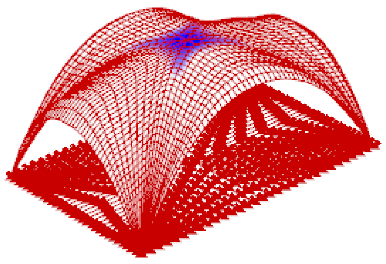


Figure 7: vault 1.675 x 2.4m

UC check of modular vault 1.675x2.4m:

The tension/compression in principle direction 1

- *0.29 < 0.3 N/mm2 (tension)*
- *-0.72 < 3 N/mm2 (compression)*

The tension/compression in principle direction 2

- *0.29 < 0.3 N/mm2 (tension)*
- *-1.46 < 3 N/mm2 (compression)*

The deflection of the structure

- *3.7 < 12 mm (deflection)*

test support thickness vs FEM resultant force
*(-5.56 * 1000) / (16.1^2 * 100) = 0.21 N/mm2*

- *0.21 < 3 N/mm2 (compression)*

Modular vault 1.675x2.4m passed all UC checks

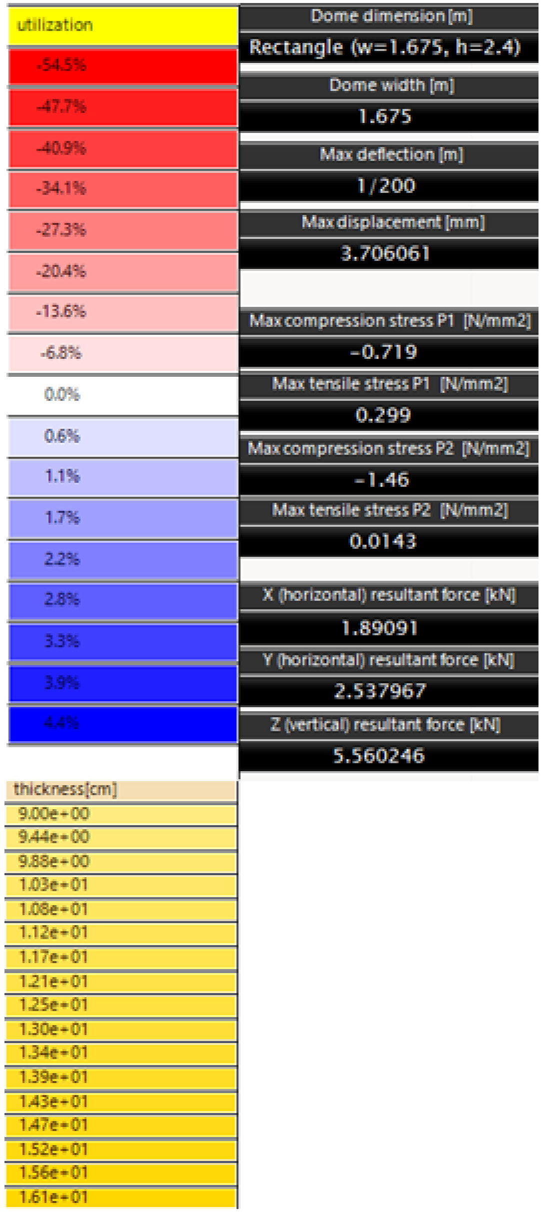


Figure 8:FEM

Modular vault 1.675m x 3.6m

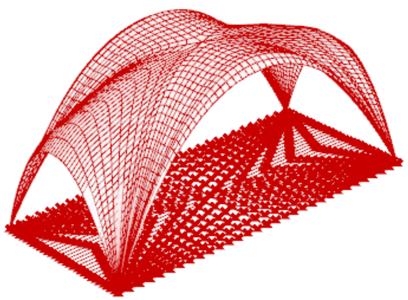


Figure 8: vault 1.675 x 2.4m

UC check of modular vault 1.675x3.6m:

The tension/compression in principle direction 1

- *0.85 < 0.3 N/mm2 (tension)*
- *0.29 < 3 N/mm2 (compression)*

The tension/compression in principle direction 2

- *0.02 < 0.3 N/mm2 (tension)*
- *1.8 < 3 N/mm2 (compression)*

The deflection of the structure

- *8.2 < 18 mm (deflection)*

test support thickness vs FEM resultant force
*(9.87 * 1000) / (16.1^2 * 100) = 0.38 N/mm2*

- *0.38 < 3 N/mm2 (compression)*

Modular vault 1.675x2.4m passed all UC checks

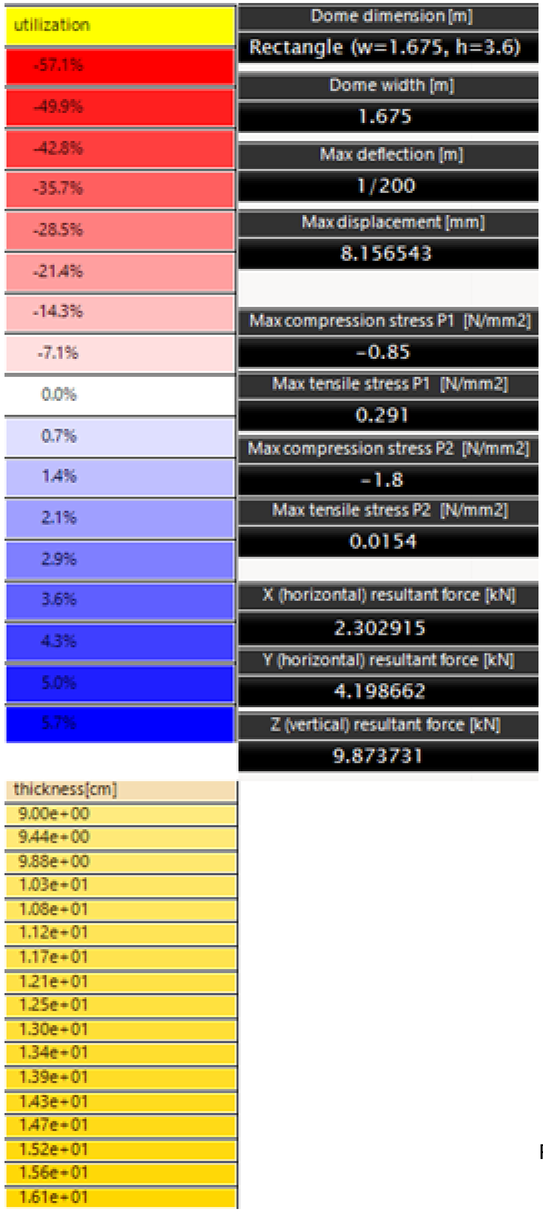


Figure 9:FEM

<u>**Modular vault 4.25m x 2.4m**</u>

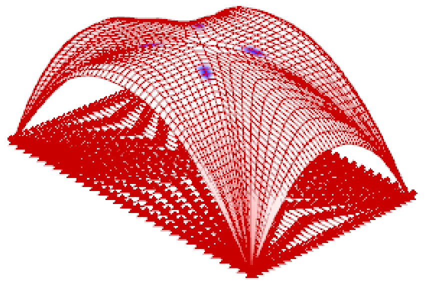


Figure 10: vault 4.25x2.4m

UC check of modular vault 4.25x2.4m:

The tension/compression in principle direction 1

- *0.3 < 0.3 N/mm2 (tension)*
- *1.22 < 3 N/mm2 (compression)*

The tension/compression in principle direction 2

- *0.01 < 0.3 N/mm2 (tension)*
- *2.28 < 3 N/mm2 (compression)*

The deflection of the structure

- *14.4 < 21 mm (deflection)*

test support thickness vs FEM resultant force

*(15.6 * 1000) / (23.1^2 * 100) = 0.29 N/mm2*

- *0.29 < 3 N/mm2 (compression)*

Modular vault 4.25x2.4m passed all UC checks

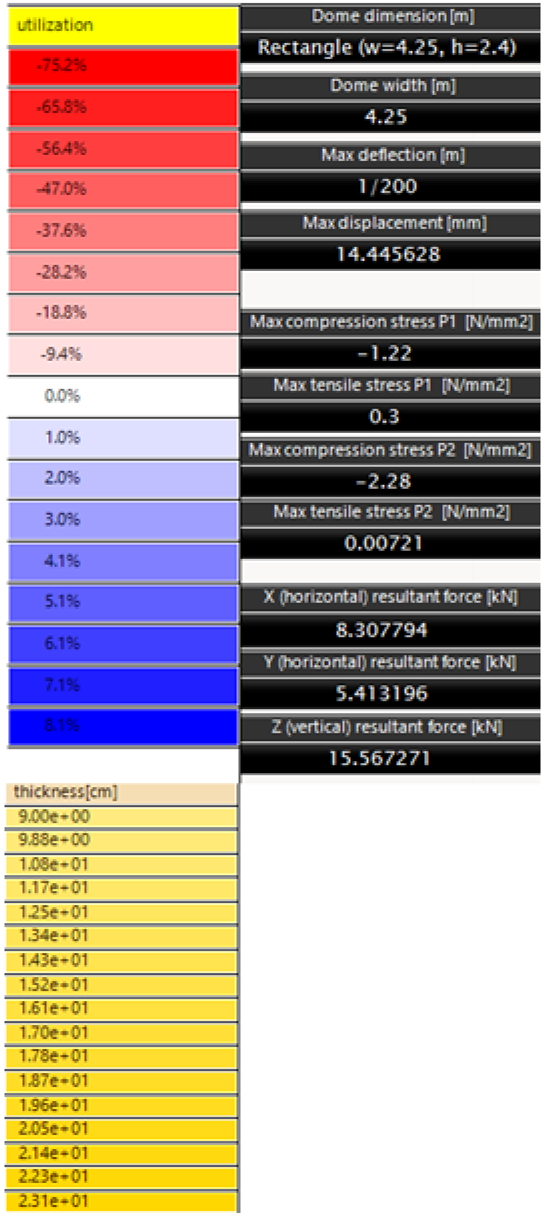


Figure 10:FEM

Modular vault 4.25m x 3.6m

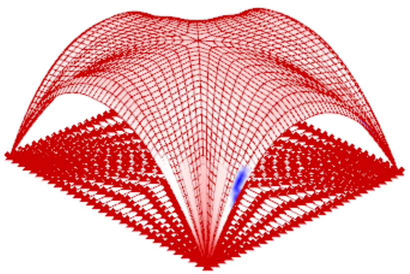


Figure 12: vault 4.25x3.6m

UC check of modular vault 4.25x3.6m:

The tension/compression in principle direction 1

- *0.29 < 0.3 N/mm2 (tension)*
- *0.72 < 3 N/mm2 (compression)*

The tension/compression in principle direction 2

- *0.00 < 0.3 N/mm2 (tension)*
- *1.63 < 3 N/mm2 (compression)*

The deflection of the structure

- *20.3 < 21 mm (deflection)*

test support thickness vs FEM resultant force

*(23.8 * 1000) / (30.2^2 * 100) = 0.26 N/mm2*

- *0.26 < 3 N/mm2 (compression)*

Modular vault 4.25x3.6m passed all UC checks

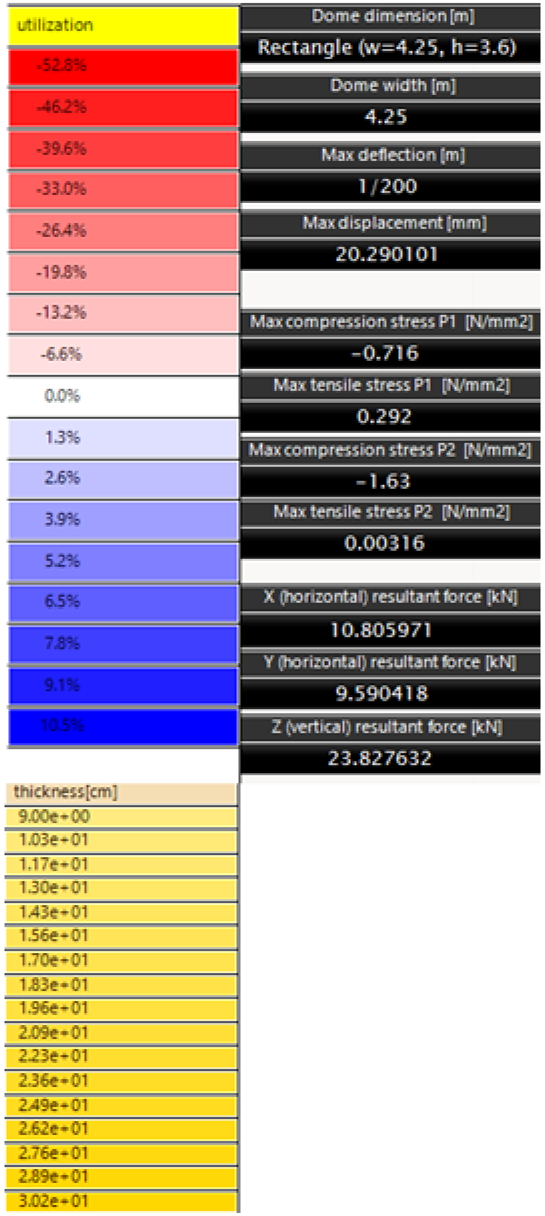


Figure 13:FEM

Modular vault 9.4m x 2.4m low

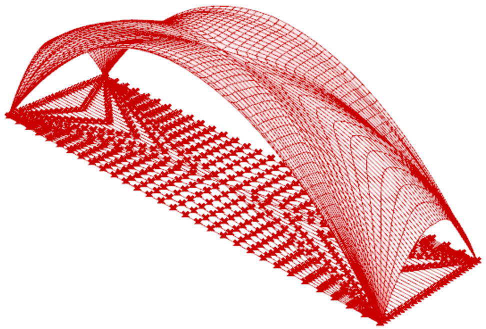


Figure 14: vault 9.4mx2.4m low

UC check of modular vault 9.4mx2.4m low:

The tension/compression in principle direction 1

- *0.24 < 0.3 N/mm2 (tension)*
- *1.03 < 3 N/mm2 (compression)*

The tension/compression in principle direction 2

- *0.24 < 0.3 N/mm2 (tension)*
- *2.36 < 3 N/mm2 (compression)*

The deflection of the structure

- *18.2 < 47 mm (deflection)*

test support thickness vs FEM resultant force

*(94.9 * 1000) / (40.1^2 * 100) = 0.59 N/mm2*

- *0.59 < 3 N/mm2 (compression)*

Modular vault 9.4mx2.4m low passed all UC checks

But needs to be checked on force vector (due to relationship horizontal and vertical force)

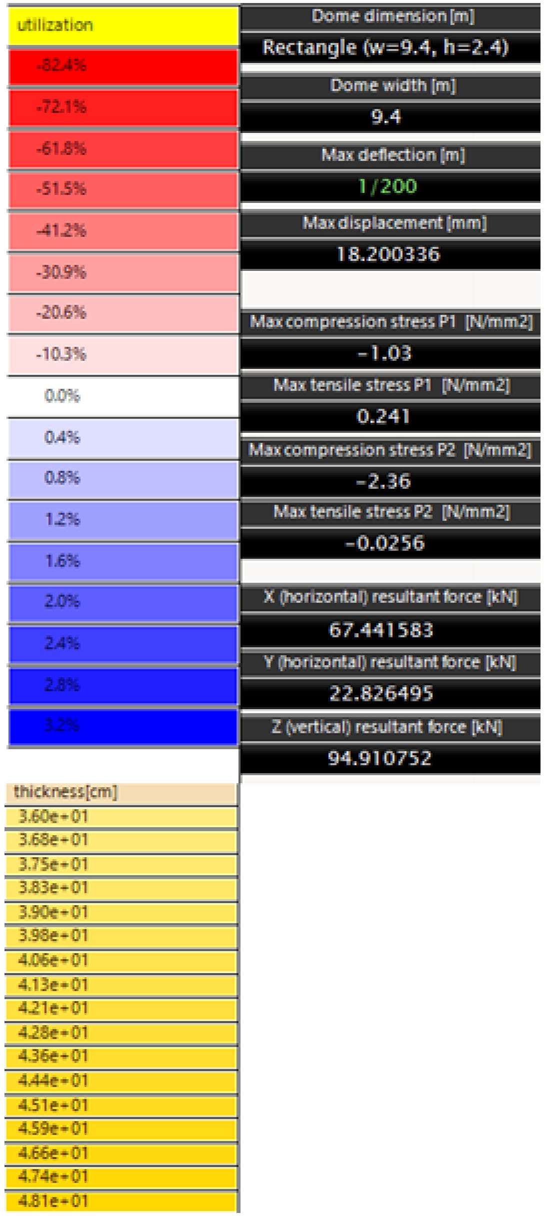


Figure 15:FEM

Modular vault 9.4m x 3.6m low

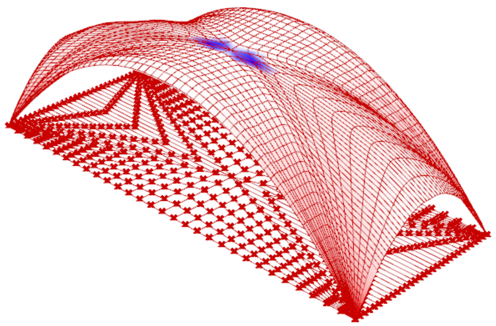


Figure 15: vault 9.4mx3.6m low

UC check of modular vault 9.4mx3.6m low:

The tension/compression in principle direction 1

- *0.29 < 0.3 N/mm2 (tension)*
- *0.69 < 3 N/mm2 (compression)*

The tension/compression in principle direction 2

- *0.02 < 0.3 N/mm2 (tension)*
- *2.32 < 3 N/mm2 (compression)*

The deflection of the structure

- *23 < 47 mm (deflection)*

test support thickness vs FEM resultant force

*(140.2 * 1000) / (45.1^2 * 100) = 0.59 N/mm2*

- *0.69 < 3 N/mm2 (compression)*

Modular vault 9.4mx3.6m low passed all UC checks

But needs to be checked on force vector (due to relationship horizontal and vertical force)

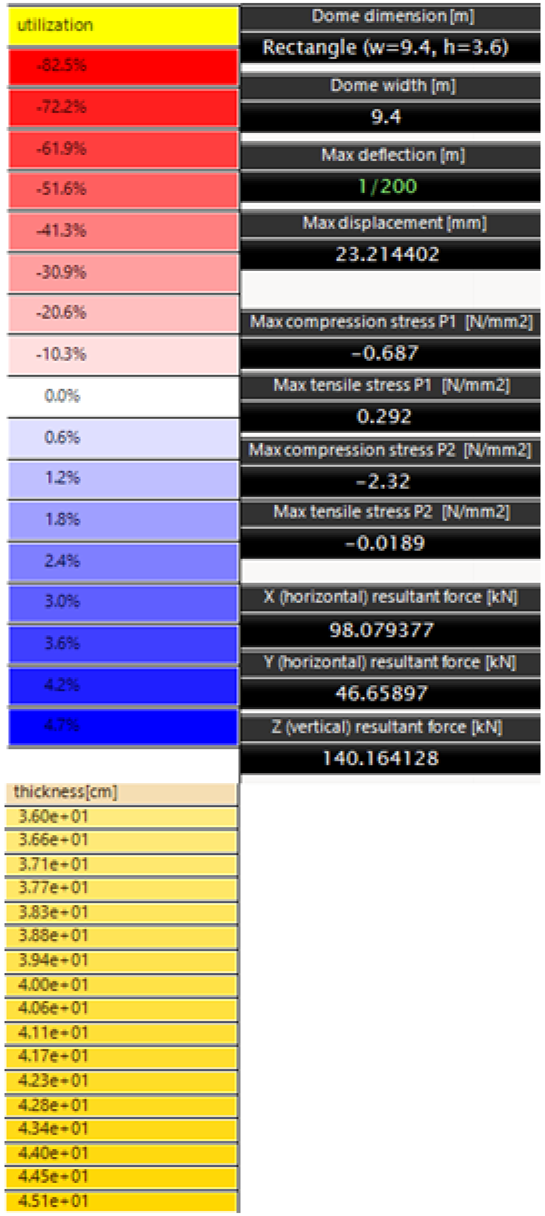


Figure 15:FEM

Modular vault 9.4m x 2.4m

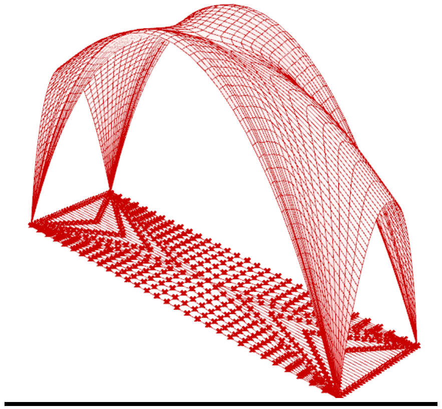


Figure 16: vault 9.4mx3.6m low

UC check of modular vault 9.4mx2.4m:

The tension/compression in principle direction 1

- *0.22 < 0.3 N/mm2 (tension)*
- *1.57 < 3 N/mm2 (compression)*

The tension/compression in principle direction 2

- *0.01 < 0.3 N/mm2 (tension)*
- *2.96 < 3 N/mm2 (compression)*

The deflection of the structure

- *24.90 < 47 mm (deflection)*

test support thickness vs FEM resultant force
*(115.16 * 1000) / (8.47^2 * 100) = 0.16 N/mm2*

- *0.16 < 3 N/mm2 (compression)*

Modular vault 9.4mx2.4m passed all UC checks

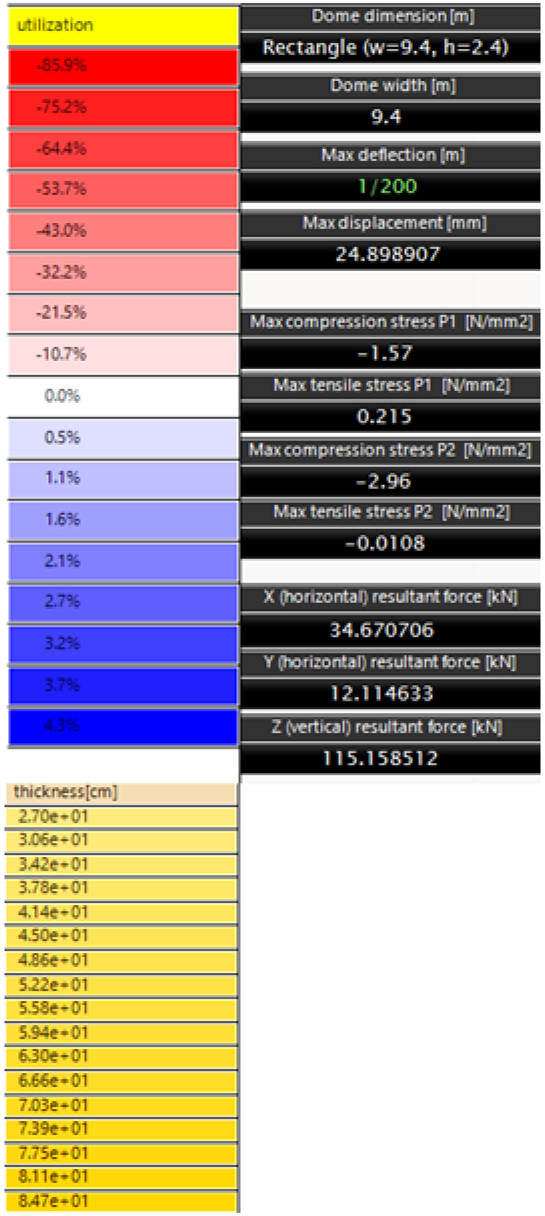


Figure 17:FEM

Modular vault 9.4m x 3.6m

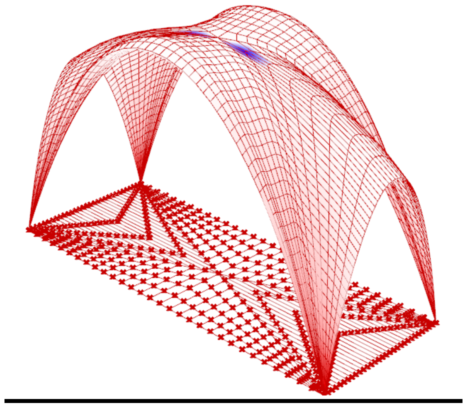


Figure 18: vault 9.4mx3.6m low

UC check of modular vault 9.4mx3.6m:

The tension/compression in principle direction 1

- *0.23 < 0.3 N/mm2 (tension)*
- *1.44 < 3 N/mm2 (compression)*

The tension/compression in principle direction 2

- *0.00 < 0.3 N/mm2 (tension)*
- *2.72 < 3 N/mm2 (compression)*

The deflection of the structure

- *33.58 < 47 mm (deflection)*

test support thickness vs FEM resultant force
*(160.85 * 1000) / (59.0^2 * 100) = 0.46 N/mm2*

- *0.46 < 3 N/mm2 (compression)*

Modular vault 9.4mx2.4m passed all UC checks

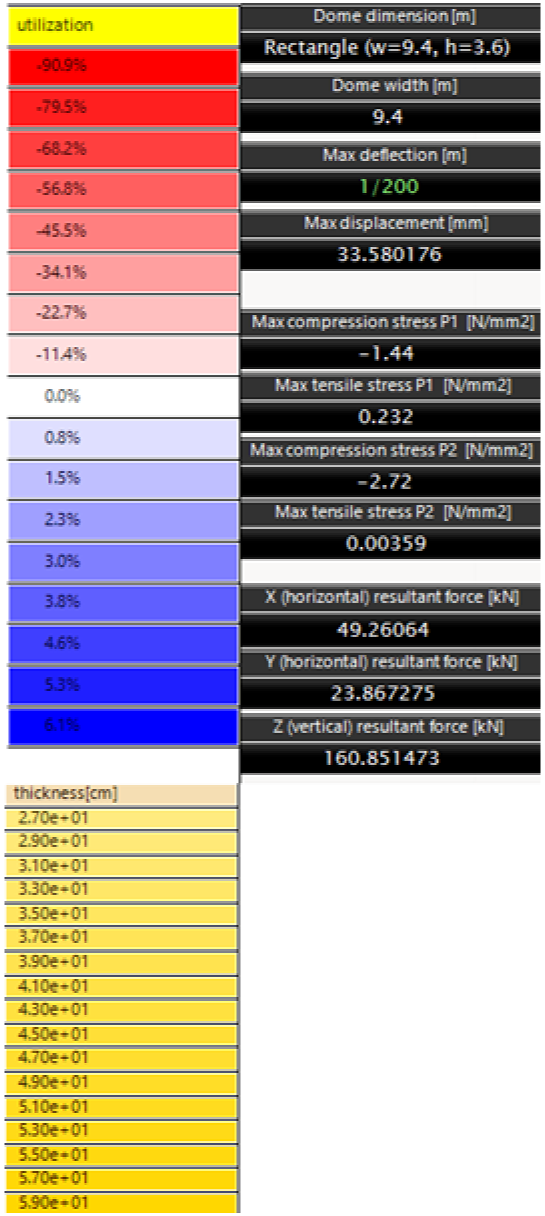


Figure 19: vault

Structural conclusion based on FEM

All structural elements passed the UC checks based on the local available materials in Zaatari. two aspects need to be annotated:

- In Modular vault 4.25m x 3.6m creep might cause the structure to deflect more then the given limit. Applying a sag of 14mm within the substructure (the deformation caused by self weight) solves this issue.
- The lower modular vaults (9.4x2.4 and 9.4x3.6) with high span have a force vector which risks leaving the column. We took three measures to prevent this:
    - Increasing the weight near column on the structure.
    - creating a structural offset of the modular vaults of 0.45m, increasing the space for the structural vector
    - Apply an extra load on the structural offset of 10.8kN, bending the force vector.
    - Digging in the modular units helps providing support in horizontal direction, when other modular units are build the provide a counter force from the opposite direction.

To conclude the main structural problems that arrise from the FEM studies are the horizontal forces of adobe 2.0 (high spans on 4 support points). During construction the use of buttresses is necessary for these spans, as most of the measures can only be applied after the structure is build.

Structural verification

FEM models showcase the ideal geometry works, without actual experiments we cannot validate the working in real life. (it remains theoretical) Definitely because the properties of the materials have an relatively high sigma (standard deviation). We looked closely at the mesh and increased the fineness where the forces were the highest. Besides this we tried to ensure that our FEM model was working correctly. We checked the input and working of the model with hand calculations:

- calculate applied force is done correctly with voranoid method.
- hand calculation of simple beam to verify working of FEM model (see next page)

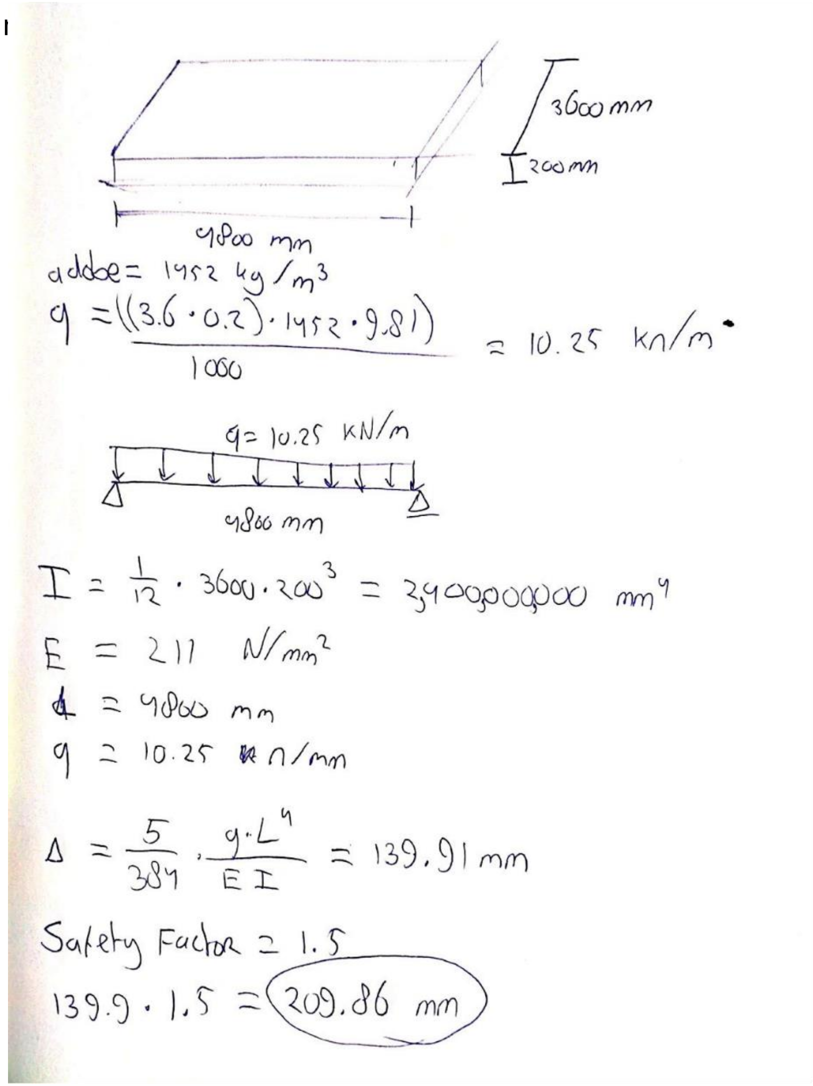
Hand calculation of simple beam to verify working of FEM model

In order to make sure the FEM model was working correctly, a simple beam was analysed and verified by the means of a hand calculation. The simple beam was first modeled in Karamba and its dimensions were as follows:

- length = 4800mm
- width = 3600 mm
- height = 200mm

Giving this the material properties of abode, which are a specific weight of 1452 kg/m3 and a young's modulus of 211 N/mm2, the total deflection resulted in 213 mm, which is caused by an equally distributed load caused by the gravitational force applied to the weight of the beam. Keep in mind that this 213 mm does also have a safety factor of 1.5 included.
At first glance 213 mm is quite low for a slab of earth spanning almost 5 meter. However, at this point it would have already failed under tension stress. So in reality a plate of earth would never be able to span such distances.

The hand calculations actually show a similar result, as seen in the figure below. The difference lies in only 3 mm, which is within 2% of the total deflection, thus proving that the FEM analysis was done in a correct matter and it accurately reflects a beam calculated by hand. The 3 mm difference could be explained by the fact that for calculating the plate, a simple beam method was used in the hand calculations. But, the plate is actually 3.6 m wide, which is enough for the beam to have some significant deflection in the other direction, in this case: about 3 mm.



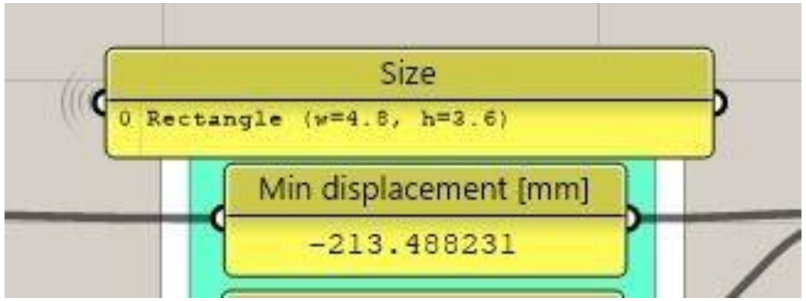


Figure 21: FEM analysis counterpart of the calculation of the simple beam

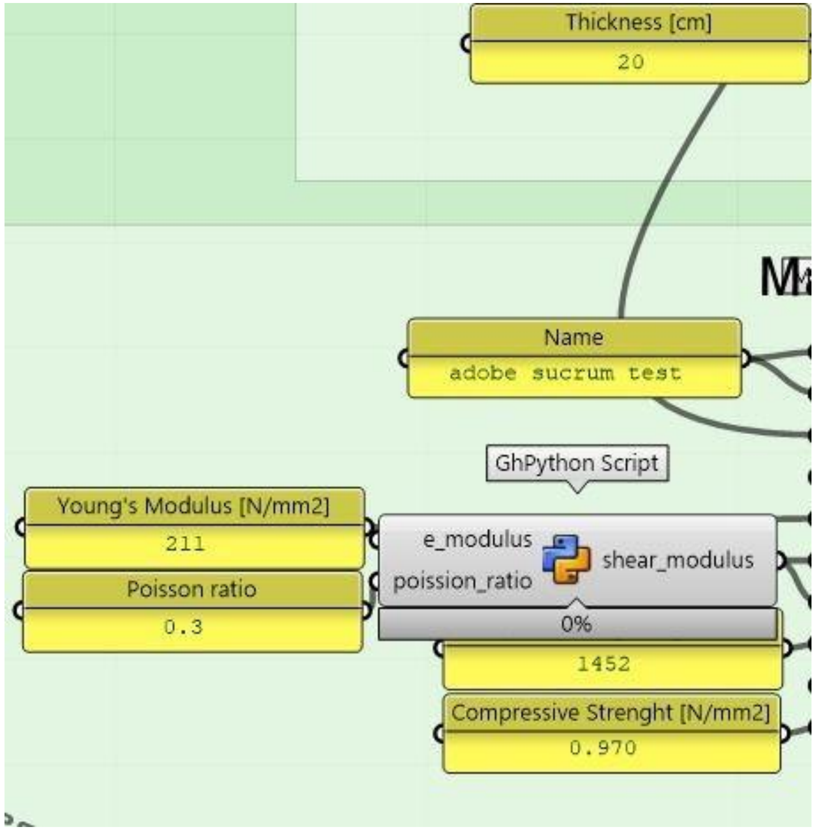


Figure 20: a hand calculation for deflection of a simple beam.

Figure 21: FEM analysis counterpart of the calculation of

Old Approach

This section deals with the result of old approach from Appendix J-2 . The achieved forms from the Kangaroo optimization were then analyzed with Karamba3D. Initially, the material properties were that of concrete, in order to find out an optimized geometry. Properties were eventually changed to that of adobe. It was later understood that material properties play an important role in determining the spring stiffness. Further the openings were made with catenary curves. Barrel vaults, domes that start from floors, from walls and from support based on our architecture plan were form found and analyzed to get tension free structure.

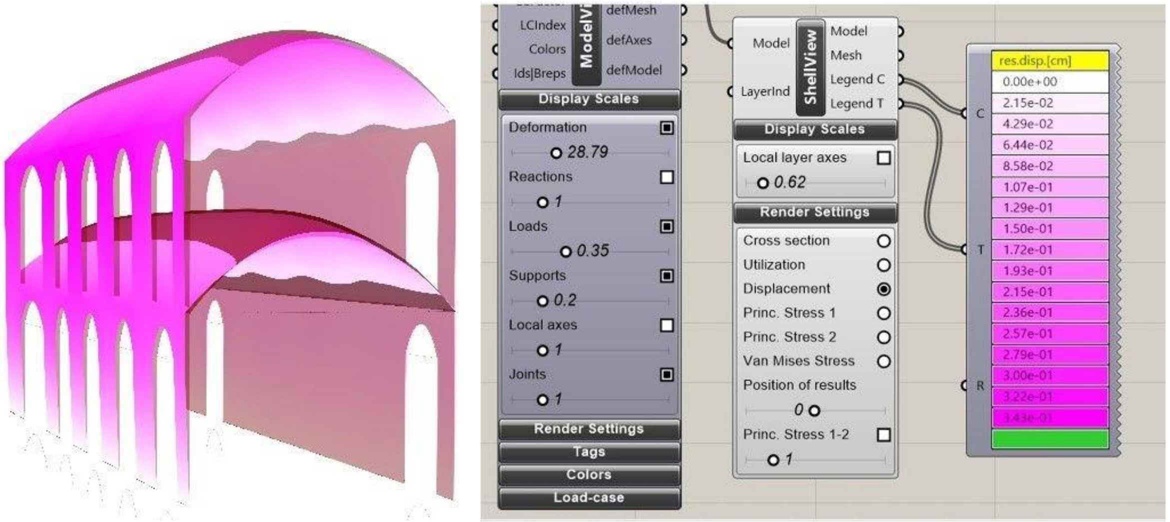


Figure 23: Displacement Analysis on a barrel vault structure with concrete as material considering housing on top floor

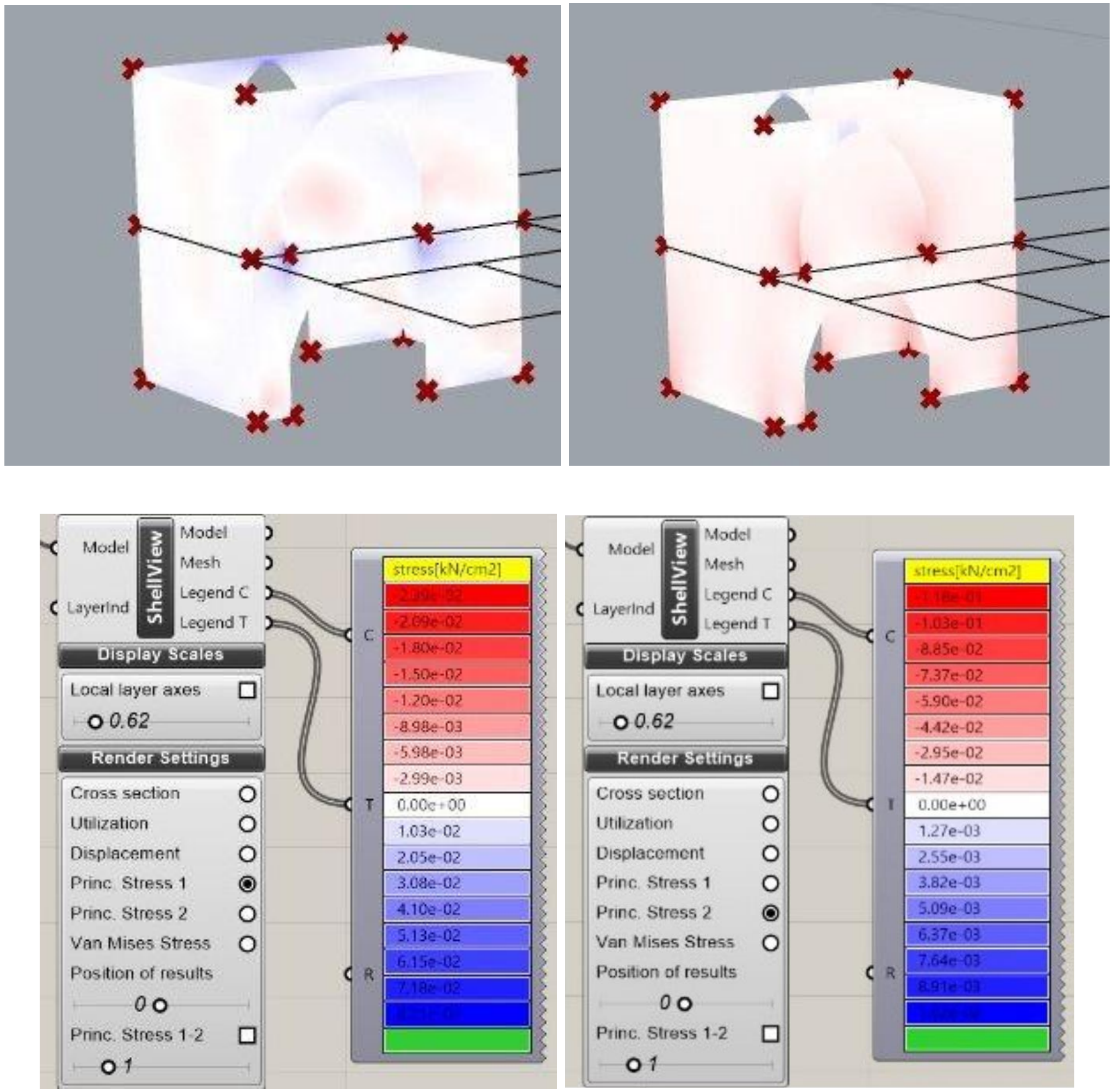
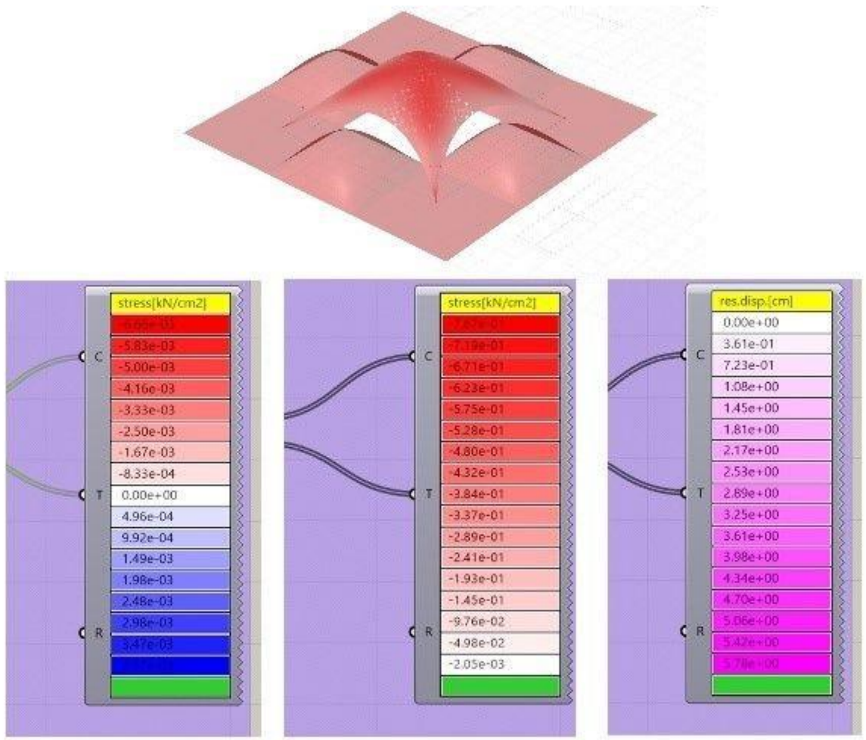


Figure 24: P. Stress 1 & P. Stress 2 with concrete as material (dome supported over walls), considering housing on top floor

Appendix Q: Structural analysis - Junction Karamba

Initial Approaches

As the junction is 18 x 18 m in size, it was nearly impossible to span the whole junction with one single adobe dome. Therefore, we decided to go with 9 domes, we tried various designs. One was with the central one being the biggest, as shown in figure xx.



Princ. Stress 1 Princ. Stress 2 Displacement

Figure 1: Layout of junction domes, here there are 8 similar dome and one big central dome. Distribution of both principal stresses and displacement of central dome are given in figure below.

Initially, 8 domes were designed to be of the same size and the central one resting on top of corner domes. This would eventually affect the form finding of the corner domes as well. Therefore, the biggest dome was form found first with script. In this approach, once the biggest dome was form found, the load on each corner domes due to the central dome was found. It was done by dividing the total weight of the dome by 4 (each corner). The closest points to the support of the central dome on the corner domes were found and load was equally distributed to these corner points to form find the corner domes. The analysis for the big domes can be seen in the figures xx.

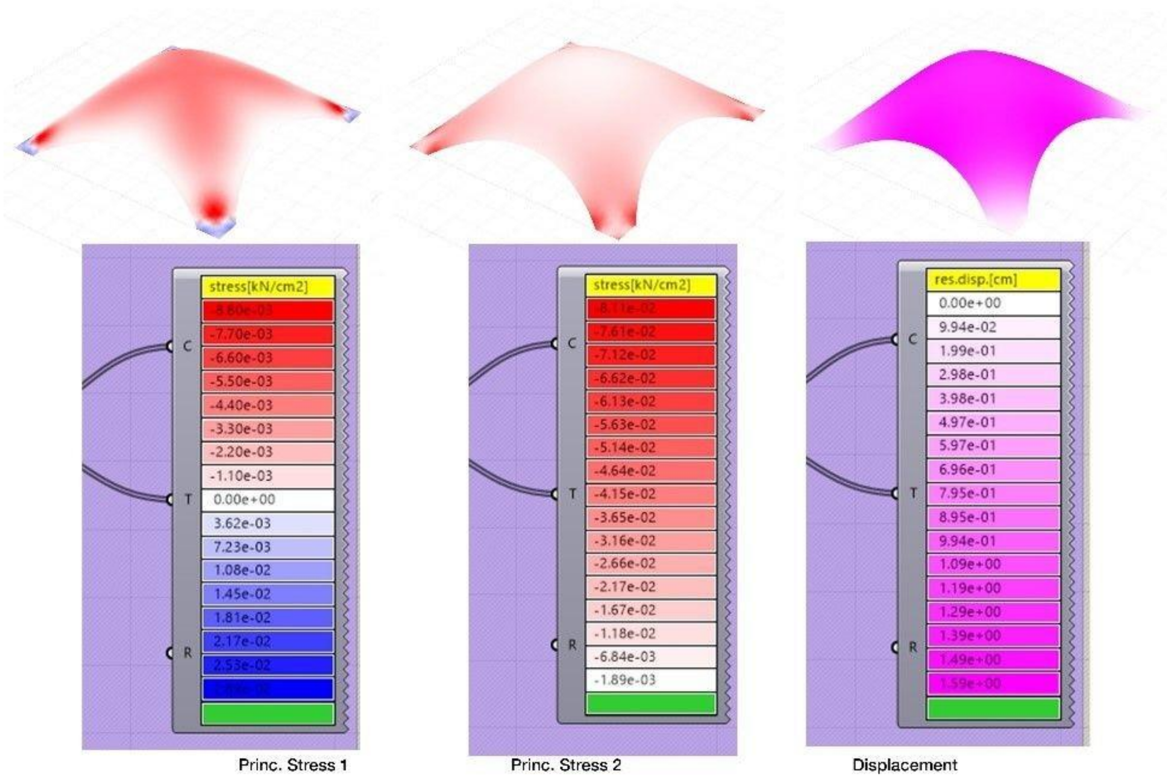


Figure 2: Central Dome 8.4 x 8.4 m size with L corners with both principal stresses and displacement

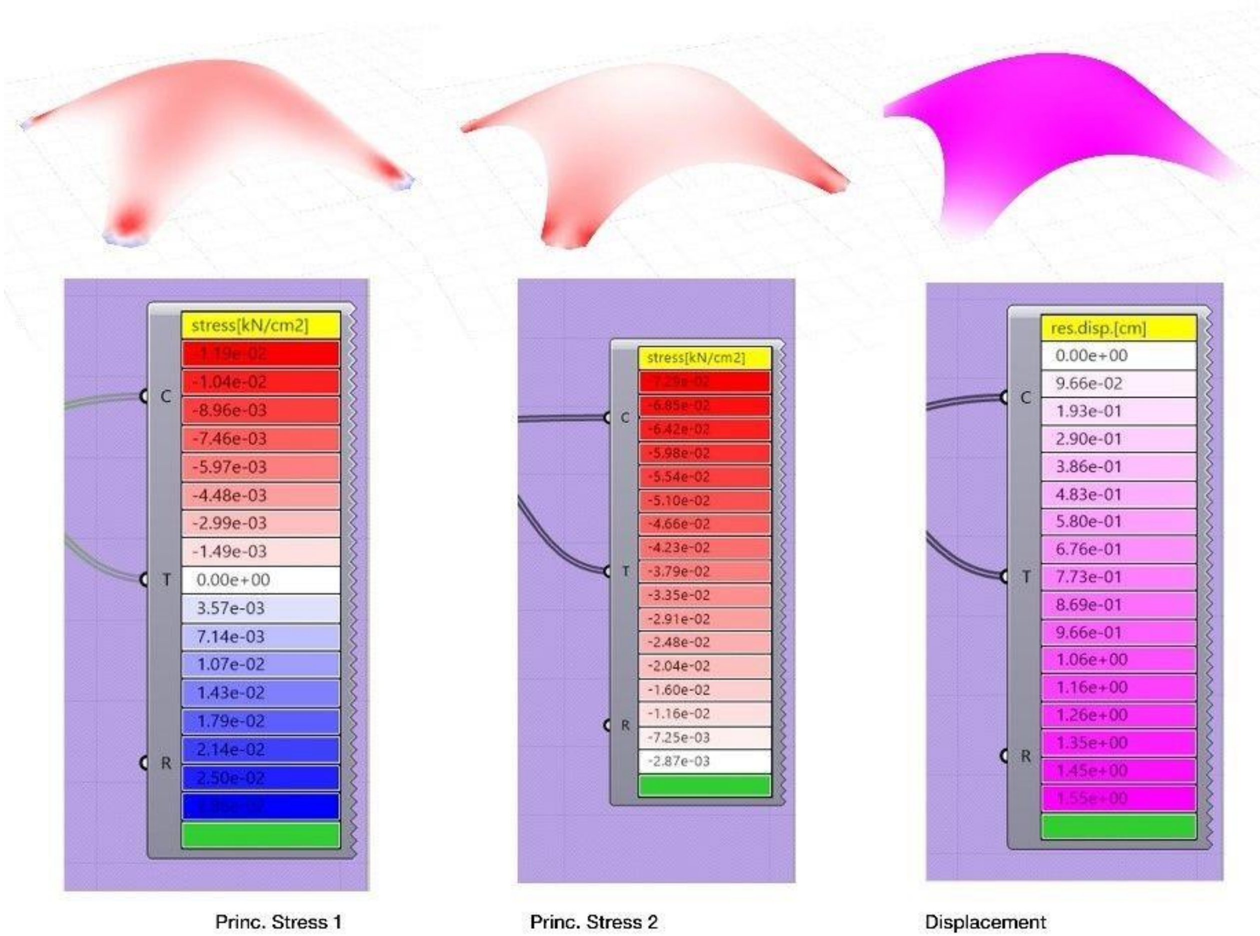


Figure 3: Central Dome 8.4 x 8.4 m size with round corners with both principal stresses and displacement

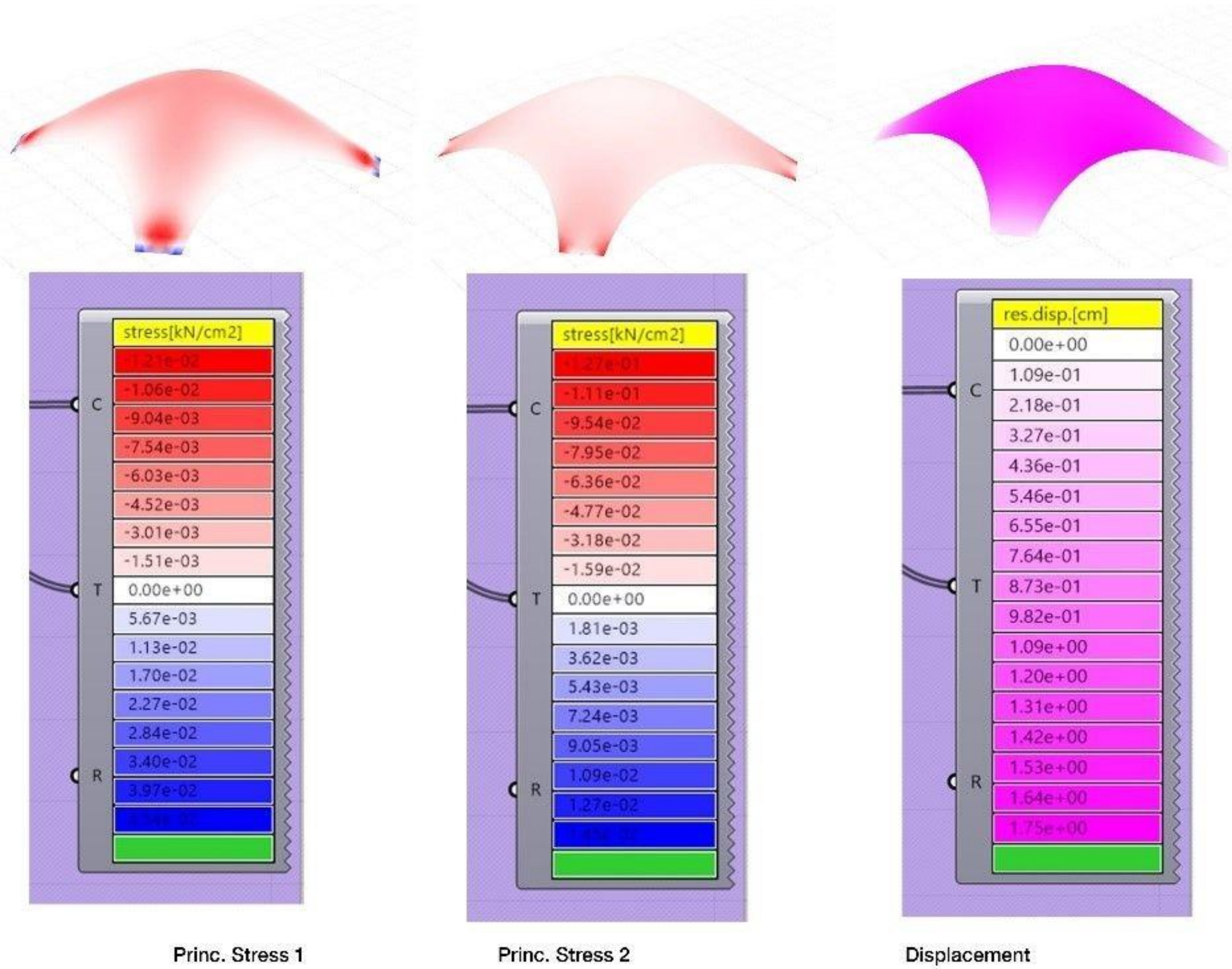
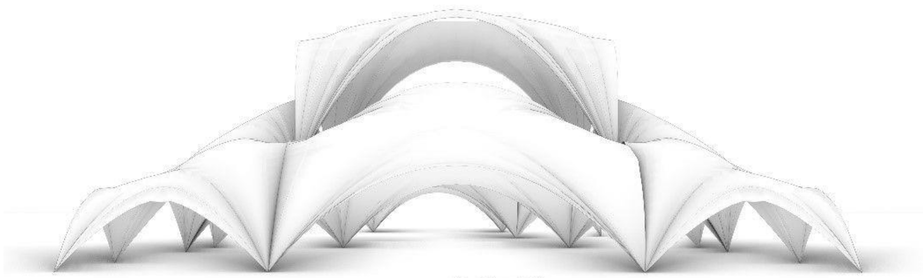
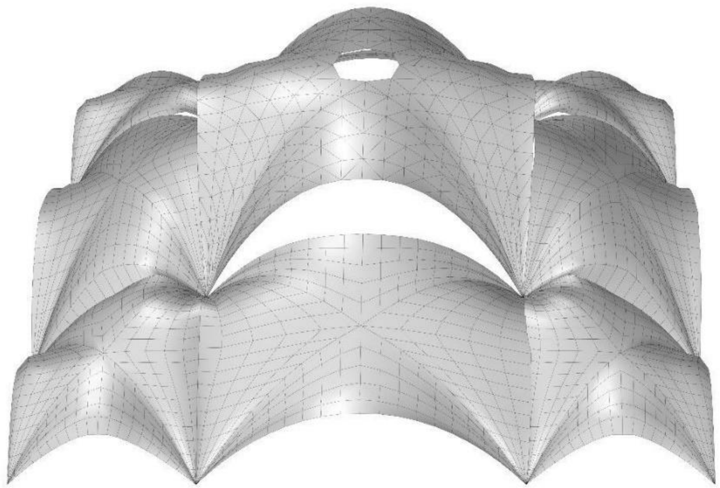


Figure 4: Central Dome 8.4 x 8.4 m size with angled corners with both principal stresses and displacement

Another option was to form as shown in the figure 5, where central dome starts at 2.4 m high supported on the columns. And vertices of each surrounding vaults close to the column are anchored to 2.4 m high. The vaults are ribbed. In this case, each dome is form found separately. The script used was the same as that of the shops and walkway with ribbed vaults with some modification for the junction.

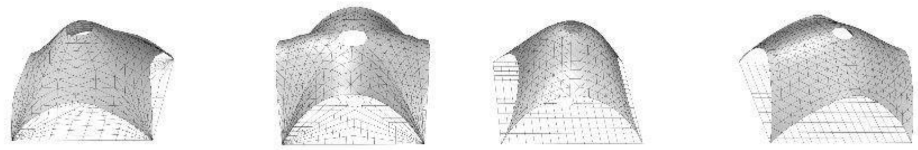




0.4

Figure 5 Option where central vault with an oculus (8.4 x 8.4 m) starts at 2.4 m high supported on 4 columns, corner domes (4.8 x 4.8 m) & side rectangular domes (4.8 x 8.4 m)

First the central vault was form found. It was then analyzed with karamba. Manually topology was defined for the central dome with oculus in rhino, due to which was fed in grasshopper for form finding. Four different options were done for the central vault which can be seen in figure 6 and a preliminary structural analysis was done to find better topology and form among the four options. Later each side vault is form found.



	A	B	C	D
Deflection	22mm	27mm	73mm	34mm
PC1	0.0169 KN/cm2	0.0162 KN/cm2	0.0043 KN/cm2	0.036 KN/cm2
PC2	0.00099 KN/cm2	0.00077 KN/cm2	-	0.00082 KN/cm2

Figure 6: Different results of form findings with different tessellation, Option B was chosen for the central vault.

Figure 7: Structural analysis on side vaults.

	Force Slider	Princ.Stress 1(N/mm2)		Princ.Stress 2		Min Displacement(mm)	
		Max Stress	Min Stress	Max Stress	Min Stress		
Small Corner Dome	-0.3	-0.416	0.244	-1.37	0.00308	-10.080121	
	-0.2	-0.47	0.264	-1.52	0.00745	-11.491645	
	-0.1	-0.545	0.391	-1.77	0.0176	-14.867499	
	-0.4	-0.399	0.213	-1.31	-0.00128	-9.478642	
Rectangular Dome	-0.4	-0.574	0.206	-2.04	0.0614	-24.210951	
	-0.3	-0.62	0.191	-2.15	0.0614	-26.231969	2.78 cm
	-0.2	-0.66	0.645	-2.28	0.0536	-28.908486	3.12 cm
	-0.1	-0.705	0.926	-2.74	0.0744	-40.241267	4.38 cm

Figure 8 Results of structural analysis of side domes and 0.4 force slider results were chosen

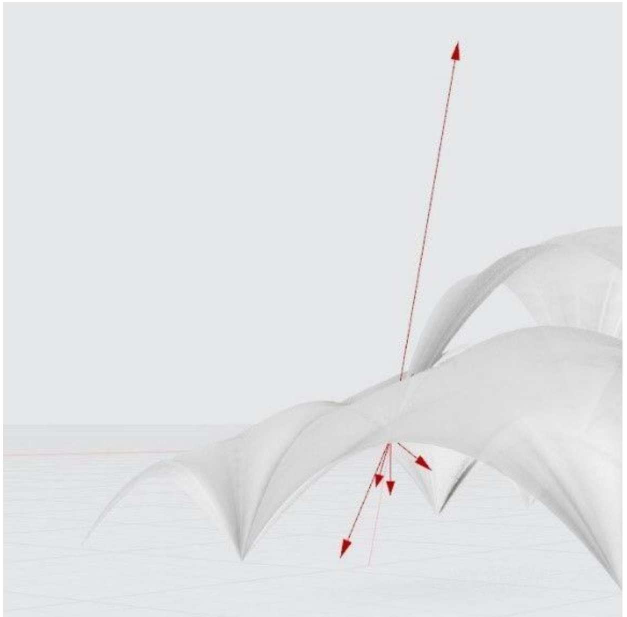


Figure 9: Force vector diagram to find the column

The force on the column is found out by adding the resultant vector forces of each vaults it has to support. This way it still could not solve the tension on both principal axes. Also, the script was not accurate enough to generate topology for side domes as some of the vertices of the domes are anchored in 2.4 m height, but the topology generated was that of the same flat plane. This script could not be changed as time was limited.

Final Approach

For the final option, it was decided to make each vault self-standing and was found with kangaroo, then analyzed in Karamba3D and optimized with opossum to meet the tension requirements in both principal axes. For this, opossum was used with spring stiffness and wall thickness (number of bricks) as variables.

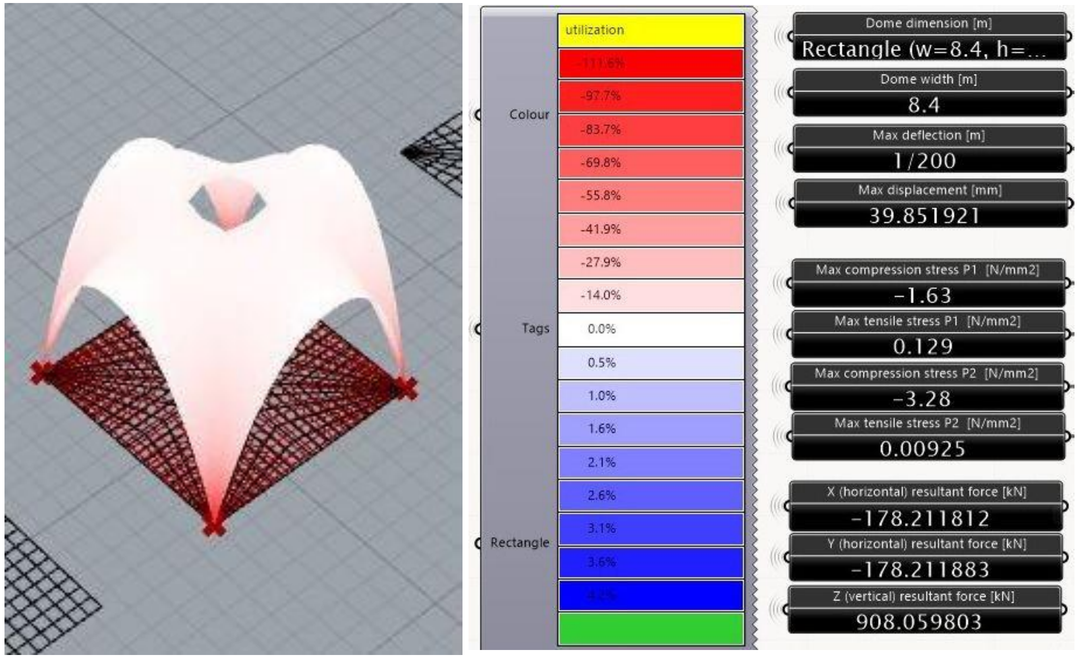


Figure 10: FEM results of final centre vault with oculus 8.4 x 8.4 m

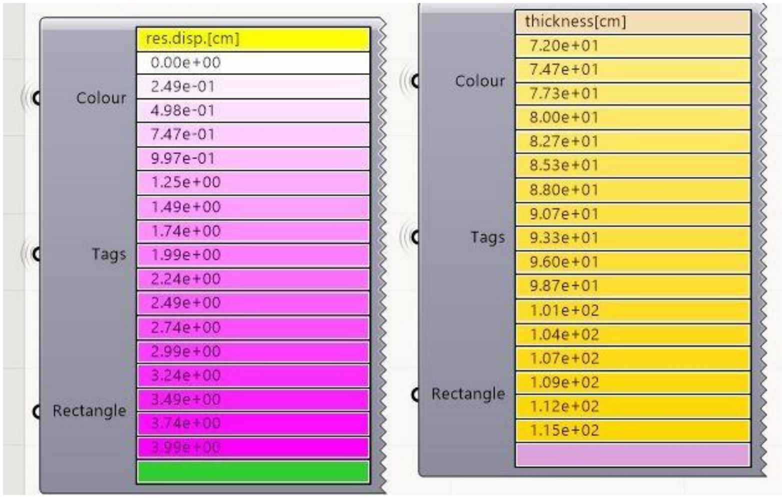


Figure 11: Structural results of final centre vault with oculus 8.4 x 8.4 m

For the central vault, the outer ribs were given 1.15 m thick, inner ribs 0.93 m thick and infills 0.72 m thick which were raised on 1 m support.

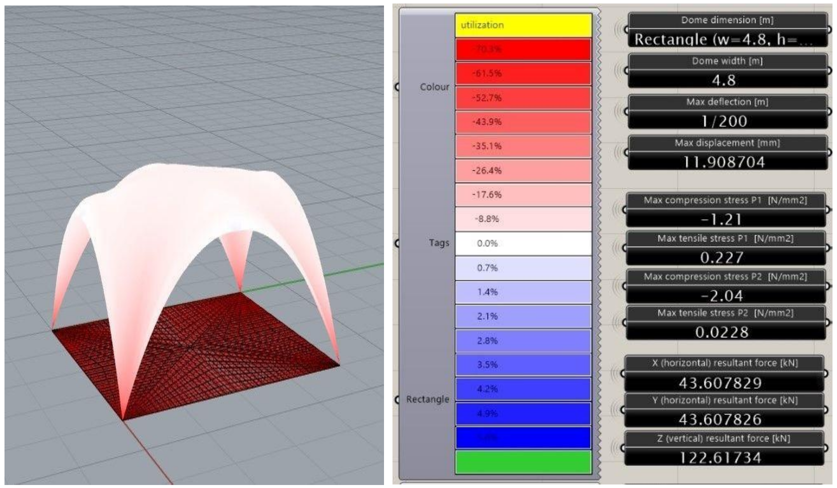


Figure 12: Structural results of final corner vault with oculus 4.8 x 4.8 m

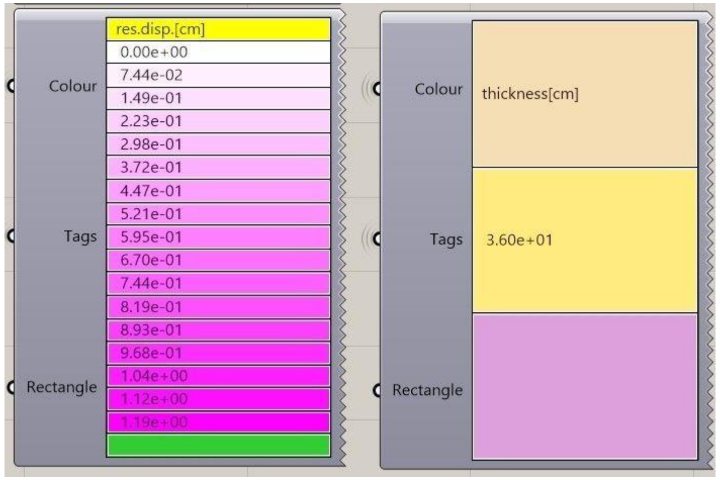


Figure 13: Structural results of final corner vault 4.8 x 4.8 m

For the corner vaults, the script output showed only one thickness, so the outer ribs were given 0.36 m and inner ribs were given 0.20m with infills, 0.15m thick which are raised on 1 m support.

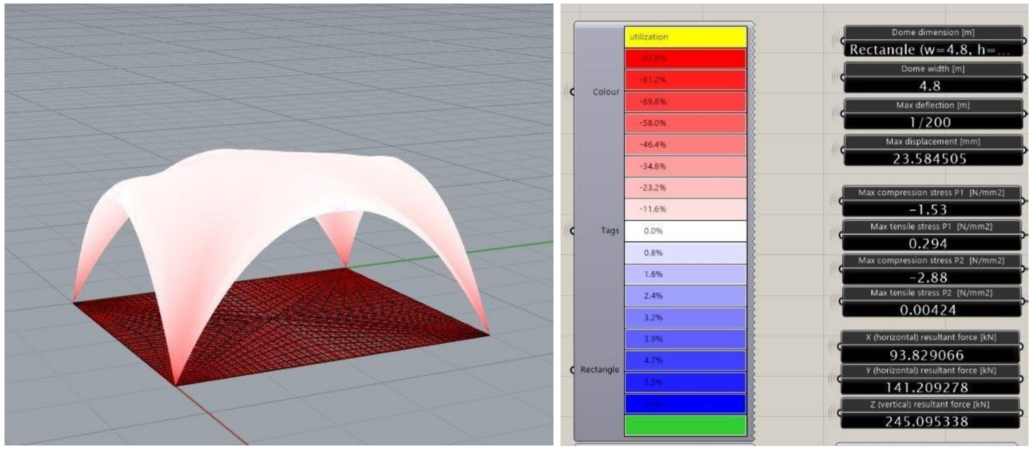


Figure 14: Structural results of side rectangular vault 8.4 x 4.8 m

Figure 15: Structural results of side rectangular vault 8.4 x 4.8 m

For the rectangular vault, the outer ribs were given 1.15 m thick, inner ribs 0.93 m thick and infills, 0.72 m thick which are raised on 1 m support

Appendix R: Structural analysis - Ansys

This section contains the finite element analysis made in ANSYS of the different elements that compose bazaar.

First, the different elements that make the junction will be analyzed, followed by the different shop sizes that make up the walkways.
The material property used for the analysis is adobe with straw, and a mesh of 30mm is used.

A load of 2 kN equally distributed with a safety factor of 1.5 is considered in every element. This load represents the load of people walking on top of the vaults or domes in the construction phase or any other event. In addition to this, a permanent load of every individual structure is considered, with a safety factor of 1.2.

The values obtained during the brick making workshop were not sufficient due to imprecision and reliability of the research, therefore we used the values based on literature research, as described in appendix P.

Material Properties of adobe (based on literature research):

- Density: 1459 kg/m3
- Young's Modulus: 211 MPa
- Poisson's Ratio: 0.2
- Tensile Yield Strength: 0.8 MPa

Junction

<u>CenterVault</u>

- Dimensions: 8.4m x 8.4m x 7.5m
- Thickness: 700 mm

Deflection

Since this is the biggest element in the bazaar (both in span and height) it is expected that it will undergo the highest deflection as well. Therefore, an average thickness of 700mm in adobe is used in order to reduce the deflection of the vault. Even with the aforementioned thickness a maximum deflection of 37mm is obtained as seen in figure 1. In real life, the vault has different thicknesses along its surface (thicker at the bottom and thinner at the top) which means that the deflection will be less than the obtained value in ANSYS.

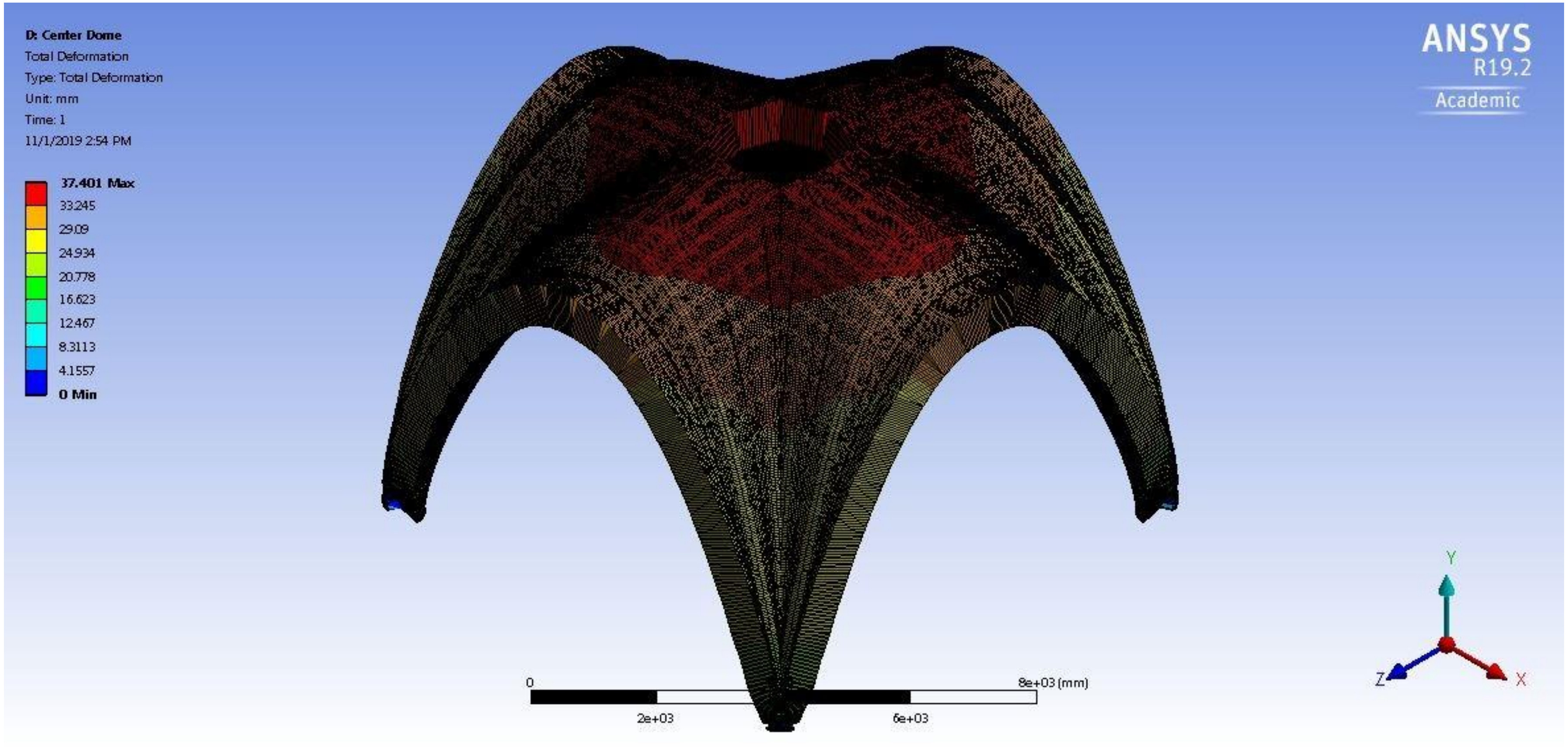


Figure 1: Deflection of the center dome in the junction.

Stress

The maximum stress obtained is of 35 MPa and it is concentrated in the bottom part of the rib vault, since this portion has less section to distribute the applied loads, as seen in figure 3. For this reason, the bottom part of the vault is connected to bigger columns which are also capable of taking the forces coming from the thrust of the vault.

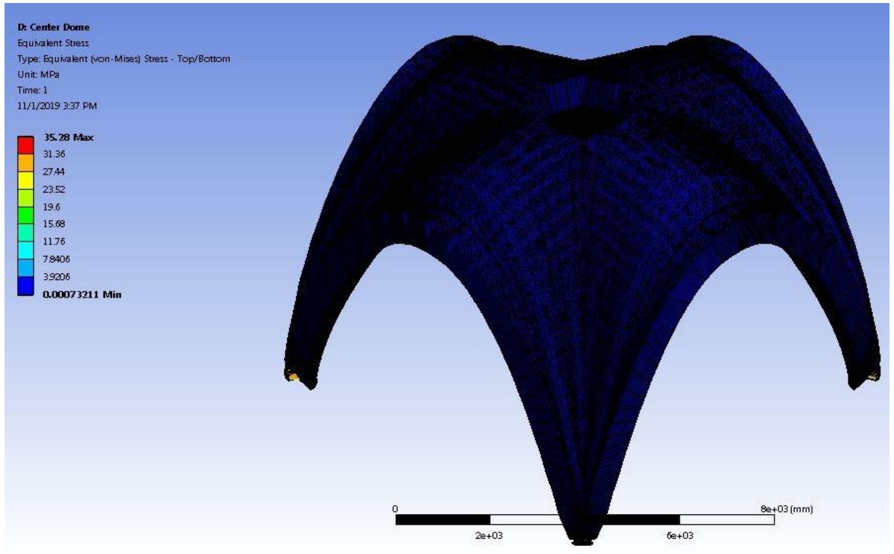


Figure 2: Equivalent stresses of the center vault

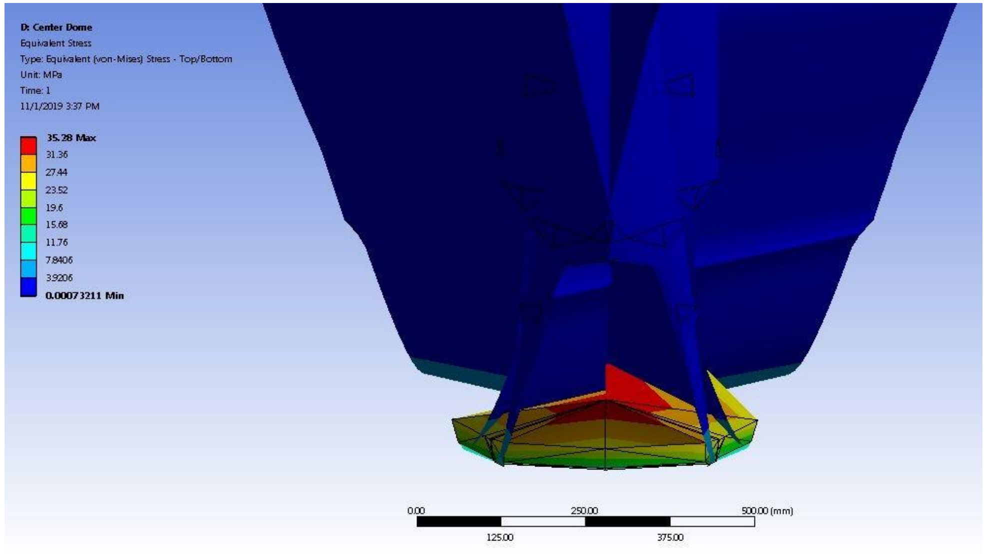


Figure 3: Zoom in on the bottom section of the center vault

<u>SideVaults</u>

- Dimensions: 8.4 m x 4.8 m x 3 m
- Thickness: 700 m

Deflection

The side vaults have the same length as the center vault, therefore the same thickness is considered. Since this element is shorter in width the deflection is much smaller than in the center vault, with a value of 17 mm, as seen in figure 4.

Stress

The maximum stresses concentrated in the bottom section of this vault have a value of 17 MPa, as seen in figure 6.

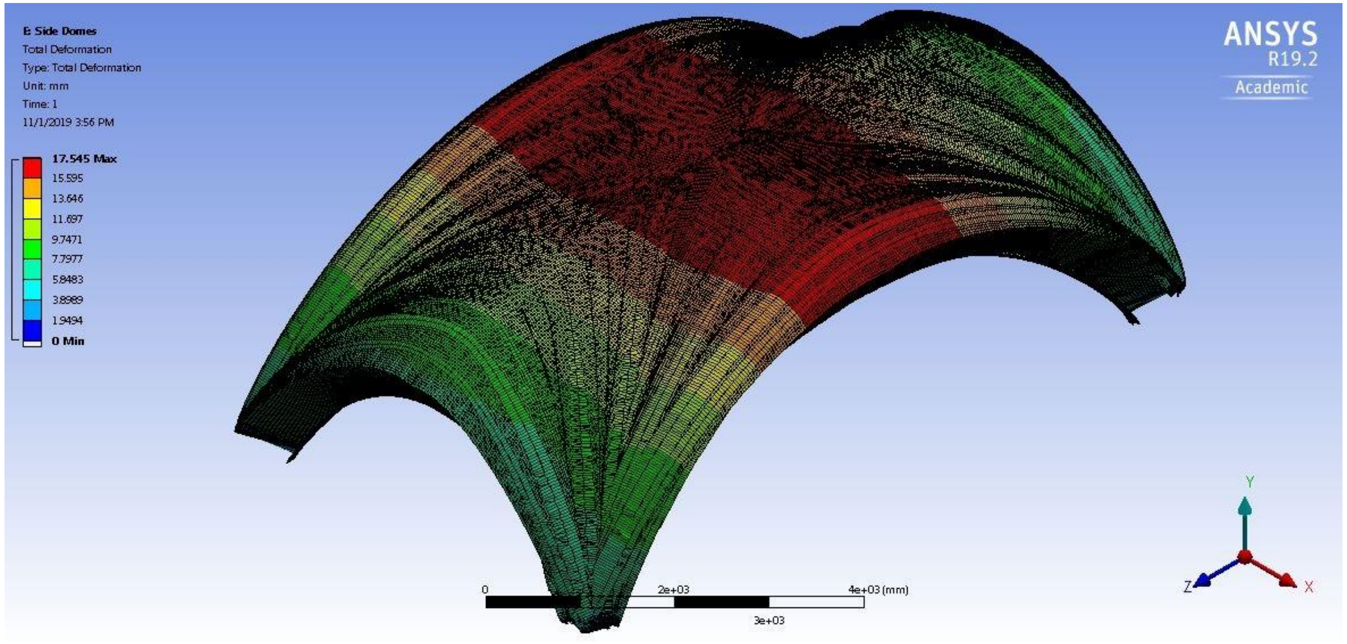
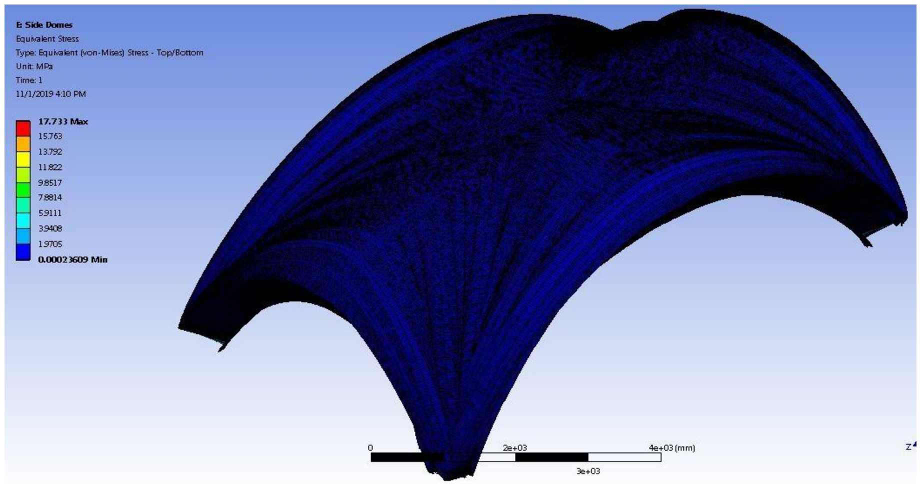


Figure 4: Deflection of one of the side vaults next to the center vault.



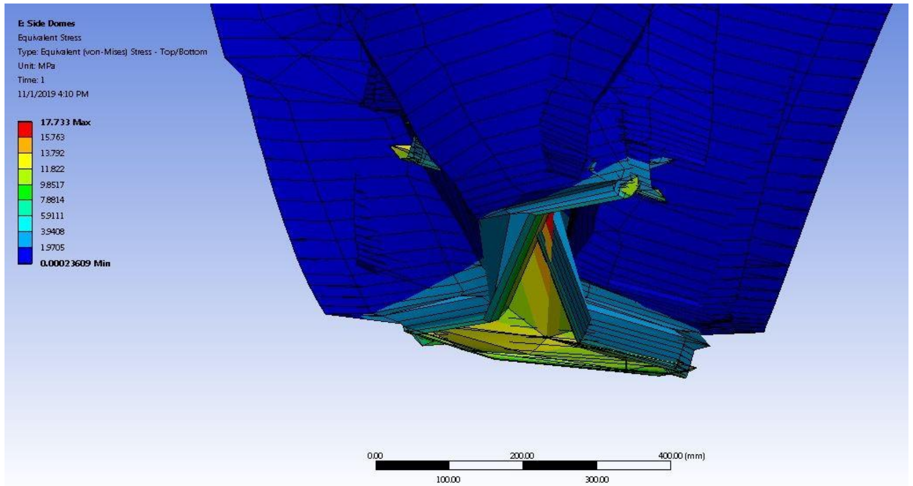


Figure 5: Equivalent stresses of the side vault.

Figure 6: Zoom in on the bottom section of the side vault.

Corner
Vaults

- Dimensions: 4.8 m x 4.8 m x 2.8 m
- Thickness: 700 mm

Defection

This vault is positioned 4 times in the corners of the junction. As this element borders the junction the same thickness as in the other elements that compose the junction of 700 mm is considered. Since this element is smaller in length and height than any other of the elements in the junction its deflection is considerably smaller, only 8 mm, as shown in figure 7.

Stress

The maximum stress found at the bottom of the structures were of 16 MPa, as seen in figure
9.

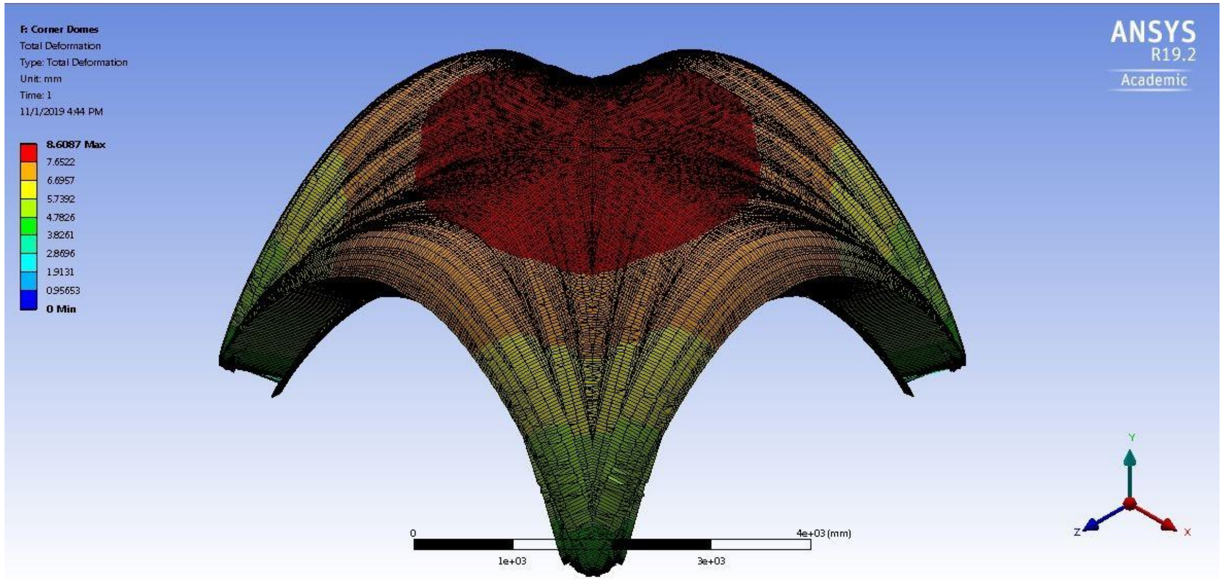
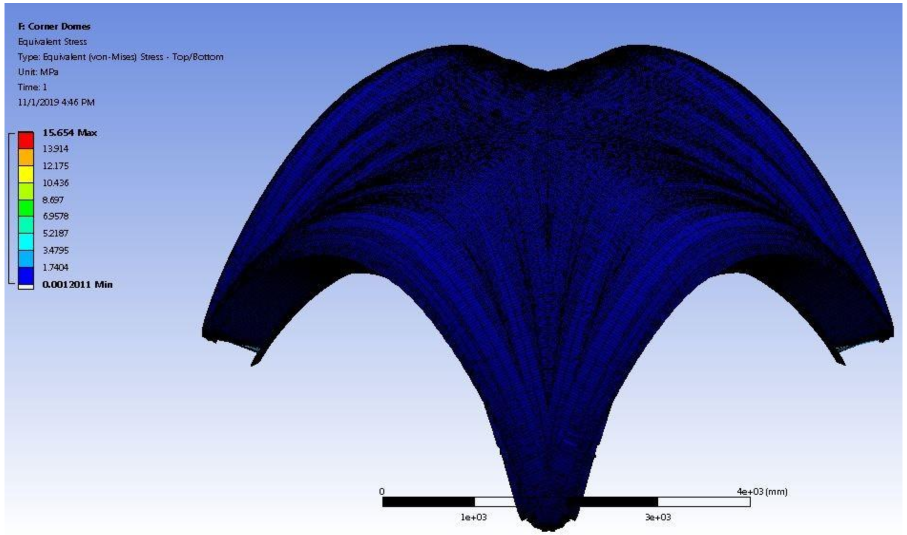


Figure 7: Deflection of one of the corner vaults.



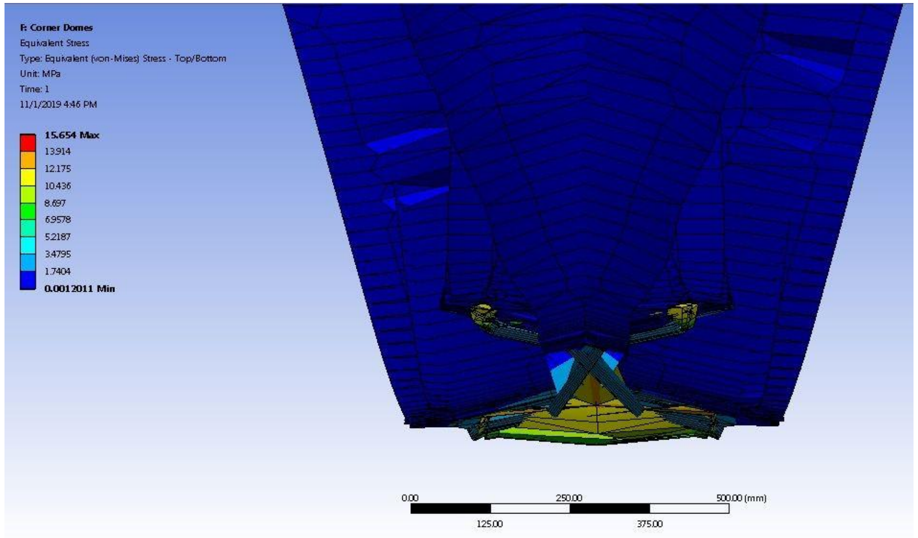


Figure 8: Equivalent stresses of one of the corner vaults.

Figure 9: Zoom in on the bottom section of the corner vault.

Shops

<u>LargeShop</u>

- Dimensions: 9.4 m x 3.6 m x 3.5 m
- Thickness: 400 mm

Deflection

As this is the biggest rib vault in the walkways of the bazaar it will have the highest deflection. Considering a material thickness of 400 mm, the deflection is very small, with only a value of 18 mm, as shown in figure 10.

Stress

The maximum stress in the bottom part of the large shop is 17 MPa, as seen in figure 12.

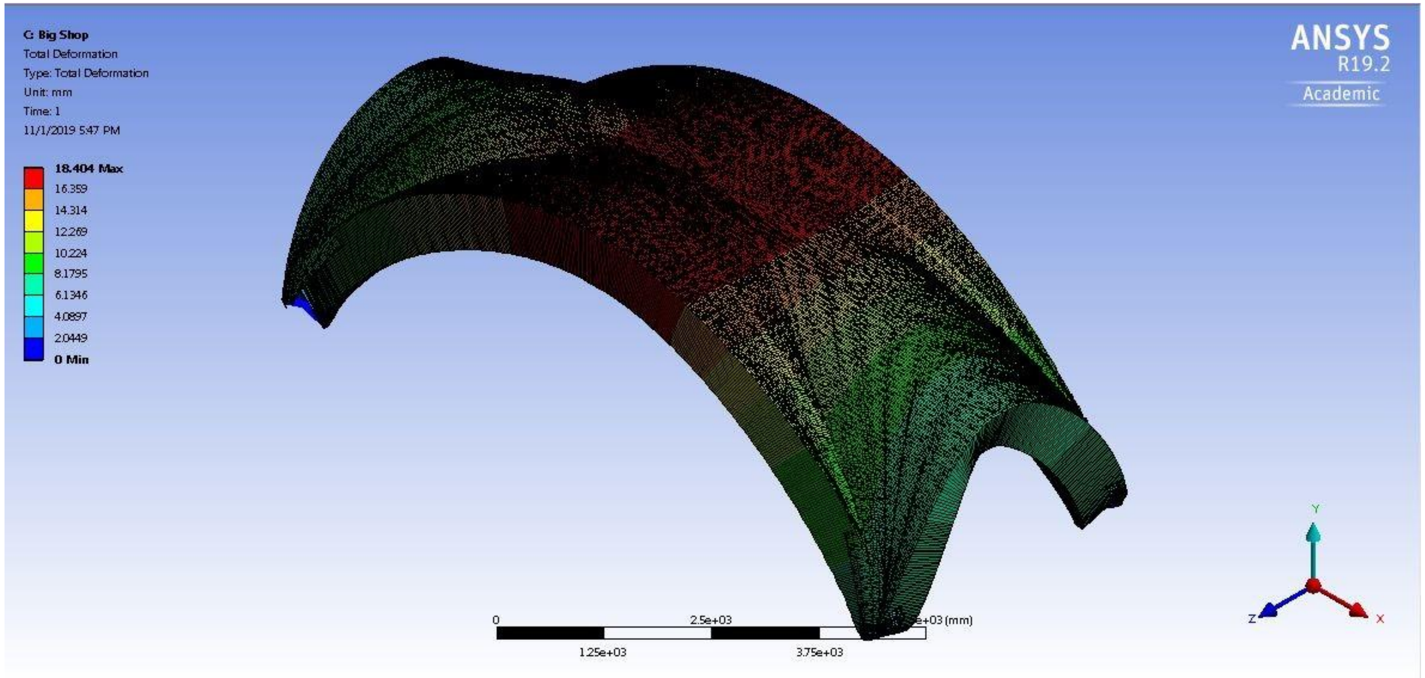


Figure 10: Deflection of the large shop.

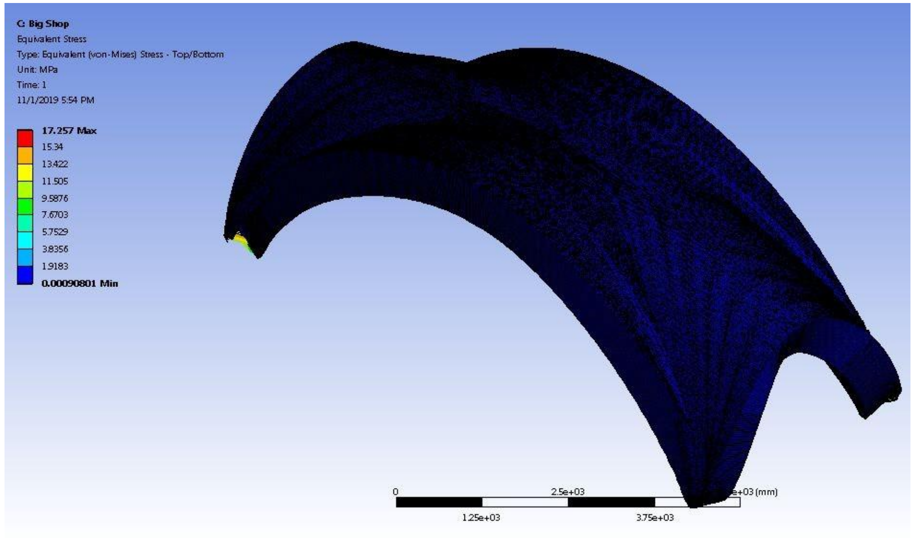


Figure 11: Equivalent stresses of the large shop.

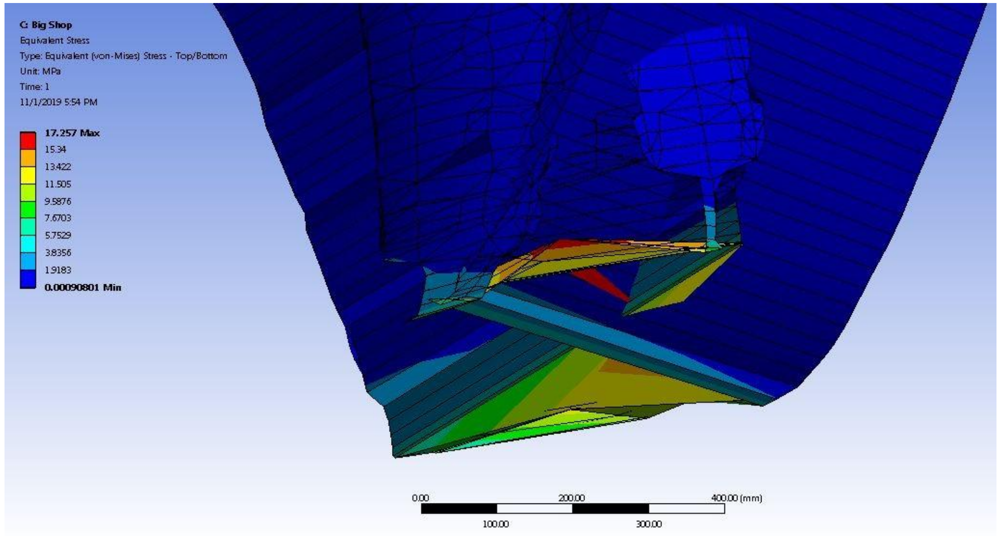


Figure 12: Zoom in on the bottom section of the large shop.

MediumShop

- Dimensions: 3.6 m x 3.6 m x 2.5 m
- Thickness: 400 mm

Deflection

The medium shops modules have a deflection under the previous established conditions of 7 mm, as seen in figure 13.

Stress

The maximum stress, as observed in figure 15, is 11 MPa concentrated at the bottom of the structure.

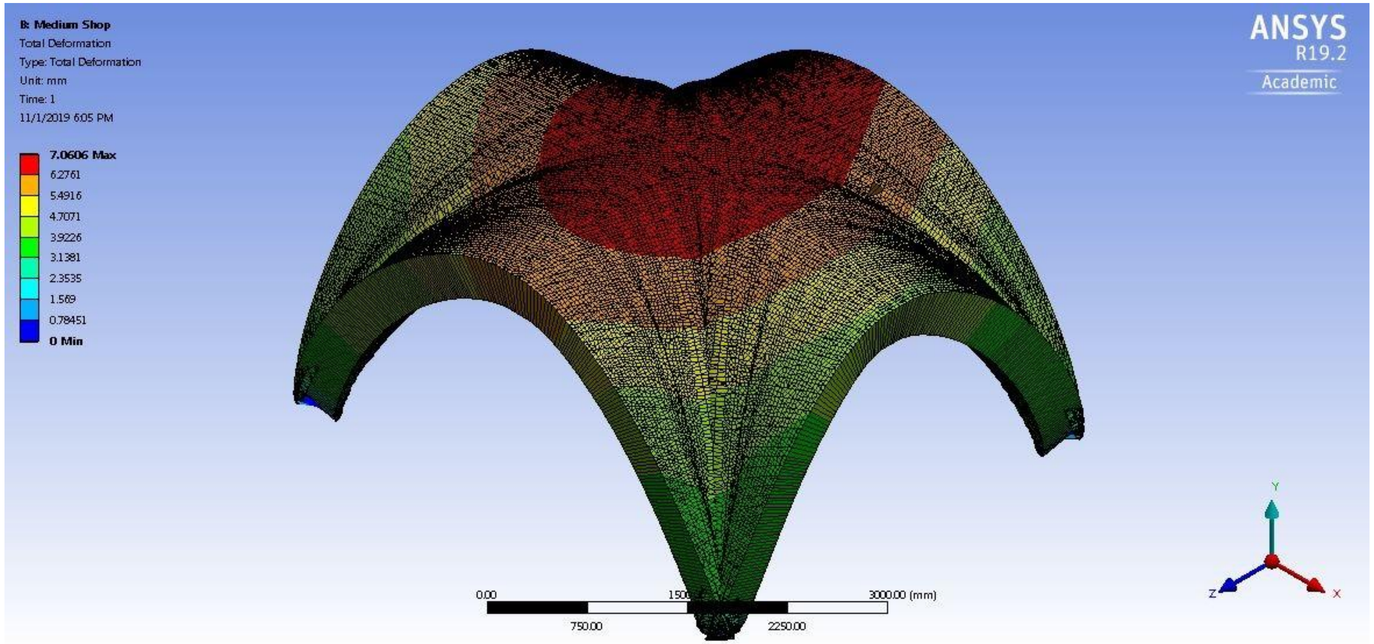


Figure 13: Deflection of the medium shop module.

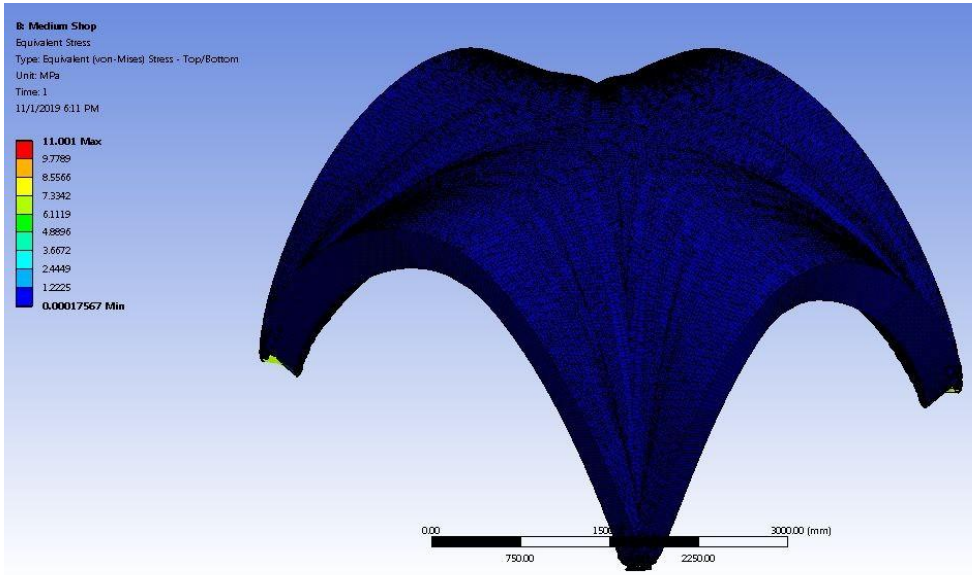


Figure 14: Equivalent stresses of the medium shop.

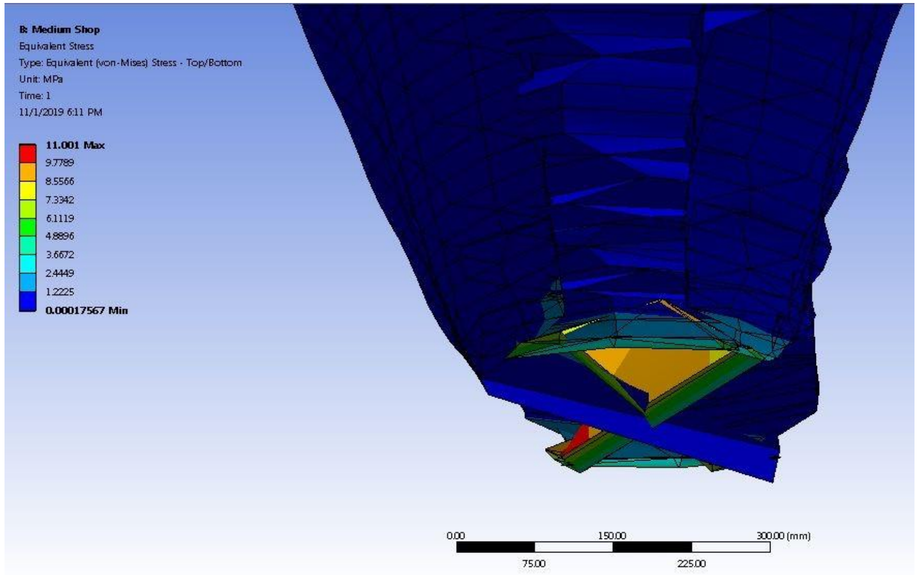


Figure 15: Zoom in on the bottom section of the medium shop.

<u>SmallShop</u>

- Dimensions: 3.6 m x 1.6 m x 2.2 m
- Thickness 400 mm

Deflection

The small shops being the smallest module in the whole bazaar configuration and maintaining the 400 mm of thickness in the walkways, undergo the smallest deflection of all the elements. The deflection of the small shop is only 3 mm, as shown in figure 16.

Stress

The maximum stress in the bottom of the small shop module is 6 MPa, as shown in figure 18.

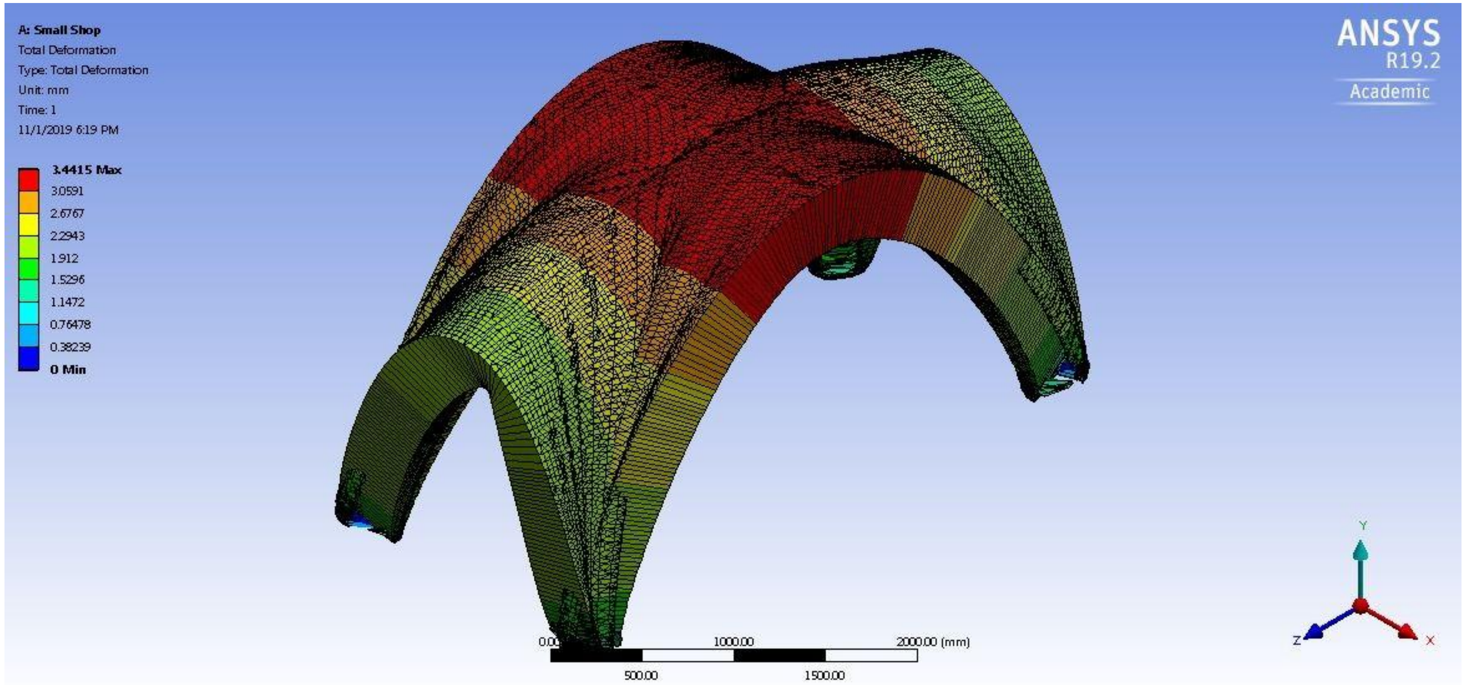


Figure 16: Deflection of the small shop module.

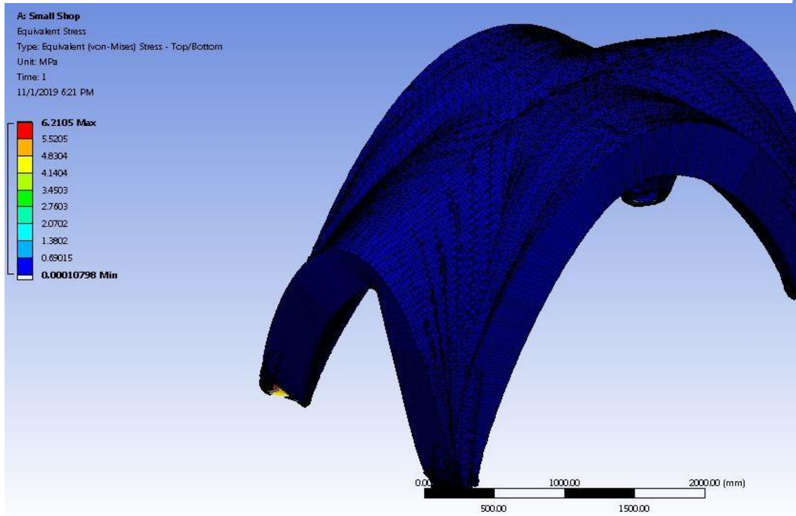


Figure 17: Equivalent stresses of the small shop.

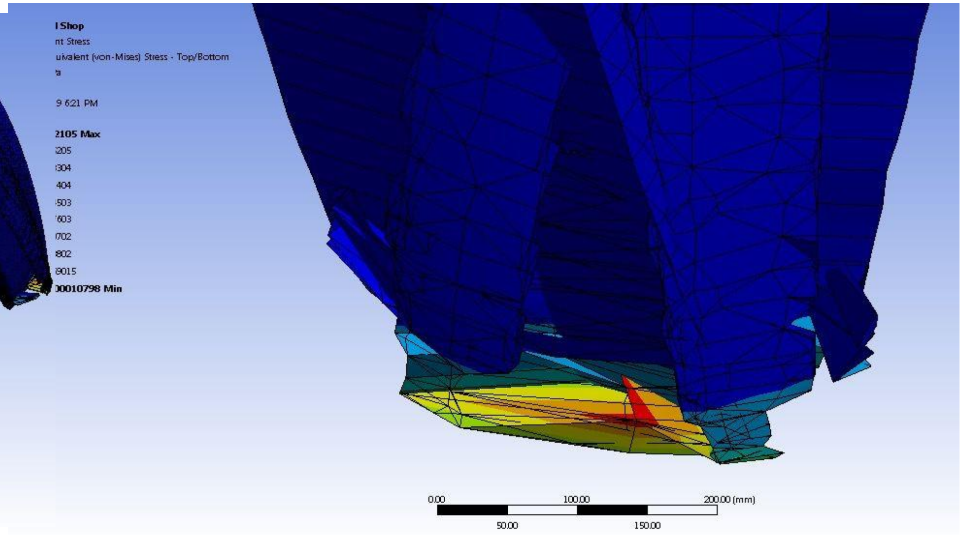


Figure 18: Zoom in on the bottom section of the small shop.

Appendix S: Computational Form finding scripts

Optimisation algorithm crossvault modules.

This script is used to go from a basic rectangular outline to a fully optimised structural module. In short the steps are as follows. Firstly a mesh is computed from the outline taking into account that the rectangle is supported on 4 points and trying to find the best mesh for that. Secondly, the mesh is relaxed using the particle spring system from the plugin kangaroo. Thirdly, forces are defined to accurately reflect a real life situation. Then, the forces, together with material properties, the mesh, and support points form the input for the structural analysis by Karamba. After this, the results are visualised and documented.

After these 5 steps, the whole process is repeated by the evolutionary solver of Opposum. This plugin will change the spring stiffness of the material and the minimum number of stacked bricks (thickness of the shell) and check the documented results. Finally, the most optimal settings are found and chosen.

Step 1: meshing

In this step the rectangle geometry is used to generate a mesh. Note that the rectangle can have different sizes, according to the shop sizes. These rectangle sizes actually comply with the output of the bazaar generation script, so in theory the two scripts could be linked. The meshing is done as follows. First, the diagonals of the rectangle are found. These are important, because this is the way the forces will want to flow: directly to the corner points (at least for a module which has 4 support points). These diagonals then form 4 “v’s” which are splined with their respective sides, creating 3 aditional curves. Next, a rectangular grid is projected over the 4 sections created by the diagonal lines, perpendicular to the 4 sides. Adding the two steps together creates a mesh that effectively transfers force through a plate that is supported on four sides and the mesh is ready for form finding.

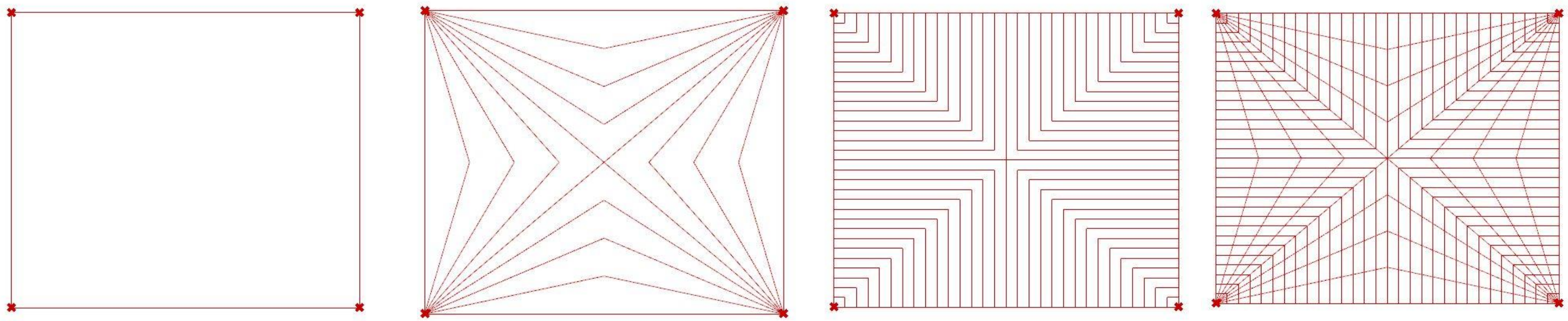


Figure 1: Step one: creating a mesh from a rectangle, a step by step mesh generation.

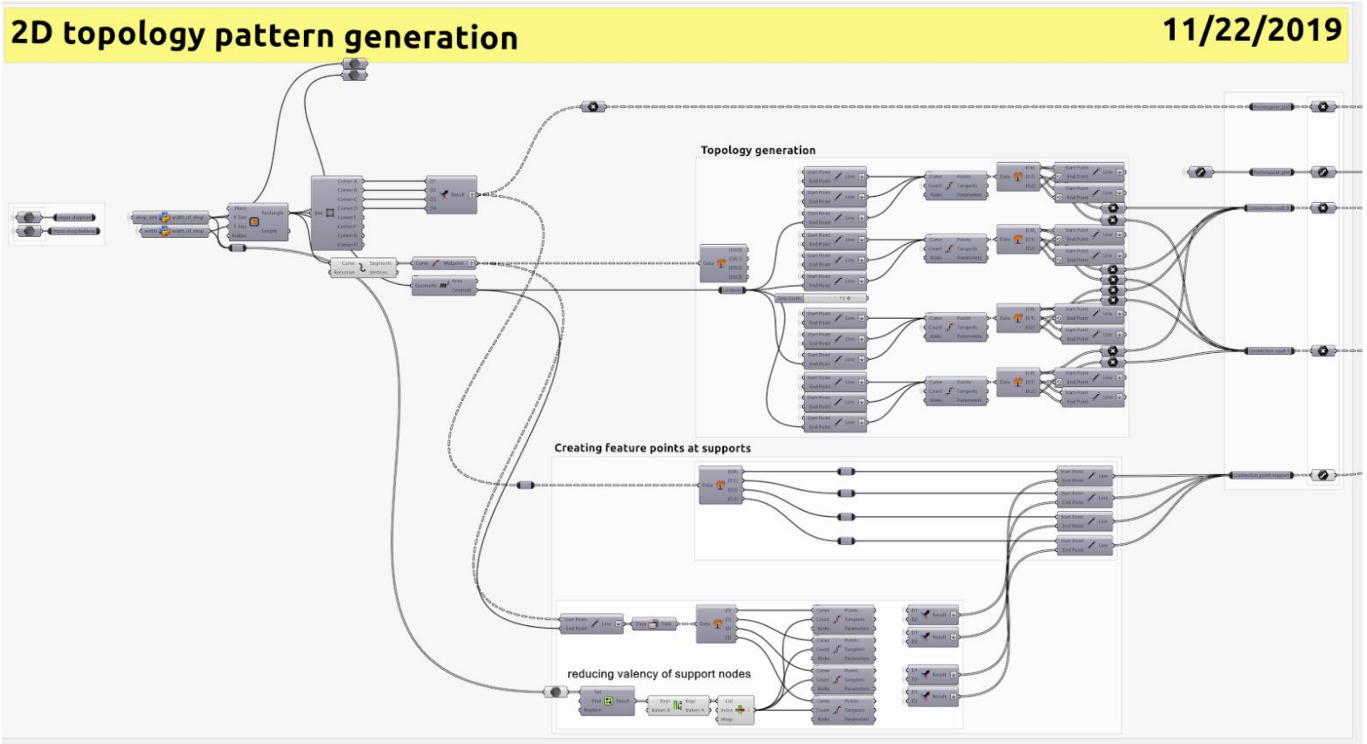


Figure 2: Step one: creating a mesh from a rectangle, the script.

Step 2: form finding

In step 2 the lines that were generated in the previous step are form found using the particle spring solver provided by the plugin Kangaroo. This plugin will apply a certain force to each particle and the springs attached to the particle will resist it a certain amount, depending on their spring stiffness. This spring stiffness is later changed by the opossum optimisation solver. Once the solver is ready, the relaxed curves are made into a mesh using the Weaverbird plugin's component "mesh from lines". This way, a mesh is made which can be used in the Karamba FEM analysis later on.

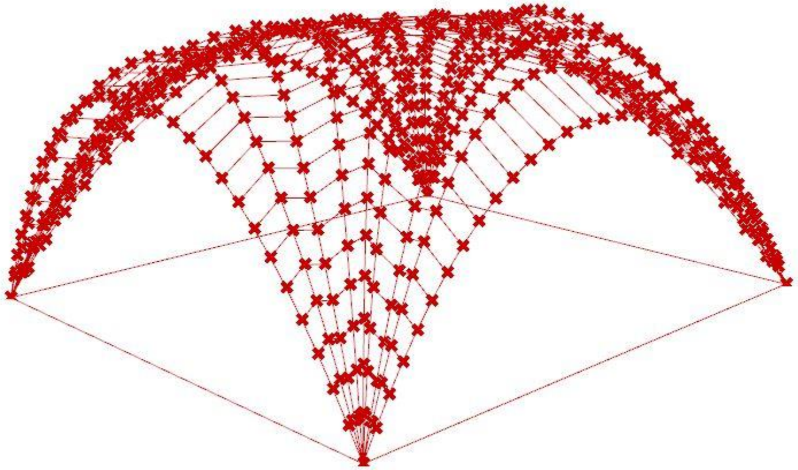


Figure 3: Form finding the mesh by using kangaroo's particle spring system solver.

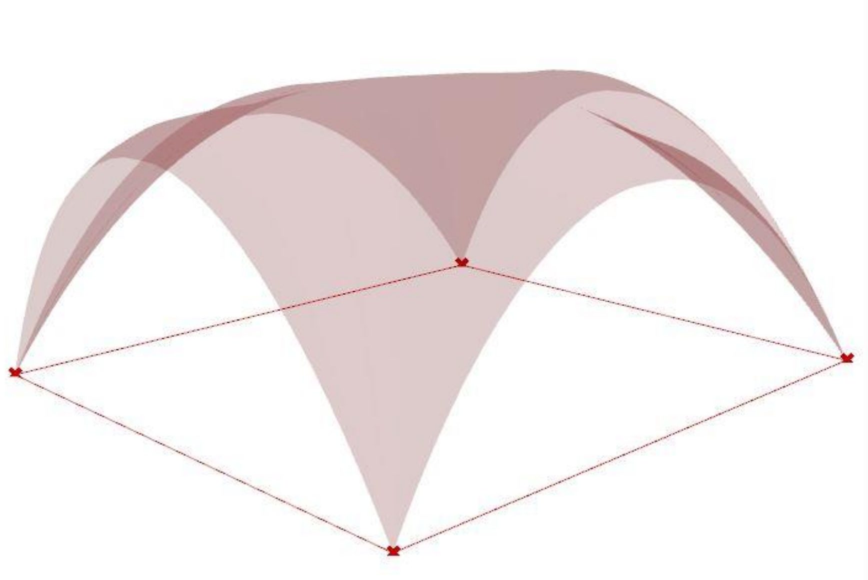


Figure 4: the shape of the resultant form found mesh.

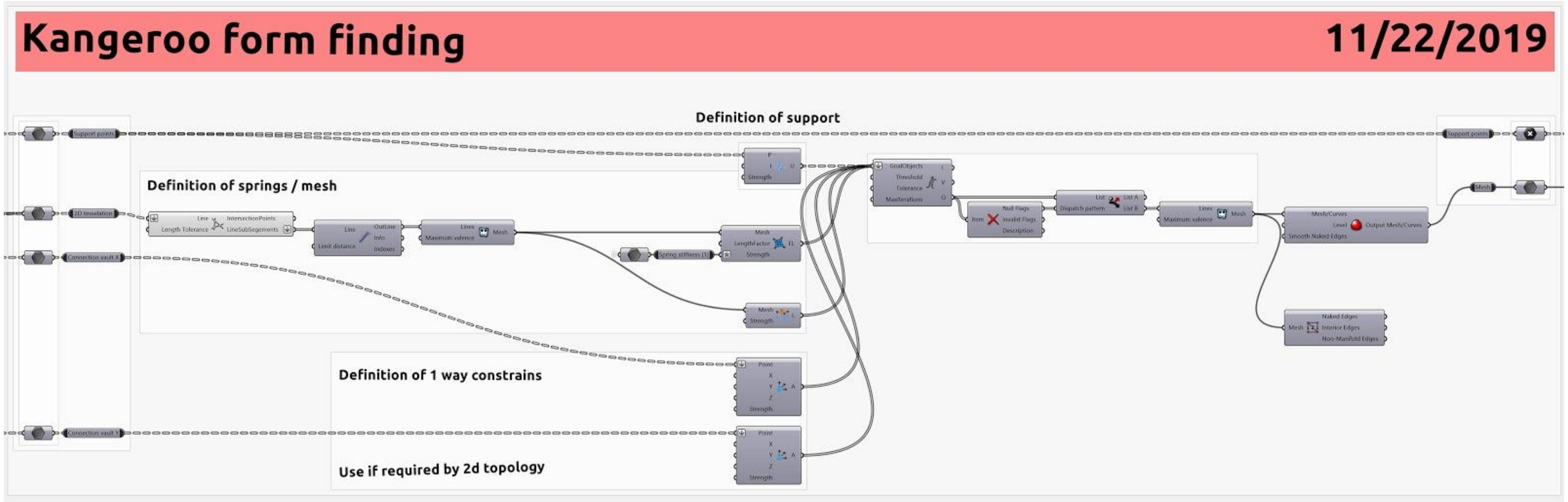


Figure 4: Step two: form finding the previously made mesh.

Step 3: Definition of forces

Each node in the mesh should have a force connected to it before the structural analysis. This force is made up of two different vectors, the gravity and additional load. The gravity can already be defined by Karamba itself but the additional loads consist of two parts, which are defined here. First of all, all the points should be able to carry a certain amount of variable load on top of it. For each point this is the same load per area. However, not every point has to carry the same area (the denser the points become the less area it has to carry). Therefore, the area each point has to carry is found using a voronoi mesh component.
After this, another load is added to the points, this is dependent on the amount of earth each point has to carry (besides its own weight). The amount increases as the points come closer to ground level, this is because in order for the 'roof' (added ground) to let water flow away on all sides, the module has to at least be flat on top if the module is surrounded by other modules (otherwise the water gets stuck). This is why near the support points, these loads increase.

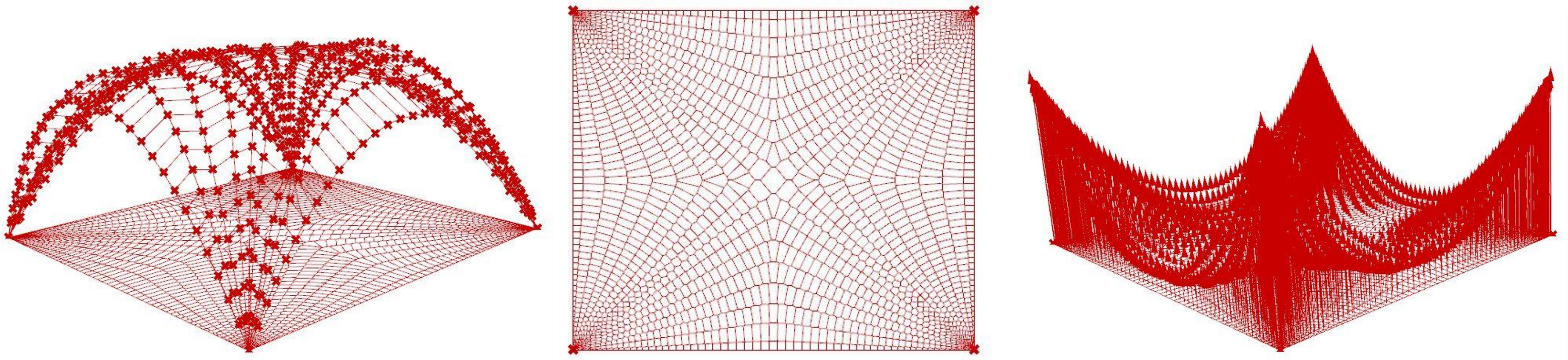


Figure 5: Step three: defining the loads. Left and middle, variable load. Right, load due to added earth.

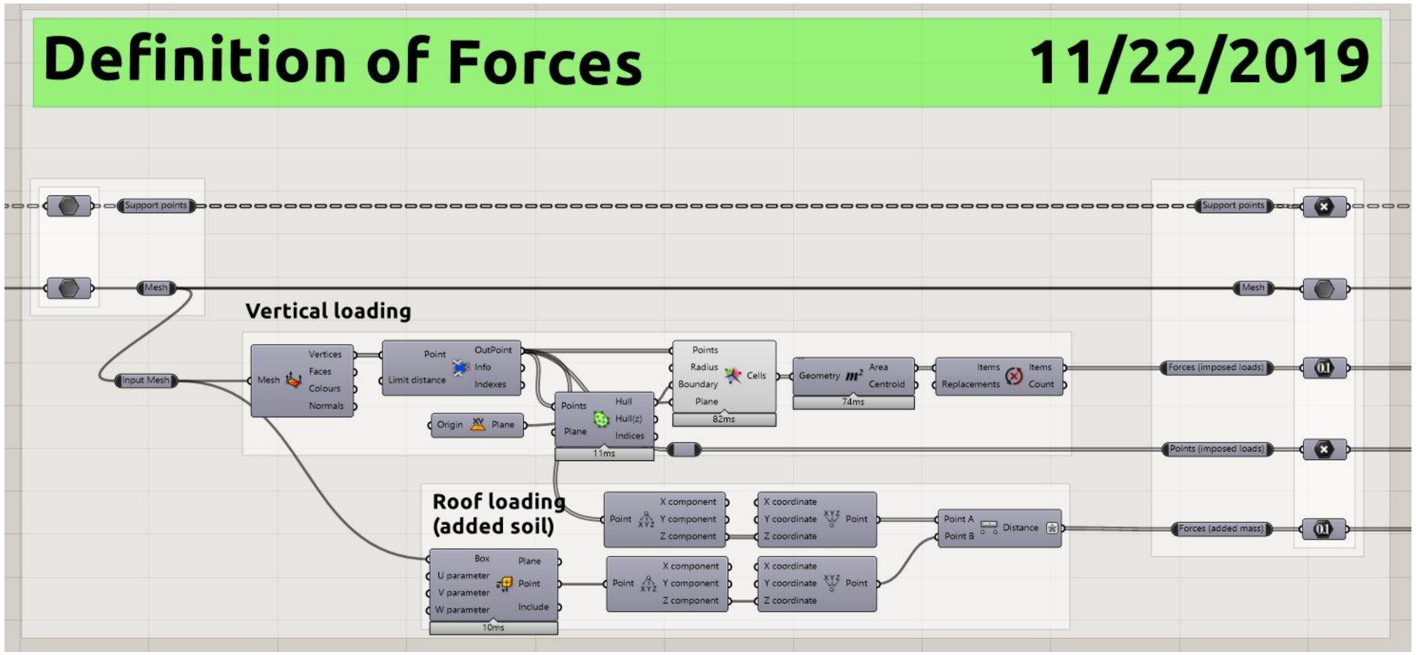


Figure 6: Step three, definition of the forces.

Step 4: Karamba analysis

Step four is not very visual, here all the results that have been acquired before get loaded into the Karamba solver. These inputs are:

- Loads (as discussed before: Gravity, variable and added soil)
- Support points, these are the four corner points of the mesh
- The mesh generated by kangaroo
- The abode material properties
- The shell thickness, which is dependent on the number of bricks

All these inputs are then put together and solved to find numerous interesting outcomes.

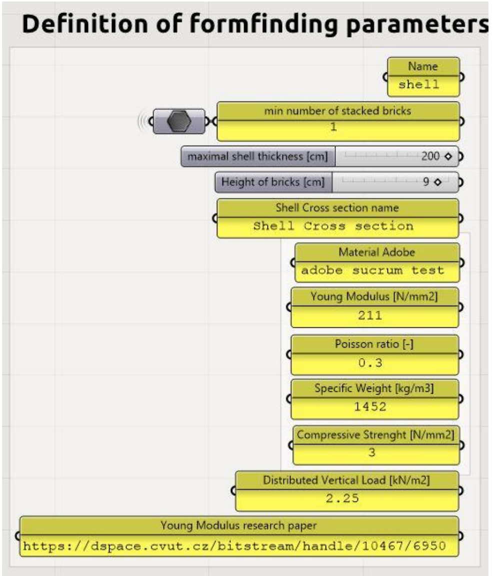


Figure 7: Step four: karamba analysis input.

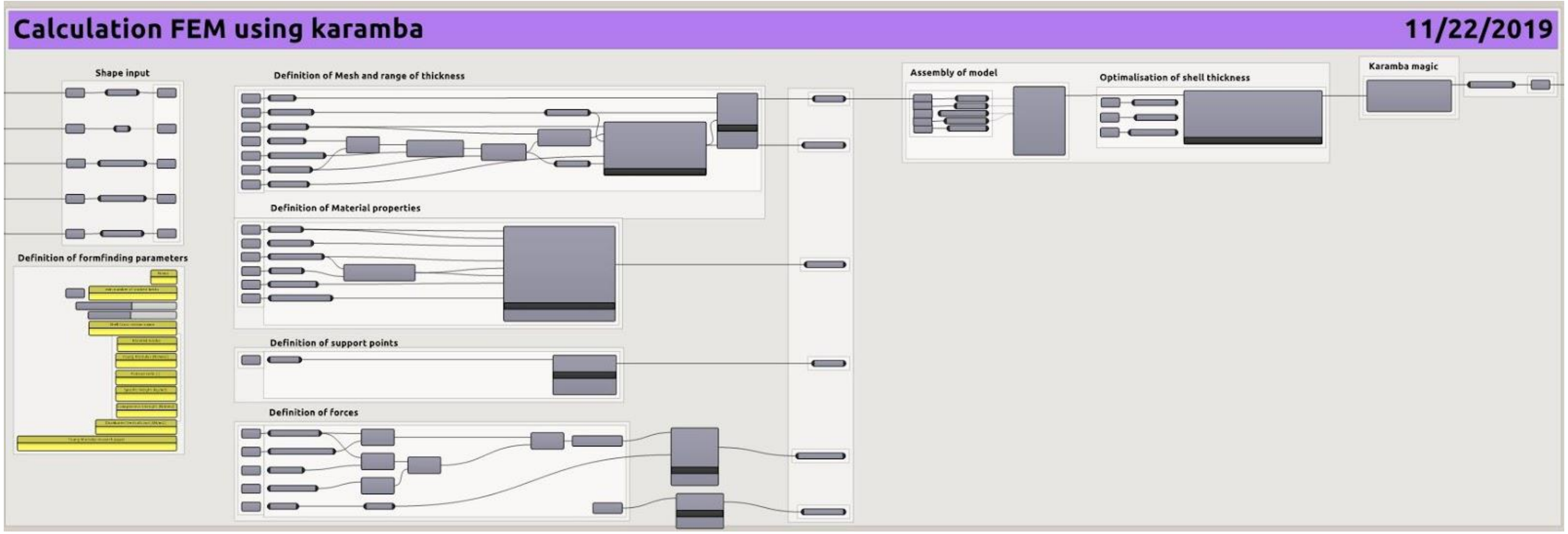


Figure 8: Step four: karamba analysis.

Step 5: Fem results

Step 5 includes the results from the karamba analysis, organised and documented. All the results are drawn from the model and sorted in such a way that the following becomes visible:

- -Maximum deflection
- -Maximum tensile stress principle direction 1 and 2
- -Maximum compressive stress principle direction 1 and 2
- -Von Mises stresses
- -Resultant force

The Fem results are similar to the ones found in appendix P. These results will be evaluated by the Opossum solver in the next and final step

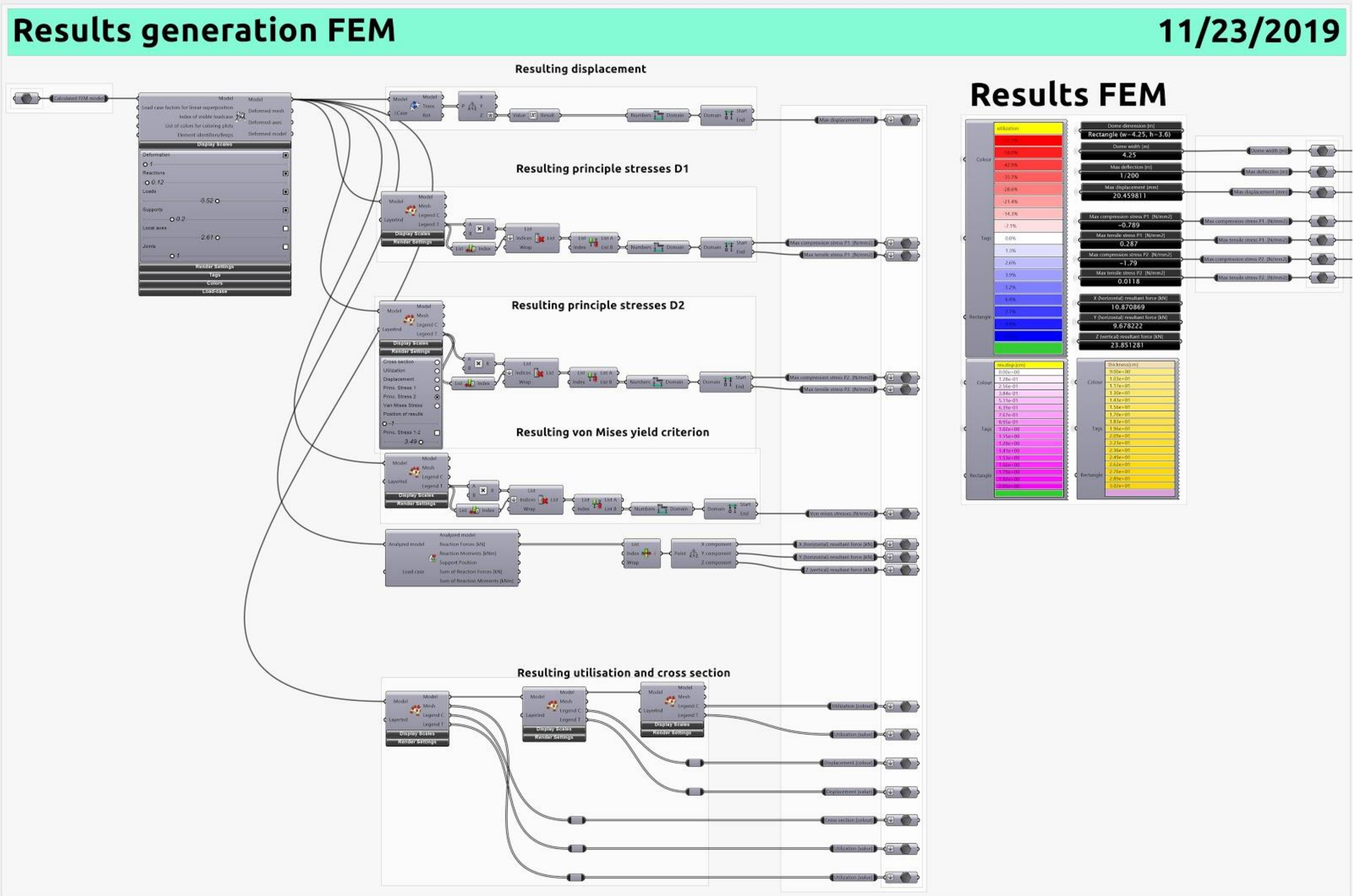


Figure 9: Step 5: Documenting the FEM results

Step 6: Opossum Optimisation

The last step is repeating the previously mentioned steps to try and find the most optimal outcome. This is done by repeatedly changing the spring stiffness and the minimum brick thickness. Because these parameters are changed, the script will rerun and Opossum will keep track of the outcomes. What is done just before that, is adding unity checks to make sure that the results do not validate the limit states. This is done for both deflection and stress in two principal directions. Eventually, Opossum will have found the most optimal settings regarding the deflection and stresses and those are the results which are found under appendix P: FEM analysis.

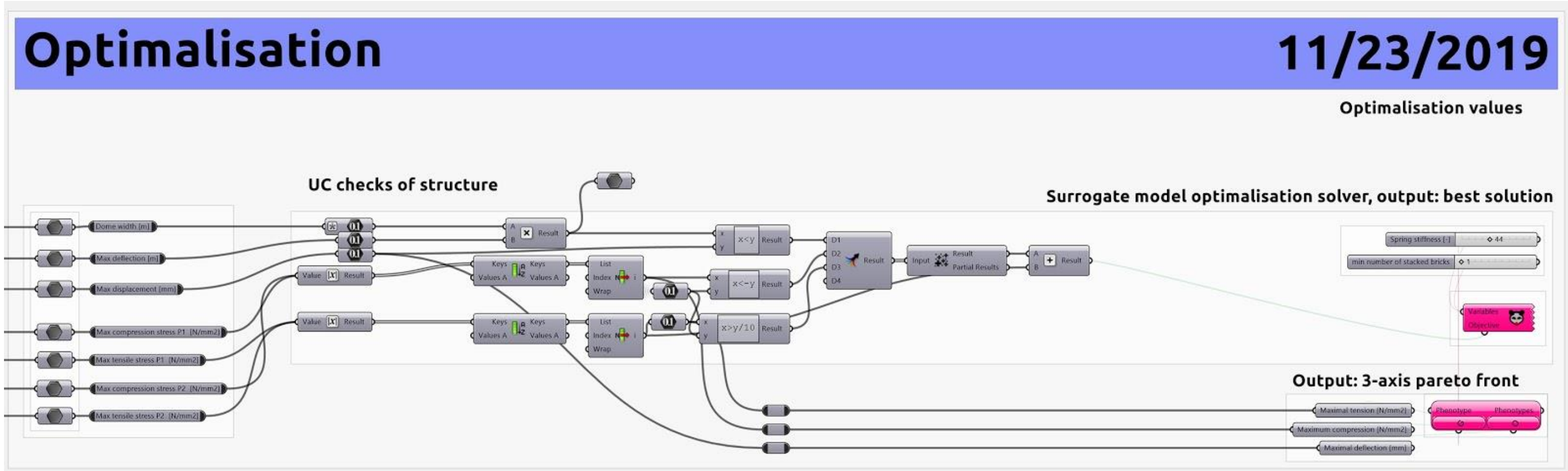


Figure 10: Step 6:Opossum optimisation and unity checks.

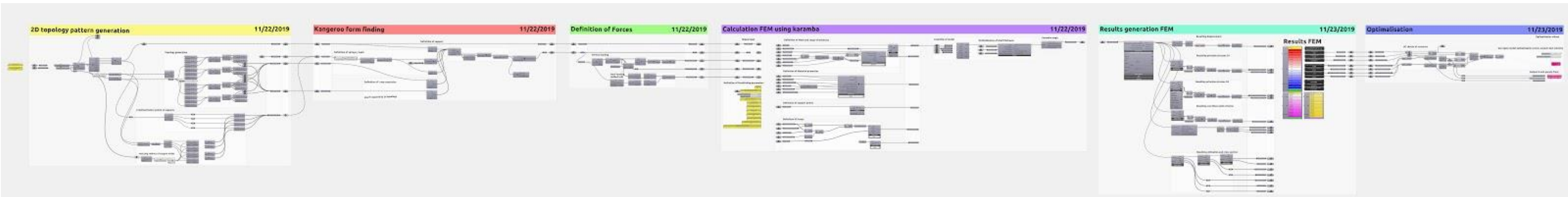


Figure 11: The total script

.Appendix T: Computational Brick bond

Brick laying:

Central within this course is the use of local resources, while we made a full construction manual on how to construct the dome, we also tried to do the same process digitally. This resulted in our brick-laying script, The idea was to generate the eventual dome, but we realised it was harder than expected. This had 3 main reasons:

- Kangeroo/Karamba3D has no ‘clean meshes’ as output
- Double curvature is mathematically impossible to generate out of rectangles
- Your assumptions define your outcome

A good example of the problems with approximating double curvature with bricks or a straight surface is mathematical mapping. Draping a cylinder with a plane is easy, the same with a circle is proven impossible without modifications:

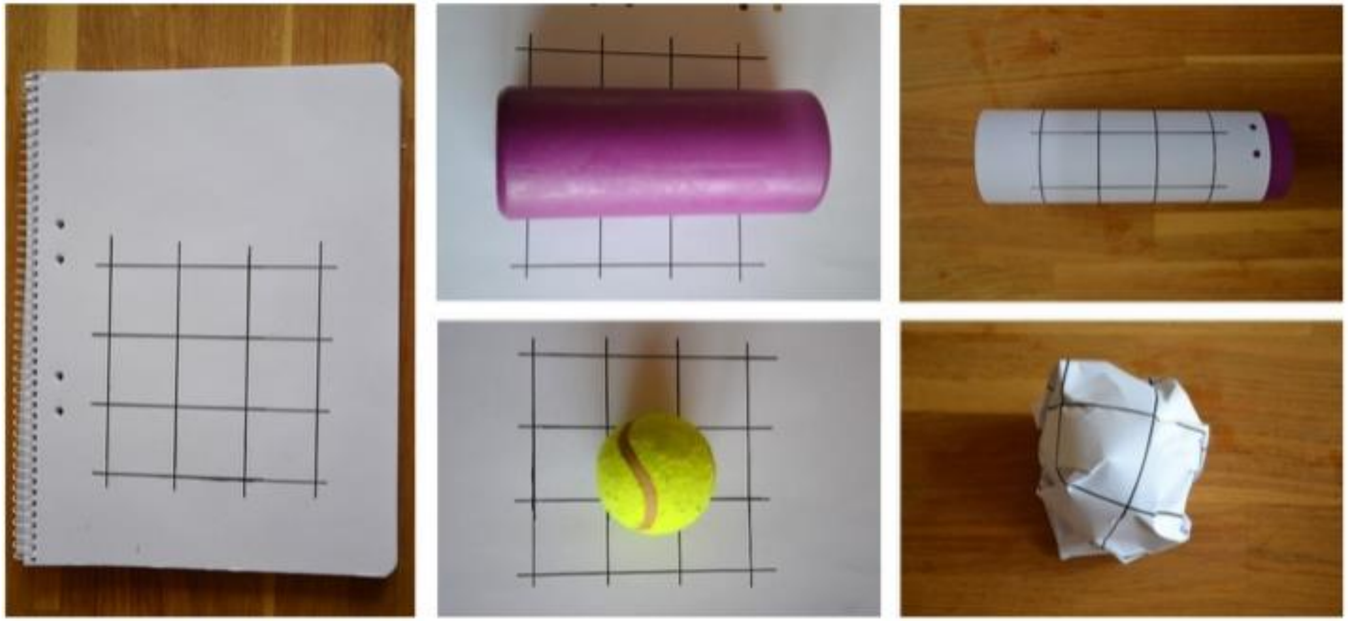


Figure 1: Draping a cylinder with a plane is very easy. Trying a similar procedure with a sphere it is proven impossible without modifications or crumbling of the paper. Retrieved from adiels, 2016

In mathematics three possible solutions are there to create a double curvature with bricks:

- Conformal mapping, angles are preserved
- Isometric mapping, distances are preserved
- Equiareal mapping, areas are preserved

Within earthy we tried several methods and combinatorial methods, the one found most successful is distance preservation together with conformal mapping, but this did not result in a 1on1 digital backbone of the vault we wanted to realise. In history many domes have been built and might form a better example than our mathematical approximation. This was one of the reasons why we chose not to further develop the computational bricklaying.

We would still like to showcase what we have done as we struggled quite a while with the three problems stated at the start. When looking at traditional shells its explainable that it works better. For example, the mortar makes it possible to compensate for the deviations and geometrical limitations, both globally and locally. This means that it allows some tolerance from the exact mathematical solution (adiels, 2016).

When looking at traditional bricklaying the layers don't know the exact position that marks every brick, instead they know the relationship and guidelines of each layer, i.e. the direction and propagation of the brick joints. We don't have this skilled labour and still want to make it possible to generate relatively ‘complex’’ shapes with bricks. Therefore, we further put our effort in investigating inflatable moulds, as these form the perfect ruler for the propagation and direction of the bricks.

Computational brick script

Our script for bricklaying contains 2 main sections

- Translating the mesh input to workable parameters
- Generating the bricks
    - outer ribs
    - diagonal ribs
    - infill bricks

Translating the mesh input to workable parameters
This part focuses on making the mesh workable and allows it to be approximated by catenary curves representing the outer curves, diagonal curves. these also allowed for the generation of surfaces which could form the basis for the generation of the inflatable mould and the computational approximation with bricks.

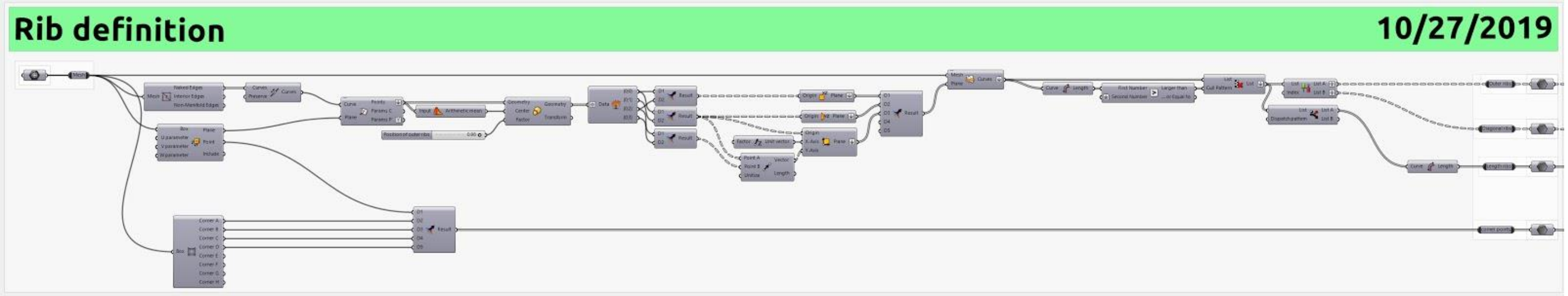


Figure 2: making the mesh workable

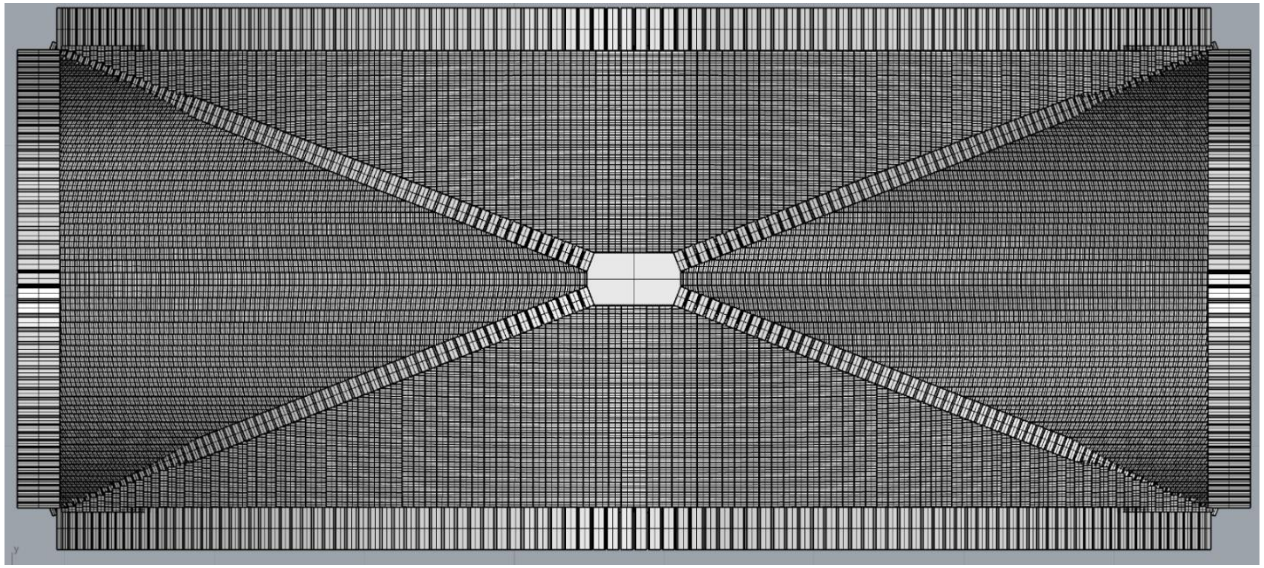


Figure 3: final outcome of the brickmaking script

Generating the bricks

This part uses the workable input and forms a parametric tool of generating ribs and infill by different brick sizes. This script can be seen in (figure 4) an example of the outcome is shown on the previous page. (figure 3) To get a further insight in the brick packing - and also the computational form-finding - i would like to refer to our GitLab where you can try them out yourself.

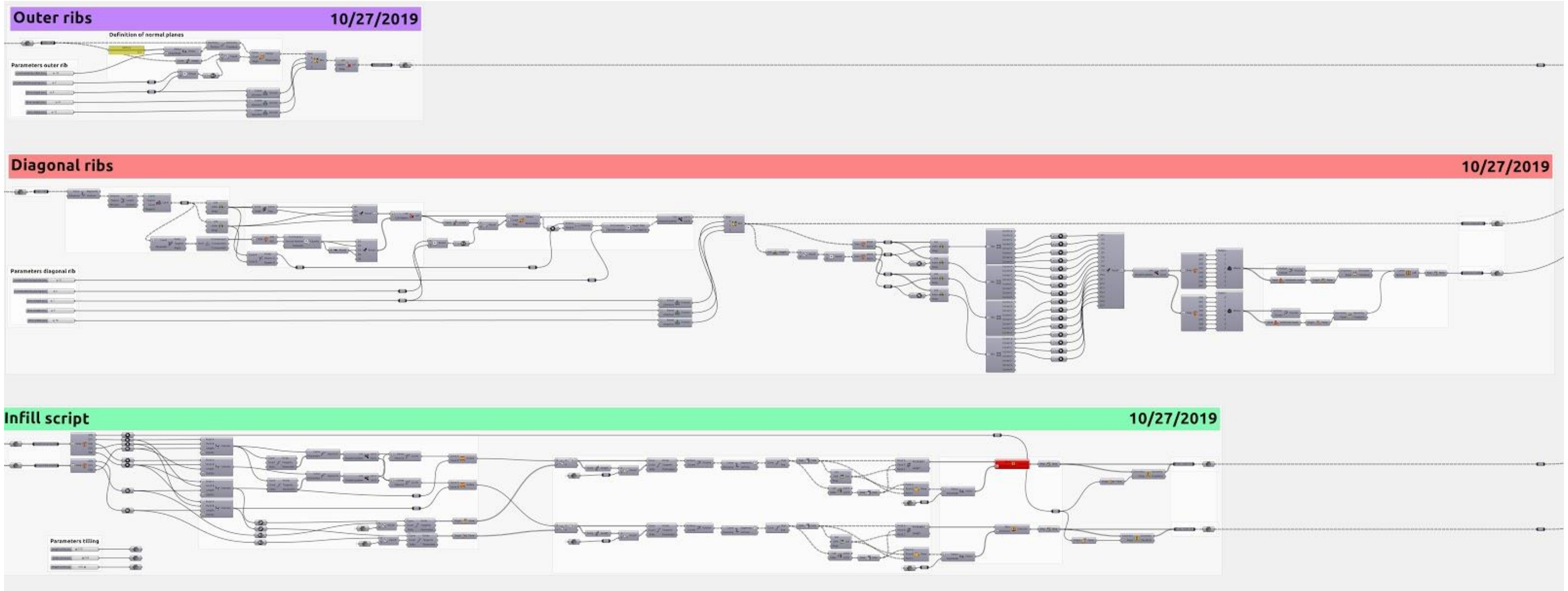


Figure 4: part of the script that generates the bricks.

Appendix R: Construction method

For creating the construction manual different sources are used. The knowledge obtained in the research above is used as general knowledge. Next to this, the two main sources are: La Voûte Nubienne, 2018 and La voûte Nubienne, 2014. Both are manuals for making nubian vaults. Basic information about placing the vault, approaching the building process and preparations are taken from these manuals. The italic text is from the construction manual itself.

Location
From the context research follows that the rain season is between November and March. Some measures need to be taken to make sure the rain does not go into the building. This already needs to be taken into account when to start location is chosen.

> *‘’**The Location***
> *Make sure that the building location is not the lowest place around you. This is to prevent water coming into your building. Also, increase the height of the ground around the edges of the walls to protect the construction from water penetration. Warning: do not extract the ground next to the construction for creating a slope or getting material. “*

Quality control: adobe

In the context research can the composition of the soil be found. These are guidelines for the construction workers where they can find the clay, fine sand and coarse sand. However, the exact place is not given. A test needs to be conduct to check if the composition of the material is right.

> *“ **Quality control: adobe***
> *Not all the earth that can be found around you can be used for making the building. To decide which soil should be used the following test need to be conducted.*
>
> ***The drop test.***
> *- Create a round ball of earth in your hand.*
> *- Straighten your arm on shoulder level.*
> *- Drop the ball on the ground.*
>
> *1.If the ball does not break don’t use it.*
> *-> too much clay.*

2. If the ball breaks in a lot of small pieces don’t use it.
-> too much sand.
3. If the ball breaks in some large pieces, use it!
-> good.’’

The workspace
Due to big quantities of the mixture and lack of material and tools an workspace need to be created by the building workers.

*“**The workspace***
A location needs to be defined as mixing and drying area. It is important that the drying place is protected from rain as this negatively influence the quality of the adobe bricks.

- Dig a big hole to mix the clay, fine sand, coarse sand and the straw or feathers in.’’
- Fill the hole with water and drain it out.
- This is to make sure the hole stays intact during the mixing and does not crumble.
- Let the hole dry for a day.
-> Mixing workspace is ready.”

Adobe mould and brick sizes

To create a building from adobe a lot of bricks are needed. To make sure these bricks have the same, wanted, dimensions a mould is needed. To speed this process are ladder or a raster can be made. The size of an adobe brick is not a fixed size, in literature different sizes can be found. An important aspect to take into account is the relationship between the size and the weight. Founded references of sizes and weight:

10,2cm x 20,3cm x 40,6cm, ~12,7kg
10,2cm x 22,9cm x 40,6cm, ~15,9kg
10,2cm x 25,4cm x 45,7cm, ~16,3kg
10,2cm x 30,5cm x 45,7cm, ~21,8
12,7cm x 30,5cm x 40,6cm, ~24,0kg
12,7cm x 22,9cm x 50,8cm, ~24,9kg
12,7cm x 30,5cm x 45,7cm, ~26,8kg
15,2cm x 30,3cm x 60,9cm, ~45,4kg
(U.S Department of agriculture, 1934, p. 4)

La voûte Nubienne (2014), uses 4,5cm x 12cm x 24cm x and La voûte Nubienne (2018) 15cm x 38cm x 17cm and 5cm x 15cm x 25cm. The brick size from La voûte Nubienne (2018) 15cm x 38cm x 17cm (~16kg) and 5cm x 15cm x 25 (~ 3kg) cm are chosen for this design. This to make sure the weight does not get to heavy, because the construction builders need to lift and place these bricks for the whole day.

"The adobe mould

There are 2 different types of brick with their own dimensions. The large brick is used for the straight structural ribs and load bearing walls, with the size 25cm x 10cm x 36cm. The second type of bricks is a bit smaller and thinner. These are used as the fill in of the roof structure and for the ribs of the smaller domes. These domes have a steeper curve, what is possible with thinner bricks. Finally some key stones are made on site.

Brick type 1

A large brick has the following dimension: 25cm x 10cm x 36cm what will give an average weight of 16kg.
-Collect the wood for the mould.
-Make the width of the wooden strips 10cm, this is the height of the brick
-The inside of the wooden frame should have the width and height of the brick.
-> Take into account that the brick shrinks during drying.
-To save time a "Ladder" mould can be created of wood instead of a single mould.
-Leave some space on the side to make it possible to lift the mould.

Brick type 2

A small brick has the following dimension: 25cm x 5cm x 15 cm.
-Collect the wood for the mould.
-Make the width of the wooden strips 5cm this is the height of the brick
-The inside of the wooden frame should have the width and height of the brick.
-> Take into account that the brick shrinks during drying.
-To save time a "Ladder" mould can be created instead of a single mould.
-Leave some space on the side to make it possible to lift the mould"

Type of bricks

Different composition of bricks are tested to find out what the effect of these materials is on the compression strength of the adobe bricks, this research can be found in Appendix M: Material study. From this research we found out that adding feathers and straw positively influences the compressive strength of the bricks. The composition with straw works slightly better than the composition with feathers. However, straw is food for the animals and thus indirectly food for the people in the camp as well. That is why this material is only used in the most critical places as the first meters of the structural ribs. The mixture for the feathers is used for the less critical parts as the upper part of the rib structure and the load bearing walls. Only adobe bricks are used for the partition walls and as fill in. The first meter of exterior wall needs extra reinforcement for two main reasons, to strengthen (for impact) and protect the wall from water (Visser, 2019).

*"**Type of bricks***
There are six ingredients needed to make the adobe bricks: Clay, fine sand, coarse sand, bricks, water and if needed straw or feathers. The exact mixture depends on what kind of brick is needed. These proportions need to be controlled at all times to make sure the adobe bricks have the right properties.

1. Brick to fill in between the ribs structure and partition walls:
-30% clay.
-30% fine sand.
-40% coarse sand.
-1 liter of water.

2. First meter of inside rib structure:
-30% clay.
-30% fine sand.
-40% coarse sand.
-1 liter of water.
-1% of total volume straw.
-> This is the place with the most concentrated stress. Straw is needed as reinforcement.

3. Upper part of the rib structure and load bearing walls:
-30% clay.
-30% fine sand.

-40% coarse sand.
-1 liter of water.
-1% of total volume feathers.

-> The stresses are slightly lower than in the bottom part, but reinforcement is still needed. Straw is only used in the needed places due to scarcity. Now feathers should be used.

4. For the first meter of exterior wall:
-Layer of small bricks.
-30% clay.
-30% fine sand.
-40% coarse sand.
-1 liter of water.

-> To strengthen and protect the first meter of wall against water and other impacts. When this is not possible, fire bricks could be used.

Mortar

When the adobe bricks are made and dried, the mortar can be made immediately before constructing.
-Mix the same ingredients together as for the adobe-only bricks without the feathers or the straw.”

Quality control adobe bricks

Due to the fact that everything is hand labor and the collecting-, mixing- and drying process can be influenced by a lot of factors and extra control step is needed to test the batch of adobe bricks. This is to prevent failure of the building during construction.

*“**Quality control adobe bricks***

The adobe bricks can be made after choosing the right material. The bricks need to be tested for their strength after they are formed and dried. This is to make sure the construction will not collapse.

The strength test

-Place two bricks 30cm apart from each other, this is around one feet in between.
-Place a third brick on top of these two bricks.

-Let one average weighted adult stand on the brick.
-> If the brick breaks don't use it
-> If the brick does not break, use it!"

Scaffolding

As on every construction site a scaffolding is needed to build above shoulder height. However, in camps as Zaatari there is a scarcity of materials and they do not have the proper equipment. That is why there is chosen for a self-buildable scaffolding from materials that can be found in the camp itself. The scaffolding can be made of the self-created adobe bricks and a corrugated sheet. The corrugated sheet can be obtained from a demolished caravan. This can be done because in the bazaar are also houses for the people in the camp. No wood or other limited materials are used by making this scaffolding. The bricks can even be recycled into new bricks.

''Scaffolding
-Place two bricks 10cm from each other on the ground
-Place two bricks on top, 10 cm from each other, turned 90 degrees compared to the 1 row.
-Duplicate this process once the other side.
-Place a corrugated sheet on top.
-Test if the corrugated sheet does not break.
-If not continue the process till the needed height.
-Place the corrugated sheet.
-Create a ramp or some small steps to get safely on the scaffolding.''

Mould for windows and doors
From our design research follows that a lancet arch is common in South-syrian buildings. Next to this, the bazaar contains domes and vaults which are based on rib vaults. The lancet arch is in the same architectural style as the rib vauls. Therefore, the lancet arch is chosen. For the arch formwork is needed, information about this formwork can be found in Appendix O: Constructing rib vaults/ domes & window opening.

"Cardboard mould
-Get a cardboard piece from the camp with minimum dimension of 600mm by 600mm.
-Draw two circles with a radius of 600mm.
-The shape of the lancet arch is formed (Red dotted lines).
-Cut this piece from the cardboard.
-Re-do these step till the cardboard has a minimal thickness of 36cm (depending on stone)
-Connect the cardboard pieces to each other with rope or glue to make it a rigid final structure."

Making the bricks
10.000 years ago buildings where already build with adobe bricks (‘Brick - History’, n.d.). In this period the people made the bricks by hand without using machines. The knowledge gathered from the brick making experiment conducted on 25 september 2019 combined with the information from La Voûte Nubienne, 2018 and La voûte Nubienne, 2014 led to the step by step description.

> ***“Making the bricks***
> *If all the materials are collected the mixing process can start.*
> *-Put all the ingredients in the right proportion in your mixing workspace.*
> *-Mix the ingredients by walking through the mixture or by using a shovel.*
> *-Put some sand on the side of the mould, to make sure the mixture will get out.*
> *-Put the mixture into to mould.*
> *-Even the surface of the mould by hand or with a trowel.*
> *->No air pockets or gaps should be in the mixture.*
> *-Leave the bricks for 2 hours to let the adobe set.*
> *-Then remove the mould.*
> *->Clean the mould before using it again.*
> *-The adobe bricks need to dry for three days.*
> *-After three days, or changing colour on the sides, the bricks can be put on their side. Let them dry after this for 7 more days.*
> *-Clean the bricks, scrape of excess mud. “*

Outline
In well developed countries lasers are used to make sure the walls and corners are straight. These lasers are not available in refugee camps. Before the arrival of the laser simple mathematical rules and ropes where used. This is what can be done in the camp.

> *“The outline of the building will come from the app. Before constructing the building the outline need to be marked on the ground. To make sure the layout of the construction is straight some basic groundwork has to be done.*
>
> *-Use the 3-4-5 rule to create straight corners.*
> *-Make sure that A=A B=B and C=C*
> *-Marker the corners and put the rope in between as guideline.”*

Foundation
A foundation is needed for every building to increase the lateral stability of the structure (Jamal, 2017). The foundation is dug into the ground and transfers the load to the earth around it. A foundation is needed for all kind of structures, also for adobe. The width of the foundation should be thicker than the width of the load bearing wall on it. This is to make sure the forces will go into the foundation and not into the earth. … The height of the foundation depends on the depth erosion and scour. If the foundation is not deep enough there is a change that the building will slide along the surface (Rodriguez, 2019). The chosen width and depth come from La voûte Nubienne, 2014.

"Foundation
A foundation is necessary for several reasons, it is needed for structural/ load bearing reasons, to keep moisture outside and against seismic activities.

Width
-Use the rope as guideline for the outer lines of the foundation.
-Make the foundation of the load bearing walls 10cm wider than the thickness of the wall.
-50cm wide walls ->60cm wide hole for the foundation;
-60cm wide walls ->70cm wide hole for the foundation.
-Make the foundation of the partition wall the same width as the thickness of the wall.
-Dig out the hole for the foundation.
-Check of the underground is flat before going to the next step.

Depth
The depth of the foundation depends on the type of wall and the type of ground digging in.
When the underground is from soft or weak soil the hole needs to be deeper.
When the underground is from hard ground/ rocks the hole can be more shallow.

Normal ground:
Load bearing wall -> 60cm deep
Partition wall -> 40cm deep

Filling the foundation
-Place the biggest rocks first on their flat side in the hole.
-Fill up with smaller stones, earth and mortar.

-Make sure the top layer is filled up with earth and mortar for a flat surface.
-Start placing the adobe bricks, keep the extra 10cm on the outside of the construction."

Straightness/ Alignment

As mentioned at outline, people in the Zataari camp do not have laser or other luxurious equipment. With simple tools, as a rope and a plumb line or rope with a heavy object on the bottom, the builders can make sure that the building is straight.

" Straightness Walls
-Get a plumb line, or a rope with something heavy on the end.
-Hold this next to the load-bearing wall or partition wall to check if it is straight.

Alignment
-The alignment of the wall need to be checked after every row."

Flooring
To make sure people do not trip and have a flat surface some kind of flooring is needed. In the camp this can be done by compressing the earth till it becomes a hard layer. A stone bedding can be added in case of damp (La Voûte Nubienne, 2018). When wanted an oil linseed oil, hemp oil, walnut oil etc.) can be added as sealer. This will reduce absorption and prevents dusting (Koko, 2014).

"***Flooring***
The flooring consist out of a minimum of two layers.

-The first layer is hardcore compact layer of ground 40mm.
-> use you feed or something heave to compress the soil.
-To minimize cracking a second layer of hardcore compact layer can be added 40mm.
-To prevent damping add a stone bedding."

Walls and openings

In appendix N: Brick bonds a research is conducted into which brick bond works structurally best. From this research the cross-bond pattern came out as on of the best. This bond is easy to make what will increase the working speed and decreases the chance of mistakes. With this bond it is also possible to create opening by leaving out a header. To increase the stability, the partition wall should be connected to the other wall. By leaving some bricks out of the wall the partition wall can be connected to this.

‘’***Walls and Opening***

When the outline is ready, the foundation is made and the floor is placed you can start with the walls. Notice that load bearing walls have different measurements then the separation walls. Mark the openings, doors and windows on the floor so it is known where and where not to place the bricks.

Exterior Walls

-Use for the first meter of bricks, the stone bricks with feathers, see pages 14 and 15.
-Lay the bricks in crossbond pattern.
-> Row of stretcher.
-> Row of headers.
-> Repeat pattern.
-Place mortar between every brick.
-Measure the alignment after every row of bricks, see page 27.
-After this the feather bricks should be used.
-Continue the bricks in crossbond pattern.
-Leave a head open in case of a partition wall, see page 32.
-When you can not reach the top.
-> make the temporary scaffolding, see page 17.
-Finish the wall.

Partition wall

-Connect the partition wall to the side wall at the place of the gabs.
-Clean the gabs and surface.
-Make the foundation of the partition wall, see page 24-26.
-Use the adobe only bricks for the partition wall.
-Lay the bricks in crossbond pattern.
-> Row of stretcher.
-> Row of headers.
-> Repeat pattern.
-Place mortar between every brick.
-Measure the alignment after every row of bricks, see page27.

-Finish the wall.
-This is needed fot the walls of the shop facing the next shop.''

Constructing the door and window

In appendix O: Constructing rib vaults/ domes & window opening the importance and working of a mould is described. The framework is a guideline and a support for the bricks. This formwork follows the intrados of the curve. It is important that the bricks touch each other in the inner curve and that there is no mortar. The mortar is used on the outside of the curve.

''Constructing the door
-The side of the domes are formed by not building the wall.
-Place the mould on the needed height on a temporary construction or scaffolding.
-Make sure you are on the right height, on a scaffolding.
-Place the bricks on their side simultaneously from the two sides.

-Place mortar between every brick.
-Work towards the middle.
-Place the keystones.
-The mould can be taken away.
-As door itself a corrugated sheet should be used.

Constructing the window
-The base and the side of the windows are formed by the walls.
-Place the mould on the needed height.
-Place the bricks for the windows on their side, but make sure the inner corners connect
-Place mortar between every brick.
-Work towards the middle.
-Place the keystones.
-The mould can be taken away.
-Finish the rest of the wall.
-The stones next to the window need to be cutted in the right shape.''

Ventilation Openings

Openings are needed to let fresh air in and create a opening with between the outside and inside. However, it is important that the openings are placed in the right place such that the structure still works.

*‘’**Pattern for ventilation holes***
Different patterns can be used to create ventilations holes.
-place the bricks as a triangle.
-Use plastic pipes or glass bottles as ventilation pipes.
-Leave one header out of the brick pattern.’’

Columns

The columns are part of the rib vault which came from the structural analysis. The columns transfer the load from on top of the structure down to the foundation. From Appendix N: Brick bonds the conclusion was that the cross-bond pattern works structurally as one of the best and is easy to construct. That is why this bond is chose for the column.

‘’***Columns***
-Find the outline of the column.
-Stack the column in crossbond pattern.
-> Row of stretcher.
-> Row of headers.
-> Repeat pattern.
-Place mortar between every brick.
-When needed place a temporary scaffolding to stand on.
-Continue till the needed height.’’

Inflatable mould

To make the constructing process as easy as possible a research was conducted to find out which helping tools, moulds, already exist. Possibilities where a radial arm and (wooden, cardboard, metal) formwork. The idea of a 3d mould instead of a 2D mould came up. This led to research into tent structures and inflatable moulds. For this project the inflatable mould is chosen, the research can be found in Appendix O: Constructing rib vaults/ domes & window opening.

‘’Using the mould
-Know which mould you need.
-Get that mould at UNICEF building.
-Place the mould on the temporary scaffolding when needed.
-> keep in mind that you also have to stand on the scaffolding.
-Place a textile tarpet before the mould is rolled out.
-Role the mould out on the designated place.
-Place the mould 40cm from the wall.
-> This is because the mould will expand. The mould should not push the wall away.
-> There should also be space to lay the bricks.
-Notice what is the front side and the back side.
-Make sure that the zipper, velcro or rope is closed.
-> this is to deflate the mould.
-Connected to the electric ventilator.
-Check if there are no problems with the mould e.g. leaks or other structural issues.
-Check if the mould is fixed to the ground and walls after it is inflated.
-> this is to make sure the mould cannot move when it is in use.
-The brick laying process can start.
-Place the bricks in crossband pattern for the ribs.’’

Repairing the inflatable mould.

The inflatable mould can be compared to an inflatable jumping castle, this was also one of the first ideas the mould originated from. The reparation of both is the same. This can be done in two ways, with a blow dryer and with glue (Sidijk, 2018).

*‘’**Repairing the mould***
There are two ways two repair the inflatable mould. The material to do this can be obtained at Unicef.

Option 1: Blow dryer
-Warm up the blow dryer.
-Cut a piece from canvas, this should be bigger than the crack.
-Make sure the corners are round.

-Put a roller on the middle of the canvas.
-Put the blowdryer under the canvas and heat from the middle to the side.
-Follow the blow dryer with the roller.
-Work from the middle to the outside
(-when there is no electricity and glue available a magnifying glass could be used to melt and glue the canvas)

Option 2: Glue
-Cut a piece from the canvas bigger than the crack in the canvas.
-Clean the canvas (with water or when possible with acetone).
-Put glue on the new part.
-Put glue on the cracked part.
-put the new part on the cracked part.
->preferably on the inside.
-Put something heavy on it.
-Let it dry for 24 hours. ''

Roof and openings

For creating the roof the knowledge obtained from appendix N: Brick bonds and Appendix O: Constructing rib vaults/ domes & window opening is combined. The inflatable mould will be used as formwork and structural support. On this mould the adobe bricks will be placed in cross bond pattern. Different type of adobe, with different compositions, are used to make sure the bricks can hold the compression strength and not to much limited materials are used.

''Roof and openings
Use the inflatable mould for constructing the roof.

Rib Vaults
-See page 39 how to use and place the inflatable mould.
-Make sure the inflatable mould is connected to the scaffolding.
-Start with placing the straw bricks for the first meter of the ribs, see page 14-15.
-Start from all sides at the same time.
-Lay the bricks in crossbond pattern.
-> Row of stretcher.
-> Row of headers.

-> Repeat pattern.
-Place mortar between every brick.
-After this the feather bricks should be used.
-Continue the bricks in crossbond pattern till the rib structure is finished.
-Fill the place in between the ribs with the thinner bricks in stretcher bond. ''

Oculus

The oculus can be found often in Persian architecture. To create a oculus with adobe a compression ring is needed to hold the pressures of the dome.

*''**Oculus***
-The inflatable mould is still active as a support and guideline.
-When brick laying the rib structures are finished, add a connection stone on the top.
-Start from here to brick the compression ring to realize the oculus by following the inflatable mould.

Openings wall/ Roof
It is not allowed to build windows in the roof due to structural forces. Windows can be created in the straight walls for example the walls between the walkway and the shop.''

Rainwater

The rain season in camp zataari is between November and March, see Appendix A: Context research. The form of the vaults and domes are optimized for structural purposes, not for rainwater drainage. This means that when nothing is done the water will lay still on top of the structure. To prevent this, material need to be added to create a slope of minimal 15 degrees to let the water flow down outside the building. The added material will be earth with a final coating of cow dung, see chapter coating. A gutter is also added to make sure that the water that flows into the bazaar is directed to the fountain.

''***Prevent rainwater***
To prevent rainwater laying on the structure an extra ceiling or filling is needed. Earth is used to make sure that the rain does not stay still and for extra weight what is good for the structural forces. A gutter is added to the sides of the street to guide the rainwater what will flow inside over the ground to the fountain in the middle.

-Fill the holes with earth.
-Put the coating on top.''

Staircases
Staircases are needed to go to a different level. In this design the staircases are needed to go to the first floor, the house, and to the backstreet. Some basic calculations can be conducted to find the number of steps and the width of the steps. To prevent mistakes the outline of the steps should be drawn on the building.

''Staircase
Depending on the space two types of stairs can be made, a ''normal'' staircase and a ''steep'' staircase.
Normal staircase: W=30 cm/ H=17 cm.
Steep staircase: W=24 cm/ H=20 cm.

Height/ steps = number of steps.
Length/ number of steps = width of steps.

-Calculate the number of steps and the length of the stair.
-Draw the outline of the steps on the wall.
-Build the steps with the crossbond pattern.
-> Row of stretcher.
-> Row of headers.
-> Repeat pattern.
-Place mortar between every brick.
-Make holes in the wall to connect the staircase firmly.''

Coating
Adobe buildings need some kind of coating to prevent deterioration; mud plaster, lime plaster, and cattle dung, whitewash have been used in the past. Mud plaster is made of clay, sand, water and straw or grass. This plaster bonds to the adobe blocks because it is made from the same material. This is an inexpensive and low skill technique but requires a lot of time because it is applied and smoothened by hand. Whitewash is made of gypsum rock, water and clay. This material can be brushed on the adobe or it is first applied on pieces of burlap and then on the adobe. Whitewash acts as a sealer and needs to be applied annually. Lime plaster is made of lime, sand, water and is applied with towels or brushes. Hatchets are needed to make the lime plaster stick to the adobe. Lime plaster is harder than mud plaster. (National Park Service , 1978) Another type of coating that can be used independent of the location is earth with cow dung (La voûte Nubienne, 2014).

‘’Exterior coating
-Mix the adobe earth together with the cattle dung.
-Roughen the surface by scrubbing the joints.
-Make the wall wet.
-Apply the coating a few mm thick.
-> apply the coating when possible in the shade to prevent cracking.

Interior coating
-A mortar mixture can be used as interior coating.
-Clean the walls.
-Moisture the wall.
-Draw a line till where the wall coating needs to come.
-Apply the coating.’’