BUSTAN

Zaatari Co-Housing and Farm

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Content

01 Introduction

In this report the design process for the project BUSTAN will be explained. BUSTAN was developed from the refugees' perspective, looking at opportunities that could be taken from their immediate context and merging it with their traditional housing typologies and culture. BUSTAN's goal was to become a co-housing system that adds value to the land, enhances living conditions and economic development through agriculture.

The course AR3B011 EARTHY at TU Delft, Building Technology Master programme had the aim of creating a set of projects that would help improve the living conditions in the Zaatari camp for Syrian refugees in Jordan. Within the course a diversity of topics, ranging from programming to the construction and structural design were addressed. One major challenge was the construction of all these projects with what was available at the site, mainly earth.

The report will be divided the same way the design process was done: information background on the Syrian refugees and their condition in the camp, the configuration design steps taken, the forming of the project, the structural analysis, the explanation of how the project developed its detailed elements and the final results.

Adding it all, BUSTAN became a set of guidelines for the refugee to build their own house. The project goes all the way from the detailed elements such as a catalog for the openings or the perfect way to lay each adobe brick, all the way to an urban configuration that grows with the camp and finally becomes a city worthy of their culture.

02 Flowchart

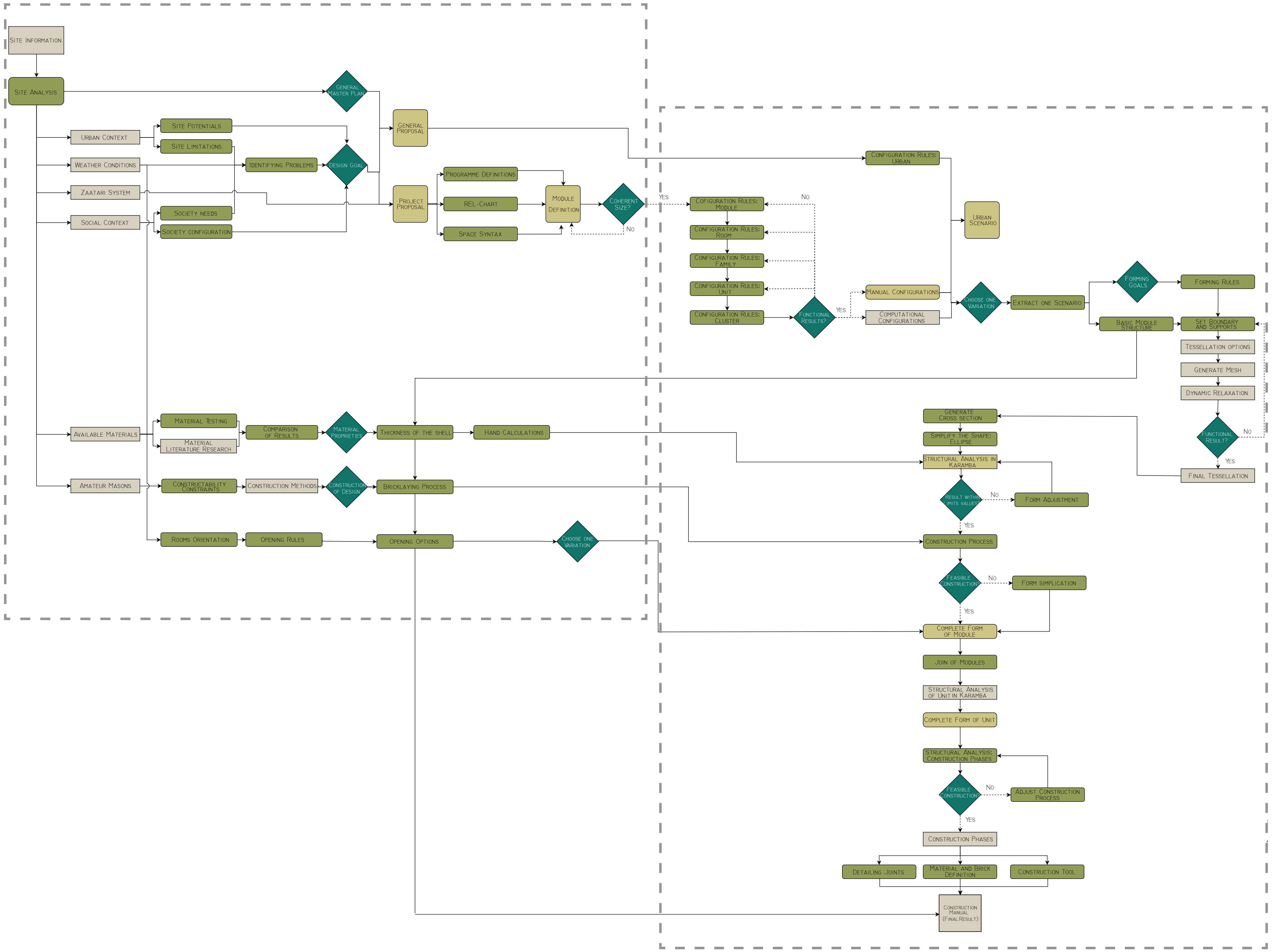


Figure 1.General Flowchart of Bustan

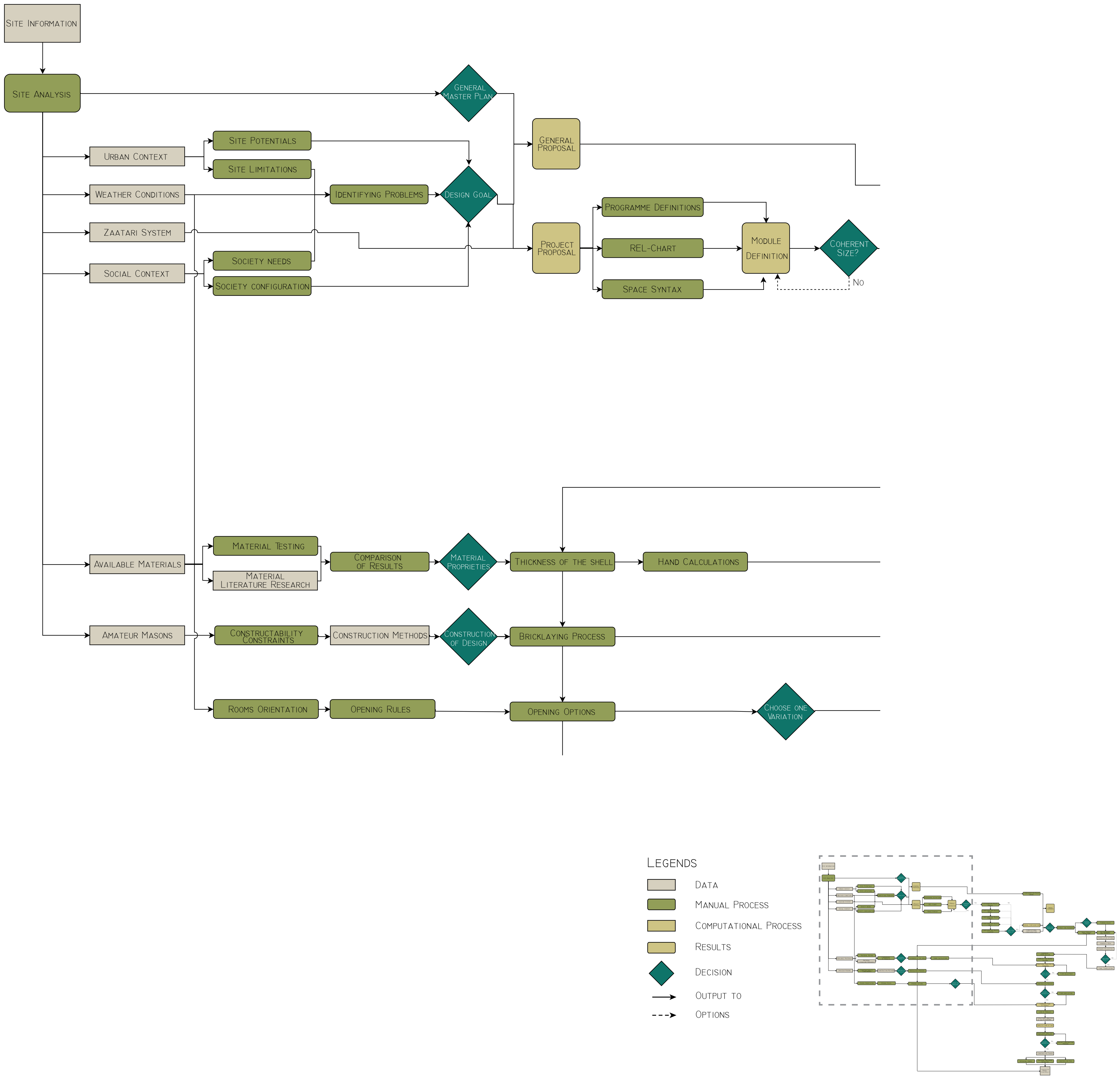


Figure 1.1 General Flowchart of Bustan

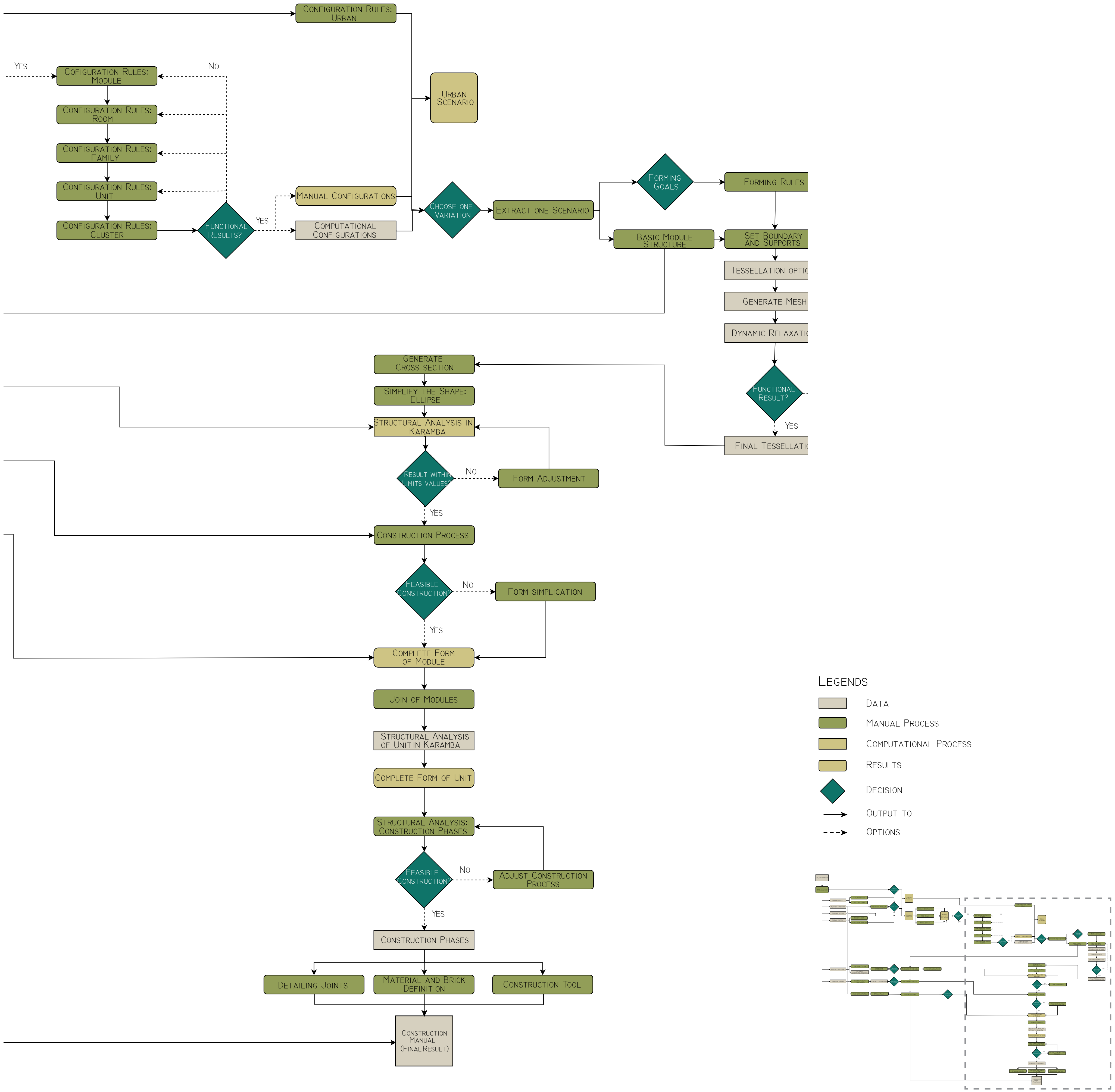


Figure 1.2 General Flowchart of Bustan

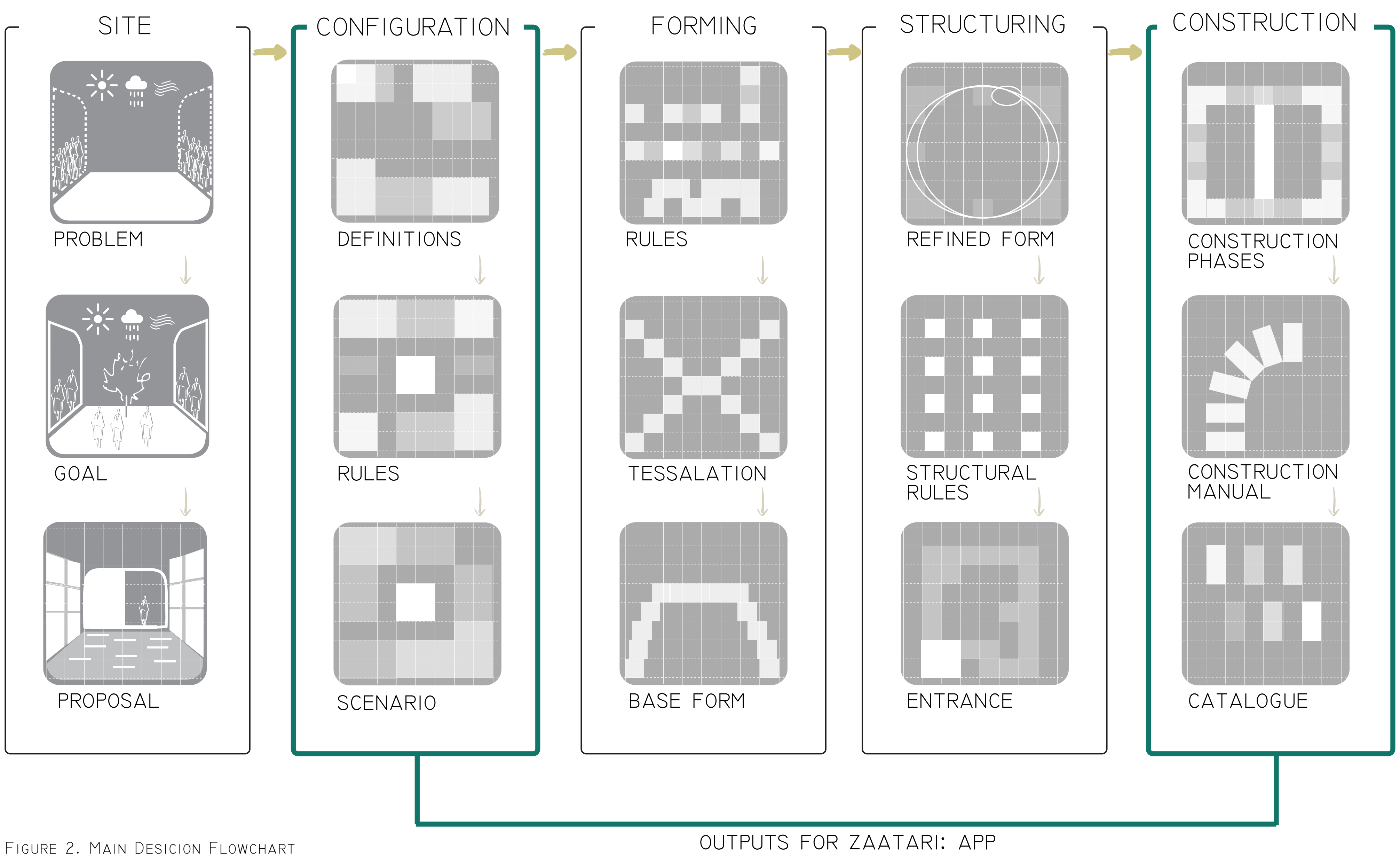


Figure 2. Main Desicion Flowchart

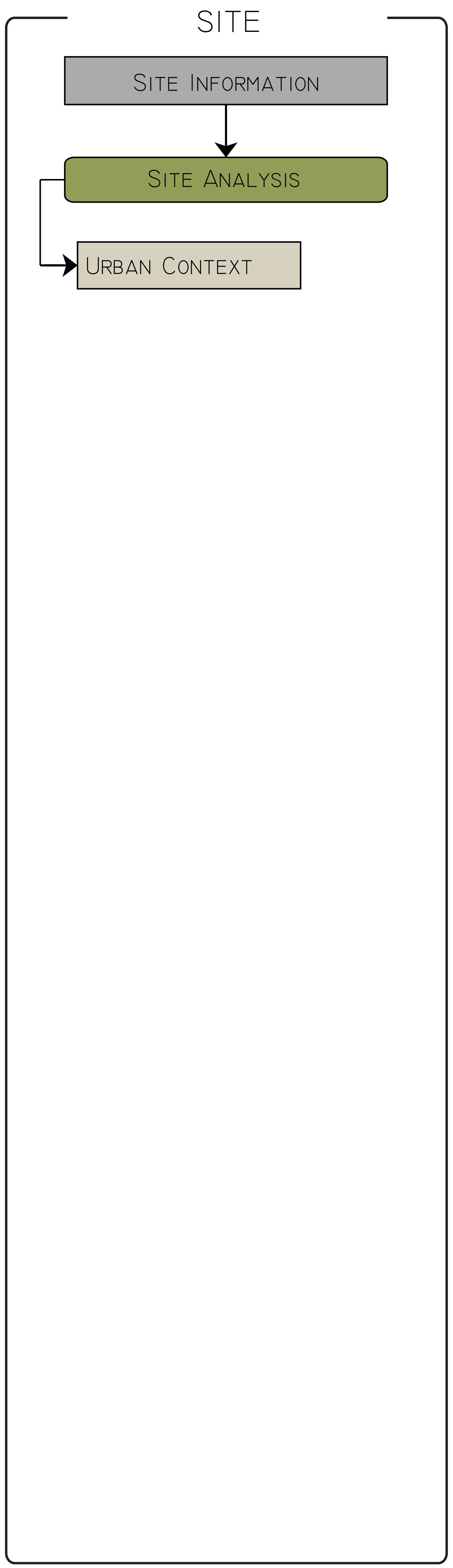
03 Site

The Zaatari Refugee Camp developed since July 2012 and within one year, the population grew up to 200,000 people (Krujit, 2014). Reaching more than five times its maximum capacity, the UN Handbook states that the development of this camp is extremely difficult, while the living conditions are deficient.

In this chapter, the urban context of the Zaatari Camp was analysed in order to find the site potential and limitations. On the other side, the social context was studied to understand how society configuration works and what are the people's needs regarding the required housing programme.

The site limitations and the people's needs helped to formulate the main problem that Bustan dealt with, while the site potential, the society configuration and the required housing programme was the base of the proposal.

Figure 3. Zaatari Camp By Rasmussen, B. (2014)



I Urban Context

The Camp is enclosed by a wall and there are three entrances with check-points. Although the site is isolated there is a trade and illegal smuggling of goods and food with the neighbouring villages (Krujit,2014).

The growth of Zaatari, its increasing number of tents and caravans and the poor urban development resulted in a lost of landscape features and green spaces inside the camp. Furthermore, the Jordanian government banned trees in Zaatari until February 2014 (Krujit,2014).

On the other side, there are olive orchards outside the surroundings of the camp. Moreover, during rainy season there is water flowing in the creek that goes by Zaatari. In spite of these facts, the camp landscape is mostly barren.

There are two main water reservoirs and there is not sewage system. In the rainy season dikes are formed in some parts of the camp resulting in sanitary problems.

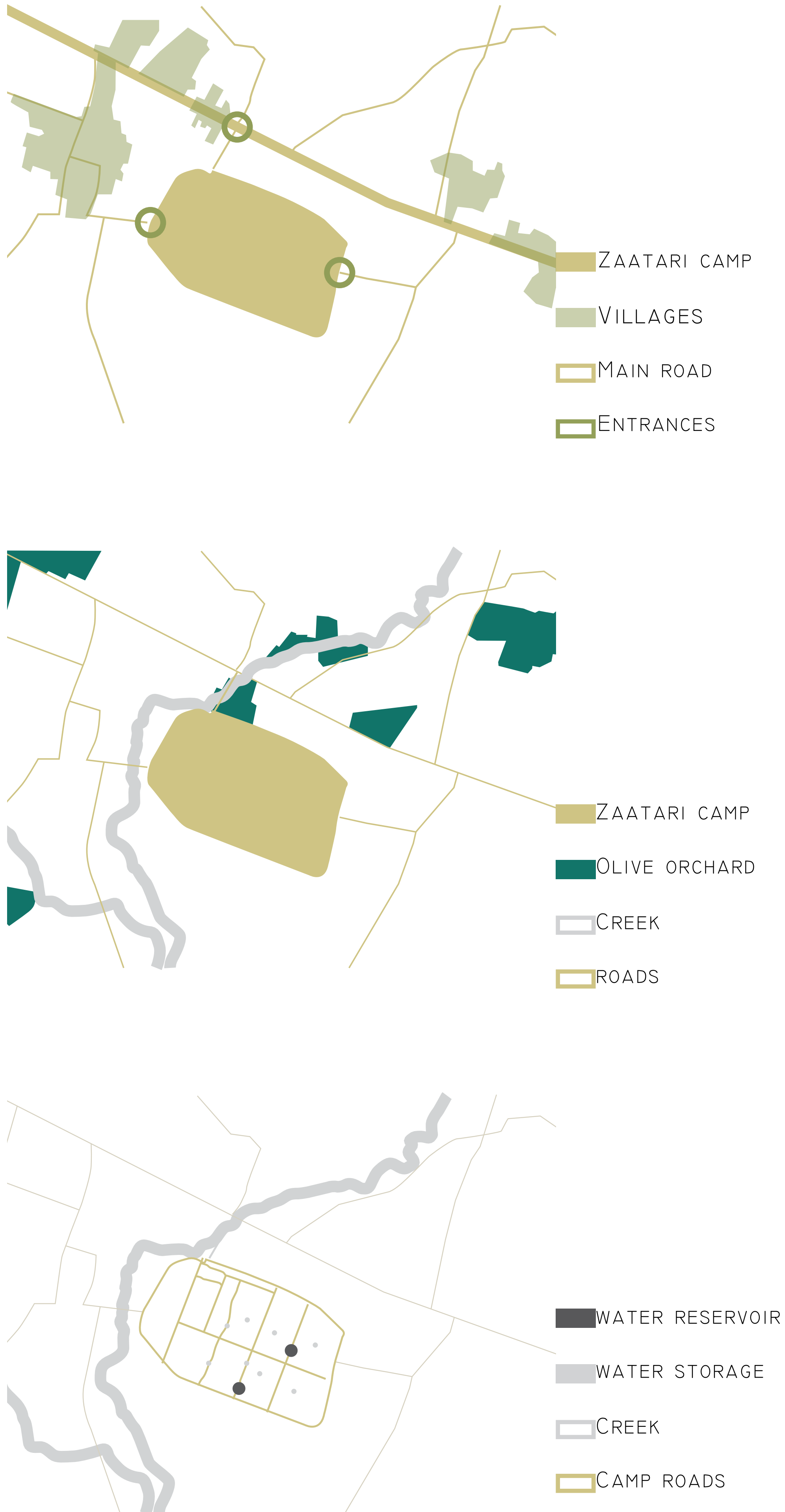
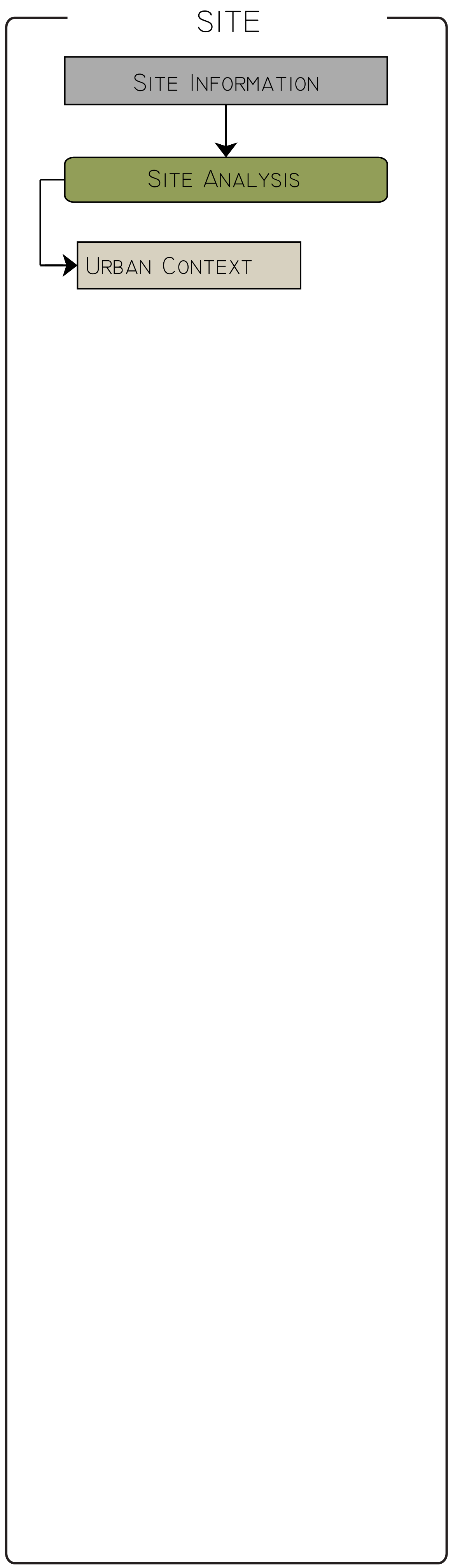


Figure 4. Zaatari Context Based on Krujit, R. (2014)



Zaatari surface area covers 5 km2 and the quick growth of the camp resulted in a grid system that divided the site in 12 districts. The ring road surrounding the districts is an open military zone, so most refugees choose not to approach it (Krujit,2014).

In order to reduce travelling distance for refugees the organizations working there spread their infrastructure throughout the camp. While most facilities are placed in temporary structures like tents, the most important services such as kitchen and sanitation have more stable constructions (Krujit,2014).

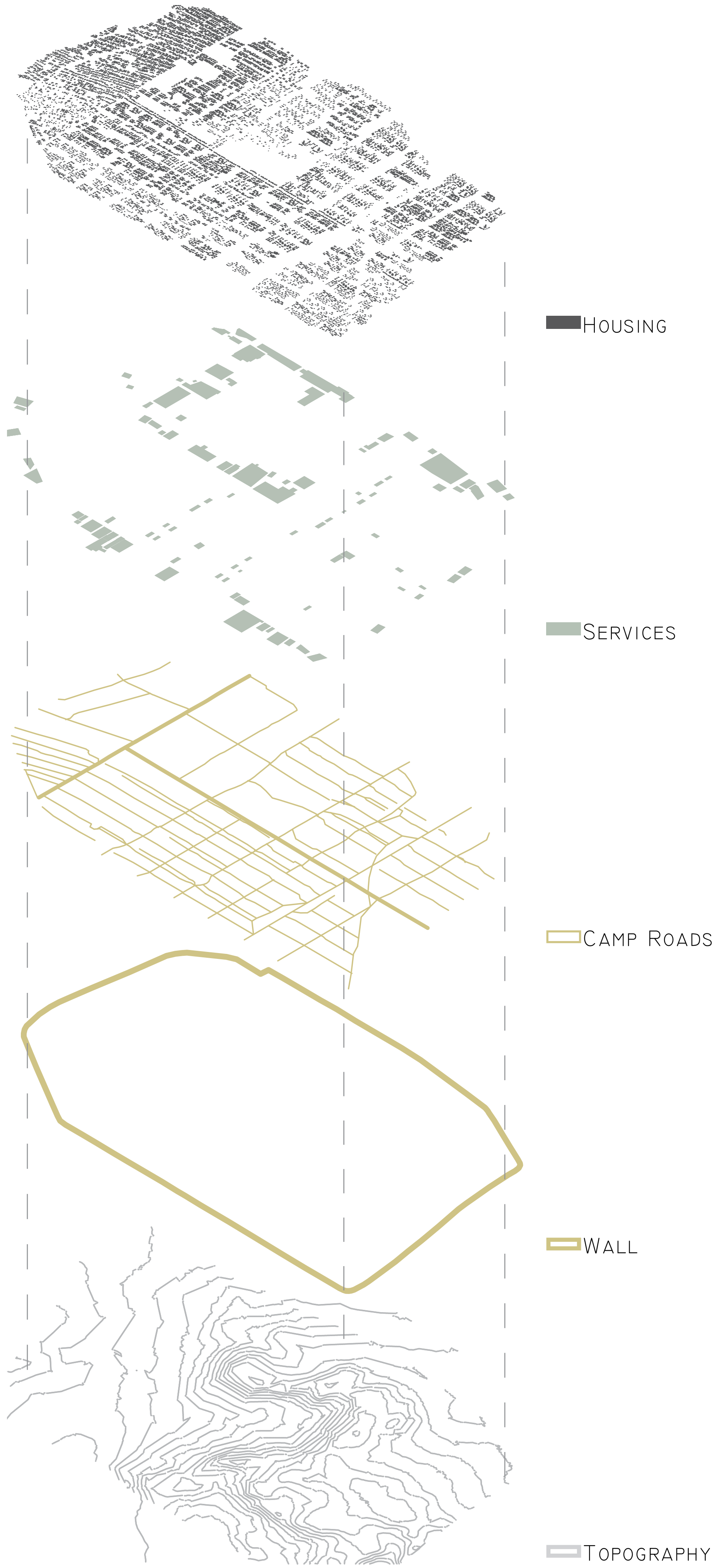


Figure 5. Zaatari Camp Layers

The roads mark the layout of the camp and surround the districts. There are two main roads that connect the entrances of Zaatari. The refugees placed their commerce and inside trading along the edge of these streets, which are highly busy during the day.

The UNCHR supplied each group of refugees a tent to live in when the camp was stablished. By the end of 2013, caravans were provided to the refugees. Nowadays these two types of structures can be seen in the camp.

The districts vary in their density. The densest districts are the older ones (districts 1 and 2). In these districts most people live in caravans. The other districts are more spread and have a mix use of caravans and tents. In these districts there is a considerable amount of unused land, given that the constructions have great distances to each other. The average family size of the camp is 5 to 6 people.

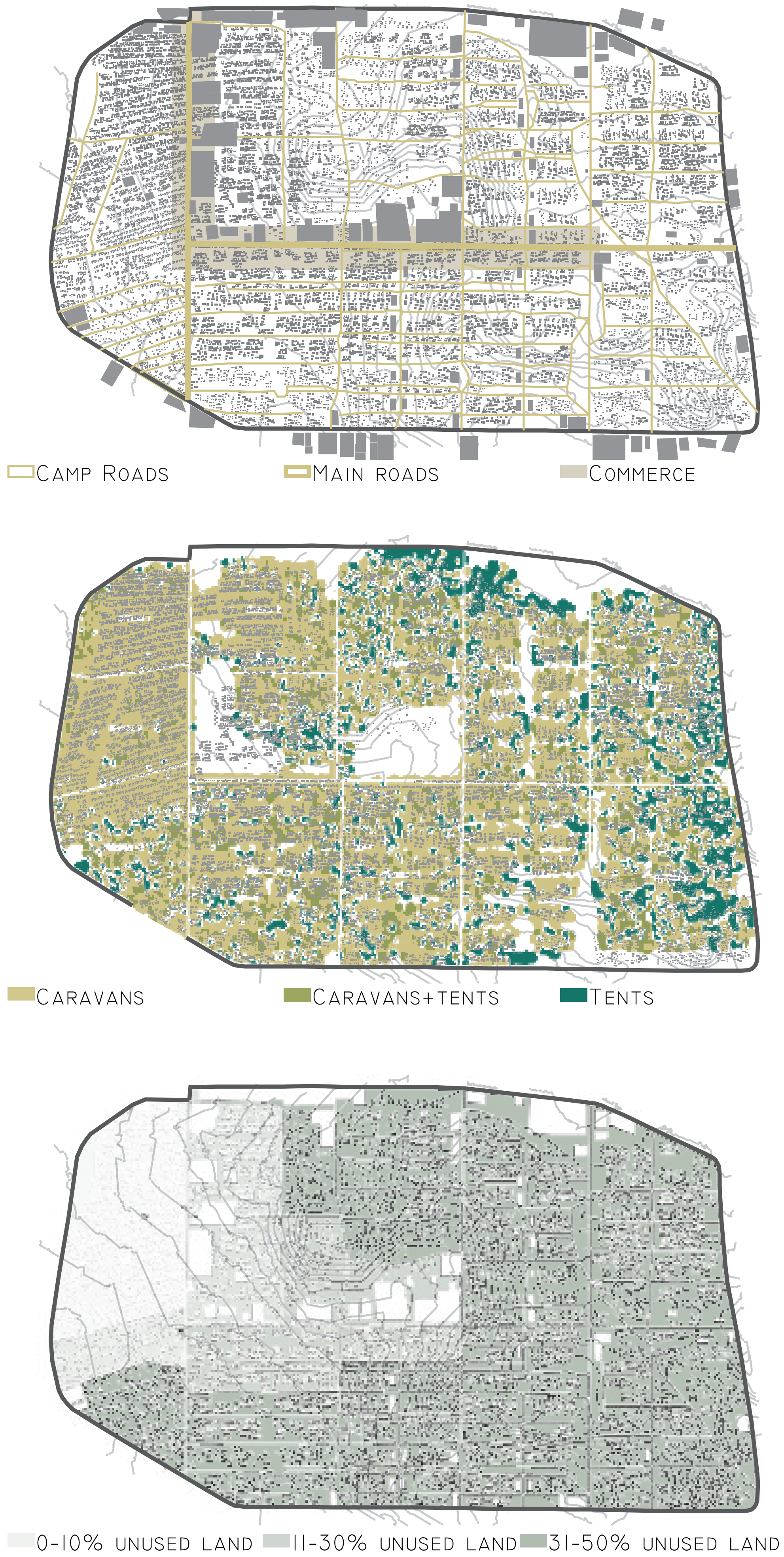


Figure 6. Zaatari Camp Information based on UN High Commissioner for Refugees (2014)

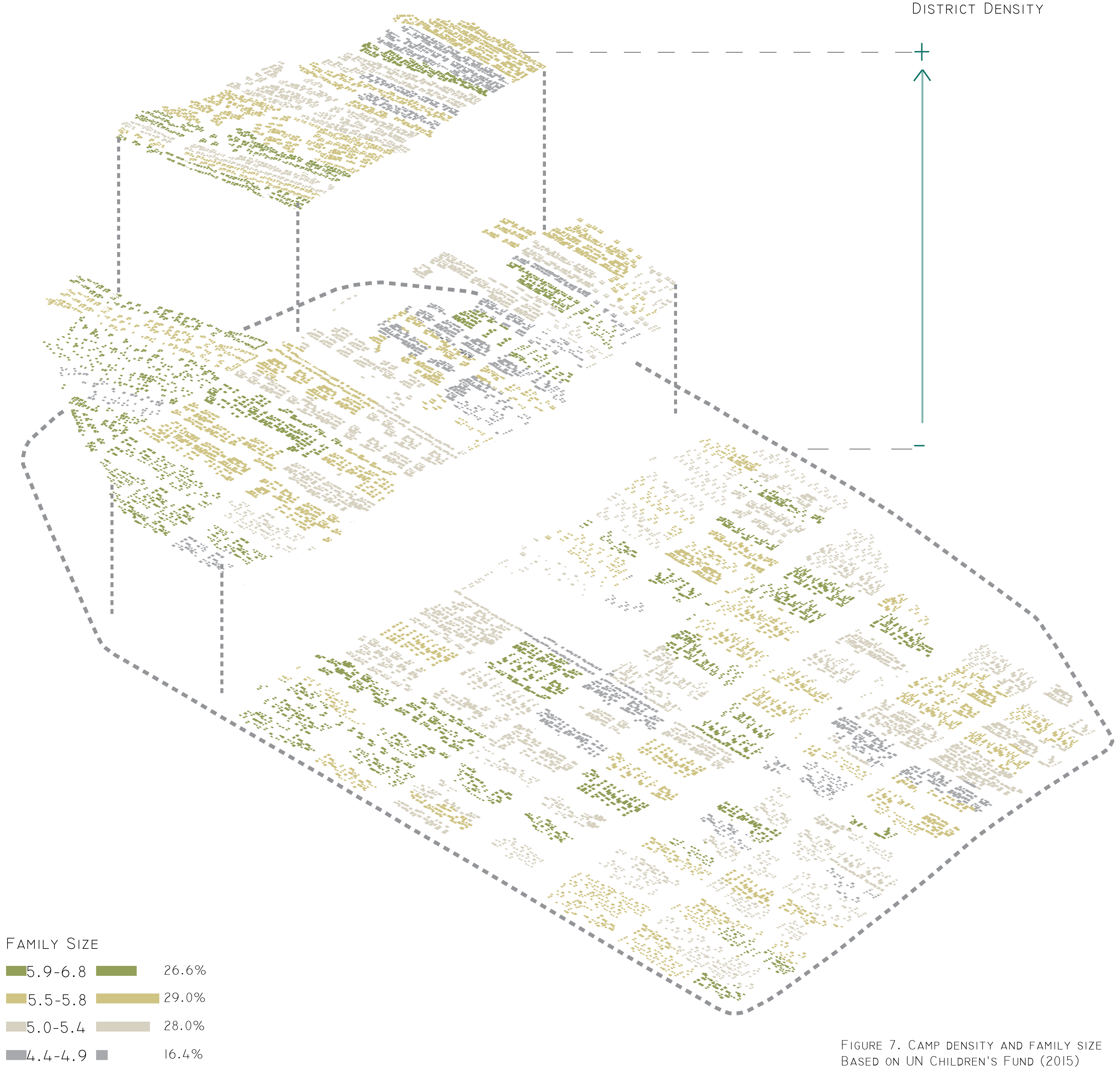
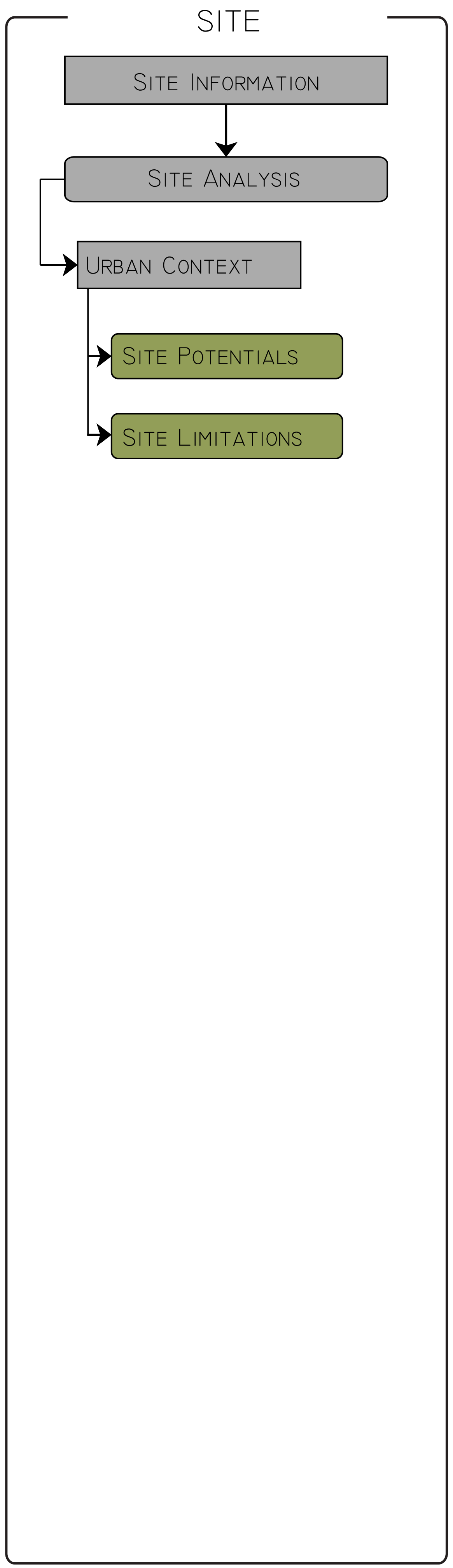


Figure 7. Camp density and family size
Based on UN Children's Fund (2015)



Site Limitatios and Site Potentials

The site limitations and potentials were found with this analysis. The limitations are the waste acummulation due to lack of garbage system and the sanitation issues due to the lack of drainage and sewage facilities, resulting in flies and rats in the camp.

The clean water shortage is a main limitation as well as the fact that there are no trees or green spaces. Furthermore the electricity network is dangerous.

On the other hand, the main potentials of the camp are: the existing olive orchads outside the camp, proving that there is a possibility of growing green areas in Zaatari, the creek that is formed during rainy season and the considerable amount of unused land.

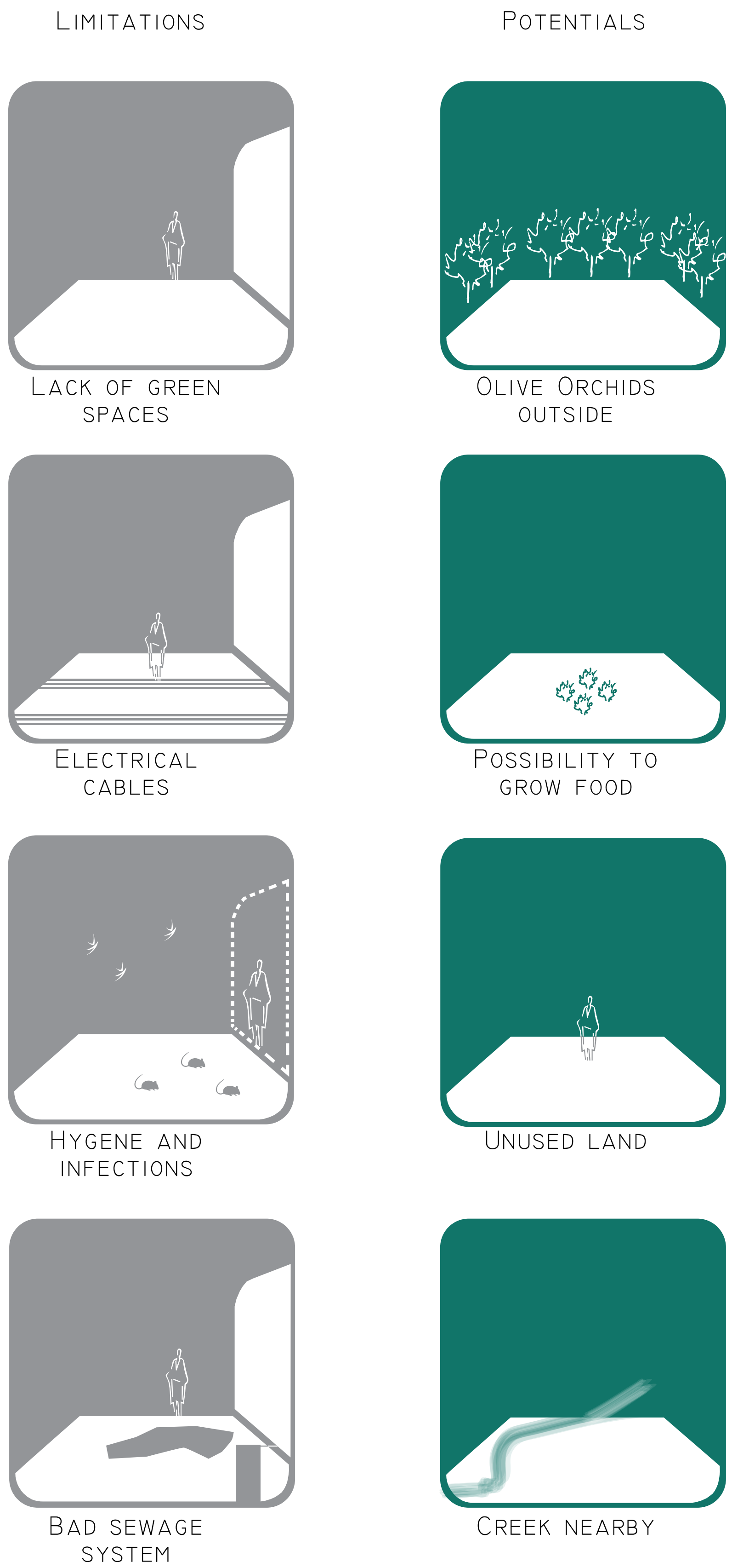
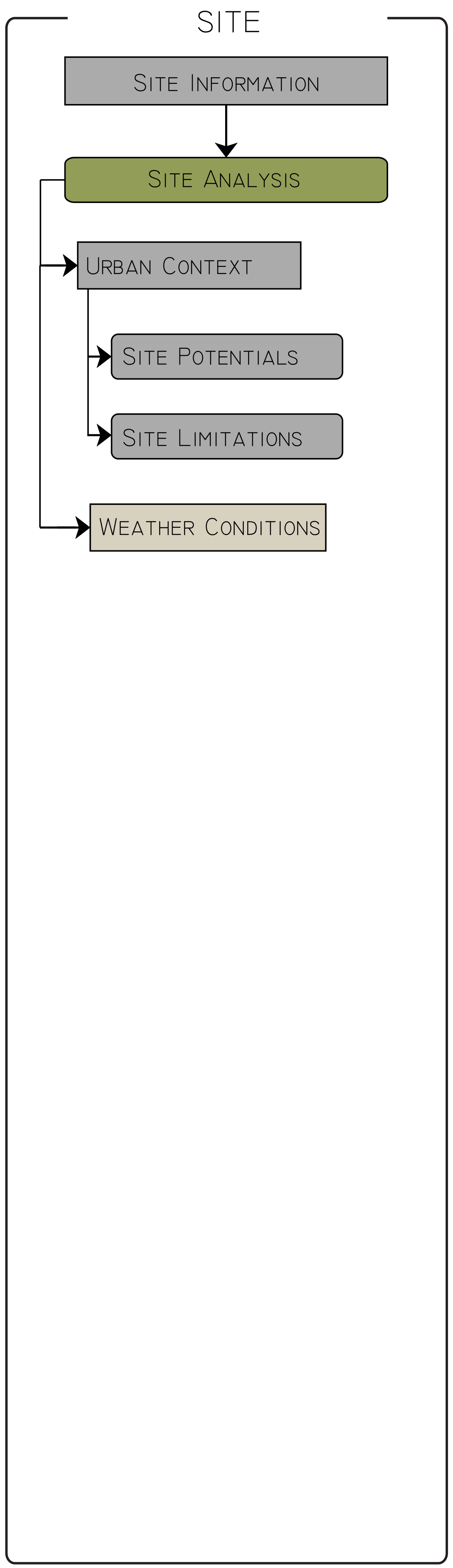


Figure 8. Site Limitations and Potentials



2 Weather Conditions

Zaatari refugee camp is located in Al Mafraq district, Jordan, in a desert reglion. The average temperature during summer time range form 19°C to 34°C and from 7°C to 13°C in winter. This also show ther there is a huge different between day and night time temperature.

The site has dry climate, as the relative humidity of the site is rather low with an average of 40%. The average annual rainfall in the region is 184mm which usually occurs between November and April.

The wind blow through the site from all direction, but the strongest is from Northwest direction.

Jordan land is consisted of four main physiographics region: vally, high-land, steppe and desert. The majority of the land is coverd with desert, while the vally and highland, located in the north, make up less than one percent of the total surface area.

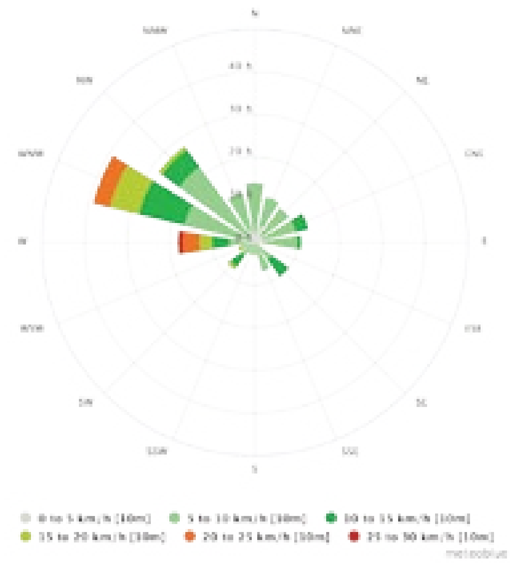


Figure 9: Average wind speed and direction in Al Mafraq, Jordan

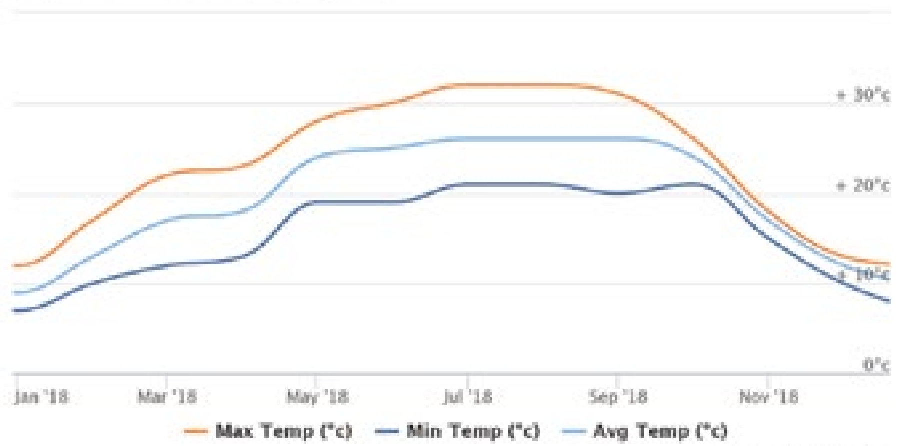


Figure 10: Average temperature in Al Mafraq, Jordan

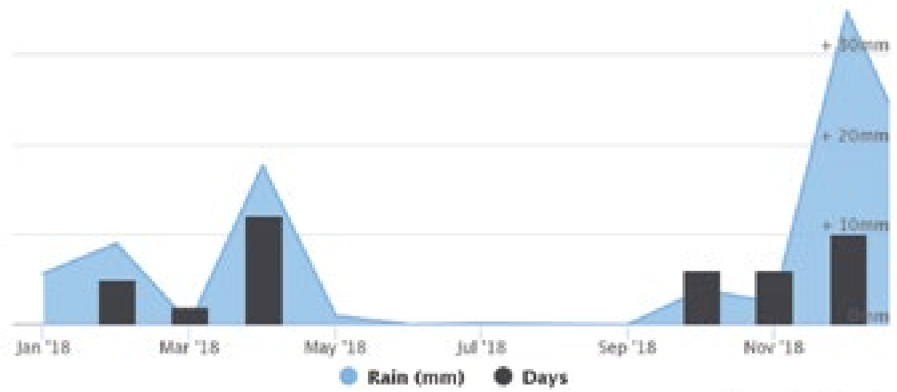
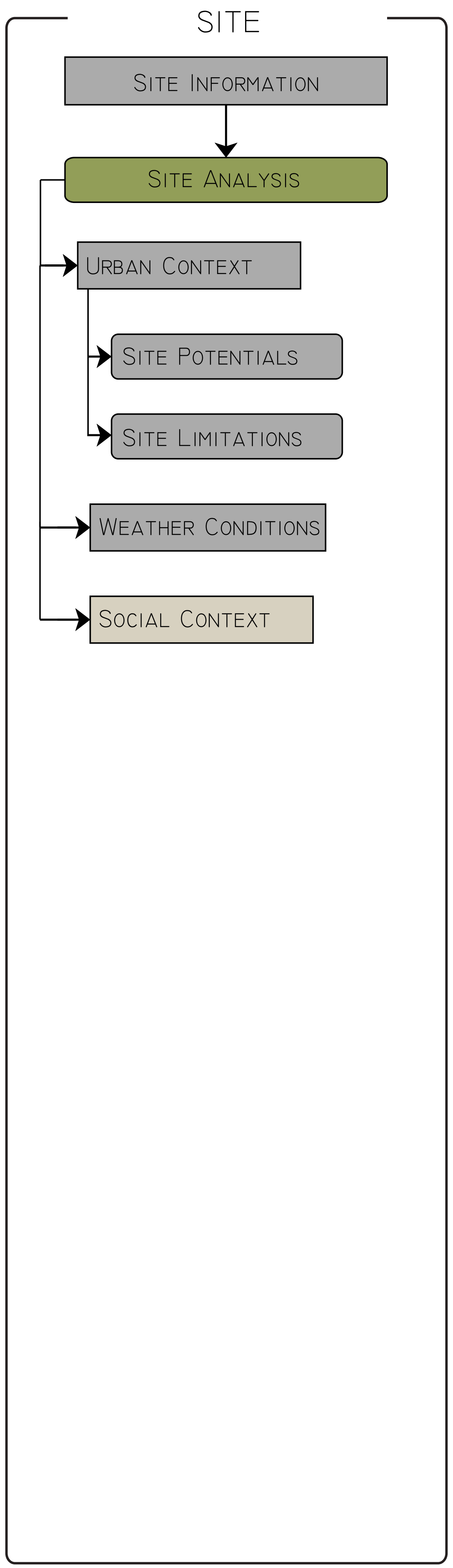


Figure 11: Average rainfall in Al Mafraq, Jordan

Figure 12: Average humidity in Al Mafraq, Jordan



3 Social Context

Figure 13: Scial Context in Zaatari Hannon, M. (2015)

Figure 14: Scial Context in Zaatari Hannon, M. (2015)

“A refugee is someone who is unable or unwilling to return to their country of origin owing to well-founded fear of being persecuted for reasons of race, religion, nationality, membership of a particular social group, or political opinion”. This was stated by The UN refugee Agency (UNHCR) in their 1951 convention.

Camps are constructed to protect and save lives and become a base for humanitarian work in the hosting country. The UNHCR also provides an emergency handbook for the construction of such establishments, though, there are still some limitations to these measures.

The handbook is made from a practical and reactive perspective of architecture, does not consider the needs of a society that thrives from their sense of belonging, community and family.

More than one third of Syria’s 23 million people have fled their home country since 2011. “This is one of the largest refugee exoduses in recent history, with no end in sight” (Kruijt, 2014) The longer the battle continues, the harder it becomes for the families at the camp, since this establishment was supposed to be temporal. While it may provide the minimal necessities of their community, it is not a city in their home country.

Previous living situation

Syrian traditional housing is divided into two major types of dwellings: the nomadic which comes from constant migration, and the sedentary that is usually linked to cities and the countryside. The latter type is characterized by stone constructions, which vary in size and color and has 5 different variations (Caso,2014):

1. The basic house is composed of two aligned living units and single story. It usually has an opening either to the front (Mastaba) for leisure activities, or to the back (Zribeh) for a stable.

2. The house with a Riwaq (The arcade house) is composed of several aligned rooms that are connected to each other via veranda (Riwaq).

3. The house with a Liwan is composed of three aligned units: two are used for living and the central unit, has a large opening on an exterior called Liwan. This is a type of multipurpose rural house.

4. The rural and urban house with courtyard varies in building shape, size and materials, depending on its owner and its number of housing units. Usually, it consists of a one-story building and the house is divided into sections: room for men, room for women, the kitchen, service rooms, bedroom and stable. They have an open courtyard, which gives the occupant a feeling of privacy and privileges the relations between the individuals of the family.

5. The Lebanese house (The central hall house) is the main characteristic element of the Lebanese house. Around a hall, or large central room, are several rooms for dwelling.

The number and size of the courtyard in Arabic house differs. This usually depends on the wealth and number of people (families) within the house.

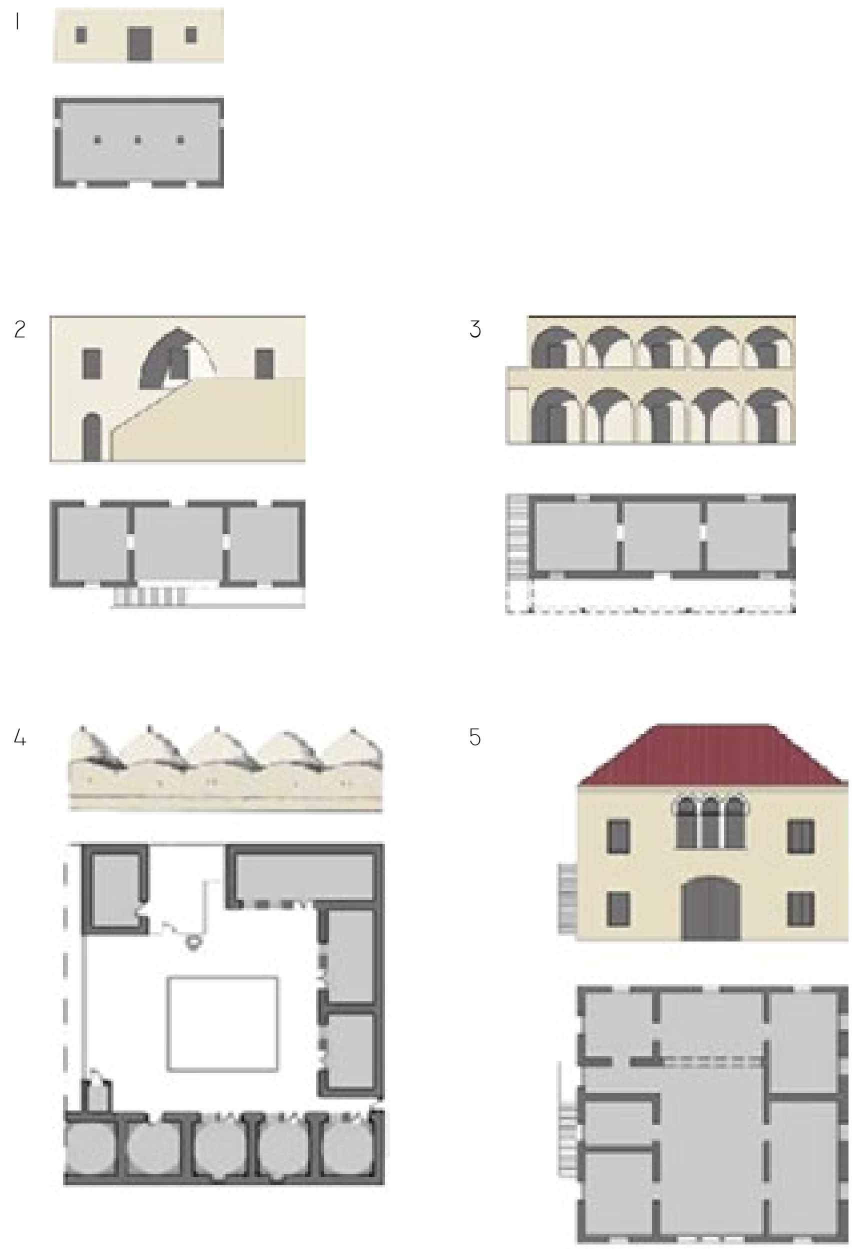
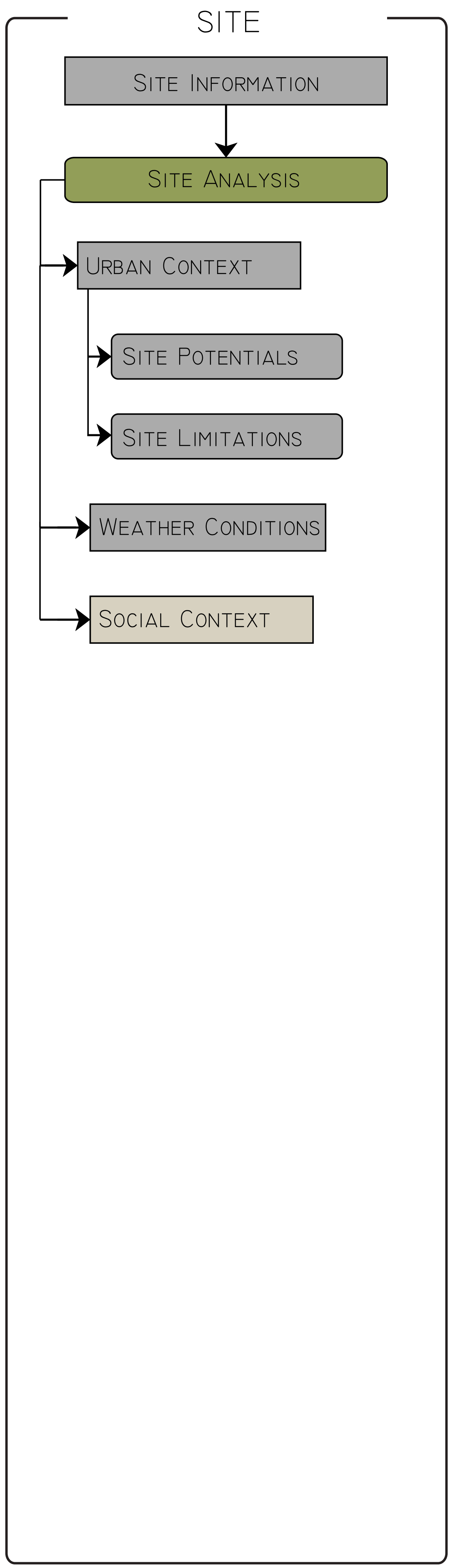


Figure 15: Traditional Syrian Houses, Caso (2004)



90 %	Refugees from Daraa
3,000	Small shops
680	Shops with employed children
65%	Employement
360	Water truck arrivals per day
200	Children born per month
5	Schools
500,000	Pita breads distributed per day

Table 1: Zaatari in Number, based on Kruijt R. (2014)

LIVING SITUATION IN THE CAMP

Upon their arrival to the Zaatari camp, each family or individual is given a tent, after that, the families also receive a caravan to counter the difficult climate. In most cases the refugees improve their own household by buying more caravans from an informal market or by moving existing caravans from other family members or friends to improve their living conditions.

In the cases of the refugees who have lived in the Zaatari camp for longer time than others, they try to make their homes better and closer to their traditional housing typologies. Some residents even appropriate public water tanks, and have a more comfortable life, but to the expense of other residents of the camp.

From observing the pictures and some extensive research it was found that ideally, a household in Zaatari is made from four caravans and tents, Sanitation in between the two caravans, and the tent is used for cooking (Stromme, L., 2013).

Due to the lack of interior spaces and hot environment, they cook outside in shaded areas, which allows for a better air quality (Edstram, M. Zaatari 360 2 UNHCR, Refugee Response).

Certain facilities will be provided at the central location (offices, healthcare, warehouses, market, community centers), while others will be decentralized throughout the camp (water, latrines, bathing, garbage, education). (Corsellis, 2005) Some other facilities can be seen at the outskirts of the camp.

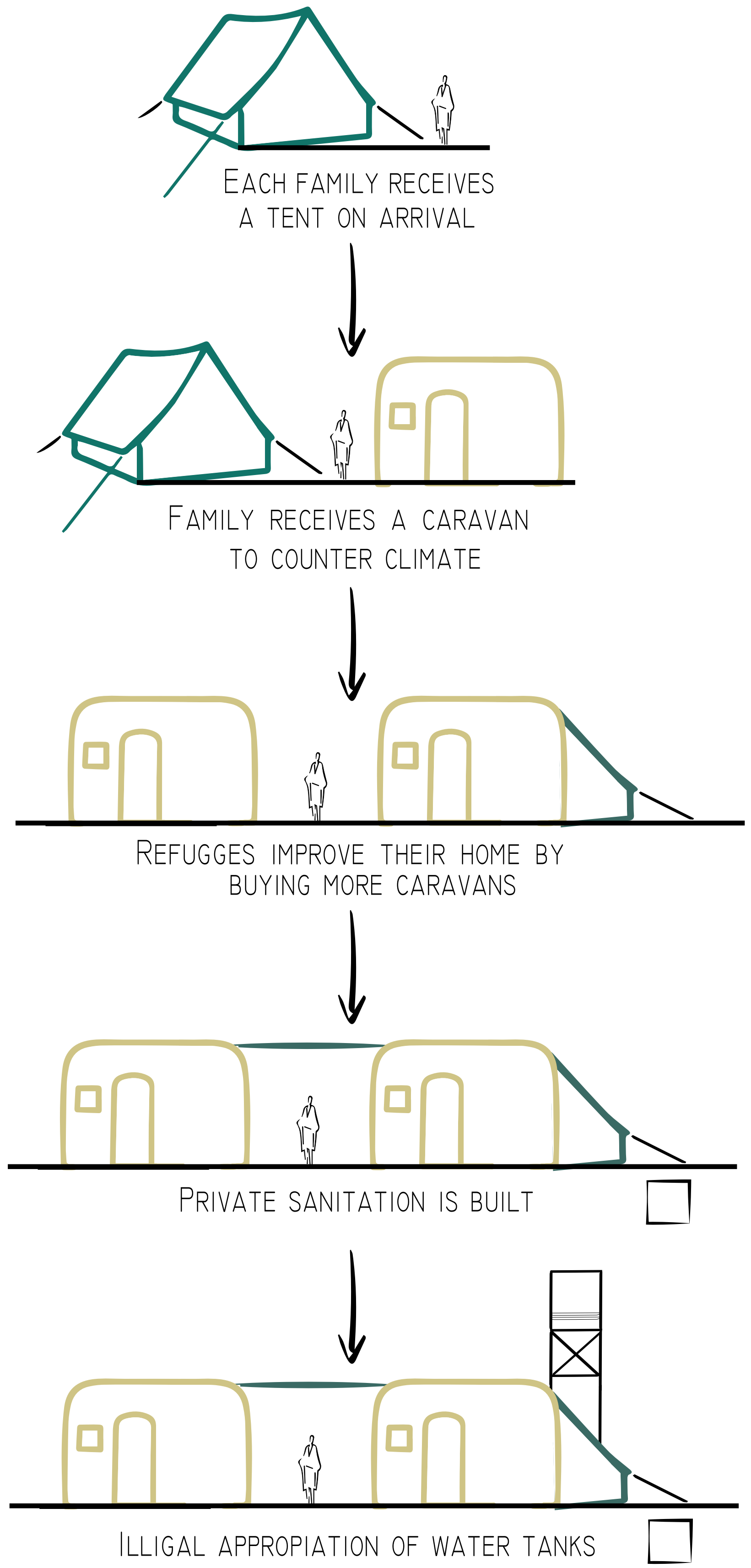
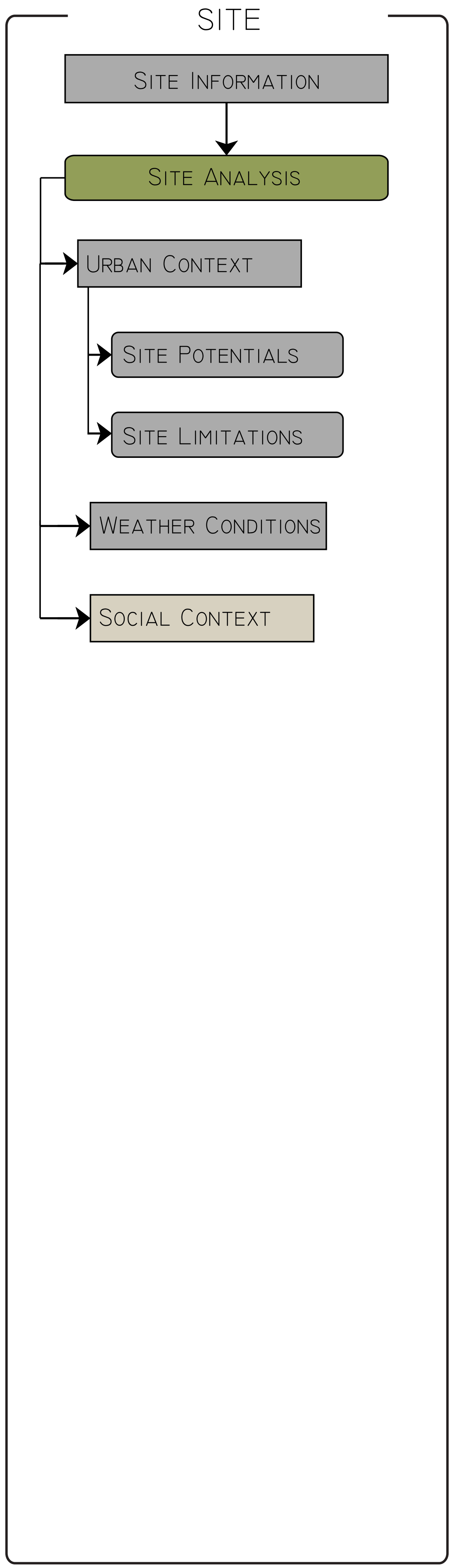


Figure 16: Living situation in Zaatari based on Stromme L. (2013)



LIVING SITUATION IN THE CAMP

In most of the cases the head of the household are females, amounting to a 42% since most men were still fighting or died in Syria (Smulovich, 2014). Most of the residents in the Zaatari camps have experience traumatic events and were close to violent situations back in Syria. Thus, their psychological well-being should also be considered.

The main limitation for the refugees are:

*Working permit : permit to work outside ths campneeds renewal every 2 weeks

*Political: they feel abandoned by the international community.

*Fear: no trust and scared of Jordan authorities and NGOs. Therefore, organized crime is present (survival of the fittest motto is present) as well as fear of going out which trappes the community.

*Authorities: forbidden to buy or use construction materials and trees. Thus, illegal trade is developed, causing illegal development not planned and well organized.

Inside the camp	Outside the camp
In 2015, Cash for Work (CfW) activities was developed by the Basic Needs and Working Group (BNLWG). As of 2018, around 15% of the total Zaatari population worked inside the camp.	Since July 2016, the Jordanian government has granted more than 100,000 work permits to Syrian refugees, allowing them to work legally.

Table 2: Working in Zaatari Source, based on WFP, 2018

Within the camp some social patterns have develop to make it into a city. People have engaged themselves into everyday life, giving themselves new work and new activities. There are now around 3000 shops within the camp. From bridal shops, to internet shops and everything in between.

On the other hand, it was documented by Kloosterman in 2014, that the refugees have started to create "secret gardens" in the camp, and have started growing vegetables and trees however they can.

The types of grains, fruits and vegetables that they can grow are: wheat, barley, olive, chickpeas, lentils, tomatoes, potatoes, onions, lettuce, herbs and garlic (Domiz Refugee Camp, 2017).

Figure 17: Working in Zaatari, New York Times (2012)

Figure 18: Activities in Zaatari, Karin Kloosterman (2014)

Society Needs

FAMILY

Average family size reported till 2017 was 5.5 per household.
The family is the most important aspect of life to Syrians. It is thought to encompass not only the nuclear family unit but also grandparents, aunts, uncles and cousins. Connections with one's extended family are deeply valued and act as a crucial support system emotionally, financially and socially (Edstram, 2019) .
Family usually overwrites almost all other obligations.

CHILDREN

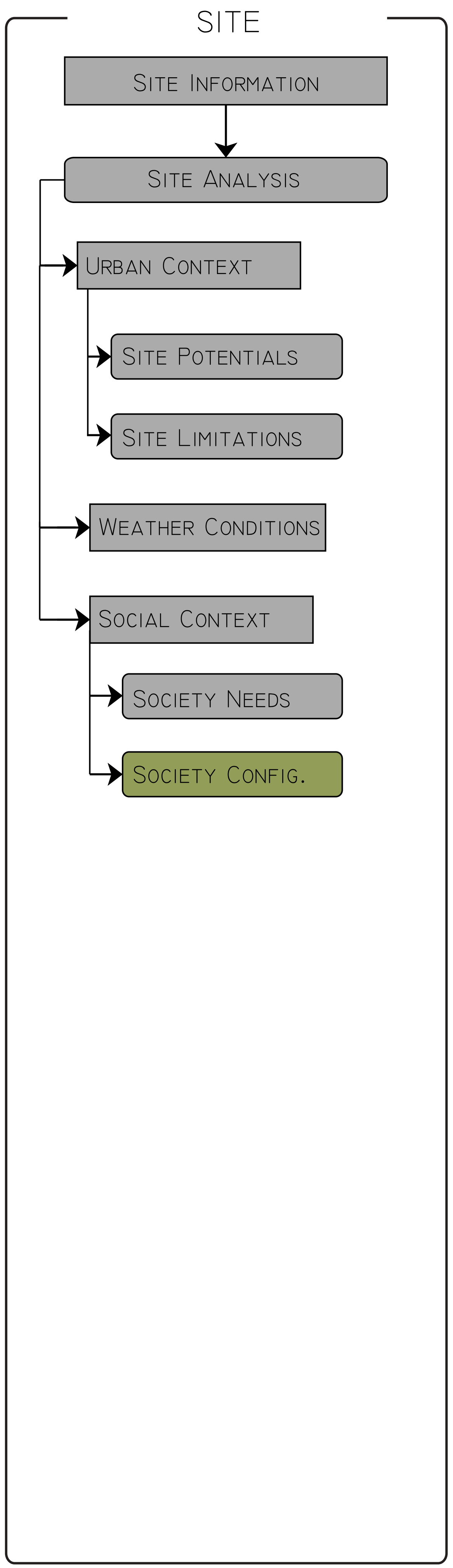
There are no proper recreational activities. (no trees)
Children facing larger class sizes and reduced hours in school.
Children are more tense, aggressive and violent.
Streets are to dangerous for children. (Water trucks drive too fast)
Syrian children living with mental health issues are a growing concern (Edstram, 2019).

WOMEN

Only 3 % of the work permits issued to Syrian refugees went to women in 2017 (Edstram, 2019).
Empowerment through employment for Syrian refugee women is needed. They have roles like hairdresser, tailoring, wedding planner, teachers, etc (Edstram, 2019).

Figure 19: Adman and family, Edstram M. (2014)

Figure 20: Women Activities, Herwig, C. (2014)



Society Configuration

As it was mentioned, the families want to have a sense of belonging and thus take matters into their own hands by moving things around. Four caravans placed together create a courtyard providing safety and privacy, and it can be seen large families or even different families living together to create a community.

A common family is considered one to six people. A community is sixteen families. The communities are often based upon cultural or familiar ties. People from similar regions, ethnic backgrounds, etc will come together. The programme found in these new compounds are the sleeping space, a tearoom, a kitchen and a improvised bathroom (Slater, 2014).

Figure 21: Living Developmant in Zaatari based on Stromme L. (2013)

4. Zaatari Systems

The existing Zaatari system followed a linear economy, where production, consumption and waste disposal were the main line of flow.

The camp had no literal recycling of waste, all the unsorted wastes went to the nearby landfills, around 1000m3 per day (Framgard. L.G.S, 2015).

Due to the lack of septic tanks around the camp, the waste water disposal on surface pits created environmental hazards, resulting to breeding ground for bacteria, mosquitos and spreading diseases (Framgard. L.G.S, 2015).

The high demand for water depleted the aquifer, as water was pumped out of wells in large volume. Infiltration of the aquifer further deteriorated the ground water quality due to the polluted surface water. (Framgard. L.G.S, 2015)

The building materials used to make the caravans were stolen and sold in the black market in high prizes for private homes, shops etc (Framgard. L.G.S, 2015).

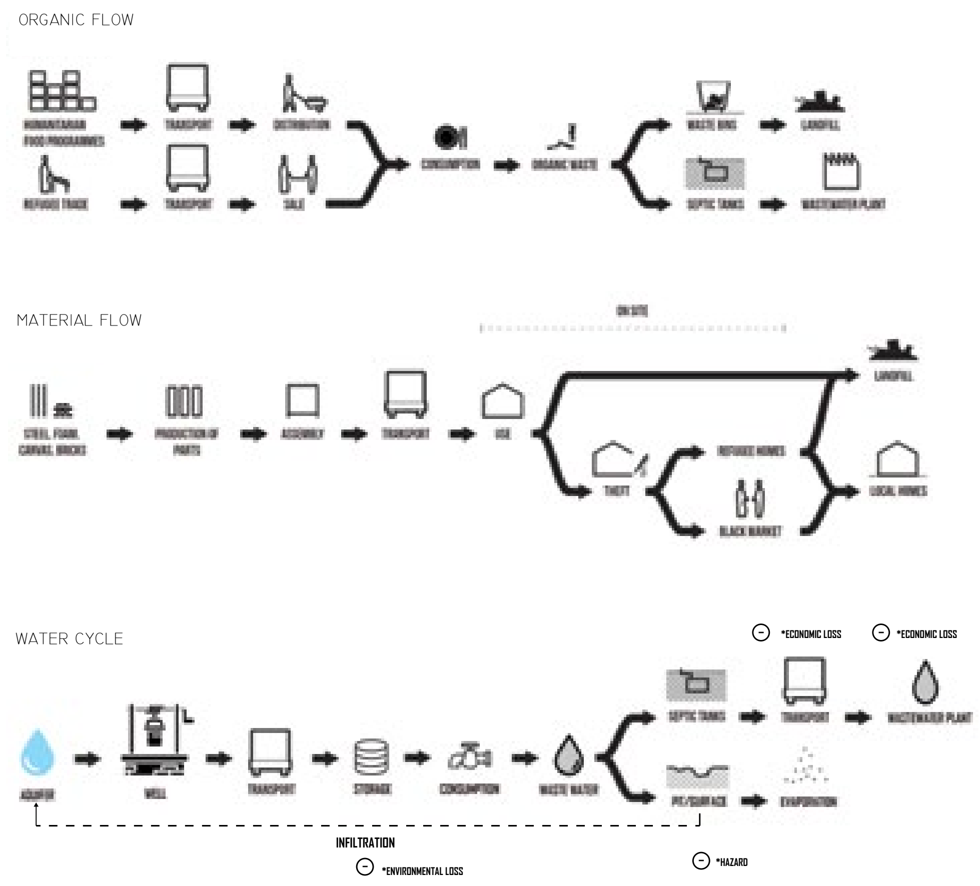
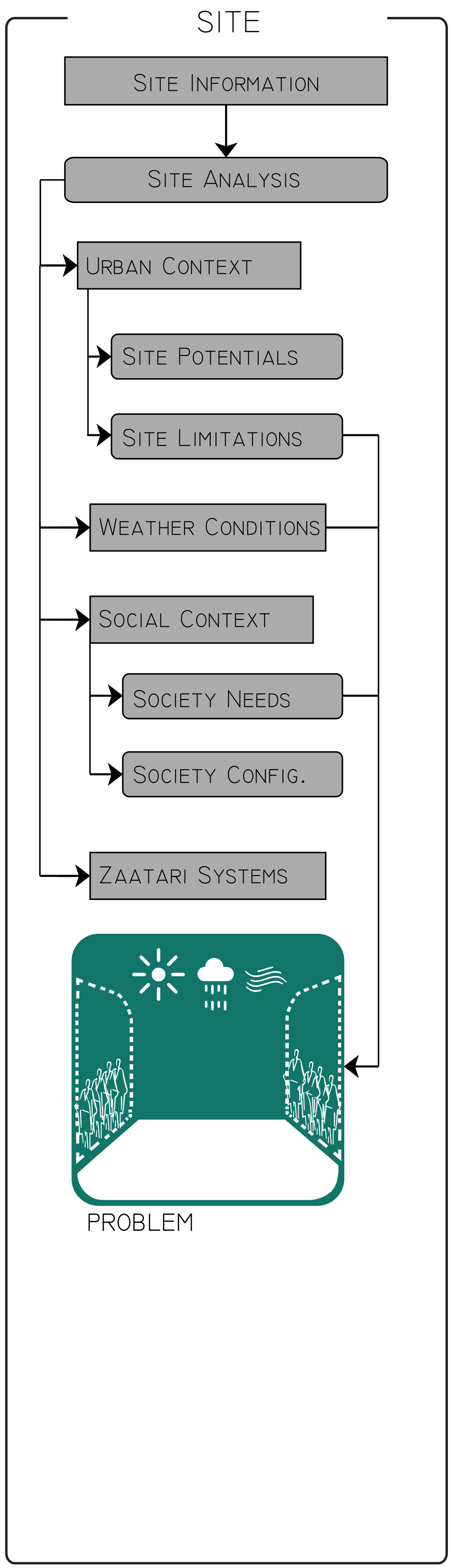


Figure 22: Chain of loss, Framgard. L. (2015)



04 Problem

Even though the Zaatari camp is meant to be temporal, it should still contribute the base of humanity needs, furthermore, also it should allow for the Syrian's to live their normal everyday lives.

Based on the site limitations and the society needs, a lot of problems were found, but for this project three main problems were chosen to tackle principally: the lack of green spaces, the housing limitations to withstand the weather conditions, the overcrowded the households with no space for community.

The solution of these main problems should work as a trigger to solve the other problems afterwards.

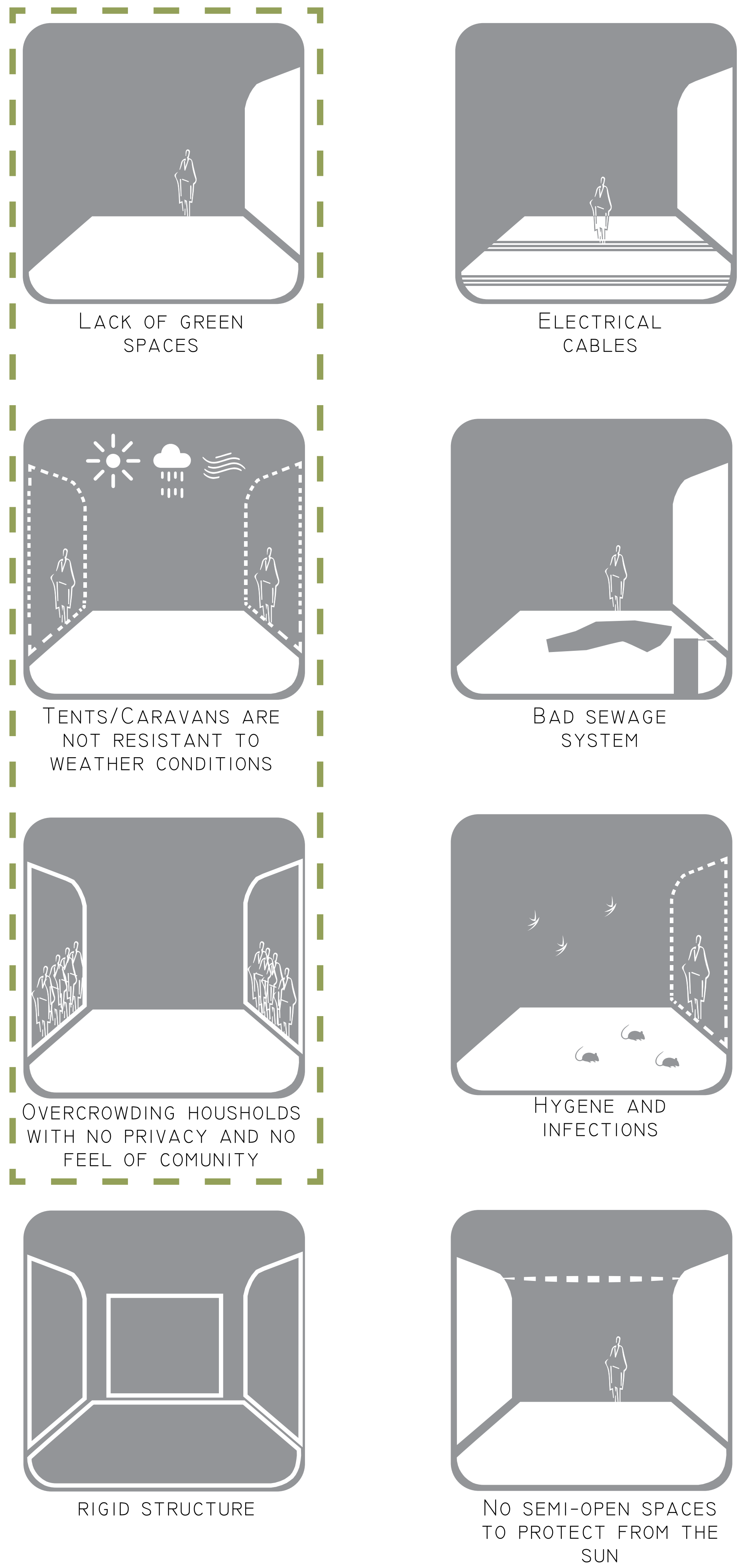


Figure 23. Zaatari Problems

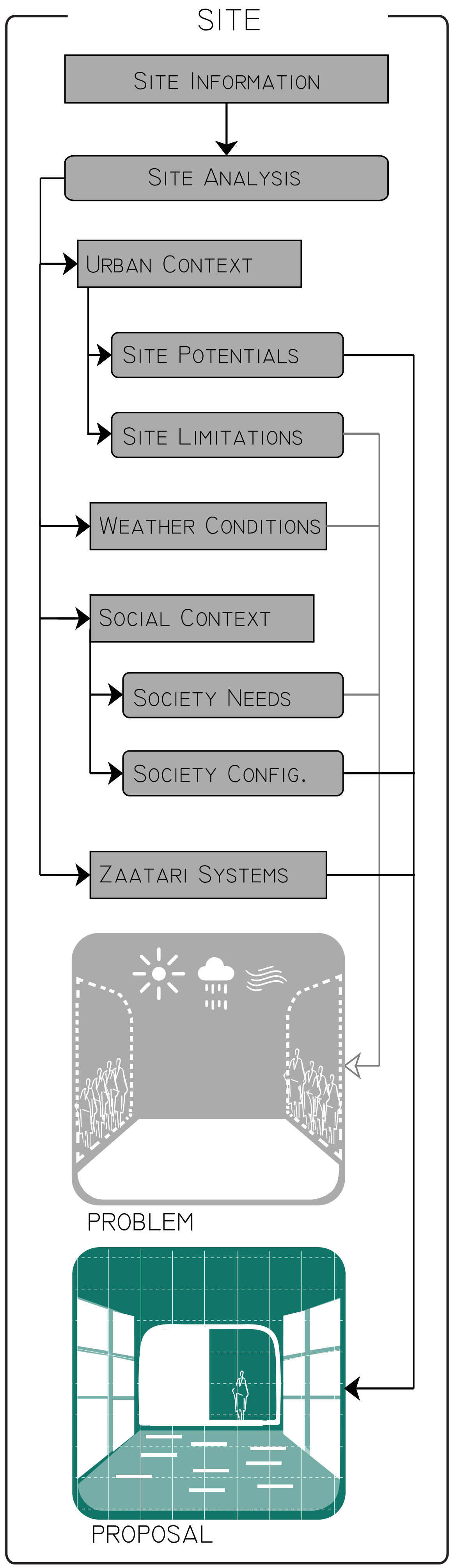
05 Proposal

The proposal of Bustan was made in three phases: fist the goal was presented, then a general proposal that explains how the project will work with other facilities was formulated and finally, a local and main proposal was established to limit the guidelines for Bustan.

The goal was made based on the problems that the project dealt with. According to the goal and the Zaatari systems a new circular proposal was presented. Projects such as the Hamman will provide grey water to the land, while the farms of the project can provide a space where the people form the skill development centre can work on. Furthermore, the food that grows can be for self-use or it can be sold to the Bazaar.

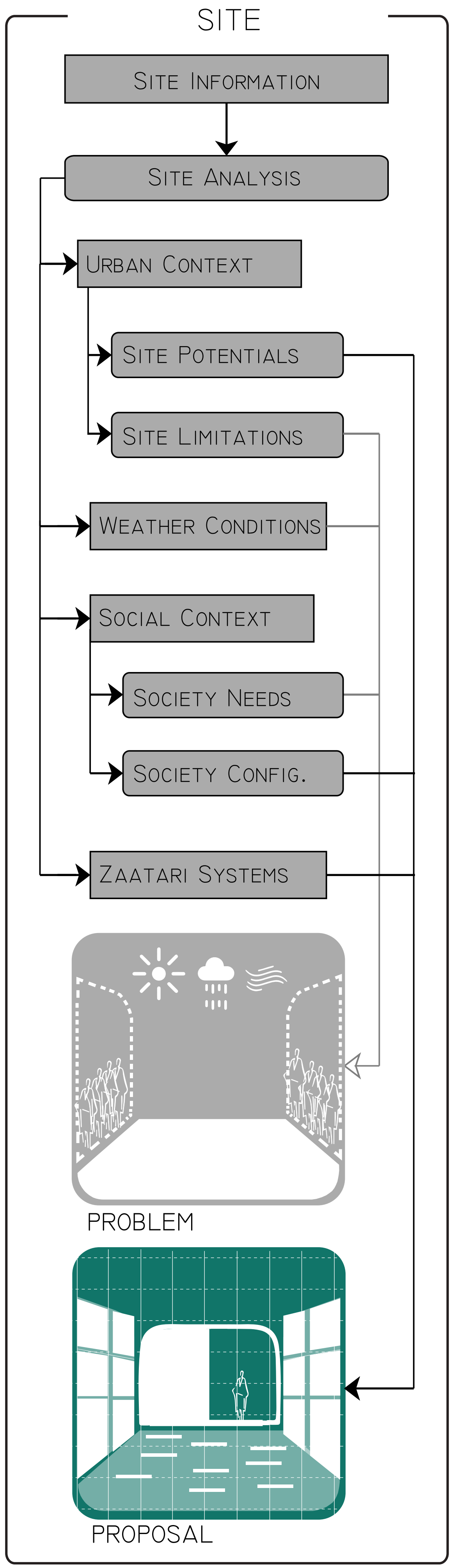
On the other hand, the site potentials and the society configuration lead to the main proposal. The potential to grow food was consider using the unused land as well as to bring in the vegetation. A modular earth structure that adjusts to different family sizes was proposed, to improve the climate of the housing units. Finally, shared services like kitchen, storage and bathroom were proposed to establish community spaces that are shared but private.

Figure 24. Bustan Proposal Approach



I GOAL

TO IMPROVE THE REFUGEES' LIFE BY CREATING A CO-HOUSING SYSTEM THAT ADDS VALUE TO THE LAND, ENHANCES LIVING CONDITIONS AND ECONOMIC DEVELOPMET TROUGH AGRICLTURE.



2 General Proposal

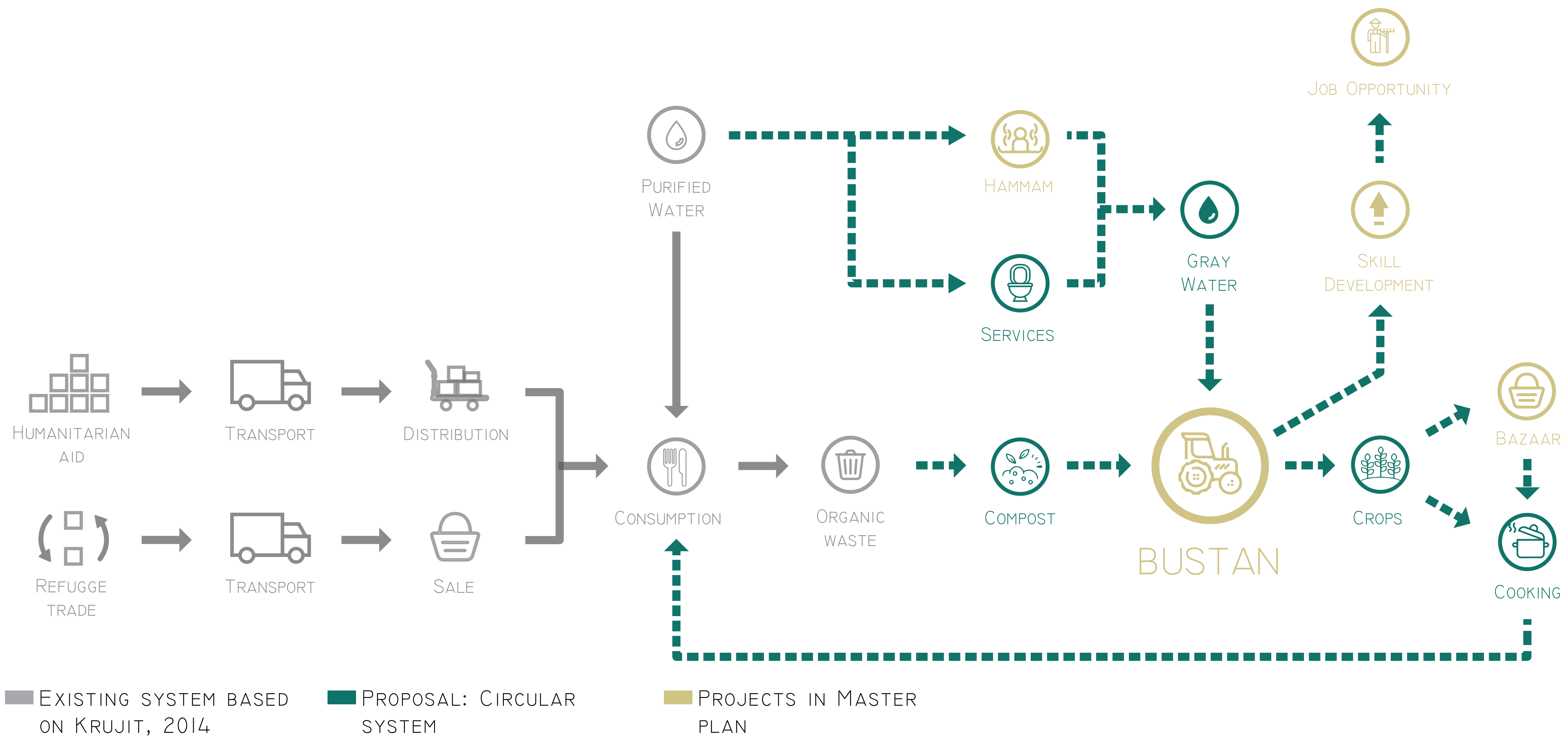
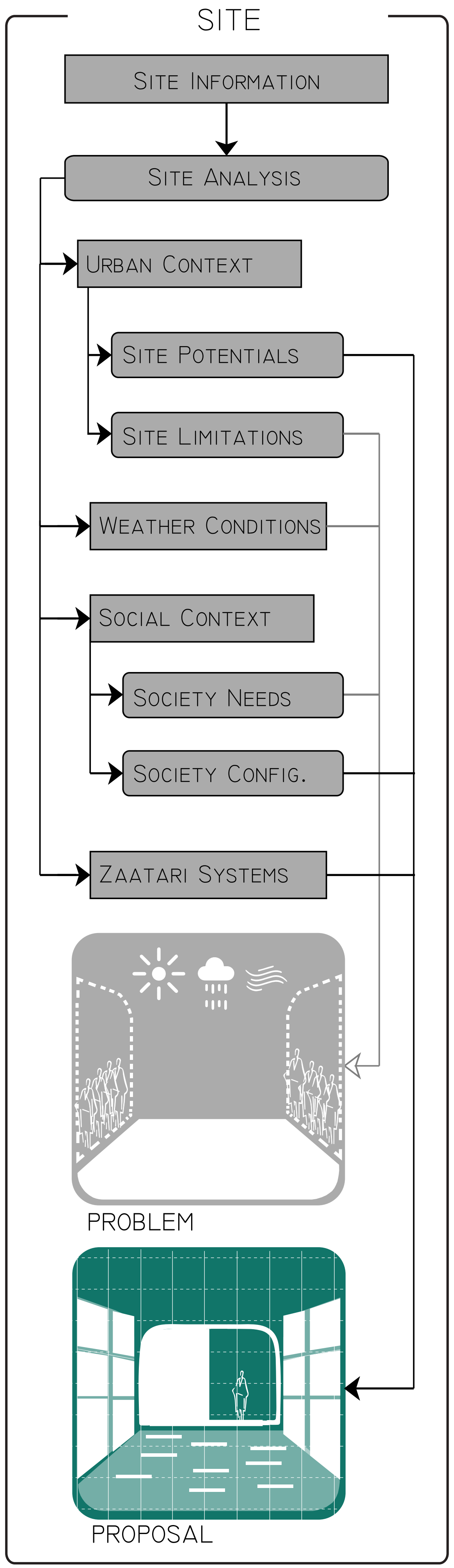


Figure 25. General Proposal, Circular System within Zaatari



3 BUSTAN

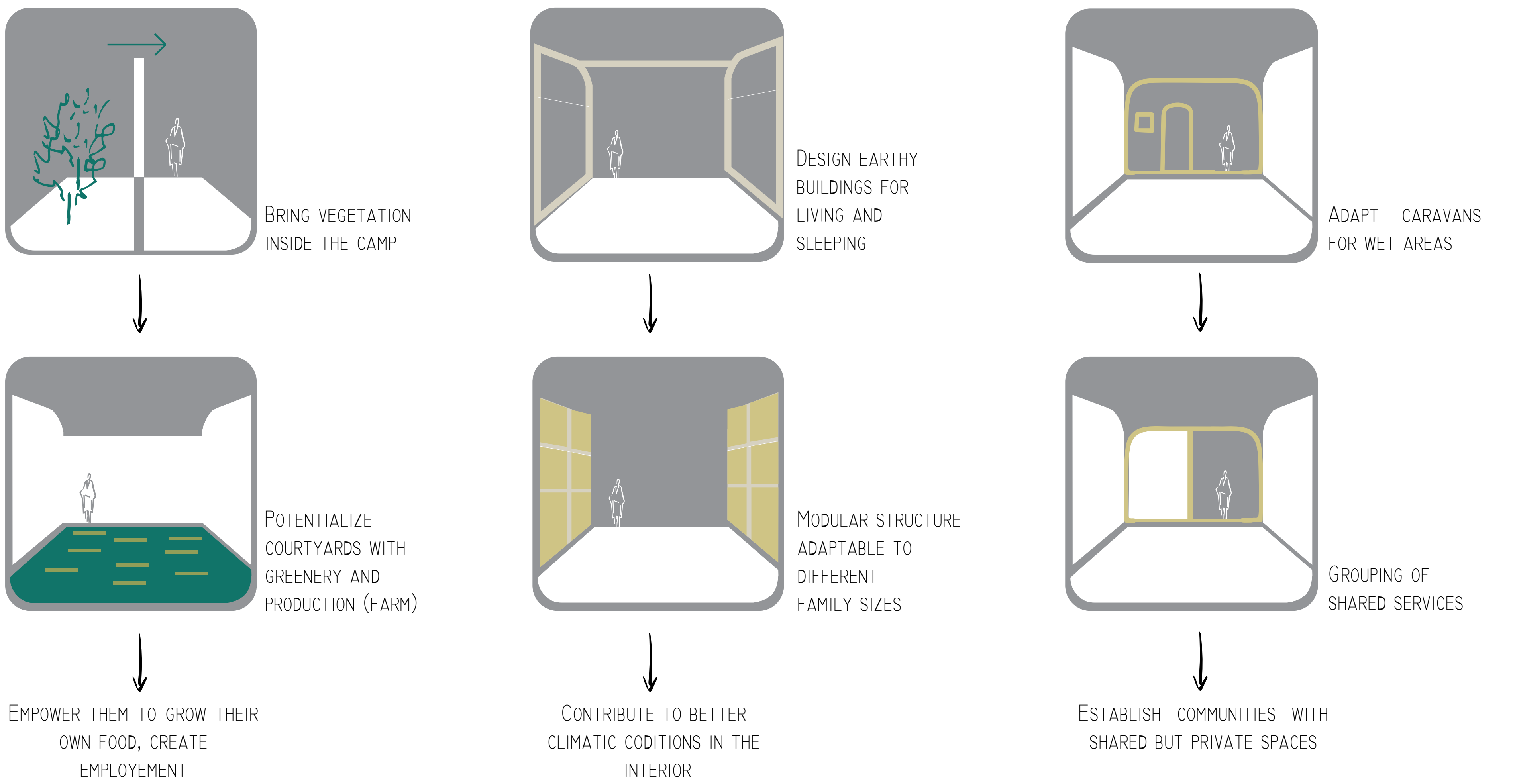


FIGURE 26. BUSTAN PROPOSAL

06 Configuration

The first approach for configuration was to make certain definitions for the project. First the general definition was made, then the programme was set, as well as the relation between the spaces with their transitions, connections and depth.

One of the main proposals of the project was to create a modular construction, therefore, a module was defined and in base of these module all the spaces where sized.

Considering all the definitions, the rules for the configuration of the project were presented. These rules were created with different scales on mind and there was the main guideline for the project development. This approach helped to systemize the design giving the flexibility that the progamme demanded.

Consequently, there was not a correct or final version of the configuration. There were many variations as a result of the rules. Once the manual and computational approaches were tested a case scenario was chosen in order to further develop the design.

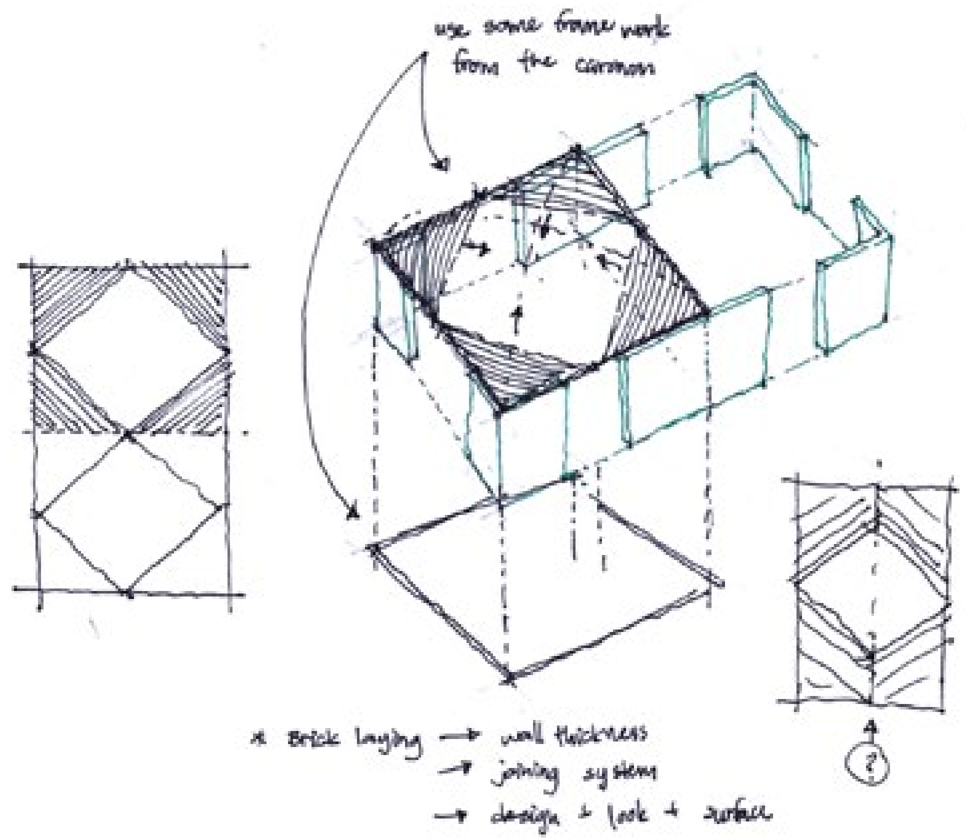
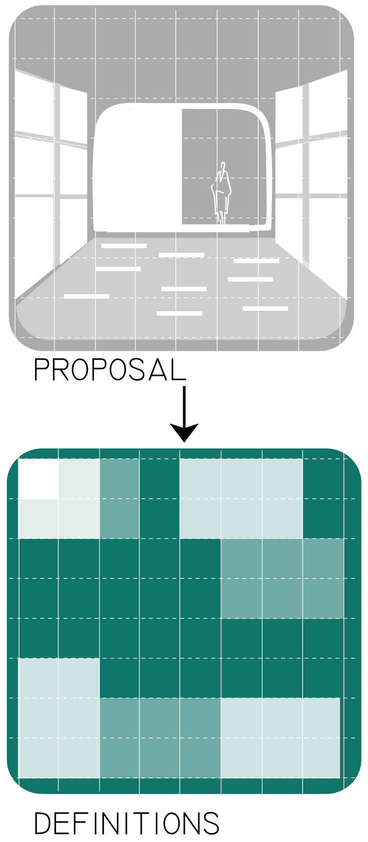


Figure 27. Configuration Ideas



I Definitions: General

To understand the project, first the scales of it had to be clarified. The smallest scale was the Pixel, which was a constrain of the material as a unit.

The Module was the product of the Pixel and were the main working unit of the project. Therefore, Modules together formed a Room. Various Rooms adjacent formed a Family, and families together formed a Unit. Finally, Units together formed a Cluster.

The Urban scale considered both the module size for the working grid and the Cluster as a replicable but changeable unit.

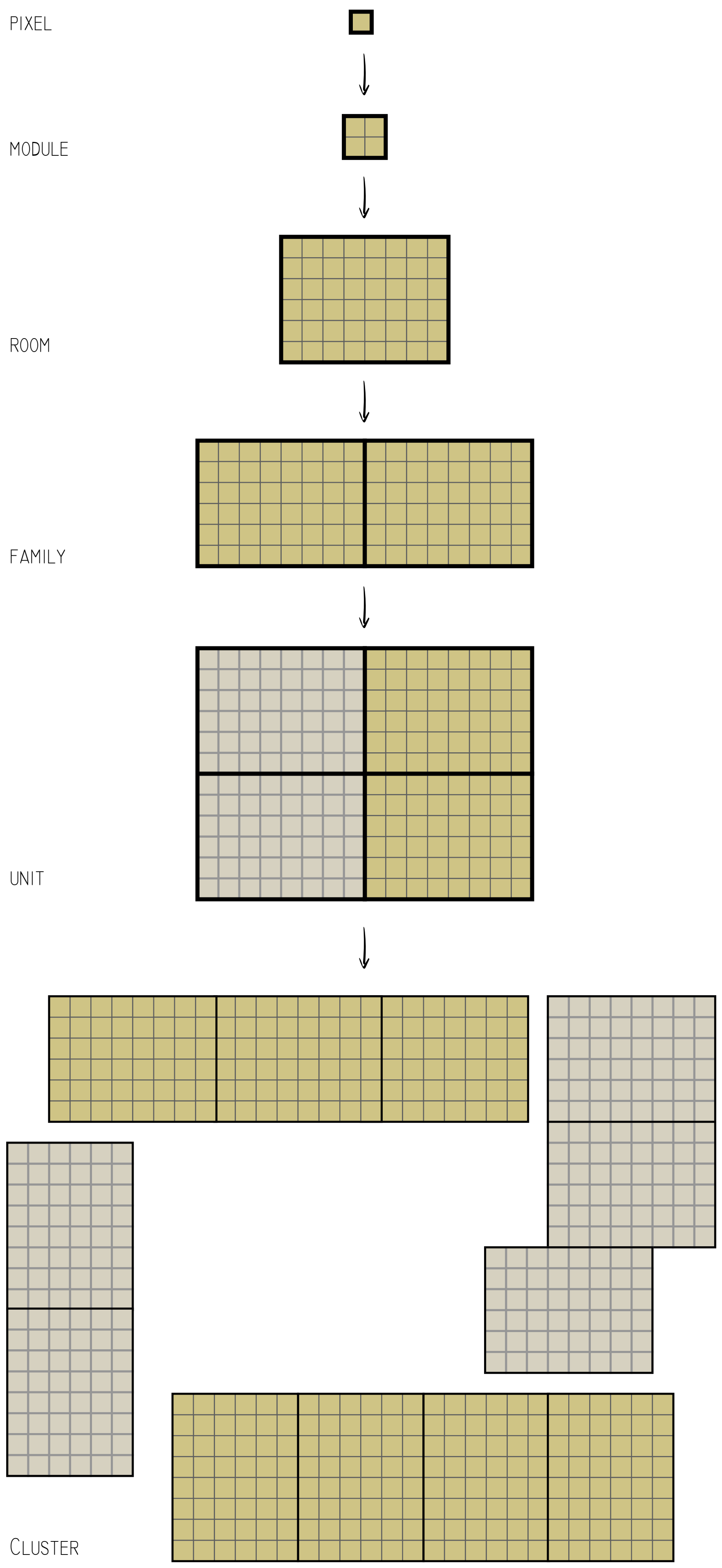
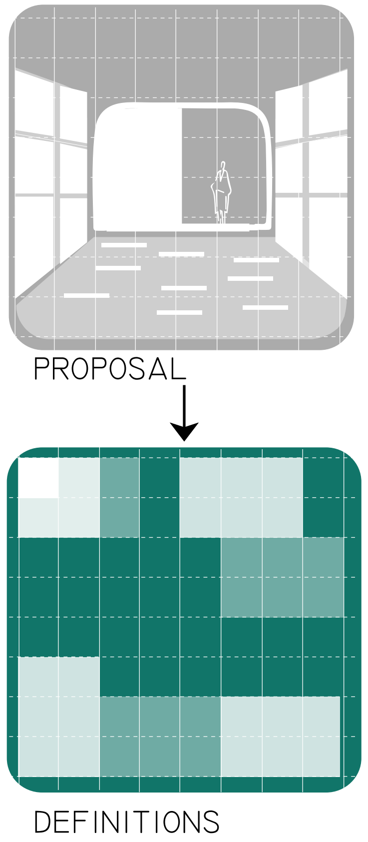


Figure 28. Scales of the project

CONFIGURATION



| Definitions: Programme

The programme was defined based on the analysis of the social context and considering the main proposal and therefore the previous mentioned scales.

The family consists of spaces for living and sleeping and their construction was proposed to be from adobe, given that this specific programme needed to be modular, adjustable and flexible.

The unit was formed by the family plus shared services. The main function of the unit was the courtyard, families would share this open space creating a community. On the other side, kitchen and toilet were designed to fit the existing caravans of the camp. This resource was already there, and it could be modified for a better use instead of disregarding it completely.

Finally, the cluster was composed of the units and a shared farm. The farm would be the main junctions between the units.

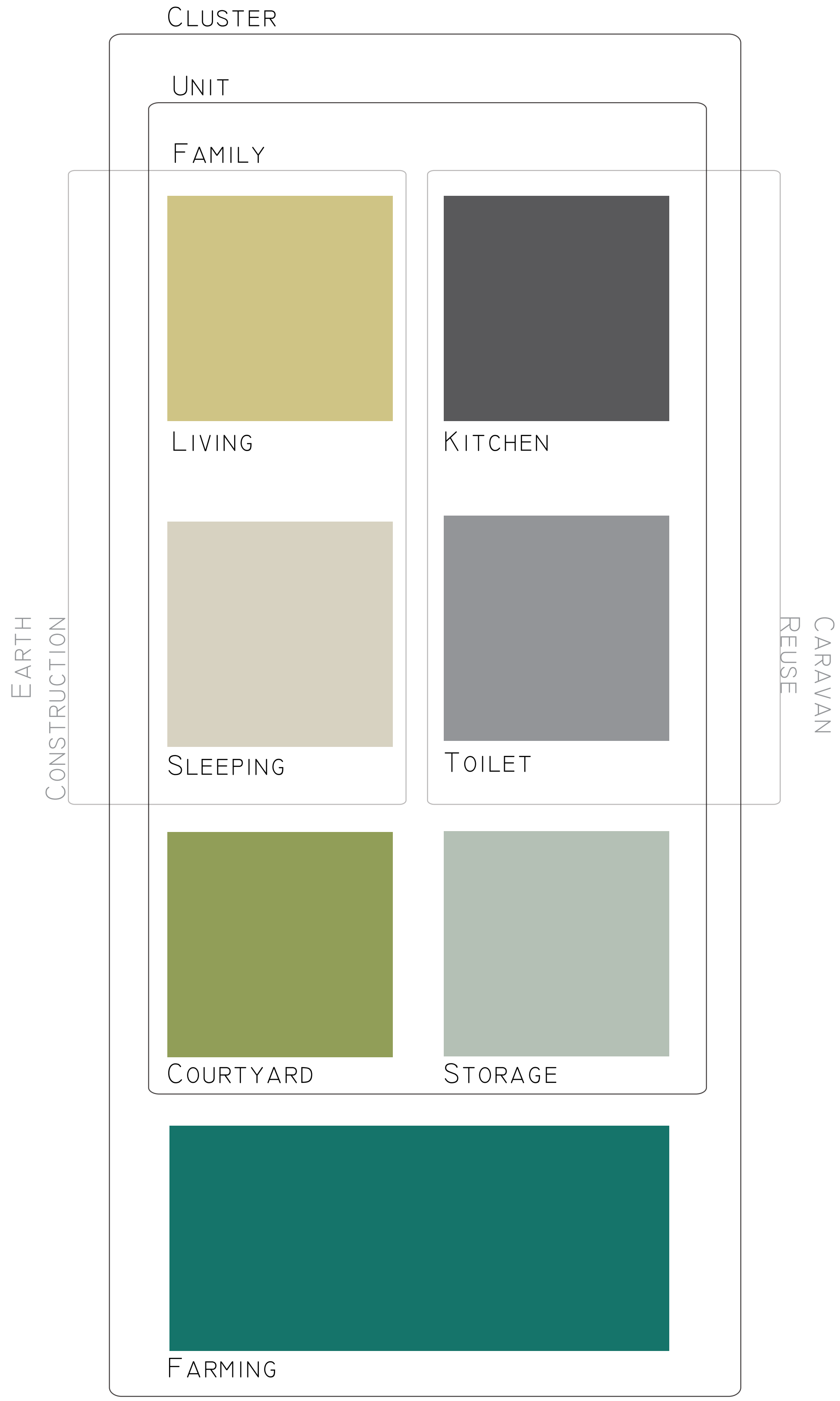
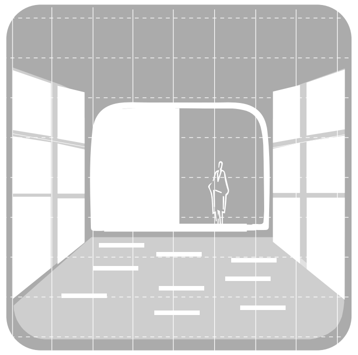
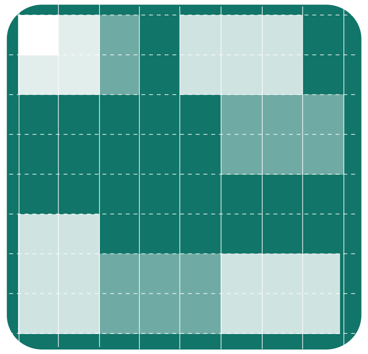


Figure 29. Programme Definition

CONFIGURATION



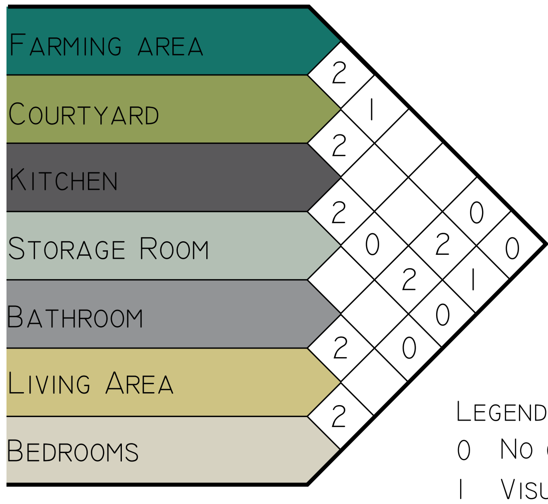
PROPOSAL



DEFINITIONS

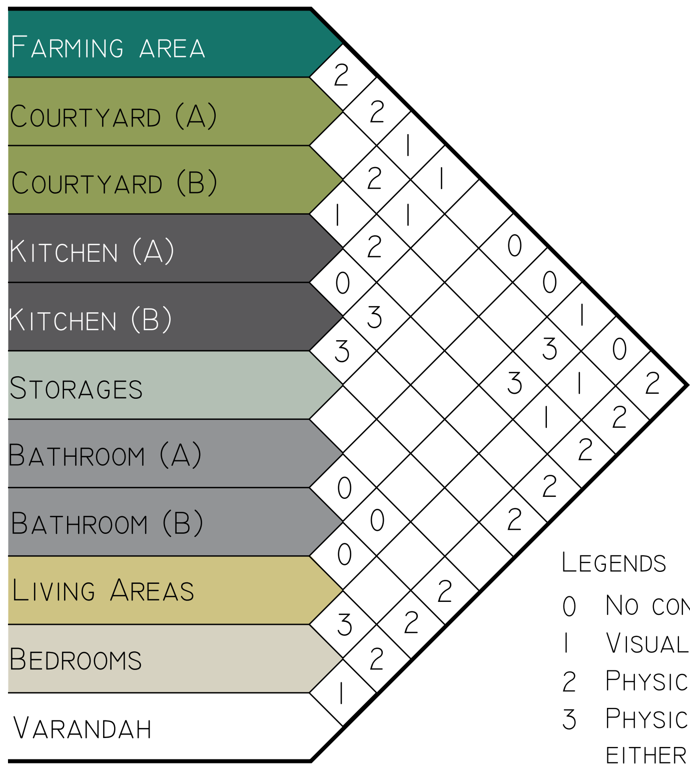
I DEFINITIONS:
REL-CHART

After the required programme for the housing was defined, the REL-chart, or the relationship chart, was developed. This chart served as an initial rule for space configuration that indicated the connectivity between each different spaces with basic numerical representation. '0' was used for spaces which should not be next to each other, '1' for spaces that were not physically connected but had a visual connection, and '2' for spaces that should be right next to each other.



LEGENDS
0 NO CONNECTION
1 VISUALLY CONNECTED
2 PHYSICALLY CONNECTED

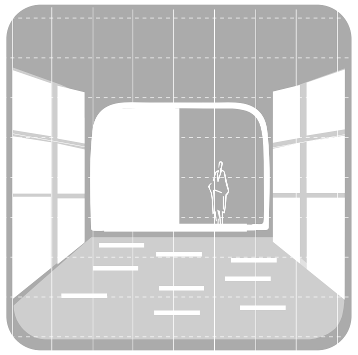
FIGURE 30. REL CHART- UNIT

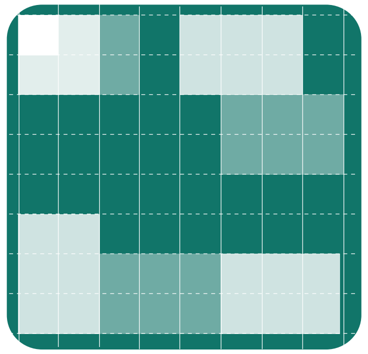


LEGENDS
0 NO CONNECTION
1 VISUALLY CONNECTED
2 PHYSICALLY CONNECTED
3 PHYSICALLY CONNECTED EITHER ONE OF THISPROGRAM

FIGURE 31. REL-CHART - CLUSTER

CONFIGURATION


PROPOSAL


DEFINITIONS

I Definitions: Space Syntax

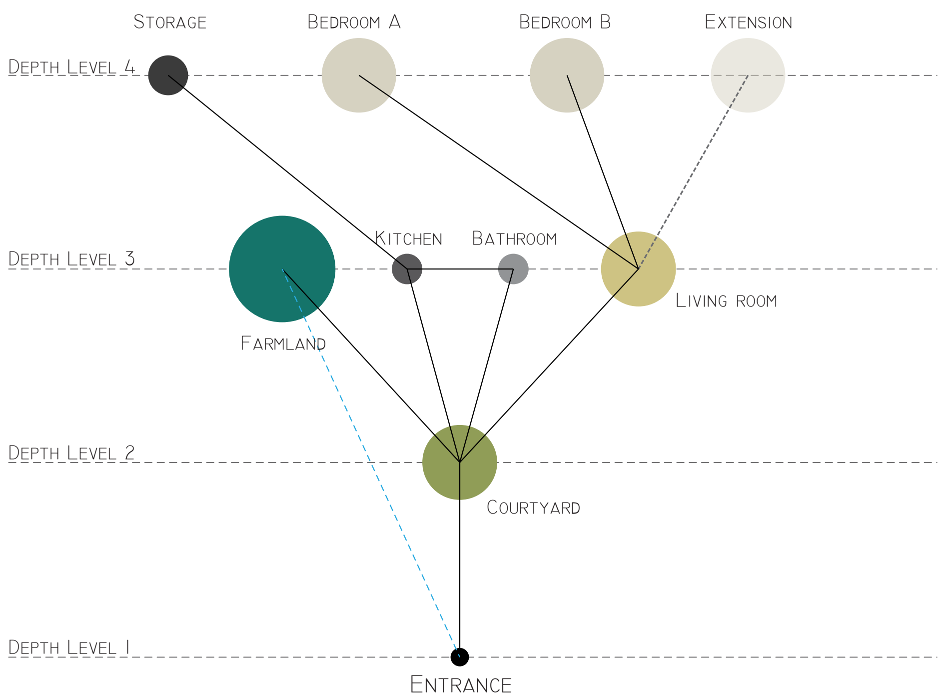


Figure 32. Space Syntax of Unit

Once the REL-chart was defined the space syntax was made with the help of the grasshopper plug in: Syntatic. This defined the level of privacy of each space and their transition between.

While the REL-chart and space syntax for a unit was simple and straight forward, the chart proved to become much more complex as multiple families were grouped together.

This increased in complexity was due to the change in the level of privacy of the programme such as kitchen and bathroom which turned into a shared facility, where the accessibility for multiple users needed to be taken into consideration.

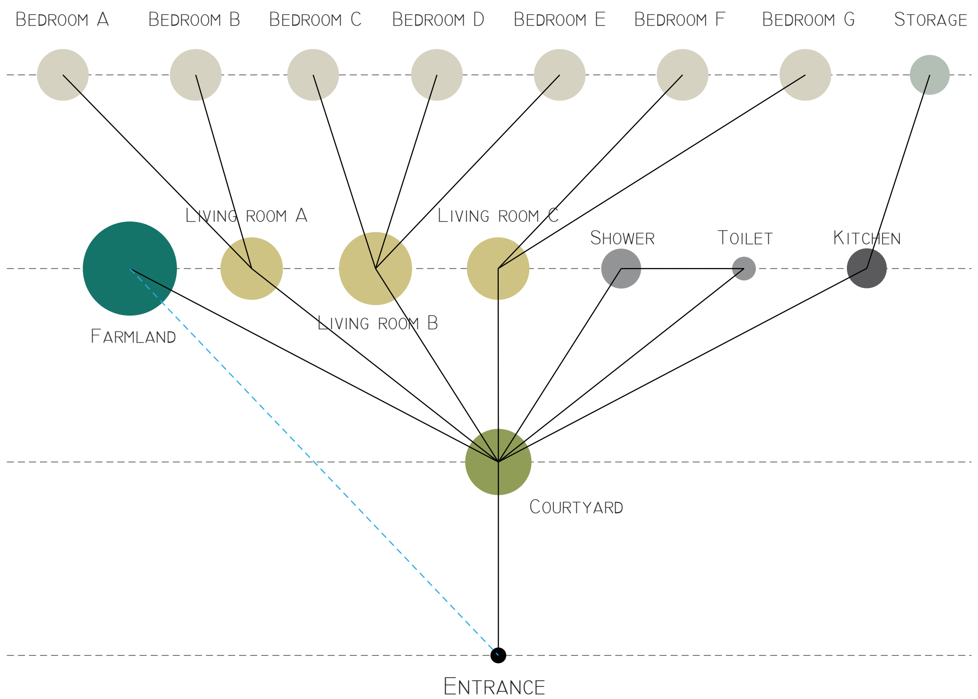
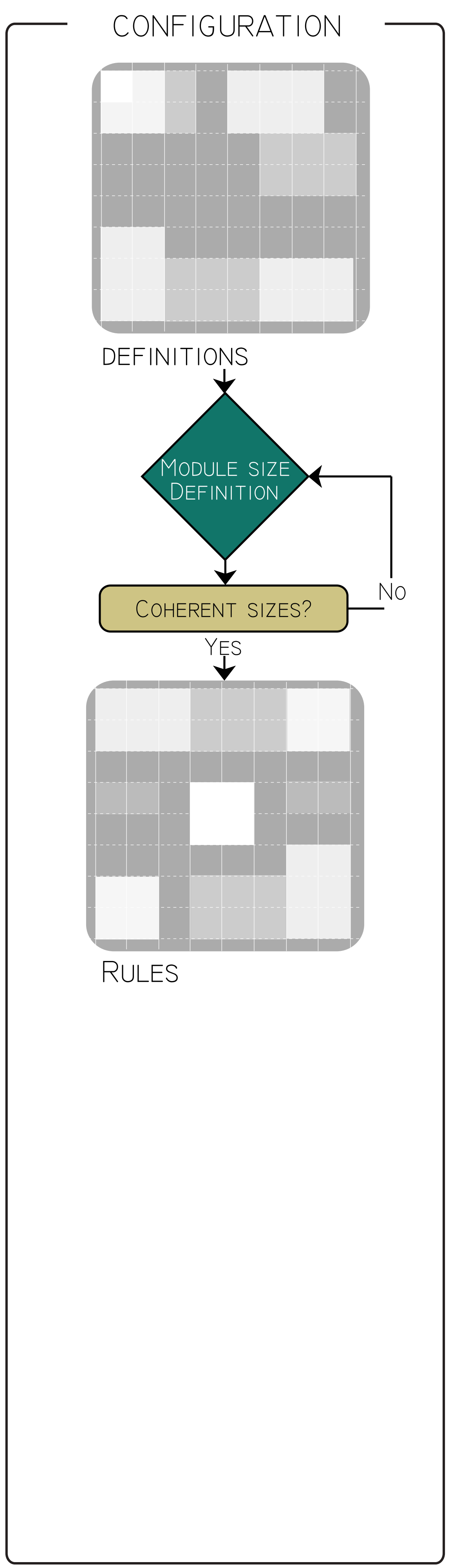


Figure 33. Space Syntax Cluster



I DEFINITIONS: MODULE

The module 1.2 m had a structural advantage for adobe constructions. Therefore, the brick length had to be a product of these number. A brick of 0.3 m was chosen as the measurement of the pixel, because it was easy to work with and to transport.

For this reason, the 1.2 m module was chosen as a first option, but for sizing the rooms and developing the rules, fractions of these modules were needed. The use of fractions while developing the configuration rules made system of the project complicated and harder to follow.

As a result, the module of 0.6 m was chosen. This desicion was made thinking of structural, material and functional constraints with no need for fractions, which made the project more cohesive, the sizing of the room complete and the rules easier to follow in x and y directions.

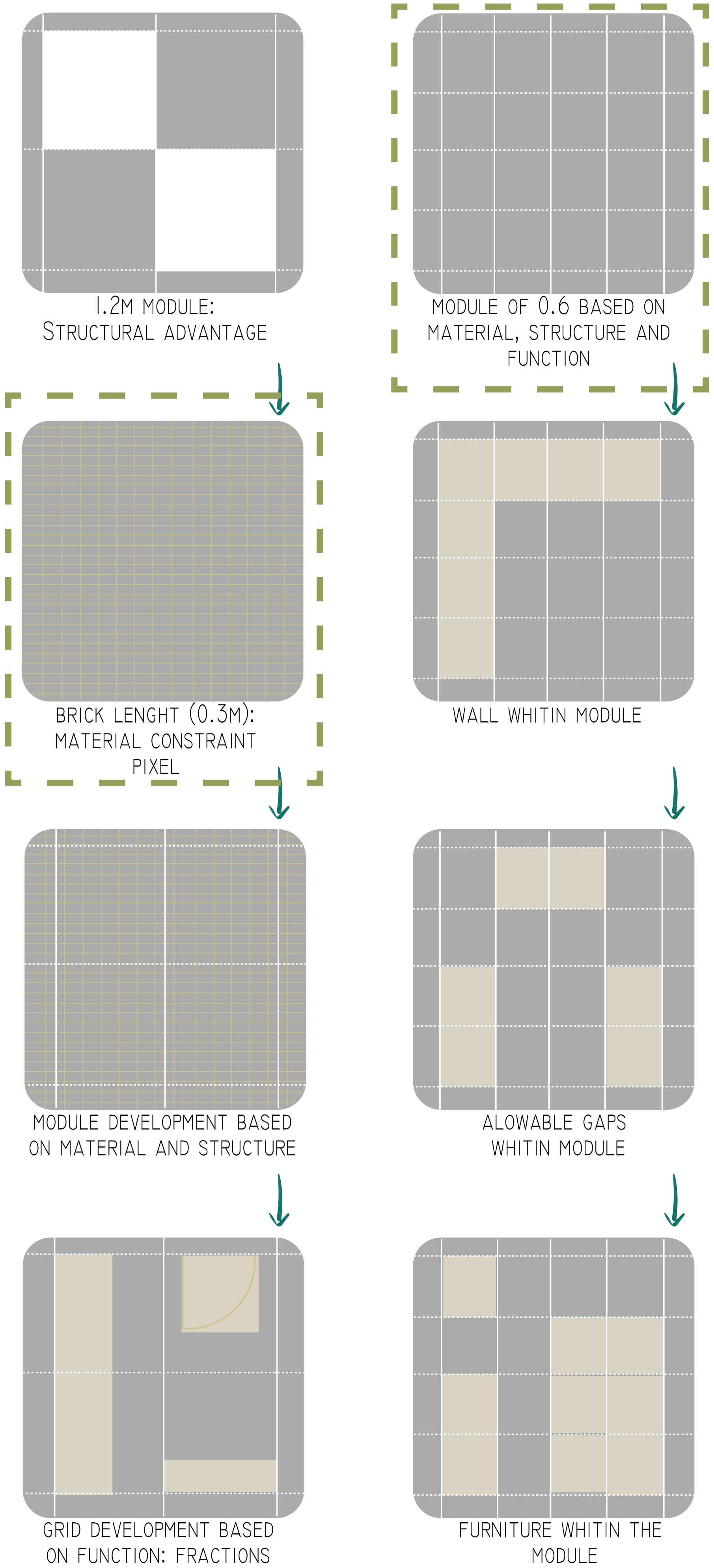
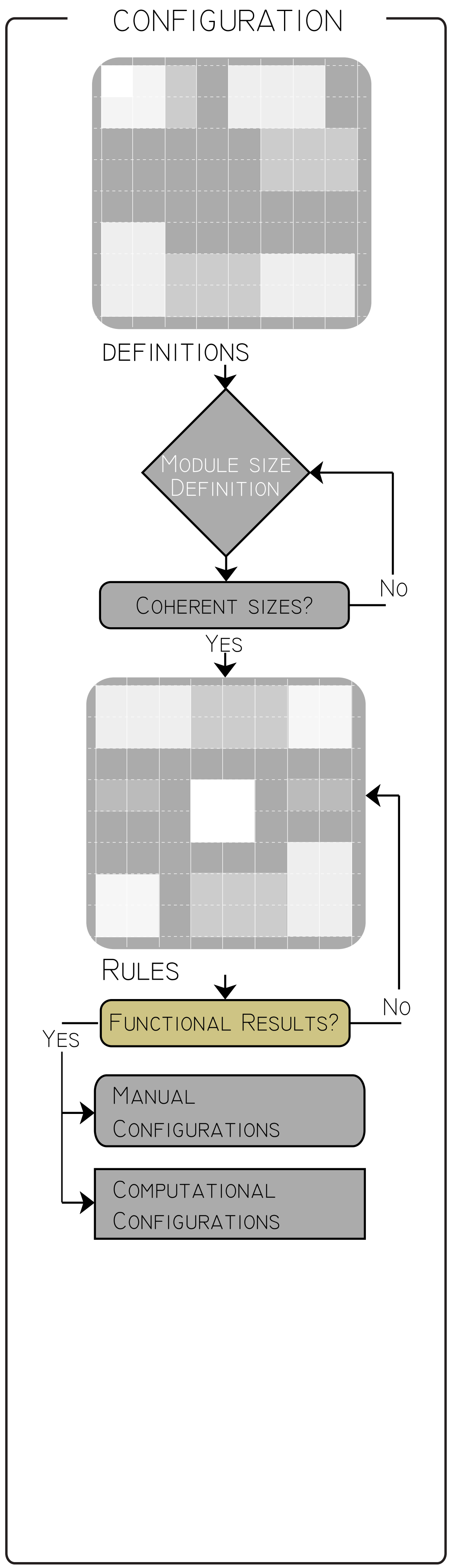


FIGURE 34. MODULE SIZE DEFINITIONS



2 Configuration Process

Phase I

In the first phase of configuration, some initial rules were established such having the farm in the center and access this farm through the courtyard. Although the rule for the courtyard was changed in the end, since more flexibility in this communal space was desired.

The use of the caravans was also defined from an early phase.
The connection of all spaces had to be through the courtyard and the earth construction. This was also discarded for flexibility reasons.

The initial module was of 3 mts x 3 mts, making squared rooms. This had the problem of creating rooms that were not the necessary size for the living conditions of the families, and it was harder for the transition from one room to another room to allow privacy. (pass through one bedroom to get to another one).

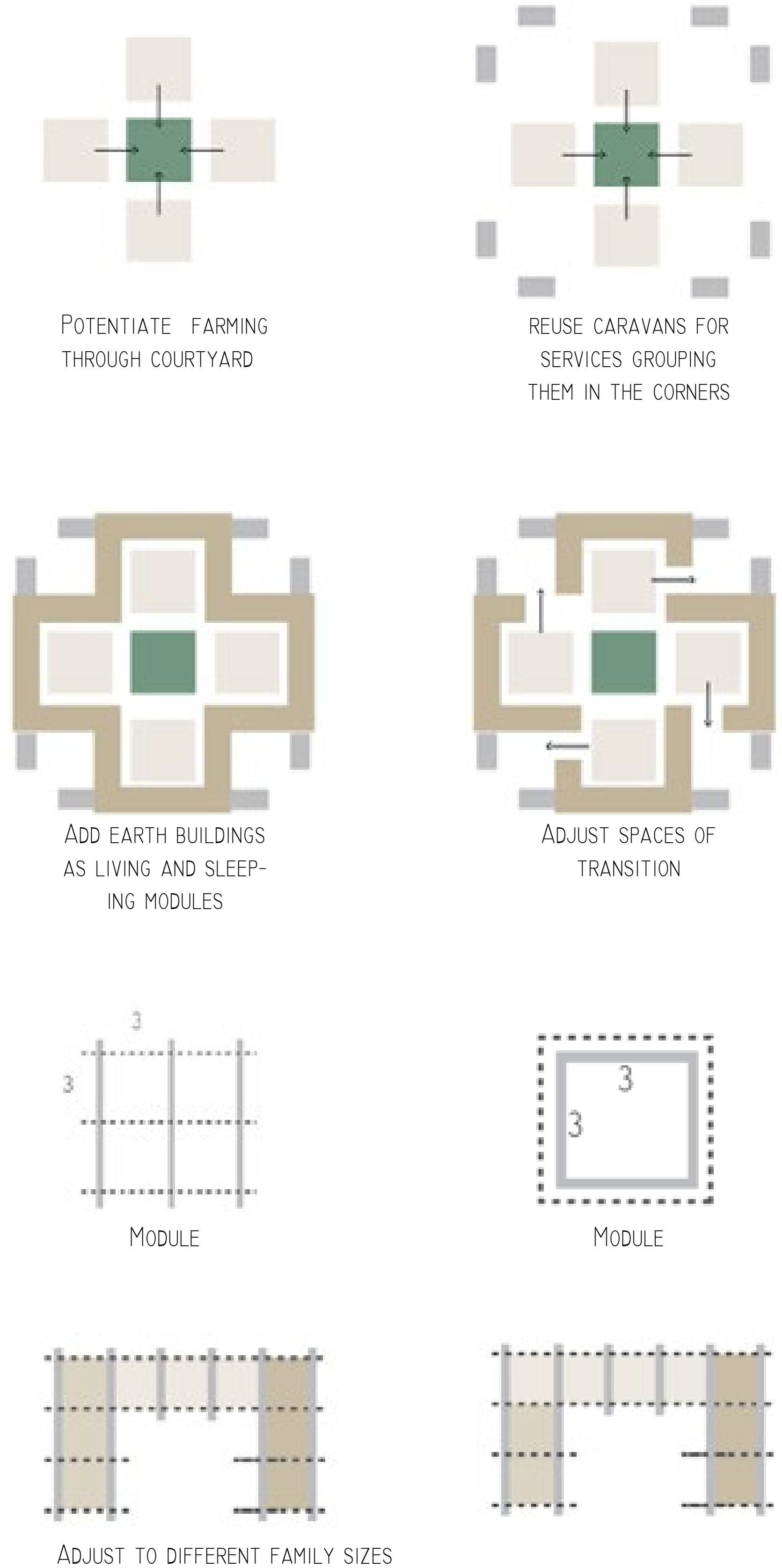
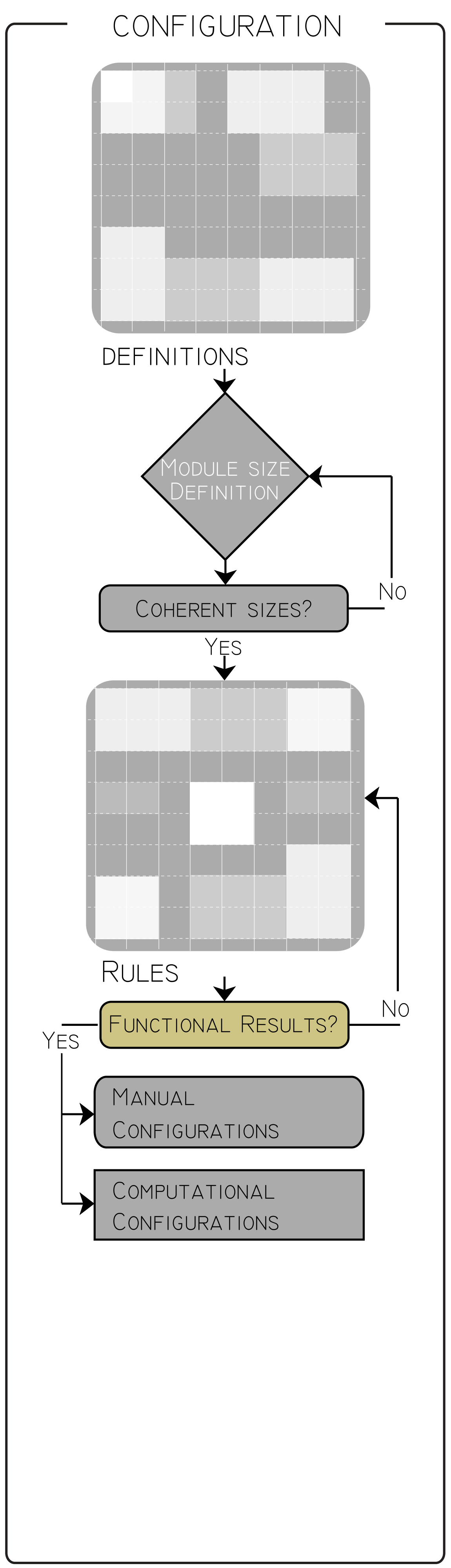


Figure 35. Configuration process phase I



2 Configuration Process

Phase 2

In the second phase the changes mentioned before were done, along with a configuration of the bedrooms to check the total of modules a family would need depending on the amount of people living together.

Each module was of 1.2 mts x 1.2 mts, and the lowest number of modules a person could get for a room was 9 modules. These numbers were changed since the decision of making the rooms bigger and more comfortable were done (initially only the minimums were considered).

Another change was getting rid of half modules, since this accounted for strange jumps when doing the manual and computational configuration of the clusters, and it could later be a source of confusion for the refugee when constructing.

For this reason, the module was changed to 0.60 mts x 0.60 mts, to avoid such half modules, confusion, and to allow more even modularity. Also, going back to a smaller element would benefit the structural configuration since working with elements smaller than our doors was easier to handle. For the complete set of rules refer to annex A before the final changes.

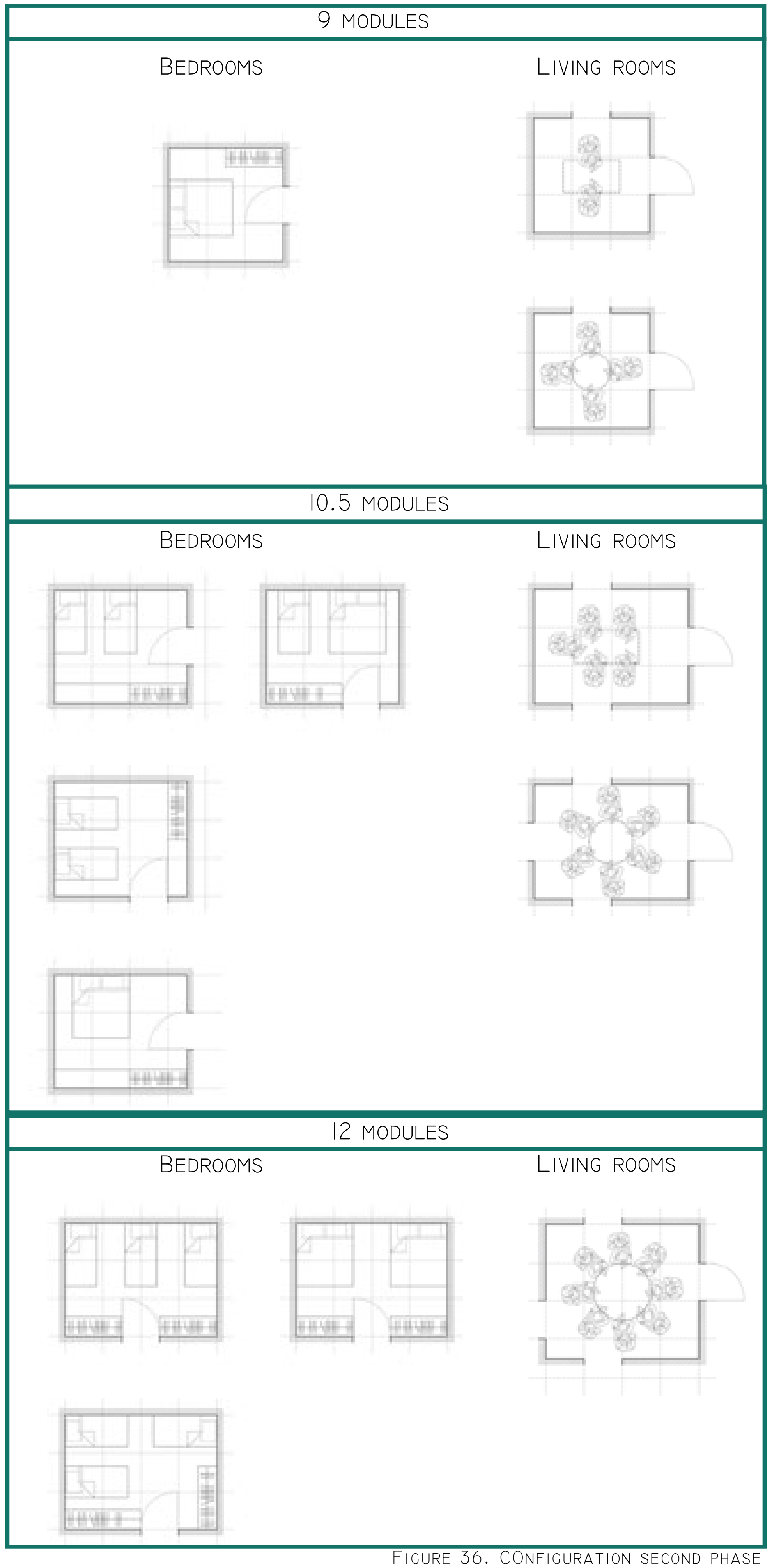
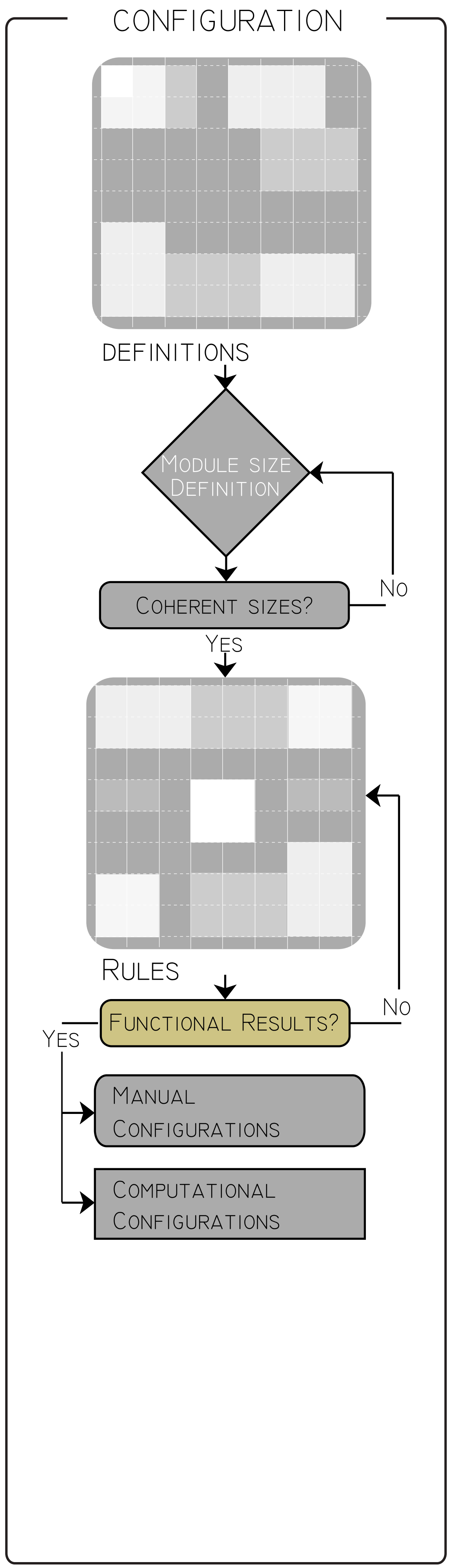


Figure 36. Configuration second phase



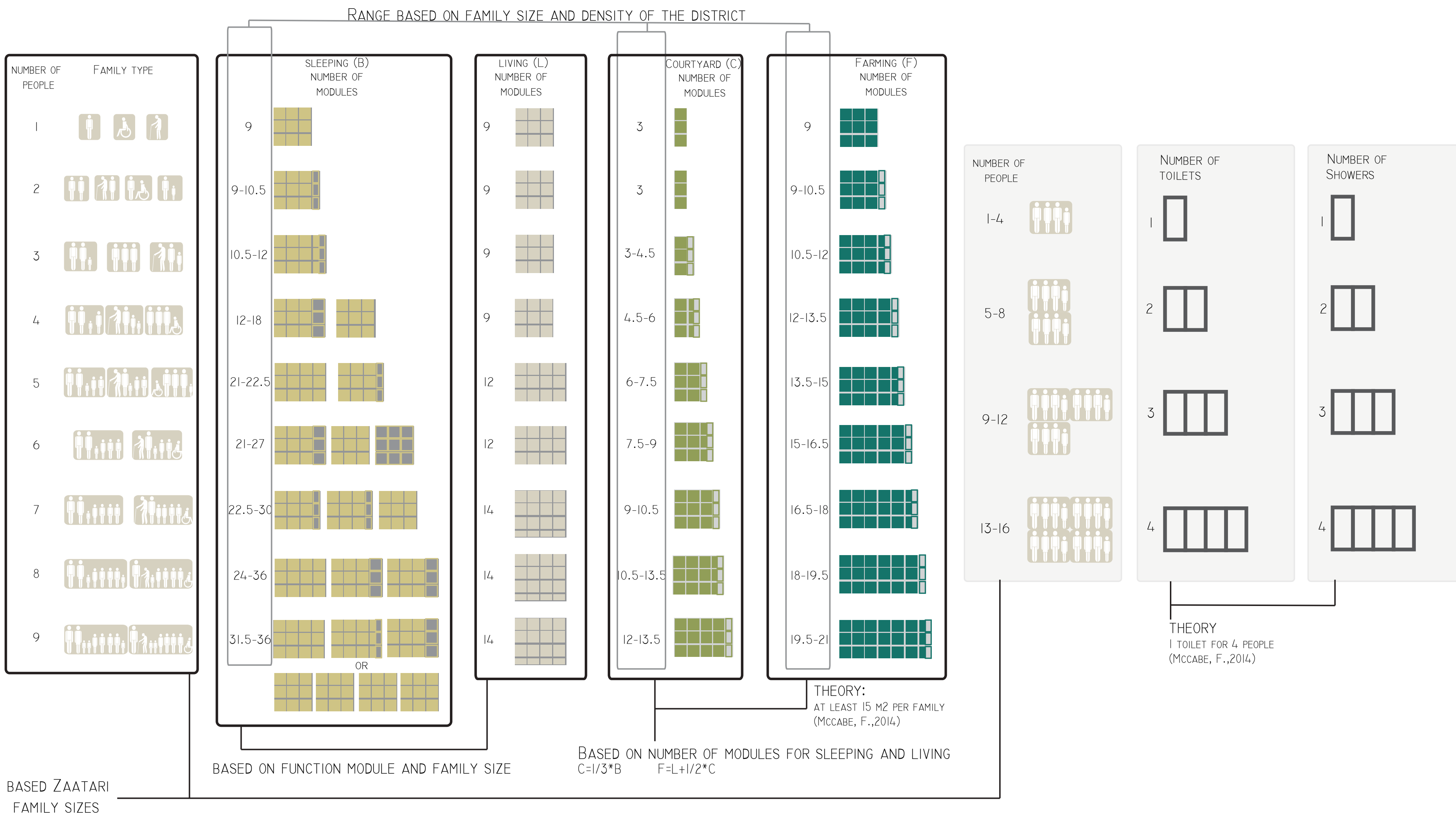
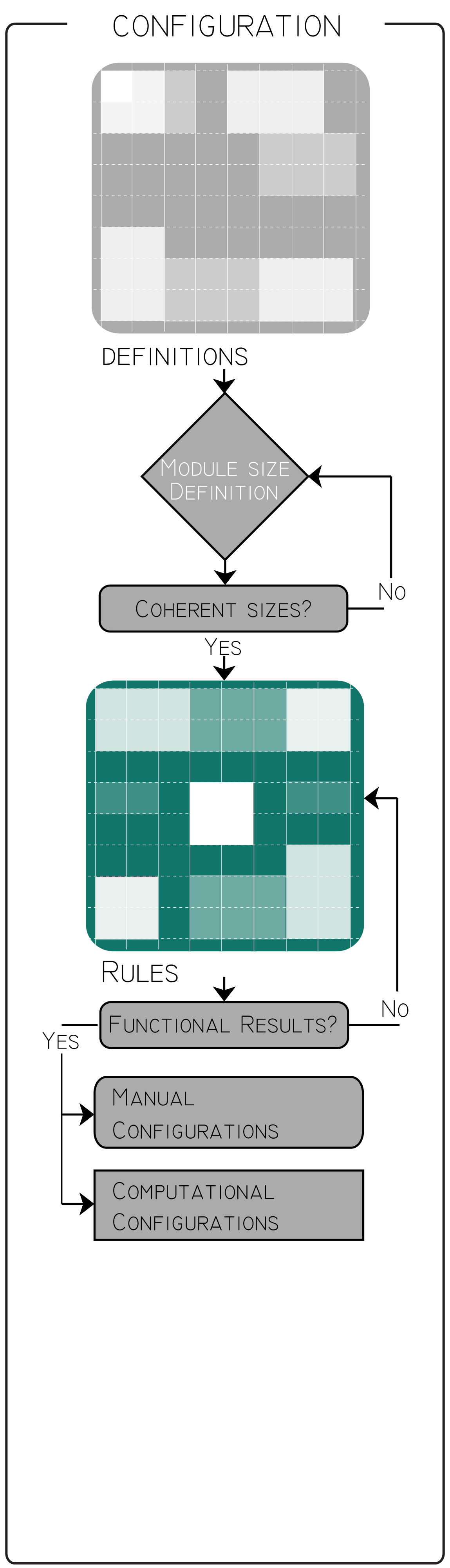


Figure 37. First attempt of generating a matrix



3 Configuration Rules: Room

For the room rules, various rooms were designed and configured in order to generate a matrix of information. The diversity of options was dependent on the amount of people that would live or sleep there. For functions like sleeping and living the previously defined module size was used.

On the other hand, for wet areas, the caravan size was taken into consideration as previously mentioned in the programme definition. The standard size and area of each space were extracted from the minimum standard size, available online. These sources include the typical Syrian traditional house and Neufert architectural standard.

Based on the room space configuration and its use, a room matrix was developed for the Zaatari refugee to assign the number of modules a family would get depending on their size.

Once the amount of bedroom and living rooms was defined, the refugee was entitled to a minimum amount of courtyard modules and a maximum amount of farming area. Once the total amount of families were defined, the total number of persons living in a cluster was known and with this number, the number caravans was assigned as shown on the matrix (fig. 40).

The ranges between the number of modules depend on the context where the family lives in: a denser context meant least amount of modules, while a spread context can acomodate more modules.

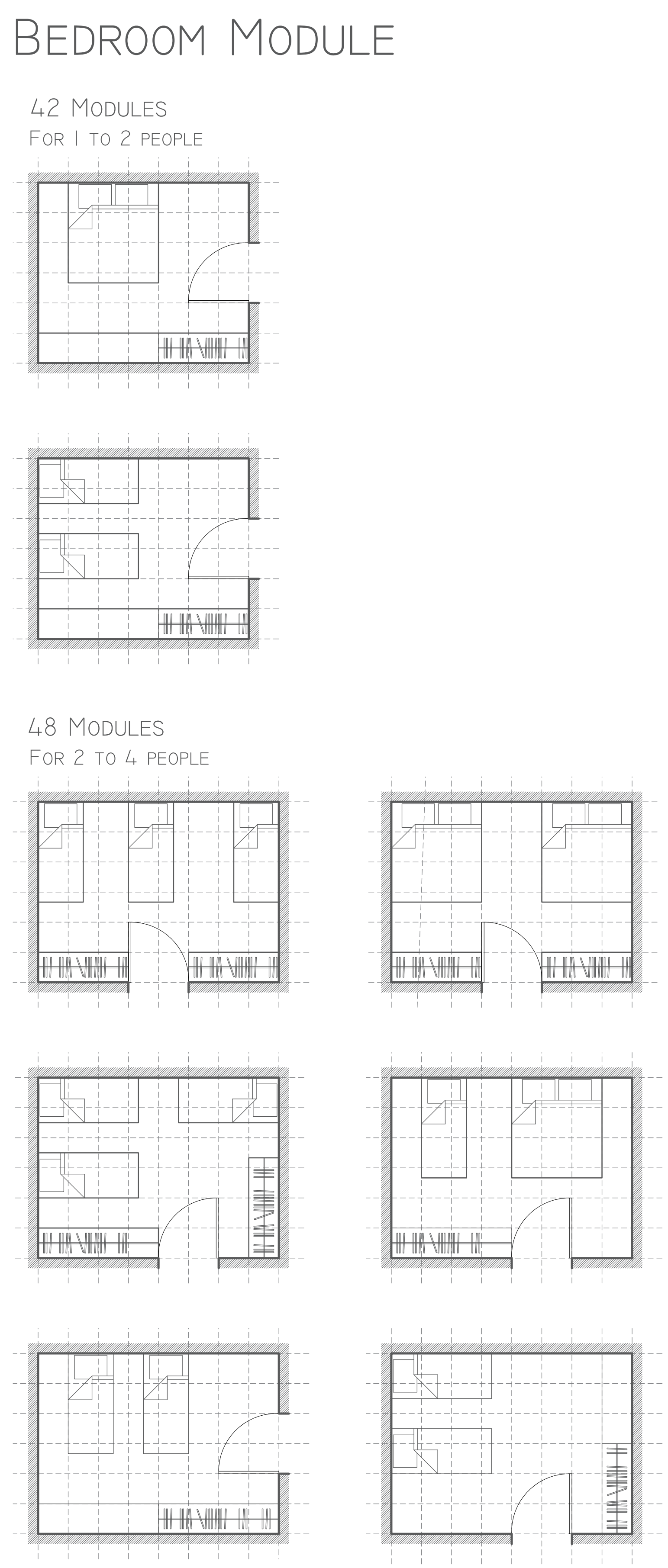
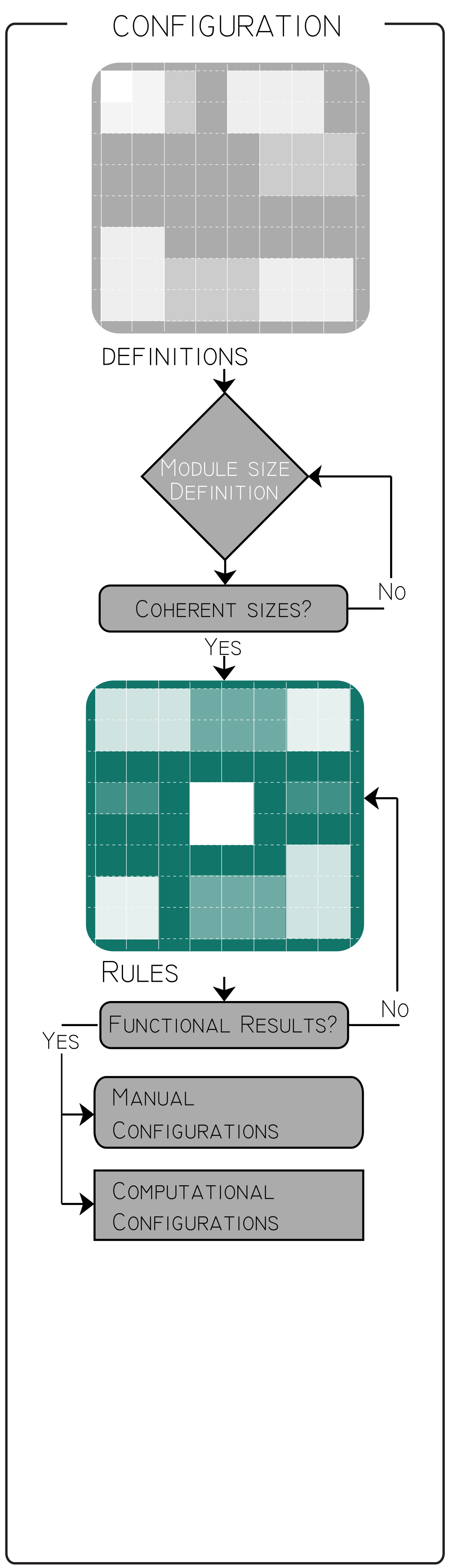


Figure 38. Number of modules for sleeping



Livingroom Module

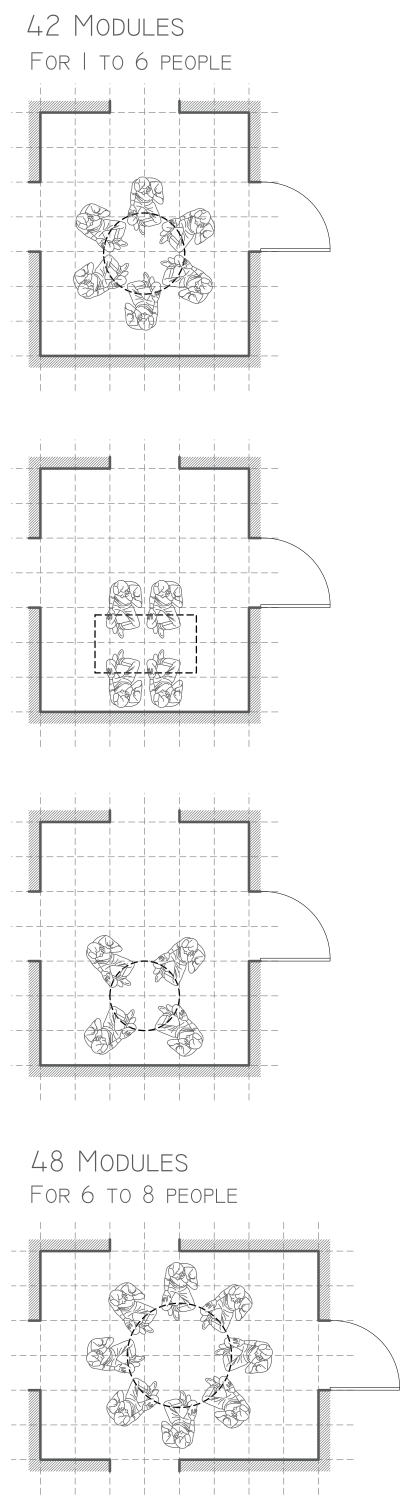


Figure 39. Number of modules for living

Kitchen & Bathroom Module

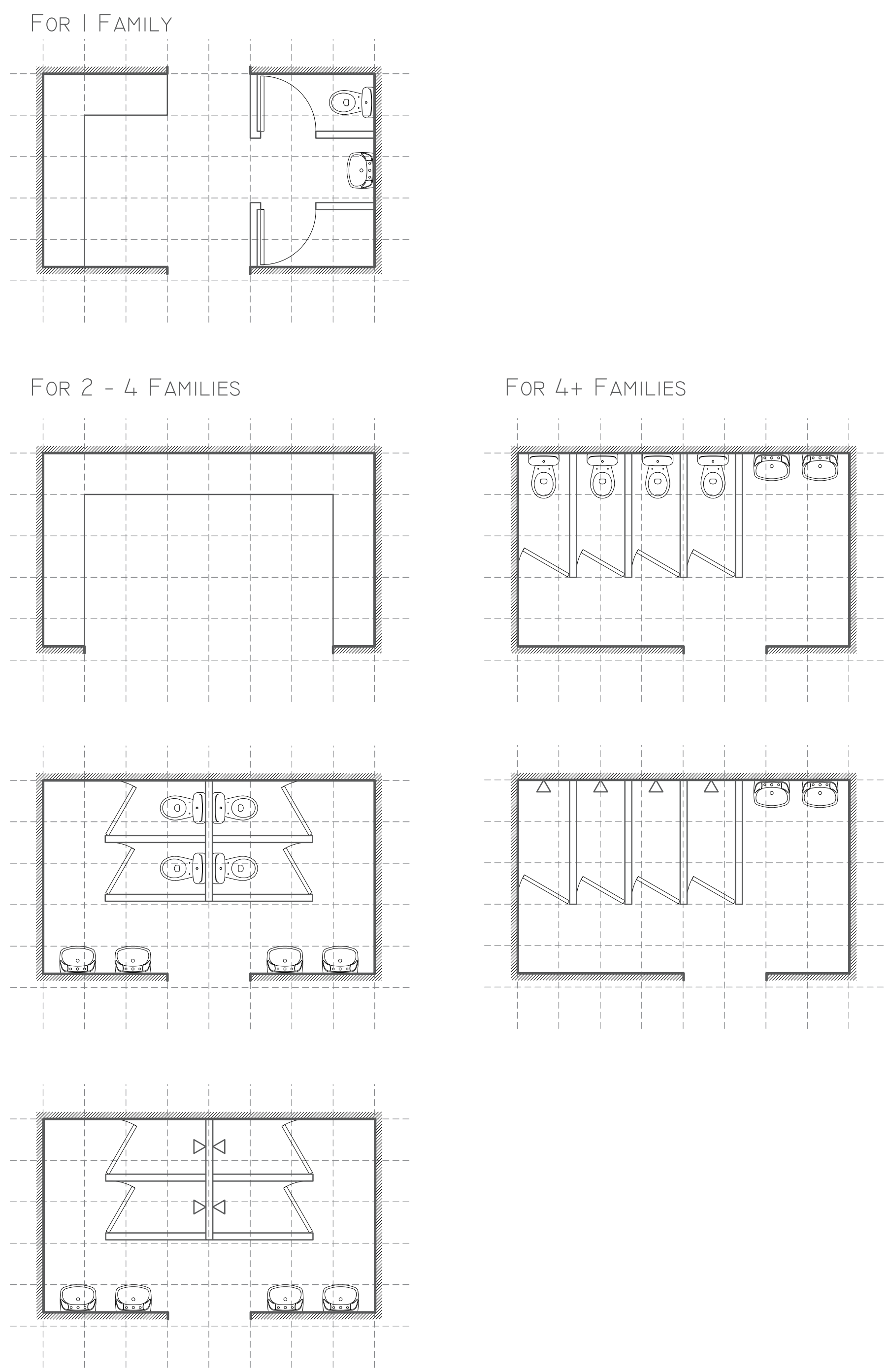
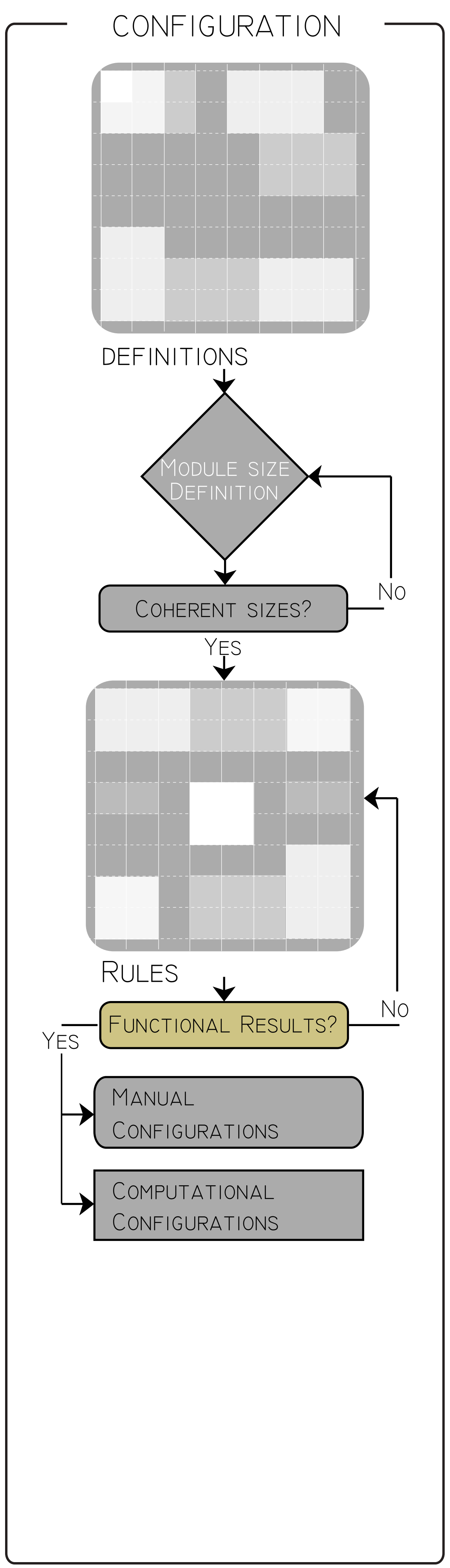


Figure 40. Caravans distribution for bathrom and kitchen



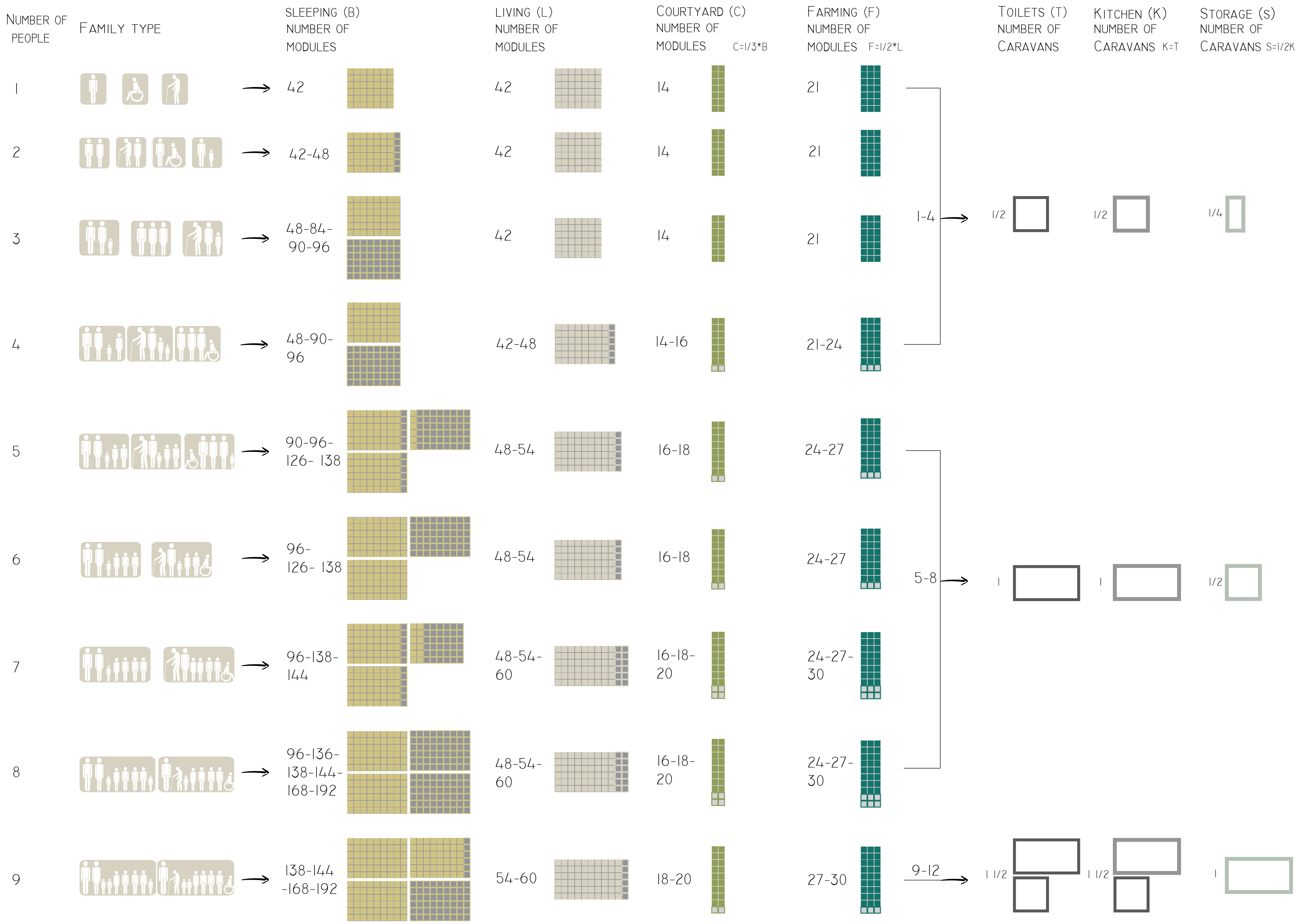
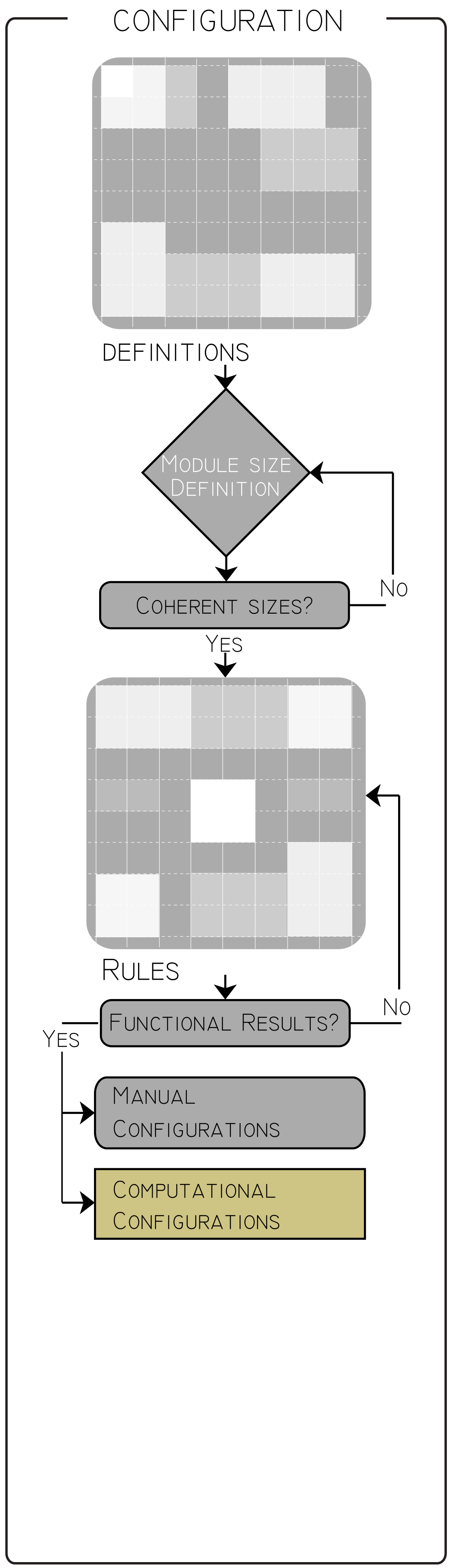


Figure 41. matrix of rules for rooms



Configuration Rules: Computational approach

The computational approach for the room rules had four main inputs: first the number of people, then the module length, height and width.

First the module was created as a box rectangle in grasshopper. Then to create the room, this module was arrayed to x direction for the length, this input was arrayed itself to y direction for the width and, finally, with the length and the width the z direction was arrayed for the height.

A phyton script was used in order to store the information of the matrix. The input for this script was the number of people. The output of the script was the array information for the module in each direction.

In order to generate the ranges of the number of modules regarding the density of the context the command ramp lift could be used in the further development.

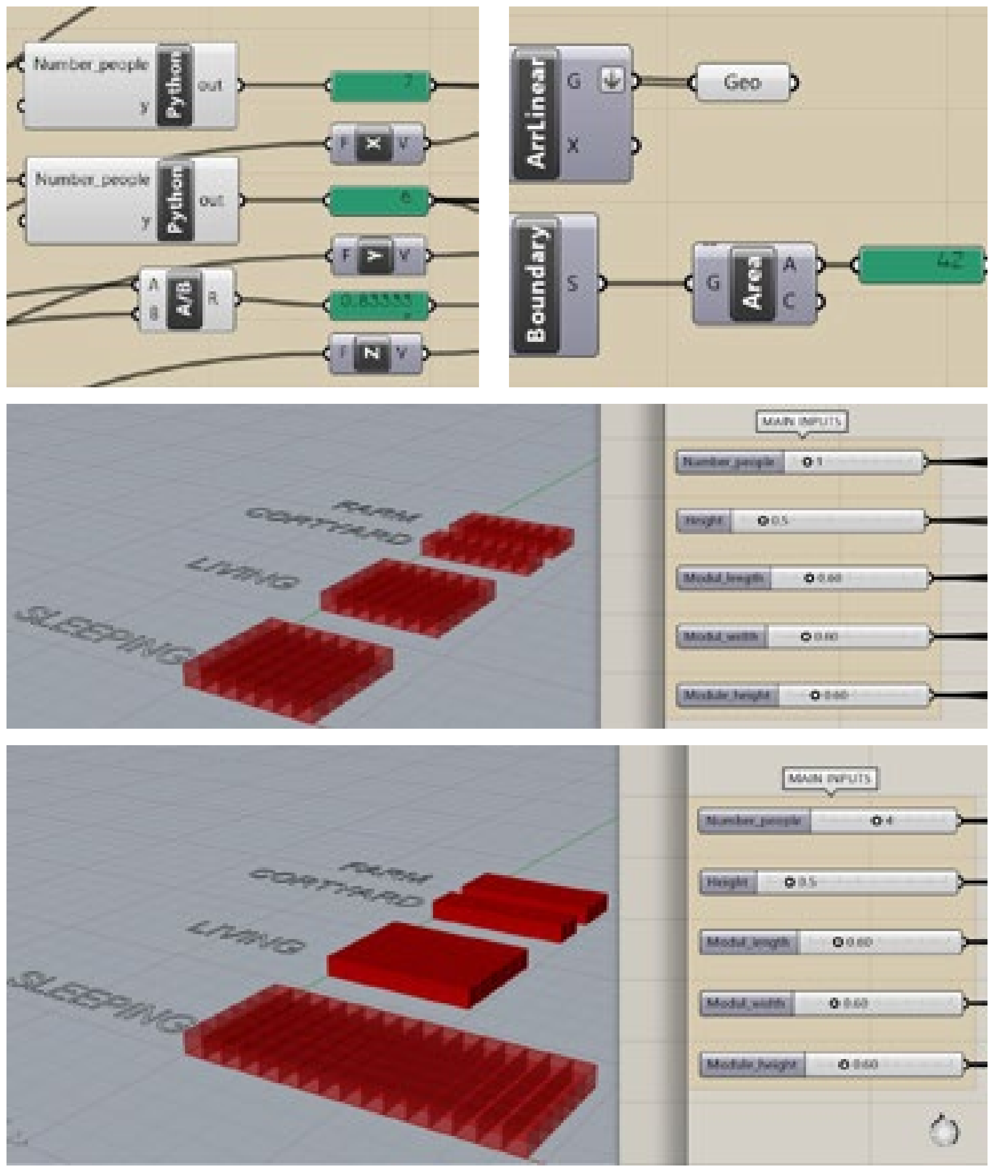
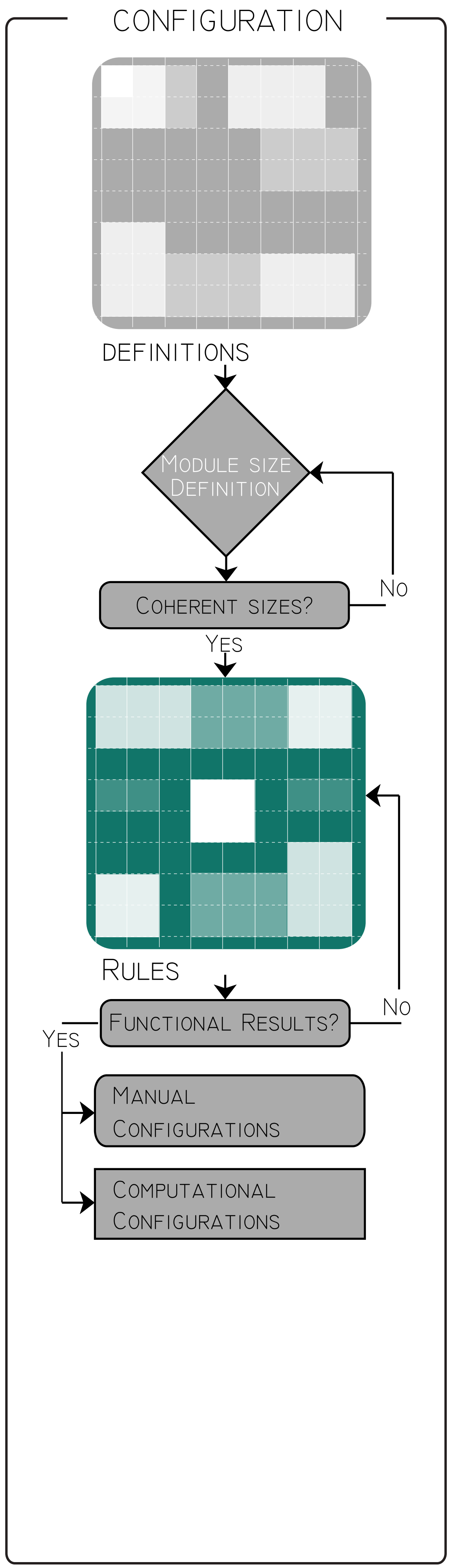


Figure 42. Room Configuration computational approach



3 Configuration Rules: Family

There were four main rules for the configuration of the family:

1. The number of rooms depend on family size and how many families want to be together. (as stated in the room matrix before) This could later be re-checked within the cluster rules to see if the space and density was allowed by the district in which the construction would to take place.

2. The bedroom had a physical connection to a living room (door), and never to another bedroom to allow privacy and for people not to pass through another bedroom to go to the communal spaces.

3. Entrance to the house was always through the living room for privacy reasons.

4. The shifting of rooms was in steps of 3 modules (structural and material constraints) This rule was added after the structural analysis and formaing analysis were made.

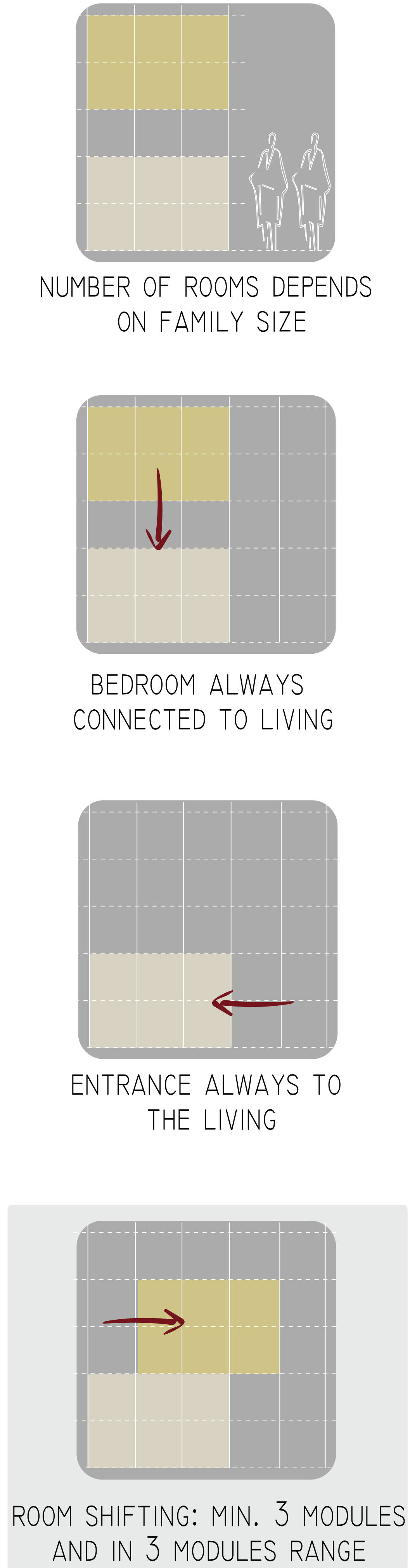
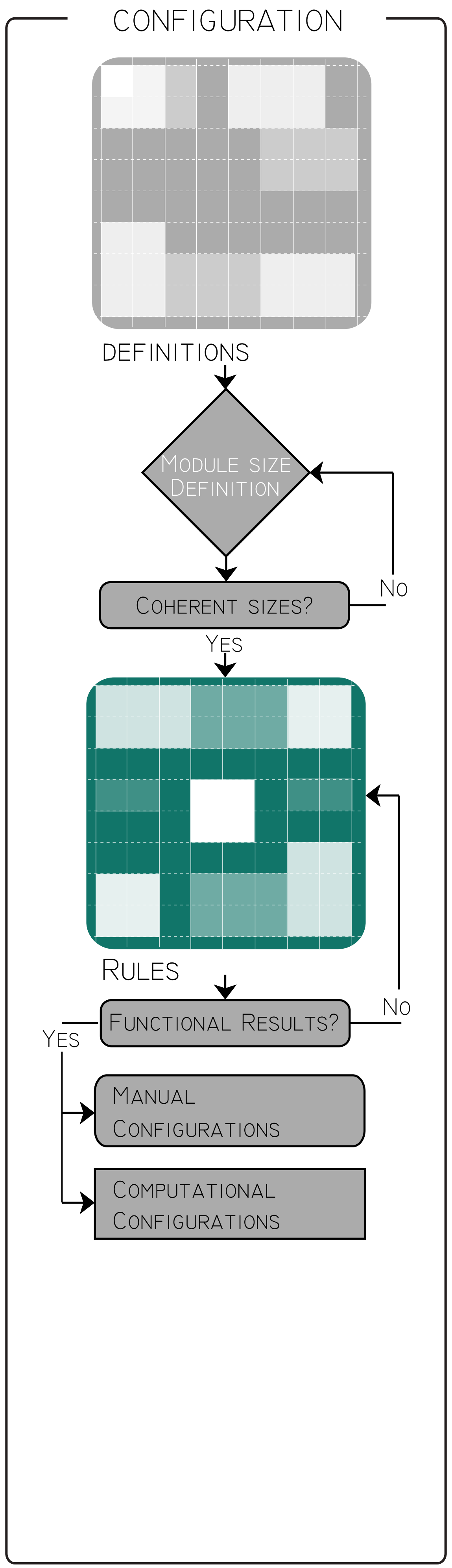


Figure 43. Family Rules



3 Configuration Rules: Unit

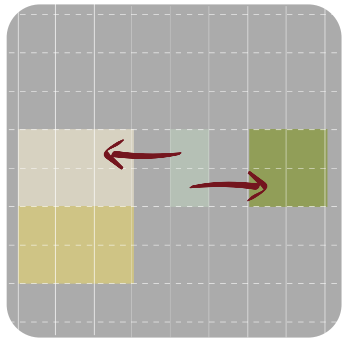
There were four main rules for the configuration for the unit:

1. Living room and courtyard should connect with a verandah to allow a transition from the private to the semi-private space.

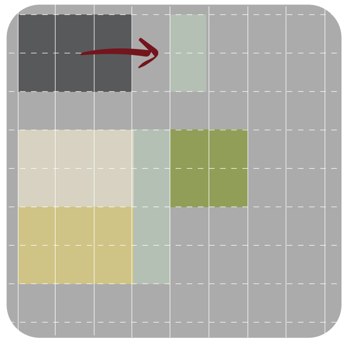
2. Services connected to family units through verandah.

3. The walking distance from services to a family equals the length of the verandah but should not exceed 72 modules. This also helped with the definition of the overall working grid later on in the cluster rules.

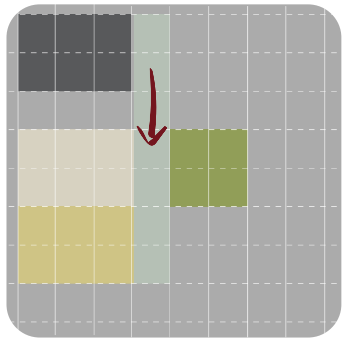
4. Size of courtyard dependent on the units (taking into account the minimum areas shown in the matrix).



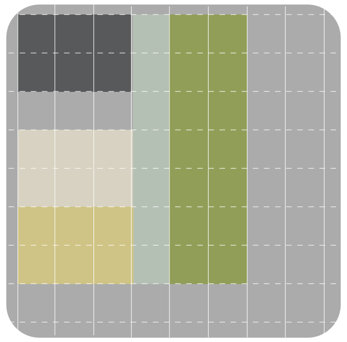
LIVING AND COURTYARD
CONNECTED WITH
VARANDAH (3 MODULES WIDTH)



SERVICES CONNECTED TO
FAMILY TROUGH VARANDAH

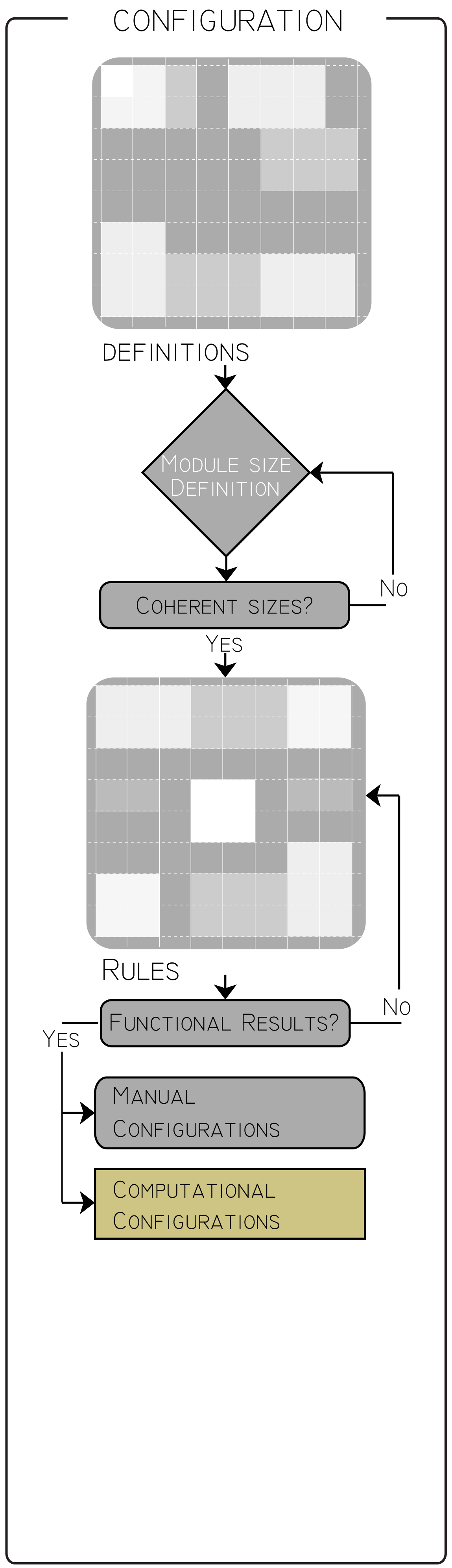


WALKIG DISTANCE FROM SERVICES
TO FAMILY = LENGHT OF
VARANDAH (MAX. 72 MODULES)

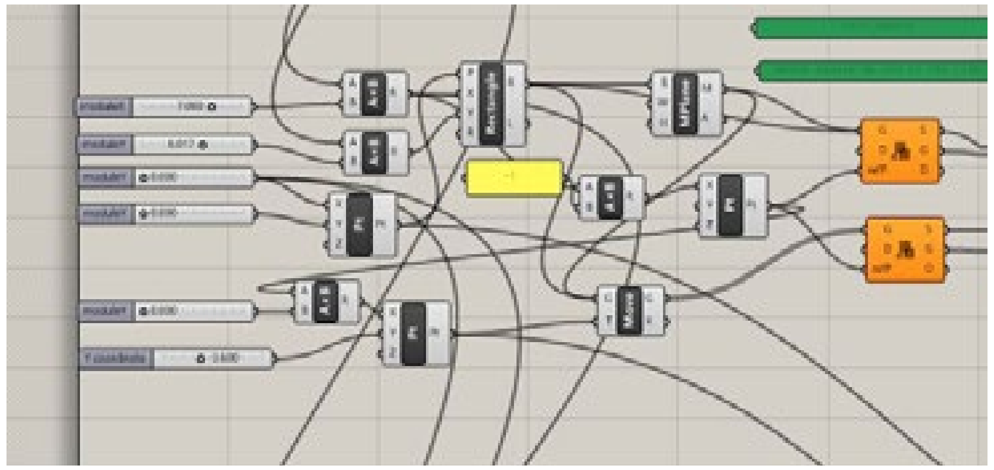


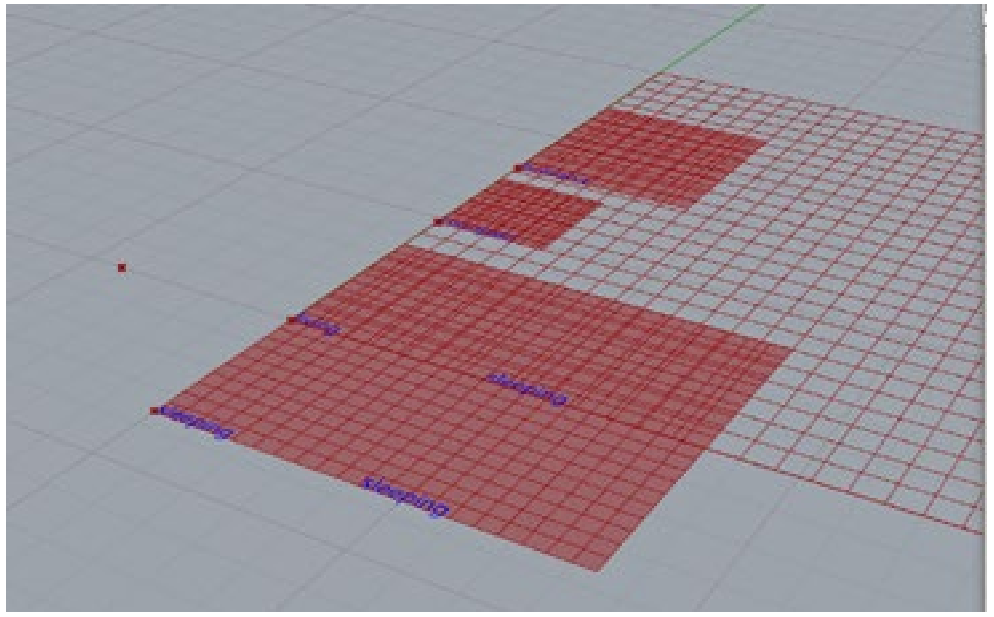
SIZE THE COURTYART
TO THE UNITS

Figure 44. Unit Rules



Configuration Rules: Computational approach



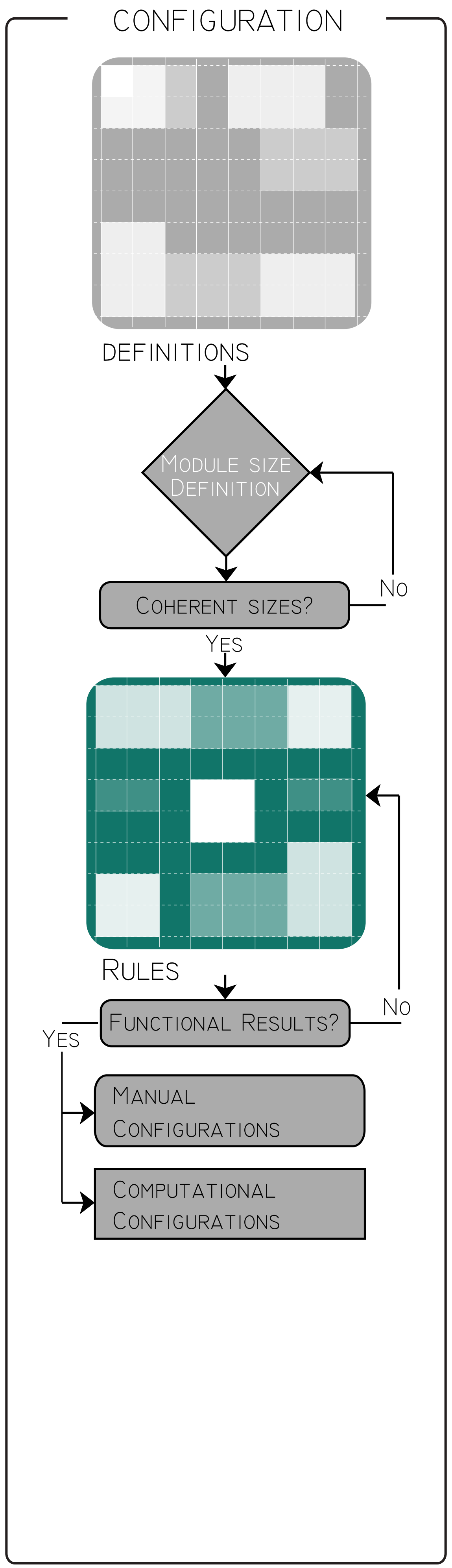


A grid was made with help of phyton so the measurement of the module could be translated to the unit. With the help from the SortalGI Grasshopper plug-in that support specification and application of both parametric and non-parametric shape rules and the generation of single or multiple rule application through pre-sets from phyton scripts, a unit configuration was tried.

With the rule that could move a square up and down regarding a reference, a simple configuration was made.

This script did not support all the rules and it should be joined with the room configuration script for more accurate and developed results.

Figure 45. Unit Configuration computational approach



3 Configuration Rules: Cluster

1.Defining the cluster size (grid) by density of the context and amount of families that want to be together (loop restarts if the space was not enough)

2. Services were located on the opposite corners of the cluster, creating also service plazas with a minimum of 48 modules.

3. Entrance on the desired side of the cluster with at least 6 modules free.

4. Farm was located at the center so that all the units could take care and look at it.

5. Size of the farm according to the modules got from the room matrix.

6. Locate the units letting 3 module space between unit and farms to allow circulation.

7. Size the length of the verandahs accordingly.

8. All the modules left become courtyard (not forgetting to check the minimums stated to accomplish the perfect living conditions)

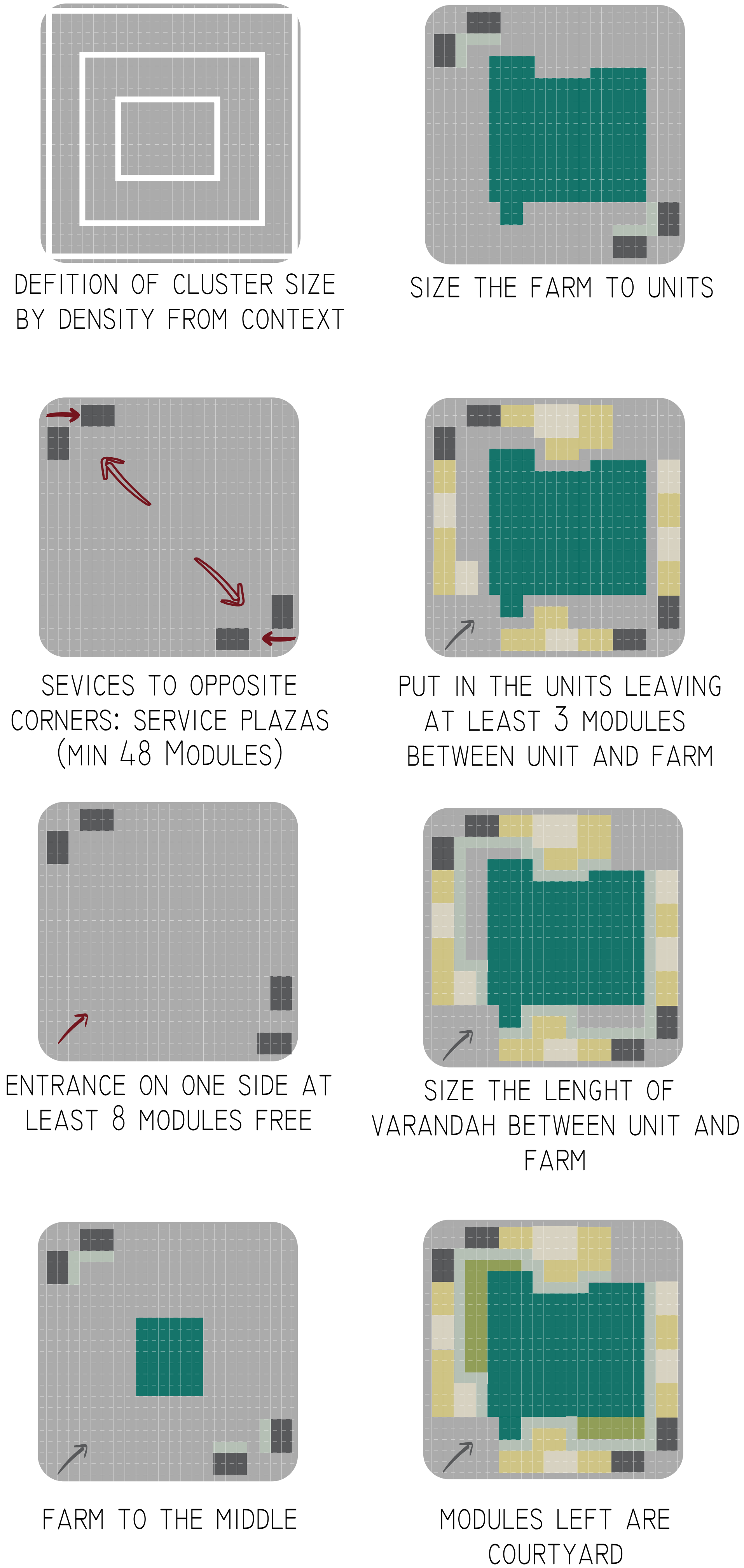
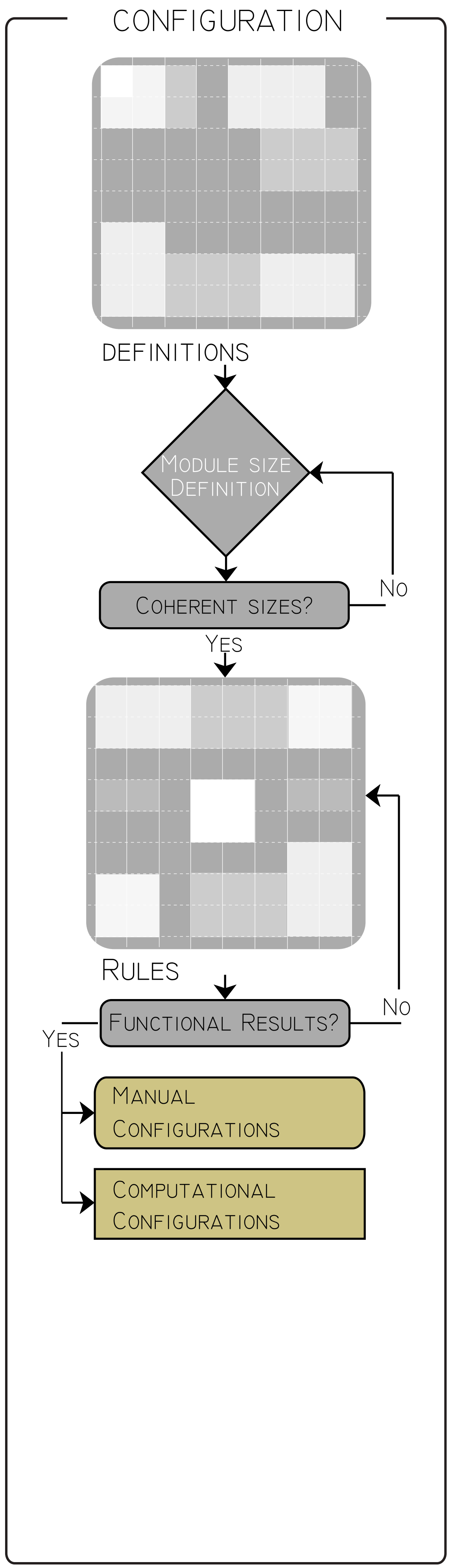


Figure 46. Cluster Rules



Configuration Rules for cluster: manual approach

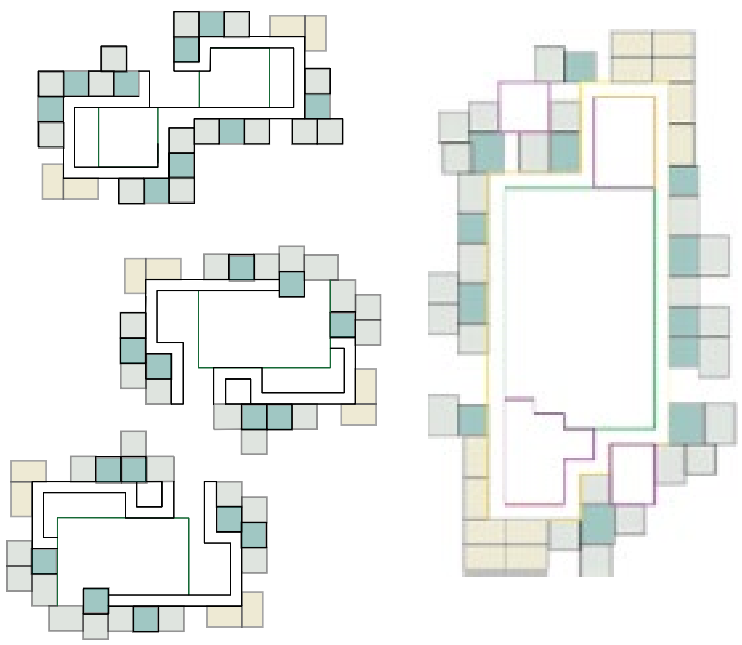


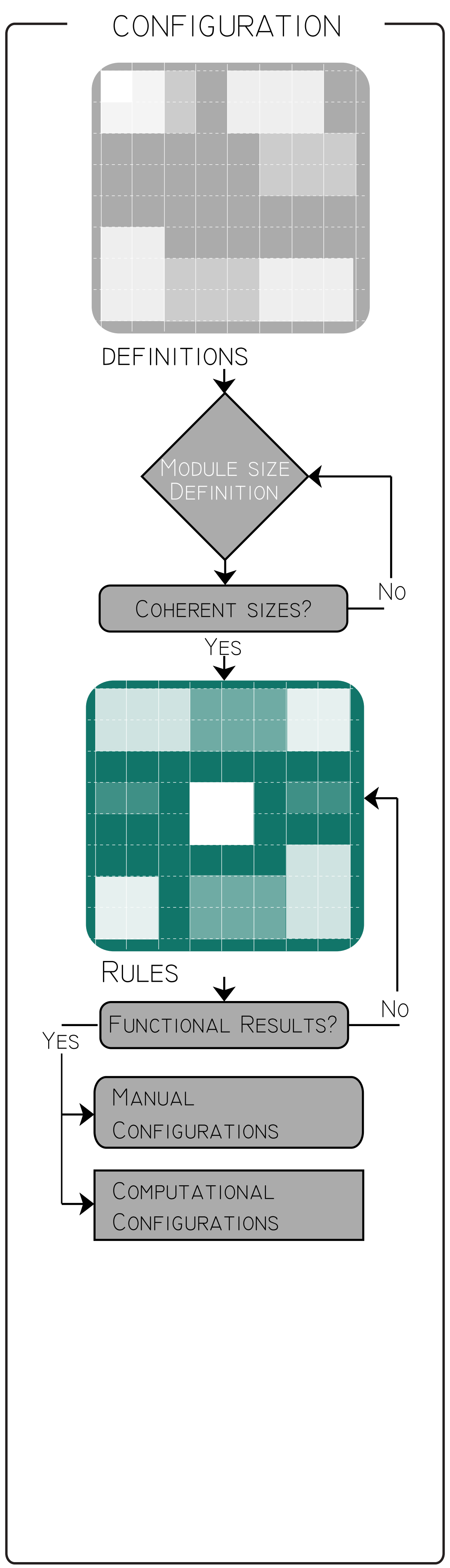
Figure 47. Manual configurations of clusters

computational approach

Figure 48. Computational configurations of large clusters

Parallel to our rule making, the application of them was also done to ensure that no problems would arise whilst the different variation of cluster were created. For the creation of small and medium variations, no problems were identified. On the other hand, creating a manual large variation of the cluster proved to be a great challenge. It took much longer, and the various iterations from the rules were harder to follow on such a bigger scale. For this reason a computational approach was tried and was suggested for the larger clusters.

With the help of an external plugin for grasshopper named Magnetizing-Floor Generator, the study of different variation possibilities of arranging the required program for the project with each other was done. The plugin requires manual input of connections between the program and an approximation of the area required by each program. All these iterations shown in the figure above were some of the possible arrangements for a cluster in the project Bustan. One example from these was chosen and was further developed into our project.



3 Configuration Rules: Urban

A set of urban rules was also developed to complement the cluster, unit and room configurations. The main idea of these rules was the organic growth of the place from a camp to a makeshift city. For these, the rules then had to revolve around three main elements: the relationship of the clusters to other clusters, the relationship of the clusters to other facilities (hammam, school, etc) and the relationship of the housing clusters to secondary and main streets and other required protection. All these by still allowing for privacy, safety and proper climatic conditions in between.

Clusters to clusters
Cluster to cluster should have a minimum of 4 modules, to avoid the creation of unused and empty spaces, or sudden closed streets. These spaces became Sabats. The junction between 4 or more cluster created a pocket plaza or small parks protected by the families surrounding it. Any empty space between two units within a cluster became an Iwan (closing the cluster without breaking the physical connection).

Cluster protection
Typical street: Minimum two modules for cluster safety plus 4 modules of pedestrian area.
Main street: Minimum two modules for cluster safety plus 6 modules of pedestrian area (more traffic)
Wind/Sand storm: Clusters located at the North west and West districts should not have jalousie towards the outside. If windows were desired, they should be operable to protect.
Cross junction street: Minimum 6 modules distance.

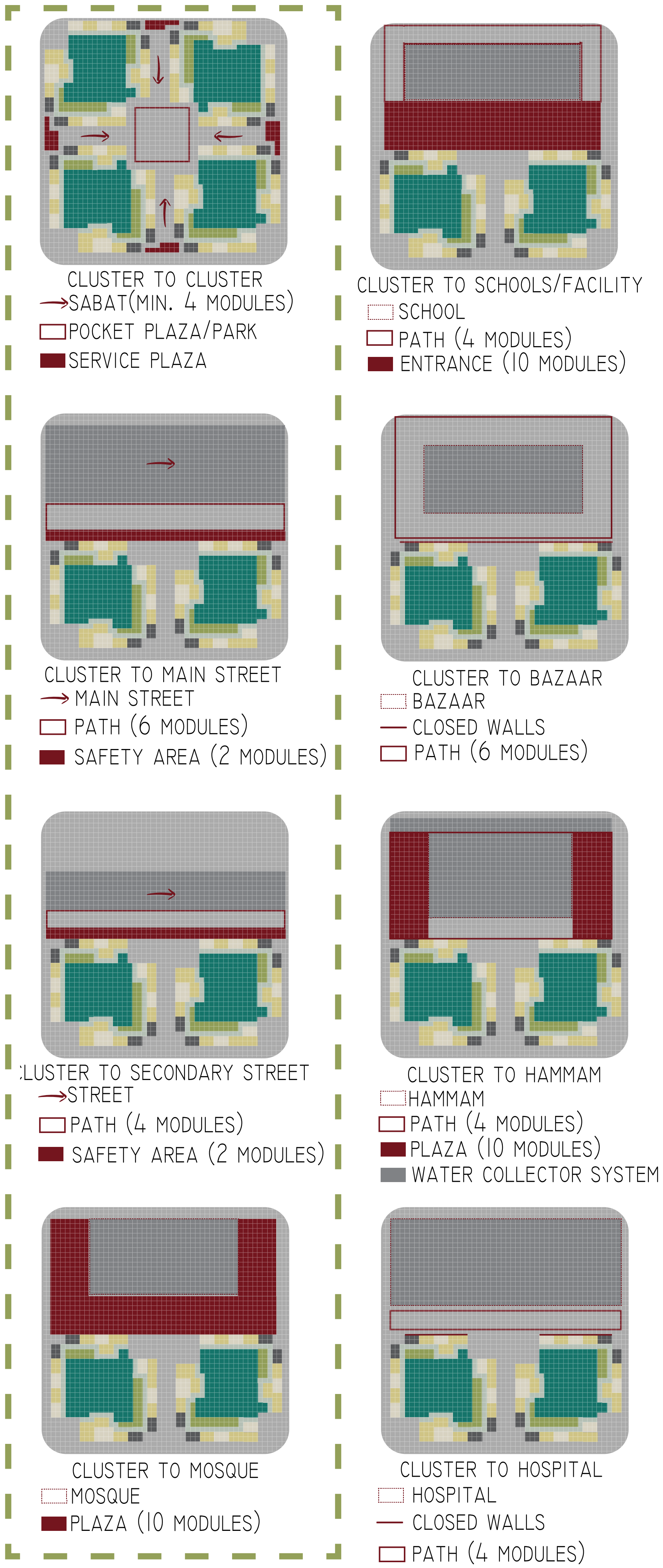
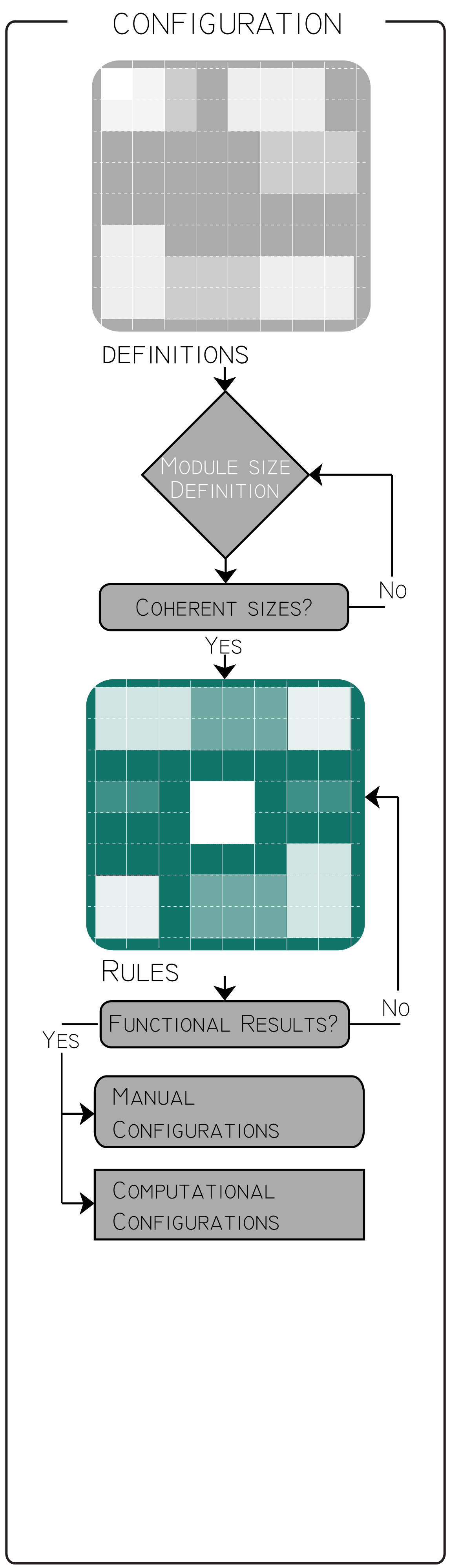


Figure 49. Urban Rules



Clusters to facilities

School: Should have an offset of minimum of 4 modules (in accordance to the biggest school being of around 37 x 35 mts, data taken from the Sand castle group) One side should be 10 modules to allow for a proper entrance. Windows towards the school can be opened to increase connection as a sense of security.

Hammam: One side should have a minimum of 4 modules offset for pedestrian movement. Two sides with 10 modules to create open plazas for religious purposes (The need for these gathering area right outside the Hammam was information obtained from Hammam group). One side should also be left empty to allow for grey water collection to be used for the farming. (size to vary depending on the Hammam's final output)

Bazaar: Minimum 4 modules of offset for pedestrian way. Closed walls towards the back of bazaar for security and hygiene reason, since there you would be probably the service doors.

Hospital: Minimum 4 modules of offset for pedestrian way. Closed walls towards hospital to allow privacy.
Skill centre: Minimum 4 modules to allow pedestrian movement. Possible plaza inclusion depending on the center's size.

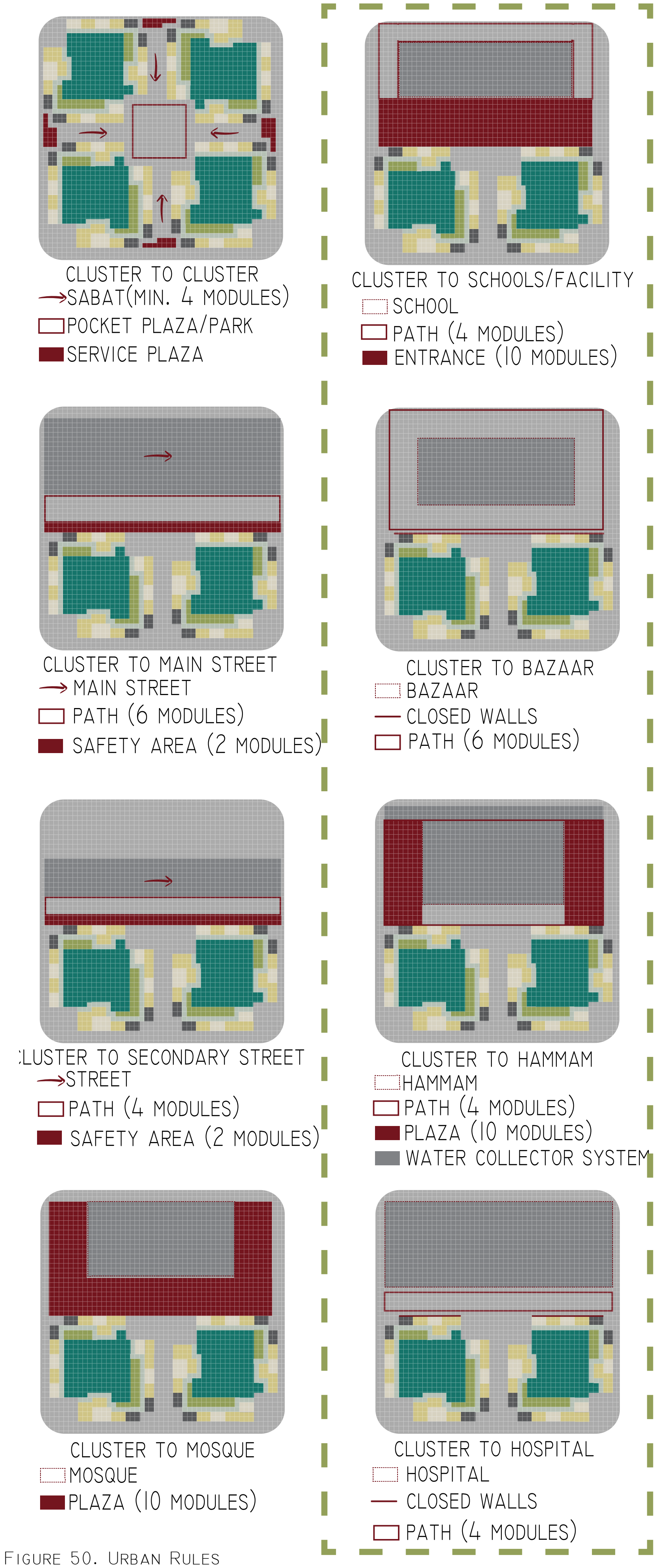
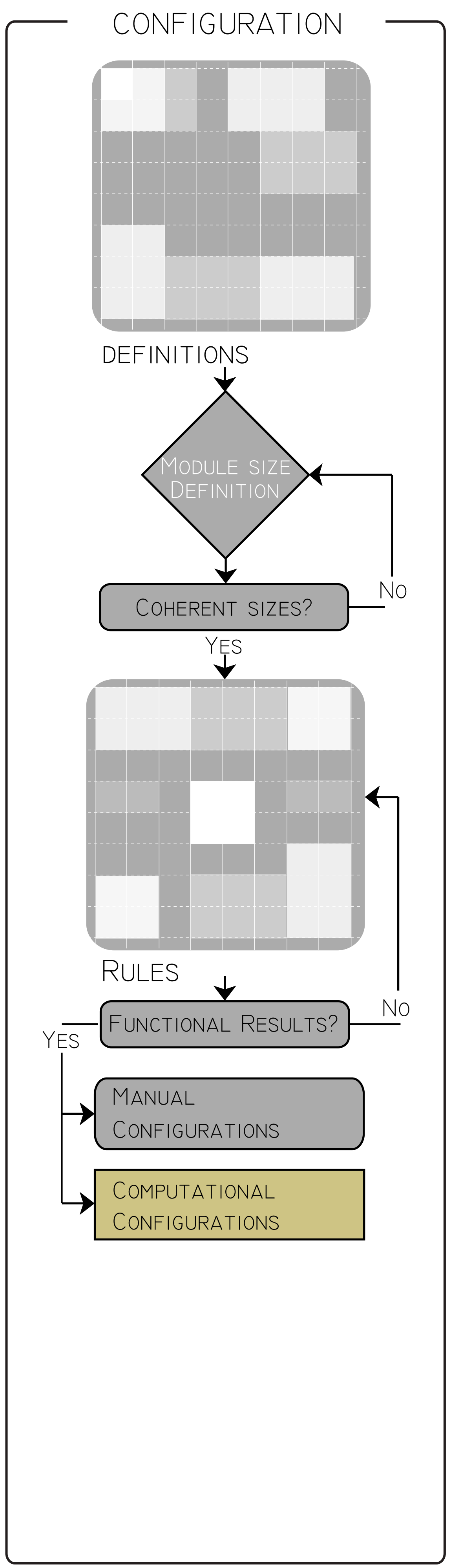


Figure 50. Urban Rules



Configuration Rules: Computational approach

The set of rules mentioned before were implemented in a computational script. Not all the rules were possible due to time and skill constraints, but the street rules along with the distances between clusters were applied.

Two districts from Zaatari camp were used as starting points, along with their existing streets. A reference point at the cross junction of the streets was added to aid the rest of the process (1).

The coordinates of the corner point (2) of the district were needed to start the organic growth of the clusters. For this the rules for the main and secondary streets were done with a small python script that offsets an existing curve a "it" desired times, a certain "dist" needed (with - or + as direction of the movement) as shown on the image to the right (3).

The last curve was extracted from the python script and the control points identified. These points then became candidates for the main corner point needed but for that the closest to the junction street was needed (although it must be noted, that this reference point could vary depending on the situation of the district, it could ultimately become an existing facility, the middle of a secondary street or any other part of the context that worked as a base).

Once the corner point was identified and its coordinates known, they were used to start the grid system for the iteration of the clusters (4).

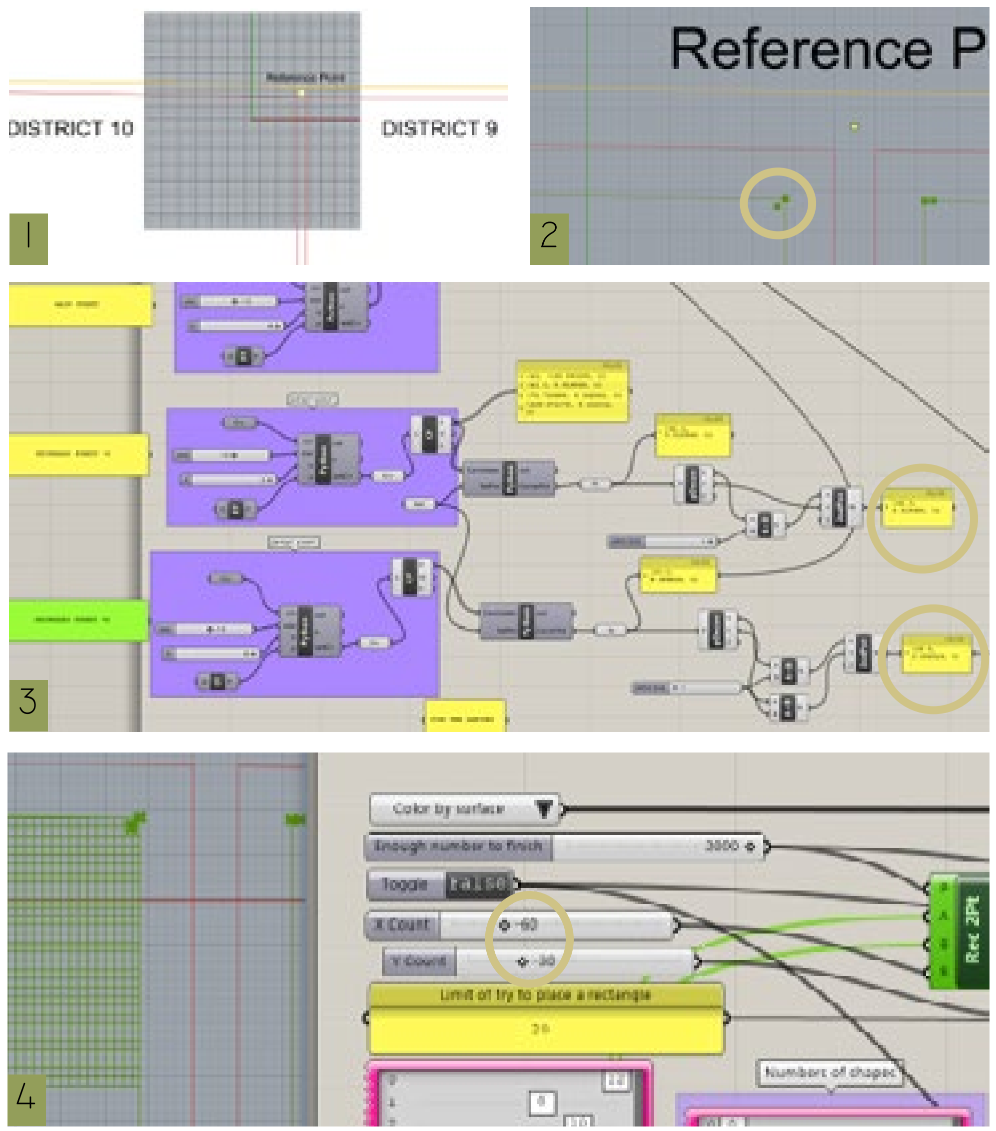
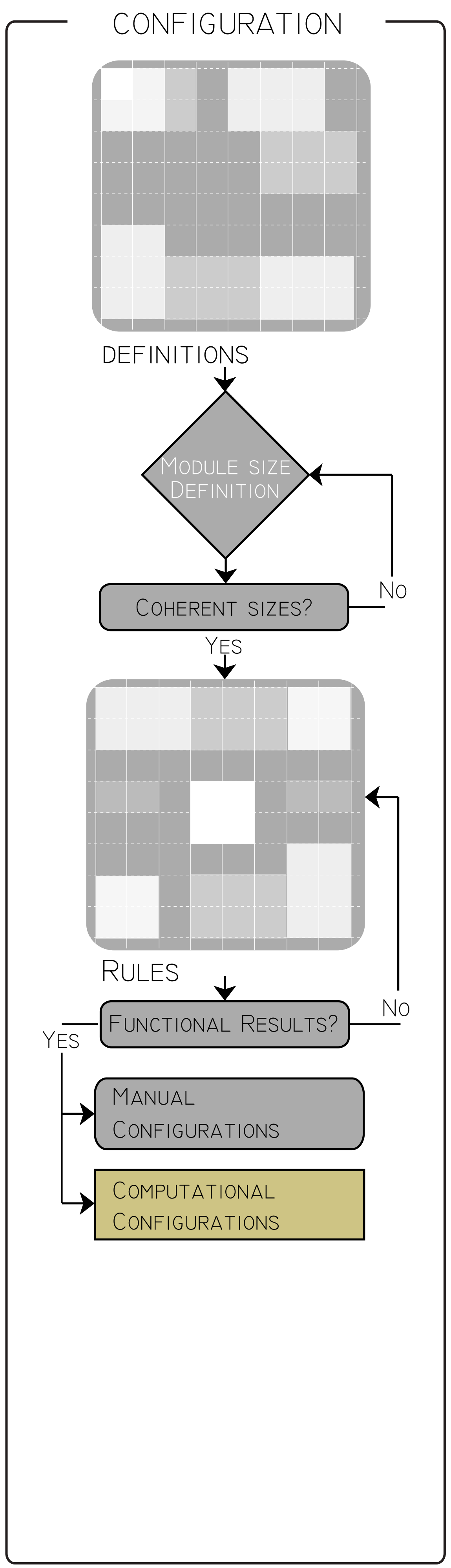


Figure 51. Urban Computational approach



Parts of the script for the creation of the clusters were used from other authors in the food for rhino blog webpage. Some were then modified and parts added so that it would perform accordingly to our set of rules (Please refer to the Rhino and grasshopper file).

The different cluster size and amount was defined (this would be the input of families wanting to live together). Some problems with the creation of the rectangles was encountered since they were placed all together as a puzzle, and the wish was to allow for circulation space in between the clusters, so a modification of the equation (6) was done to (8), so that the second corner of the rectangle jumped half a space to allow this ventilation space we defined in our rules (Sabat).

The creation and placement of the rectangles was mostly random, for now we established the bigger cluster and facilities as the first two to be placed within the grid, but this could be changed depending on the input of the family, changing parameters of (9). Finally, we obtained such an iteration of large, medium, small clusters and a facility (the square) (10).

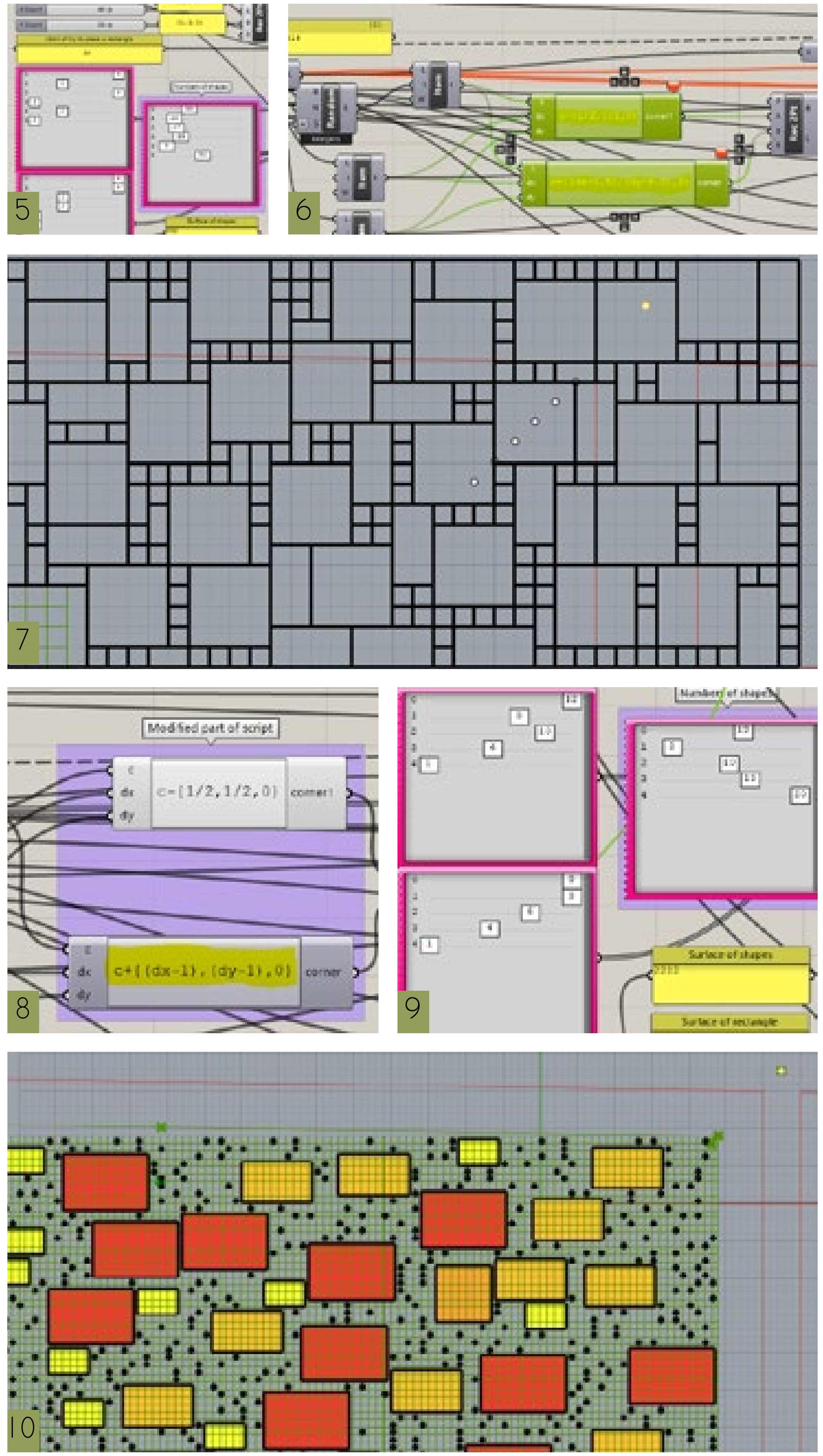
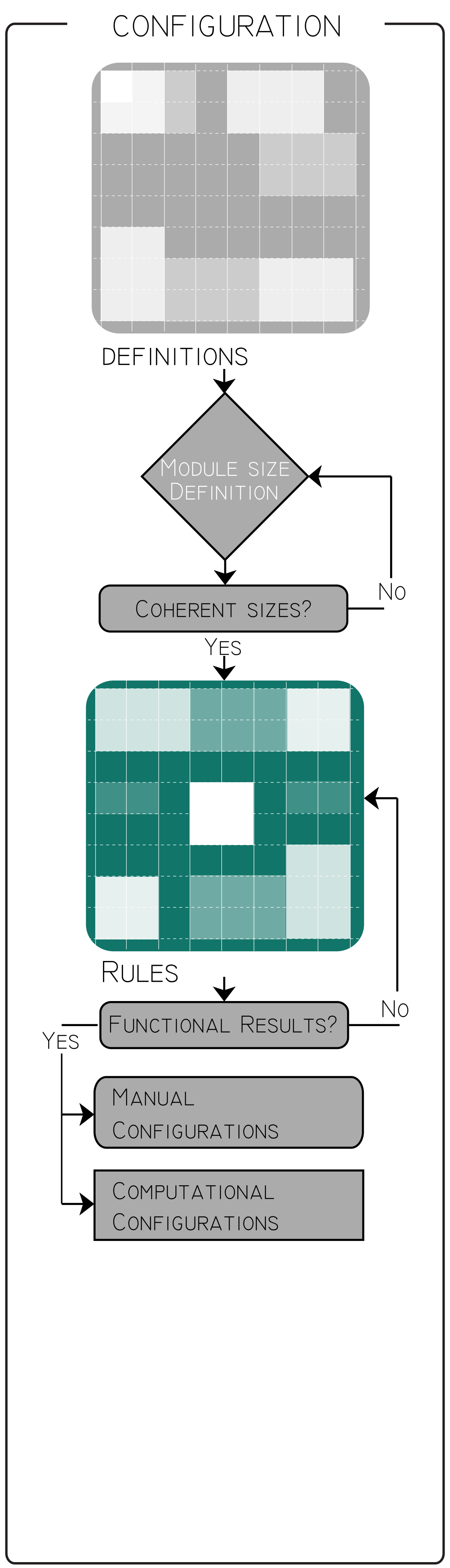


FIGURE 52. URBAN COMPUTATIONAL APPROACH



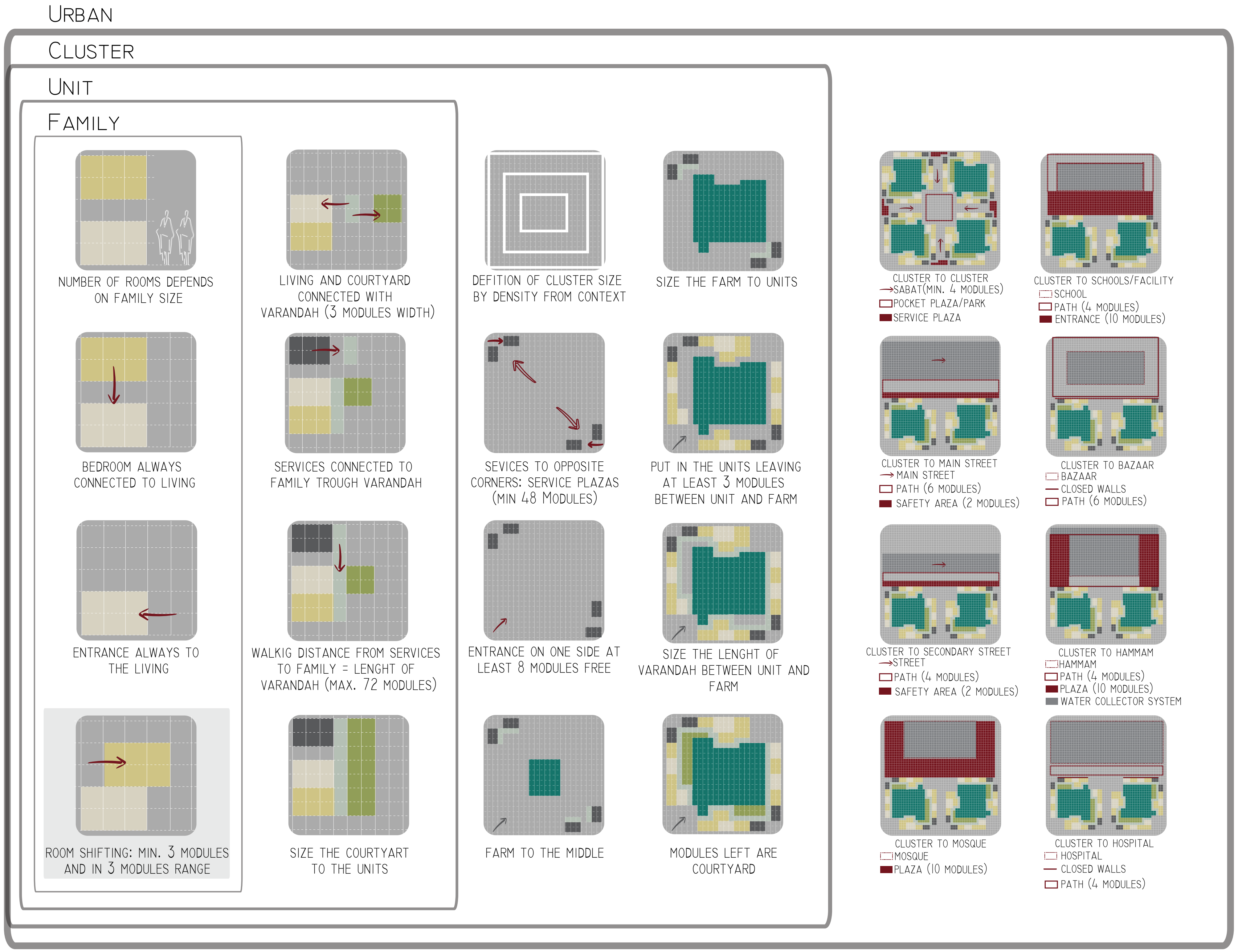
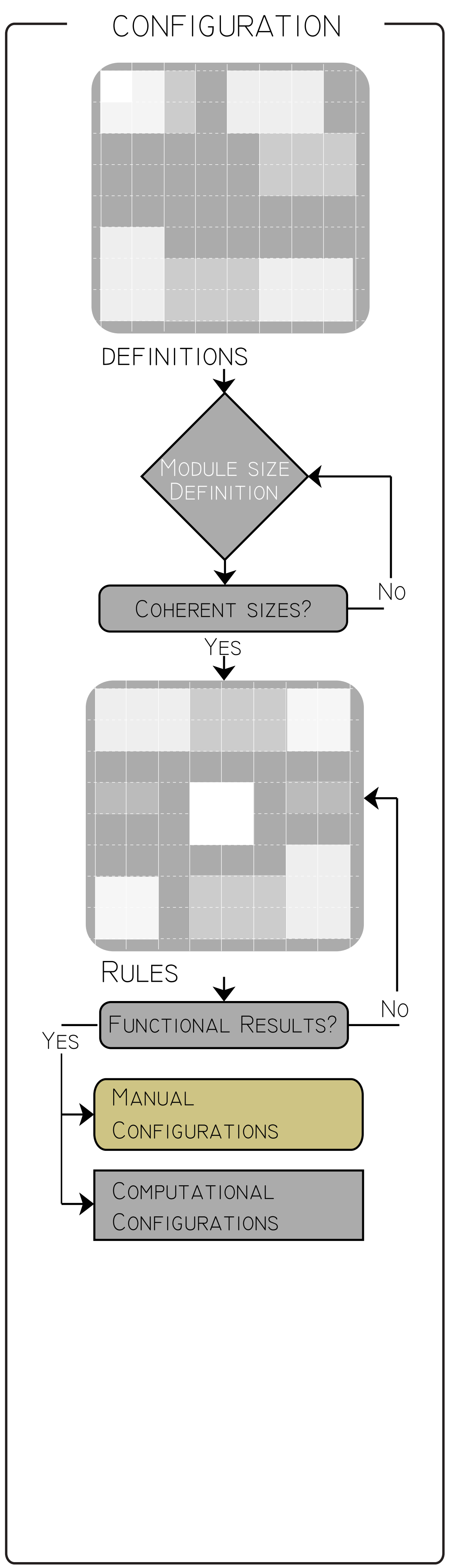


FIGURE 53. BUSTAN RULE SYSTEM



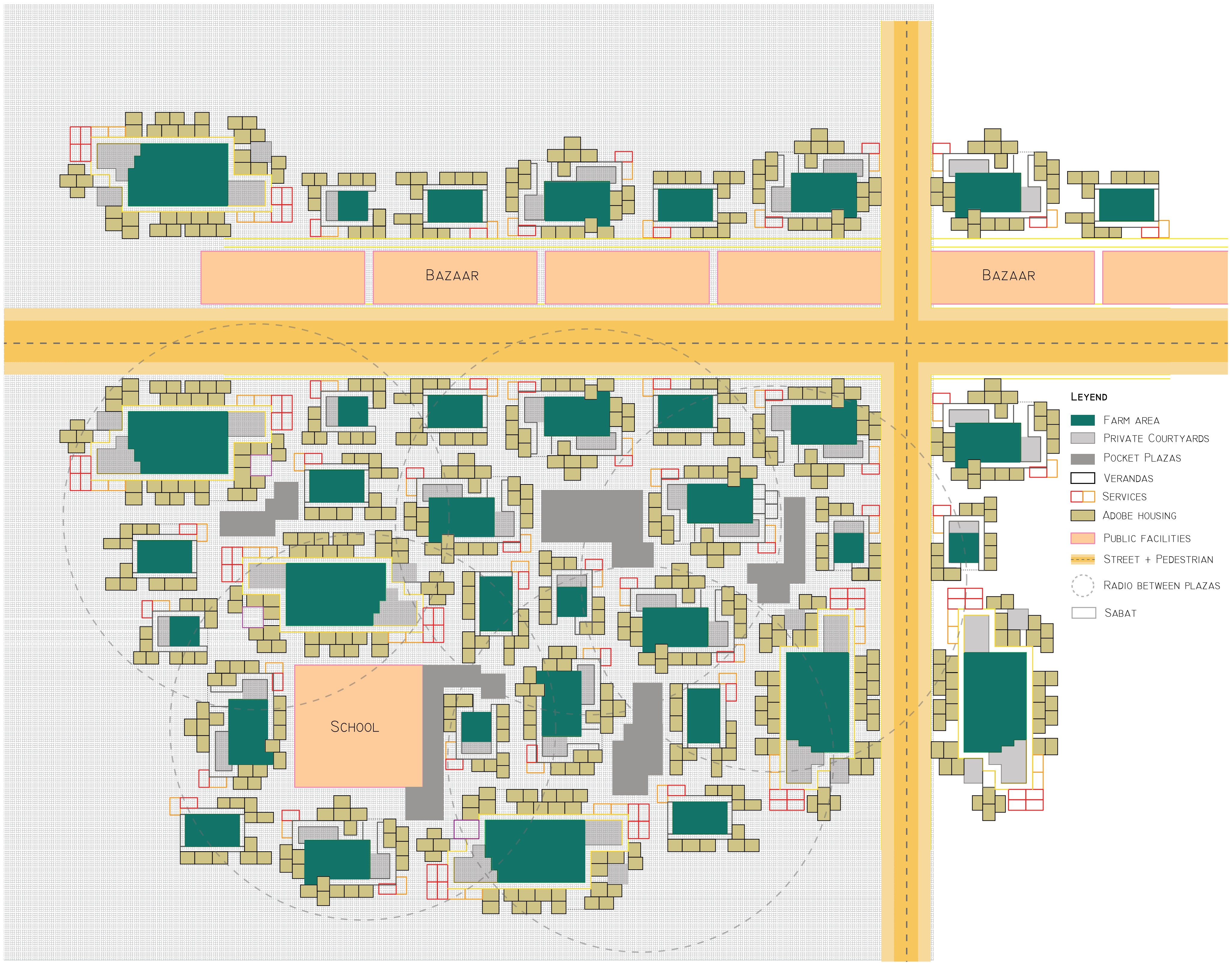
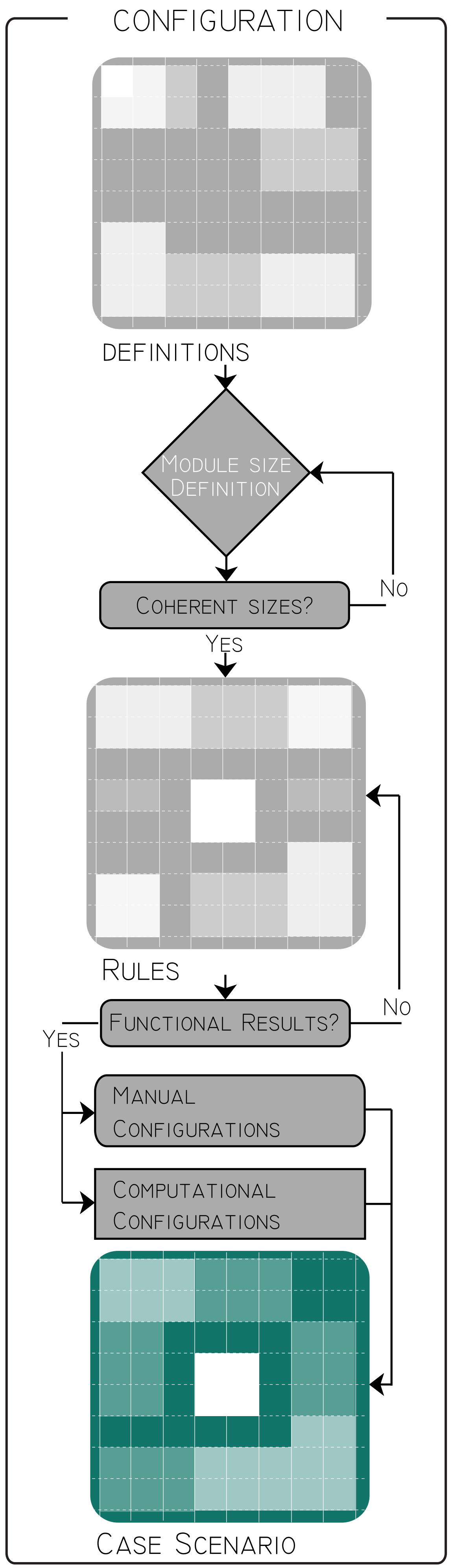


Figure 54. Urban Manual Configuration

A final urban distribution scenario was done to show all the rules applied. In this way the spaces between the cluster created interesting passages such as the Sabats and the combination of more cluster create da common plaza that could later connect with a school if needed. Thus created a new sense of city within the camp.

Figure 55. Images of sabat and plaza



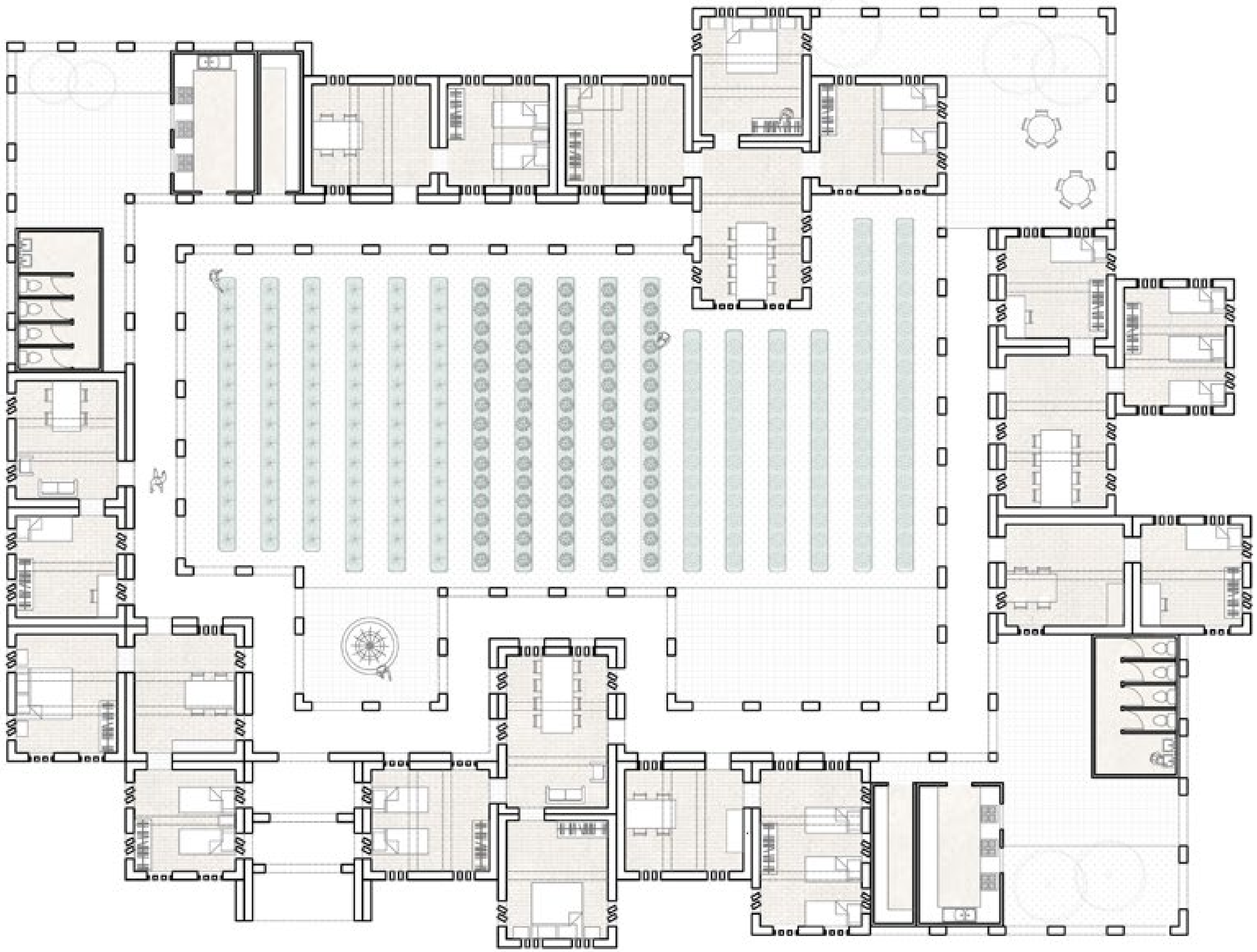


Figure 56. Case Scenario Plan

4 Case scenario

A chosen case scenario with a medium cluster, 3 units and 7 families was chosen to further develop in the forming and structuring stages of the project. This scenario was developed manually and helped to give the final tunings to the configuration rules and the rules later on established for the structural and construction parts.

07 Forming

Main forming goals were set to begin the forming process, this were made based on what the configuration needed from the form.

Based on these goals, a set of rules for forming the rooms was made: these rules defined where to put the openings, the supports, the connections and the ridge points. Thus, these rules where applied to different room configurations to build the unit.

Then the first approach of forming process was presented in order to see the development of the project until a final tessellation was chosen to form the unit.

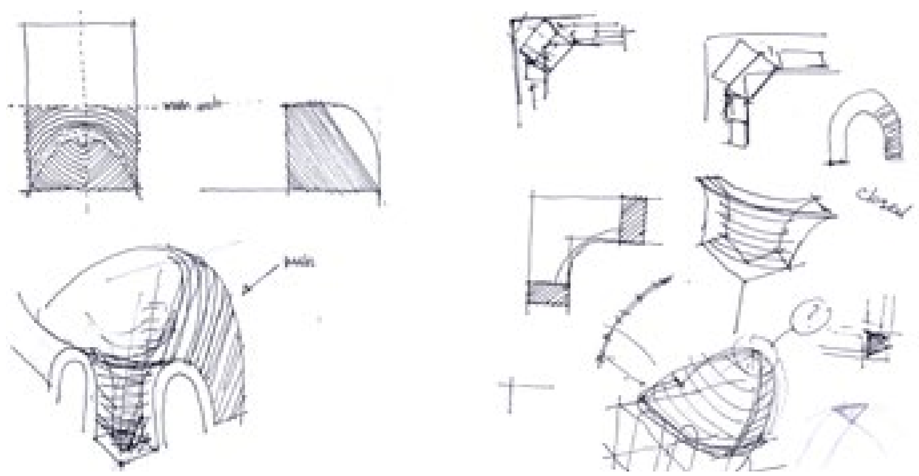
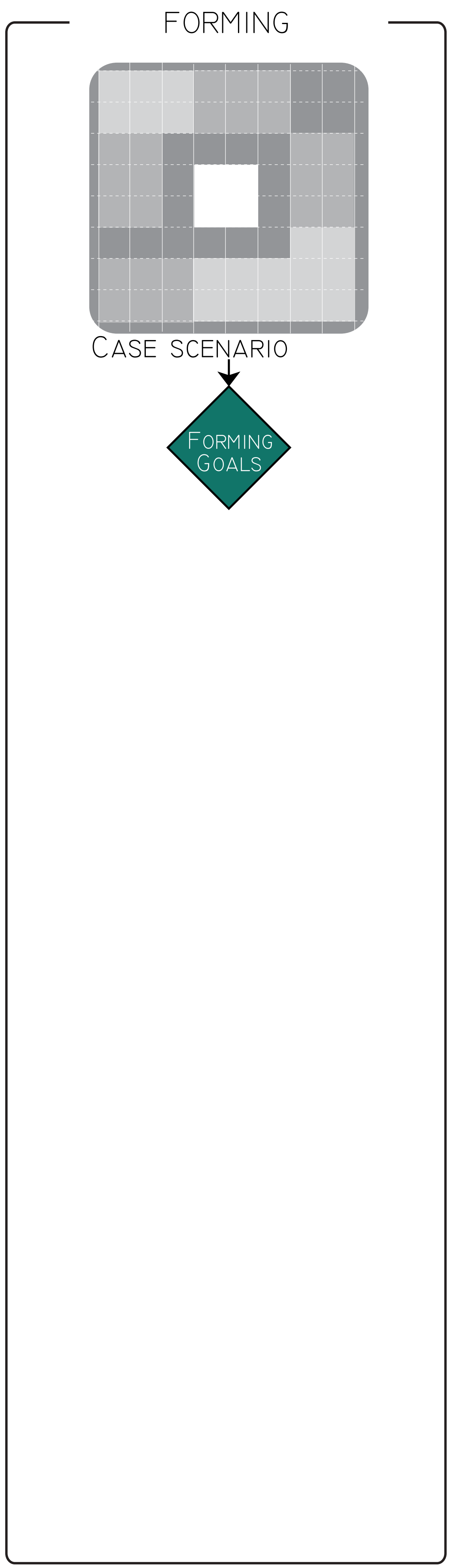


Figure 57. Forming ideas



| Forming goals

A set of goals were set in order to start the forming process. These goals were based on the proposal, the programme and the configuration decisions that were explained in the previous chapters.

To fit the main proposal three goals were set: first, the idea of a modular and easy to replicate form was announced. Also, in order to collect rainwater for farming, the correct slab to all sides of the form was set as another goal.

The variation in the configuration of the project set the forming goal of having a flexible design that can adapt to each configuration possible. There are many scenarios, and a room can have between one and eight openings depending of their use. Therefore, the maximum number of openings was considered for the forming process, if this variation can be formed, so can the others.

This decision allowed the project to have a free facade, which means that the openings can be filled completely or have different patterns depending on the design. Having this flexibility is vital for housing because the user can choose how they want their openings to be: from a proposed catalogue or even designing by themselves.

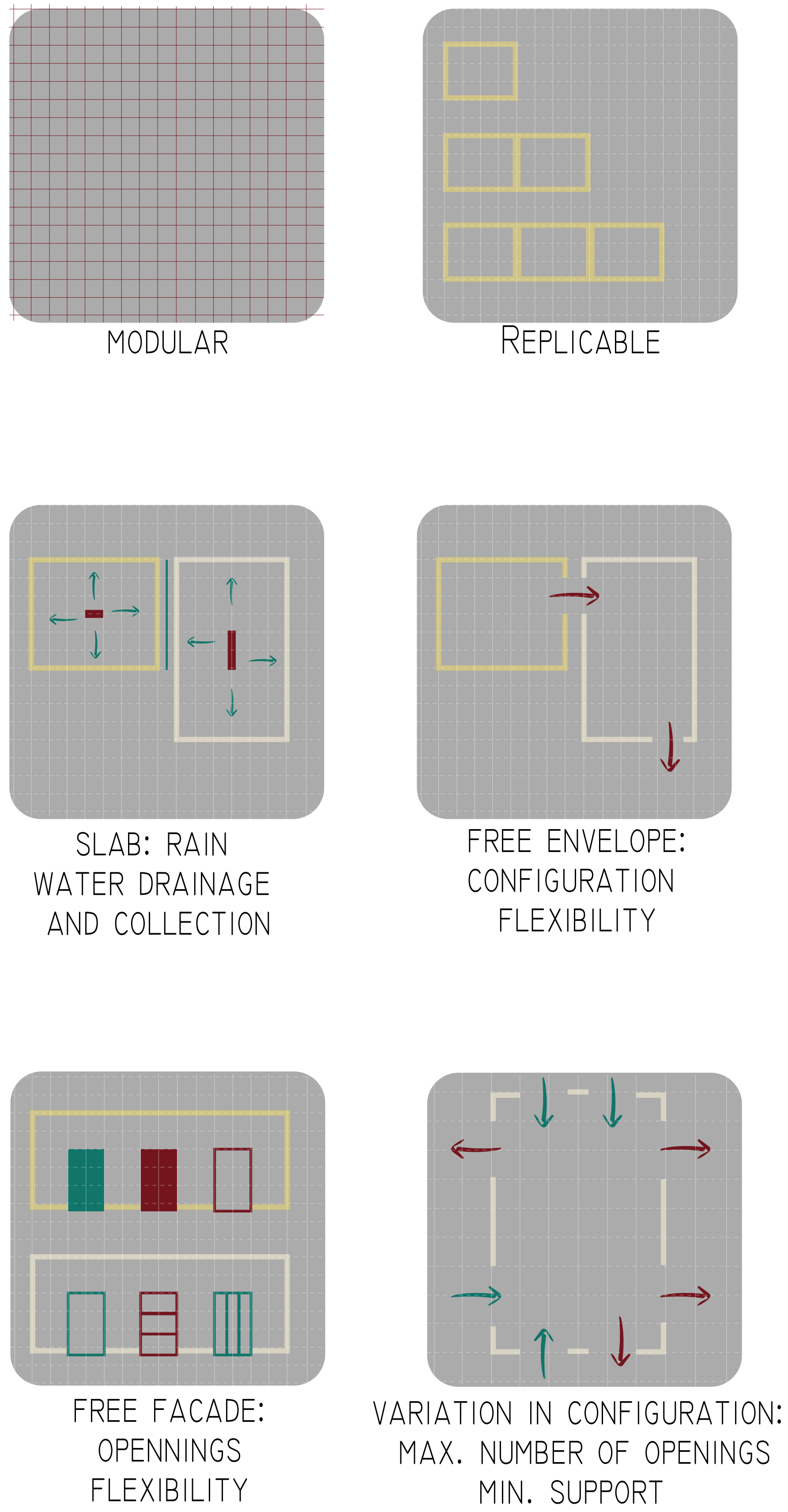
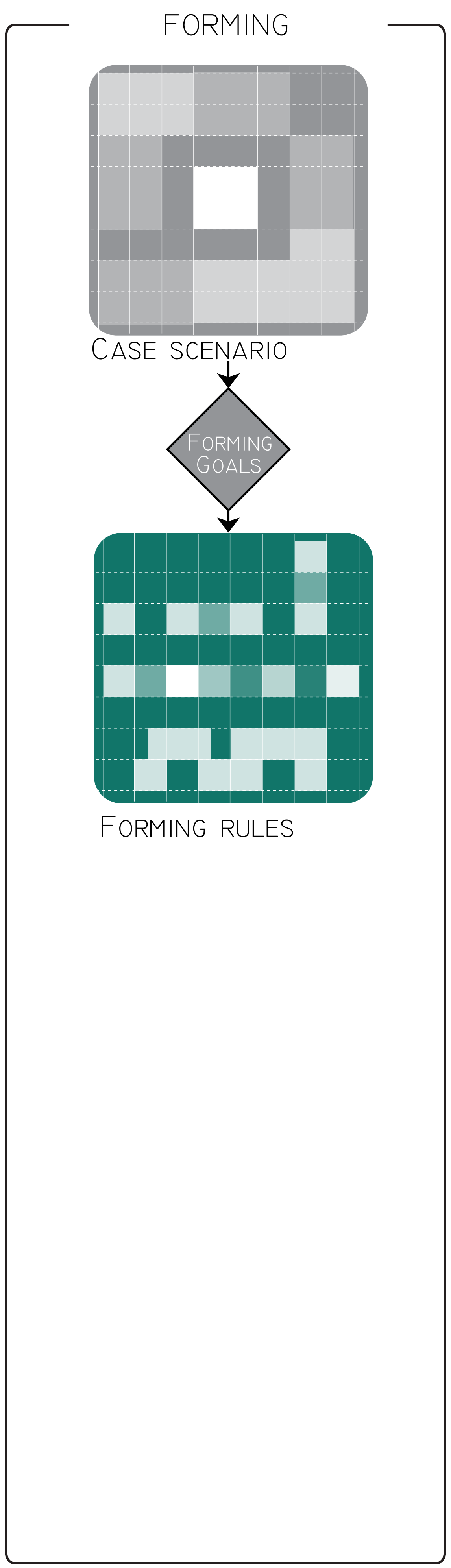


Figure 58. Formig goals



2 Forming rules

Based on the goals it was determined that the forming process should consider the configurational grid. The shape will come from the configuration and should be designed such that opening could be possible in all four sides. The main structure should be the result of these main constriants.

Based on these rules, a unit from the configuration was chosen to continue the forming process. The rules consider the walls, the openings, the joints ,and the top ridge points so that the rooms have the same height.

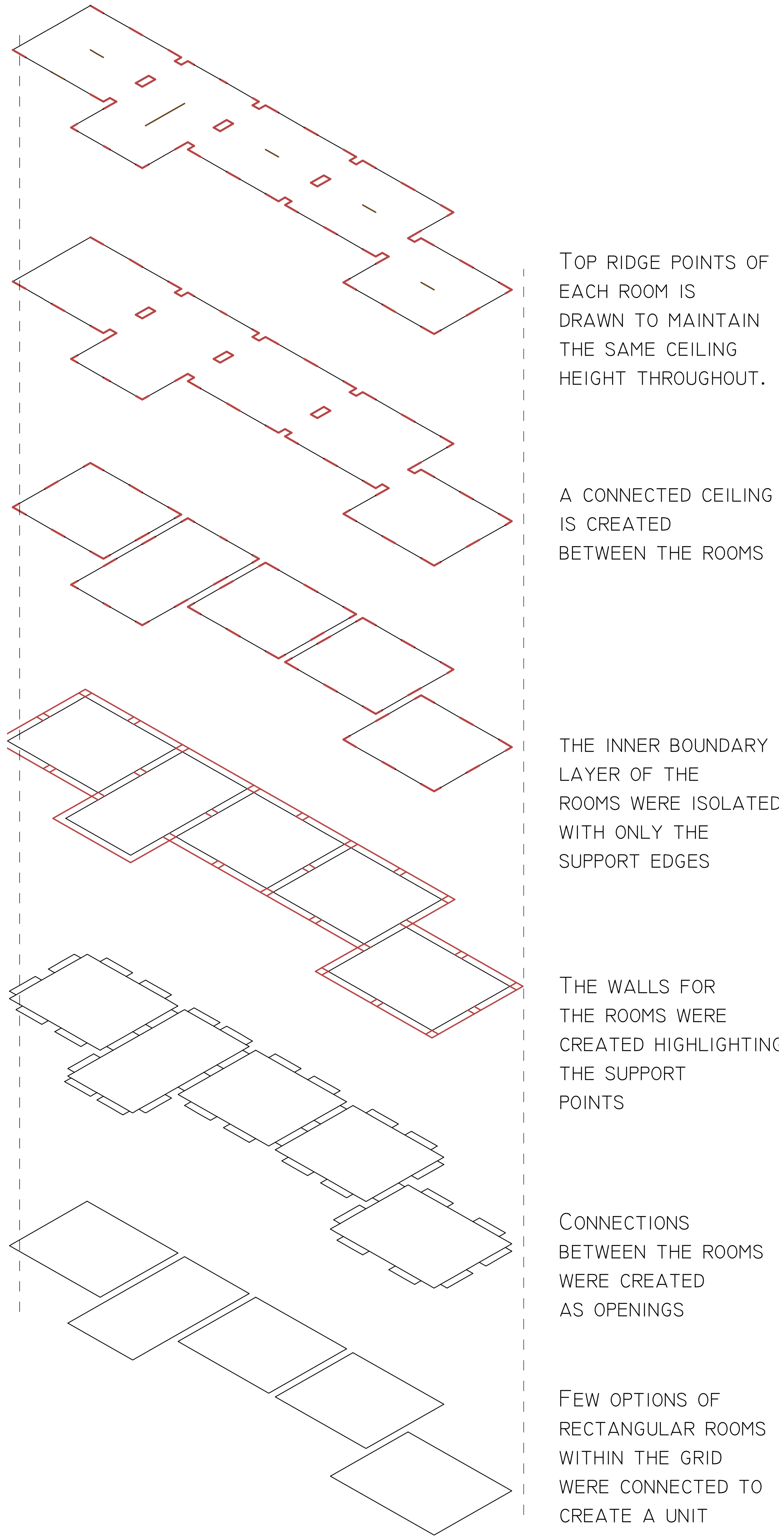
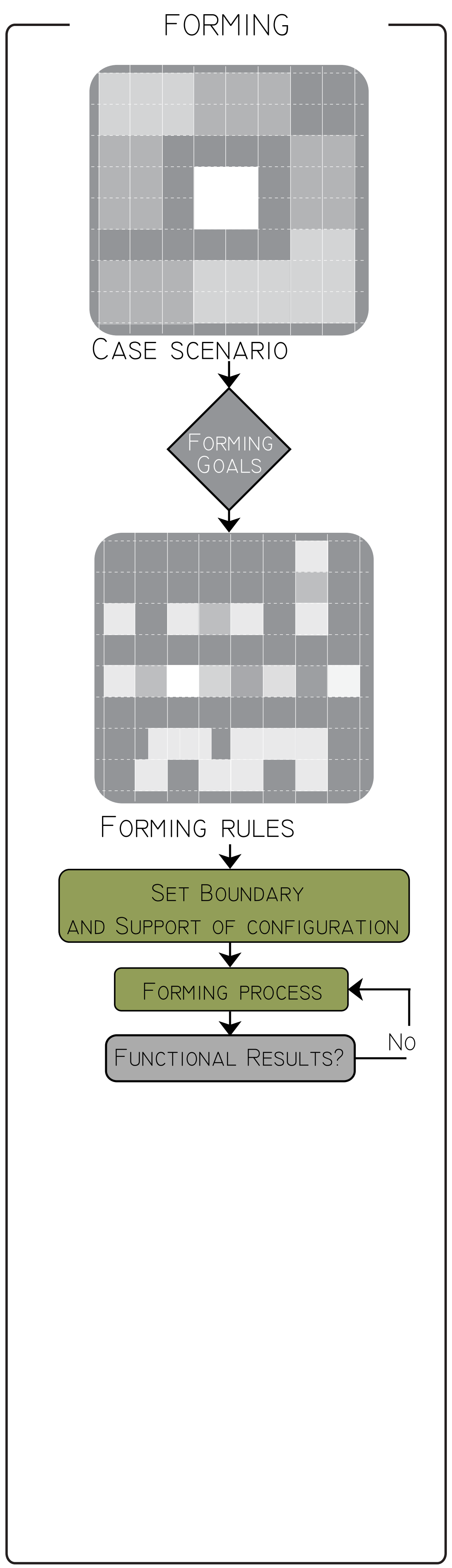
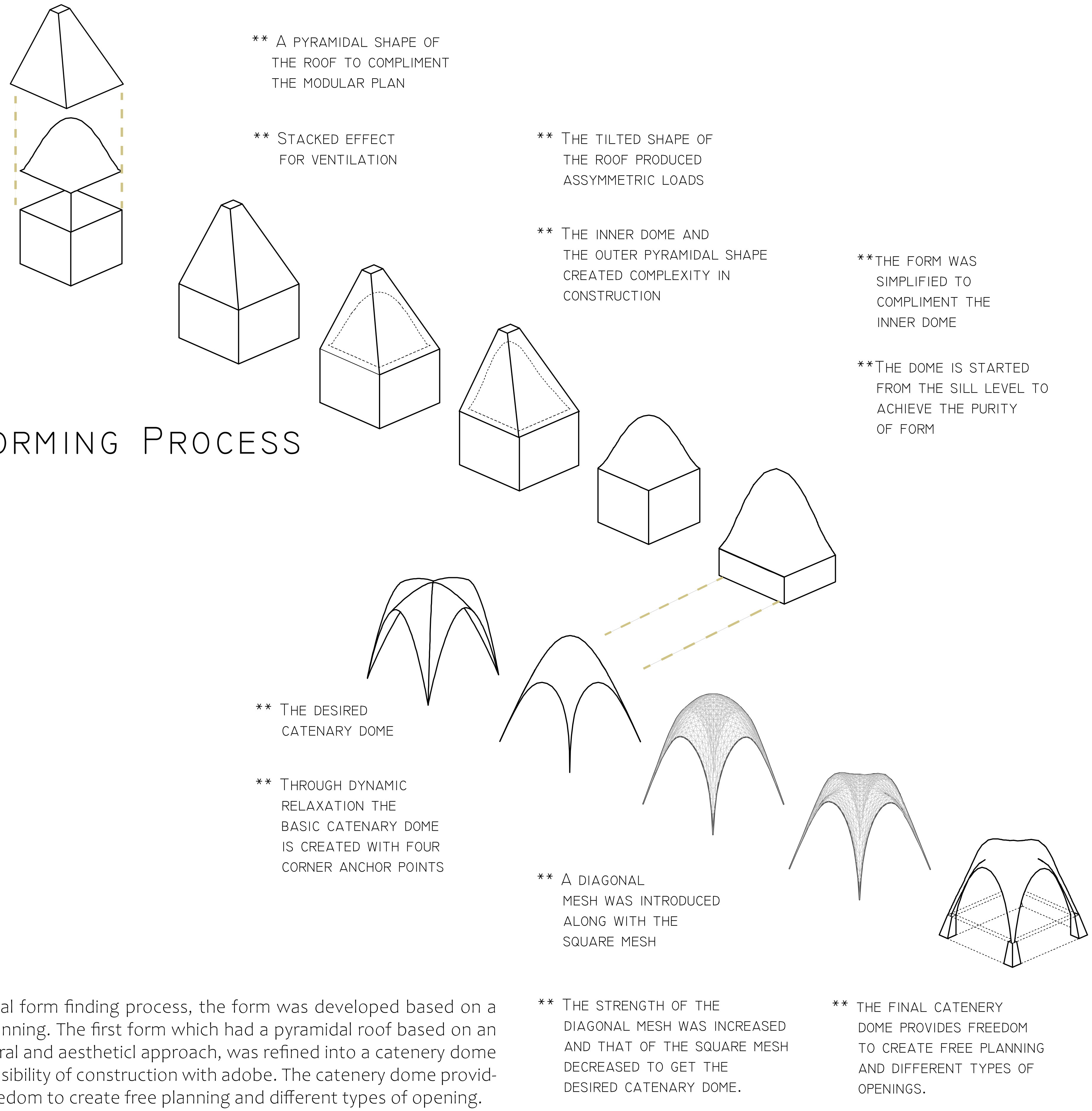


Figure 59. Formig rules

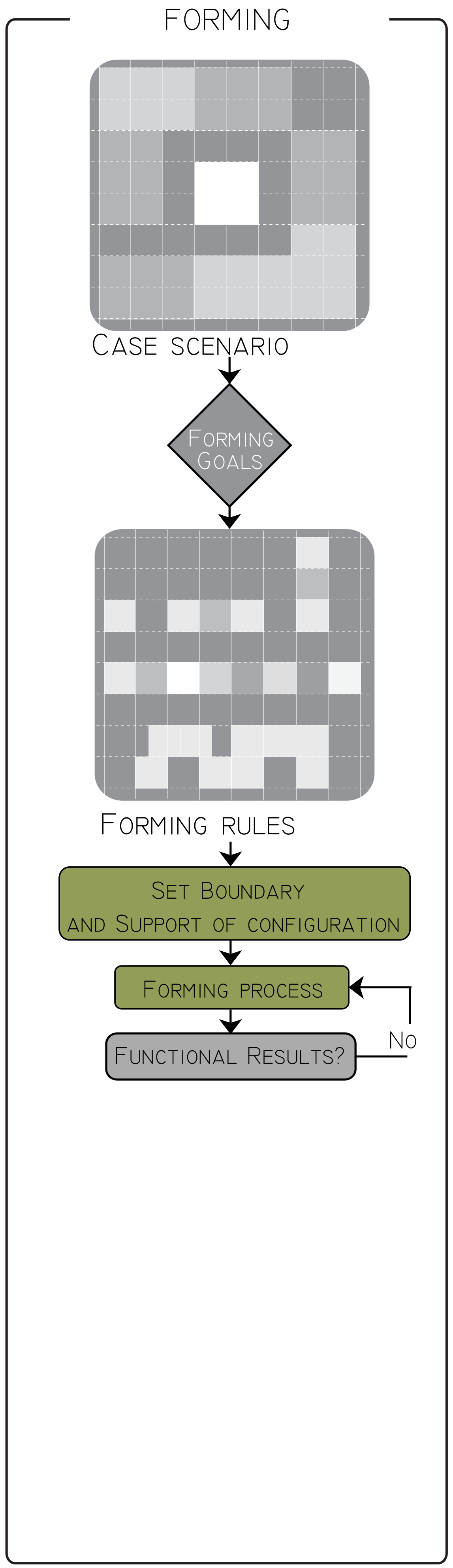


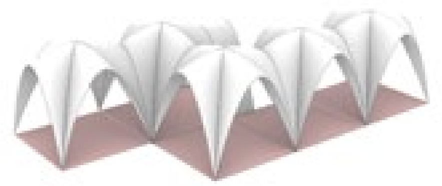
3 Forming Process



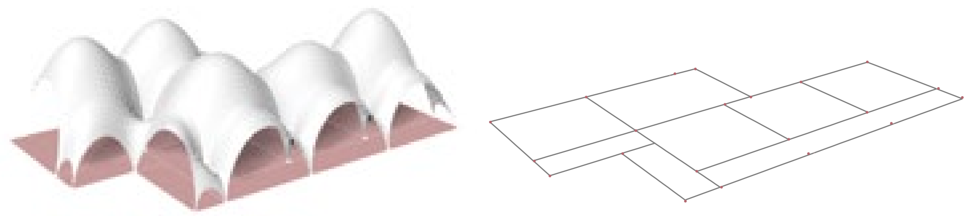
In the initial form finding process, the form was developed based on a square planning. The first form which had a pyramidal roof based on an architectural and aestheticl approach, was refined into a catenery dome for the feasibility of construction with adobe. The catenery dome provided the freedom to create free planning and different types of opening.

Figure 60. Initial Form Findng





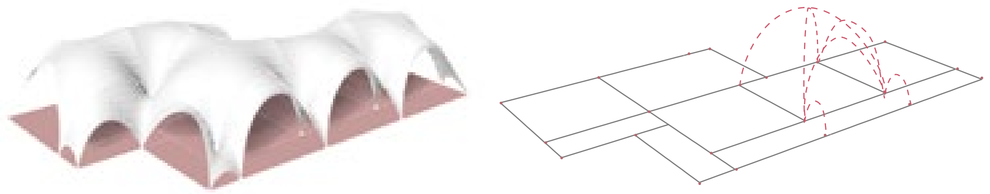
DESIRED FORM



STEP 1

Through dynamic relaxation the square mesh system resulted in steeper domes

The support points are provided at the corners of the rooms

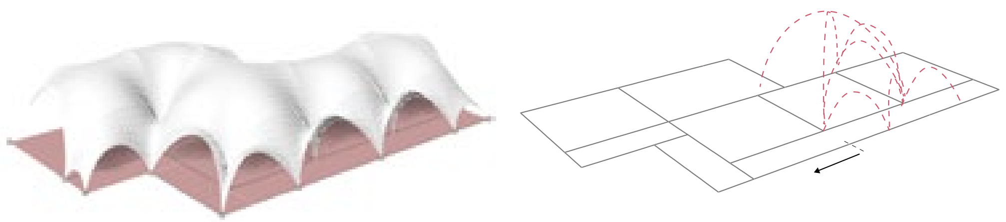


STEP 2

Diagonal meshes are introduced to tighten the dome shapes to lower height

For the corridor the support points are taken parallel to the points of the rooms

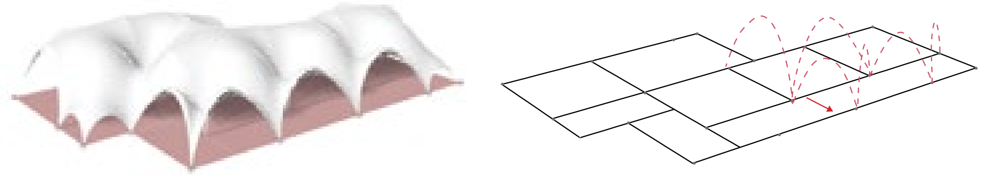
Due to the same loads on the whole mesh and small width of the corridor the iteration resulted in lower height of the arches along the corridor



STEP 3

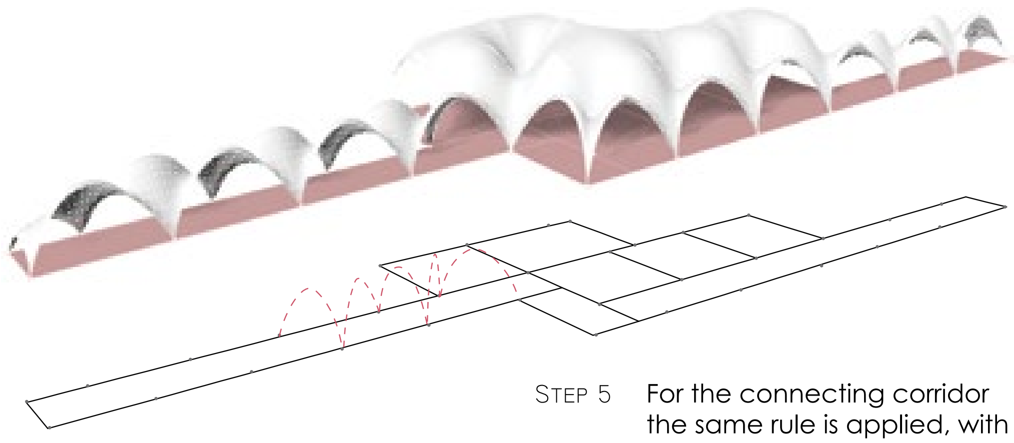
The points at the corridor level were shifted to the mid point of the rooms to achieve the adequate height of the corridor

The corners of the corridor still had a low height



STEP 4

The width of the corridor was increased from 1 module to 1.5 module



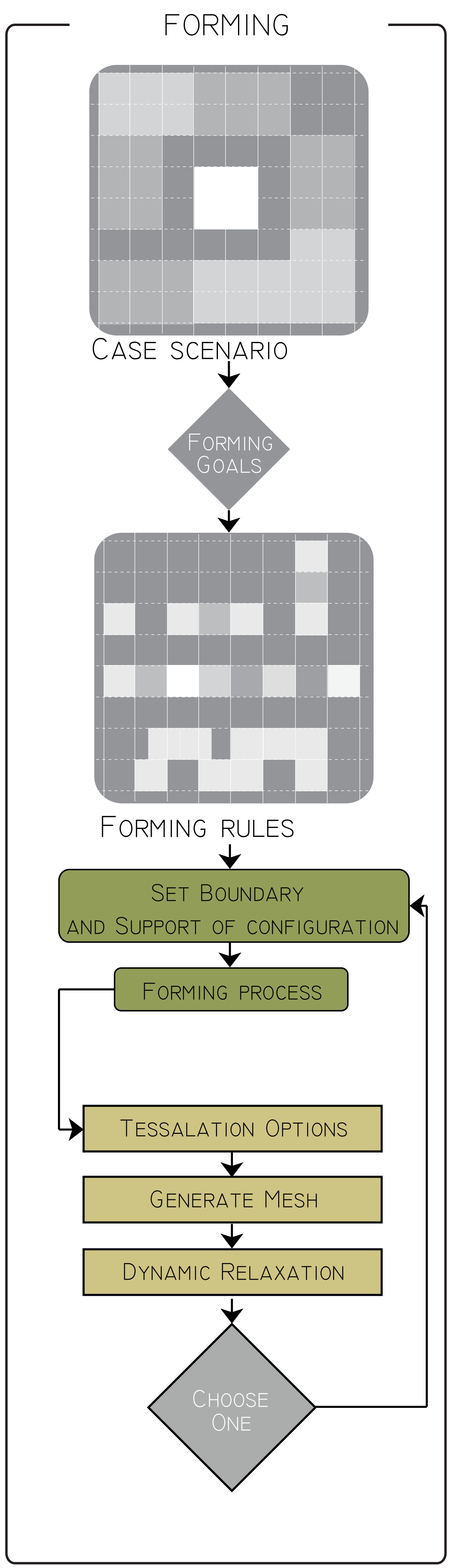
STEP 5

For the connecting corridor the same rule is applied, with anchor points at alternate positions along the corridor.

Through the process the desired height for the rooms and the corridor is achieved

FIGURE 61. INITIAL DYNAMIC RELAXATION

According to the steps described above, a dynamically relaxed shape of the desired form was developed using kangaroo. However, the aesthetic quality and the constructability of the structure was still in question.



First tessalation approach

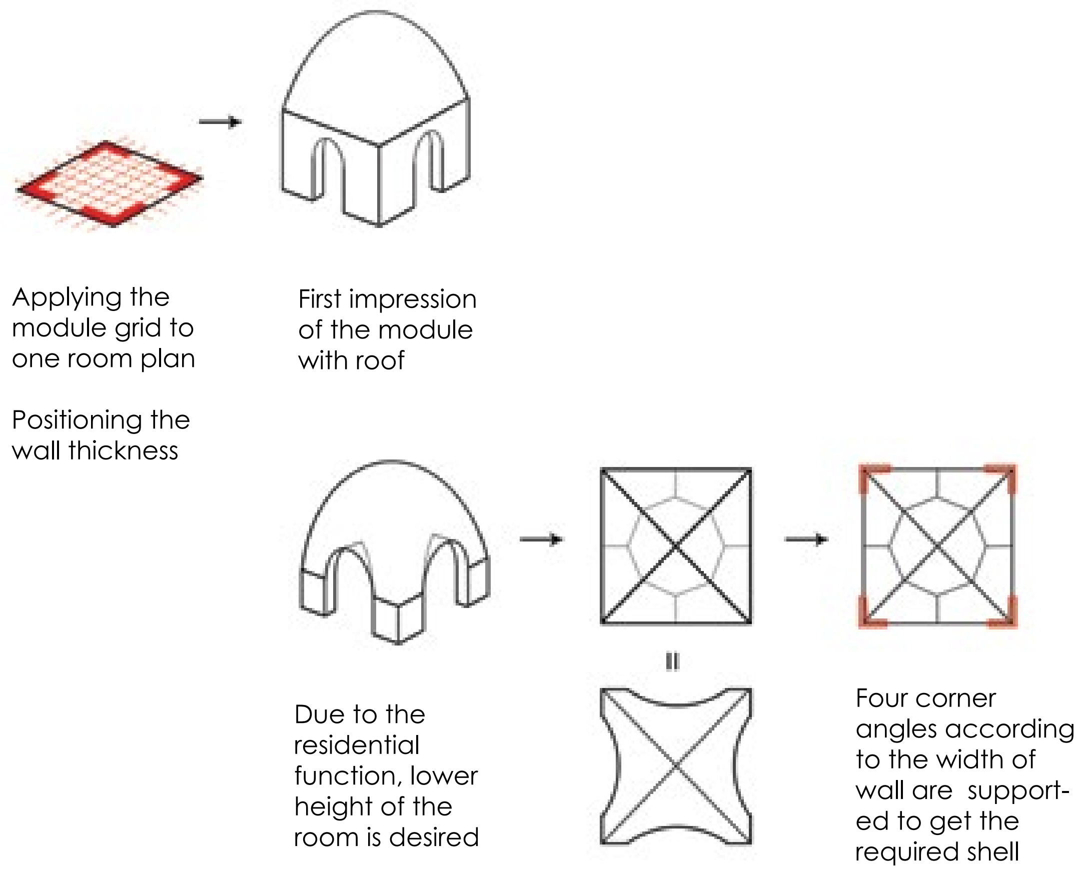
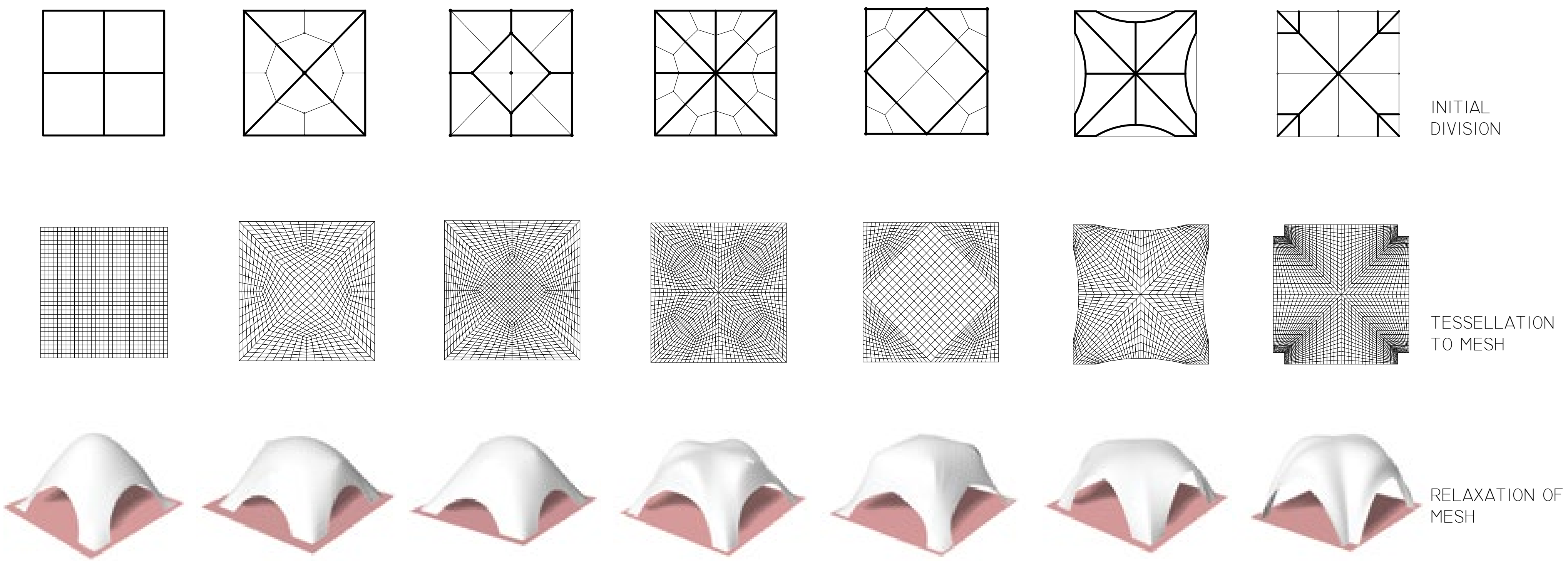


Figure x. Initial Geometry prior tessalation



To check The form

Convex Corners

Diagonal at the Corners

Bumps on the Surface

To merge Previous two

Bumps on the Surface

With further Divisions

Groined vaulted Dome

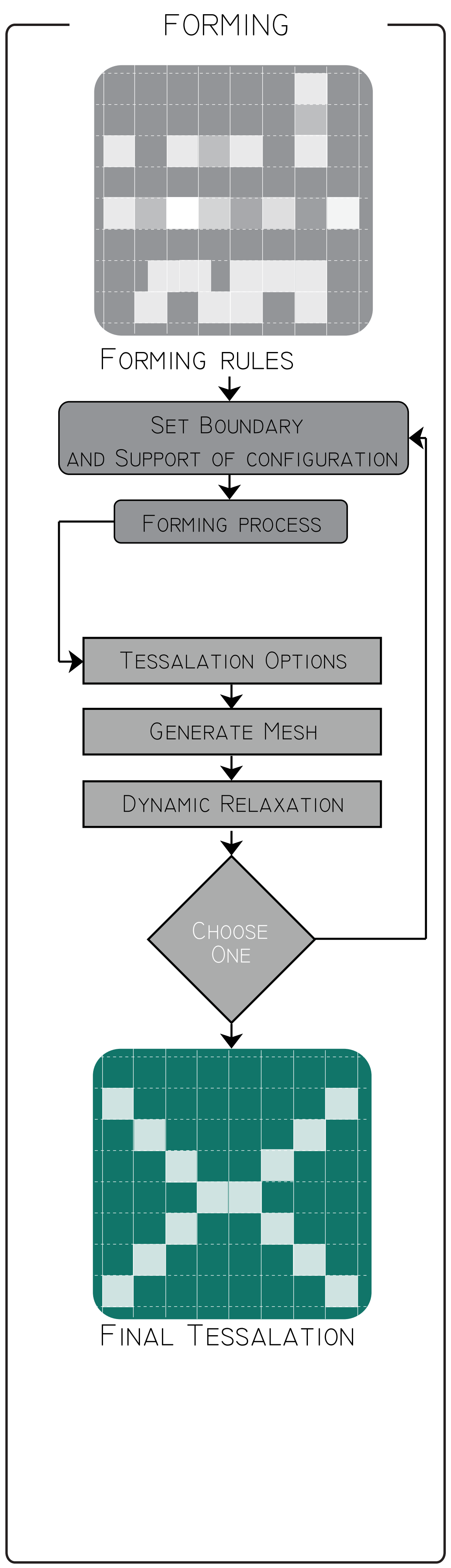
Trying third with Bigger rectangle

Irregular Curvatures

Cutting the edges of the rectangular geometry

Cutting the corners of the rectangular geometry

Figure 62. Initial Tessalation Process



4 FINAL TESSALATION

The tessellation lines were generated using weaverbird plugin in grass-hopper. The component Constant Quads Split Subdivision takes up to the enclosure of four edges and subdivides it in quadruples. the subdivided lines were applied with uniform strength and load which gave dynamically relaxed surface using the solver
component in Kangaroo plugin.

From the initial trials of tessellation, the tessellation for smooth surface, straight corners and with side openings was figured out. However, the next task was to apply it to the rectilinear surfaces.

The aim was to get tessellation for the shape similar to cloister vault after dynamic relaxation and get the relation of height of roof to the height of doors feasible for the spatial requirements of the room.

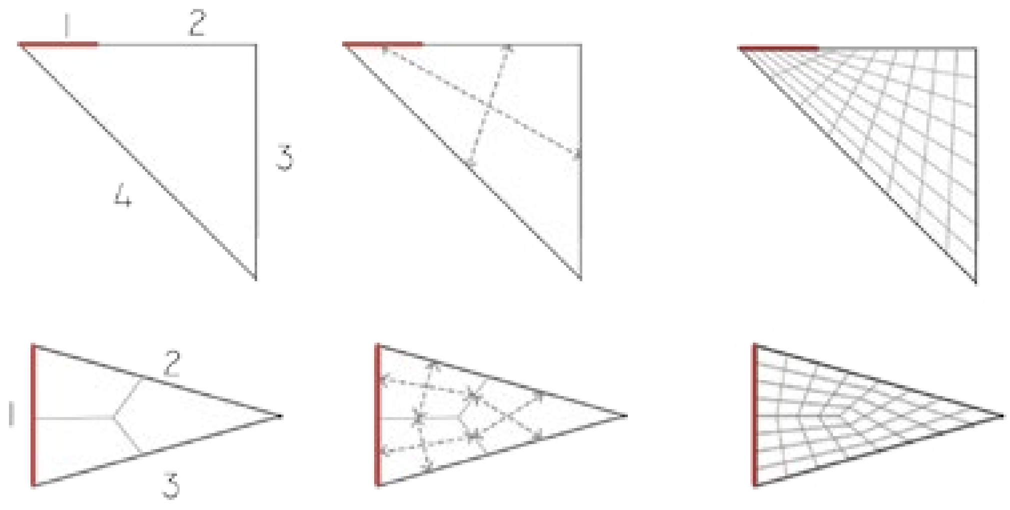
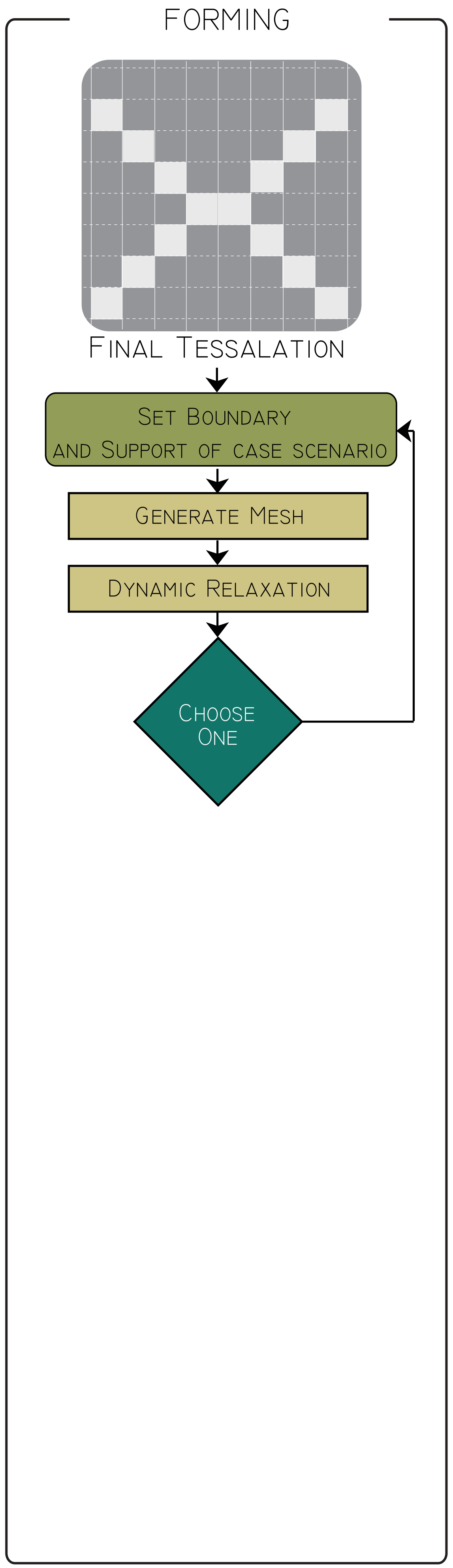


FIGURE 63. TESSALATION OF A FORM



Final tessalation approach for room

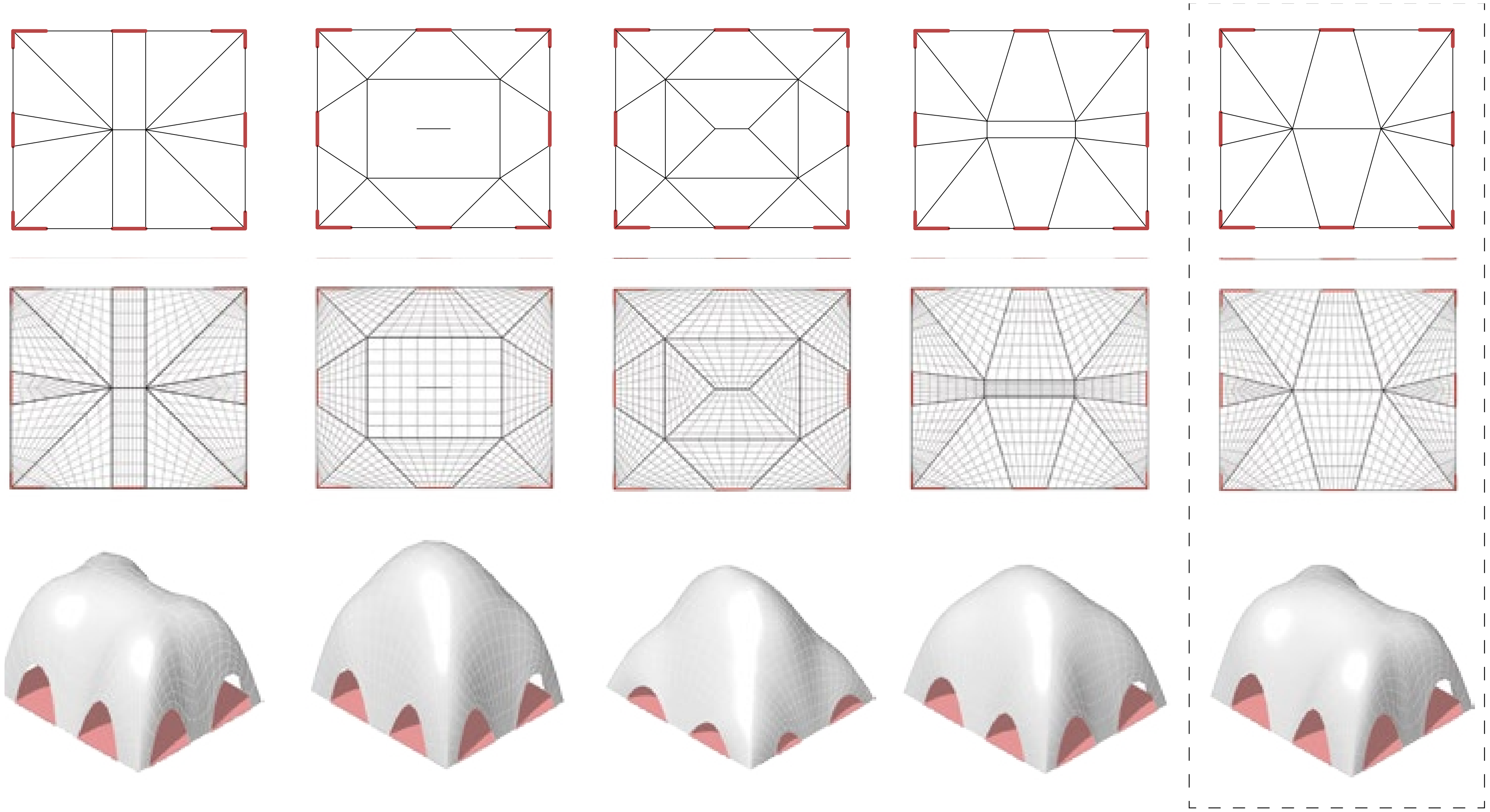
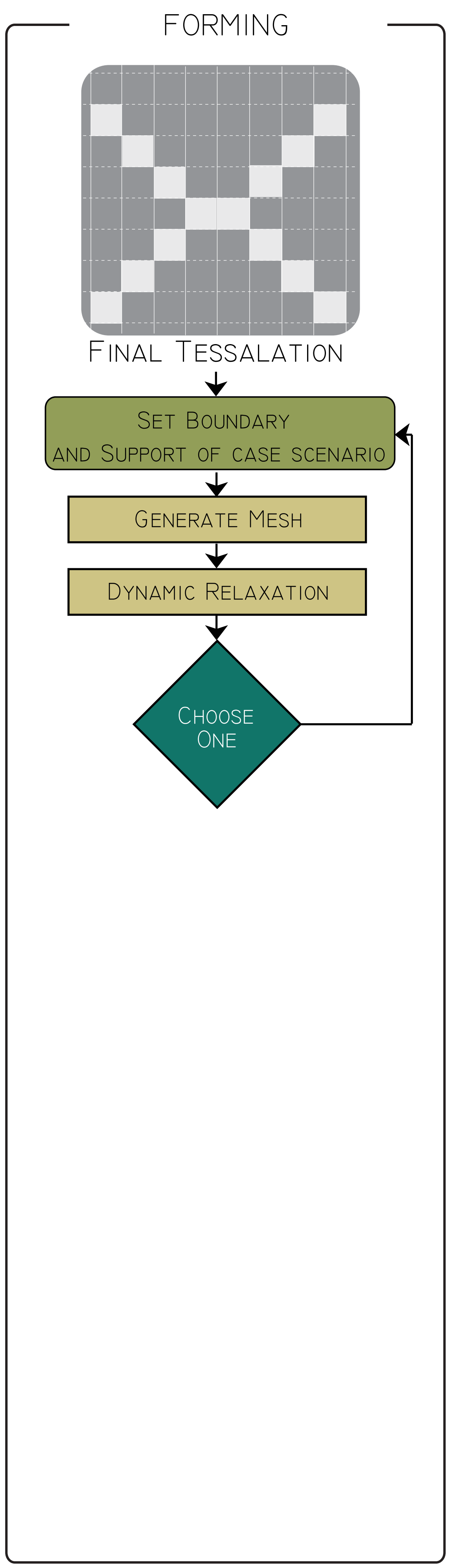


Figure 64. Final Tessalation for room



Final tessalation approach for adjacent rooms

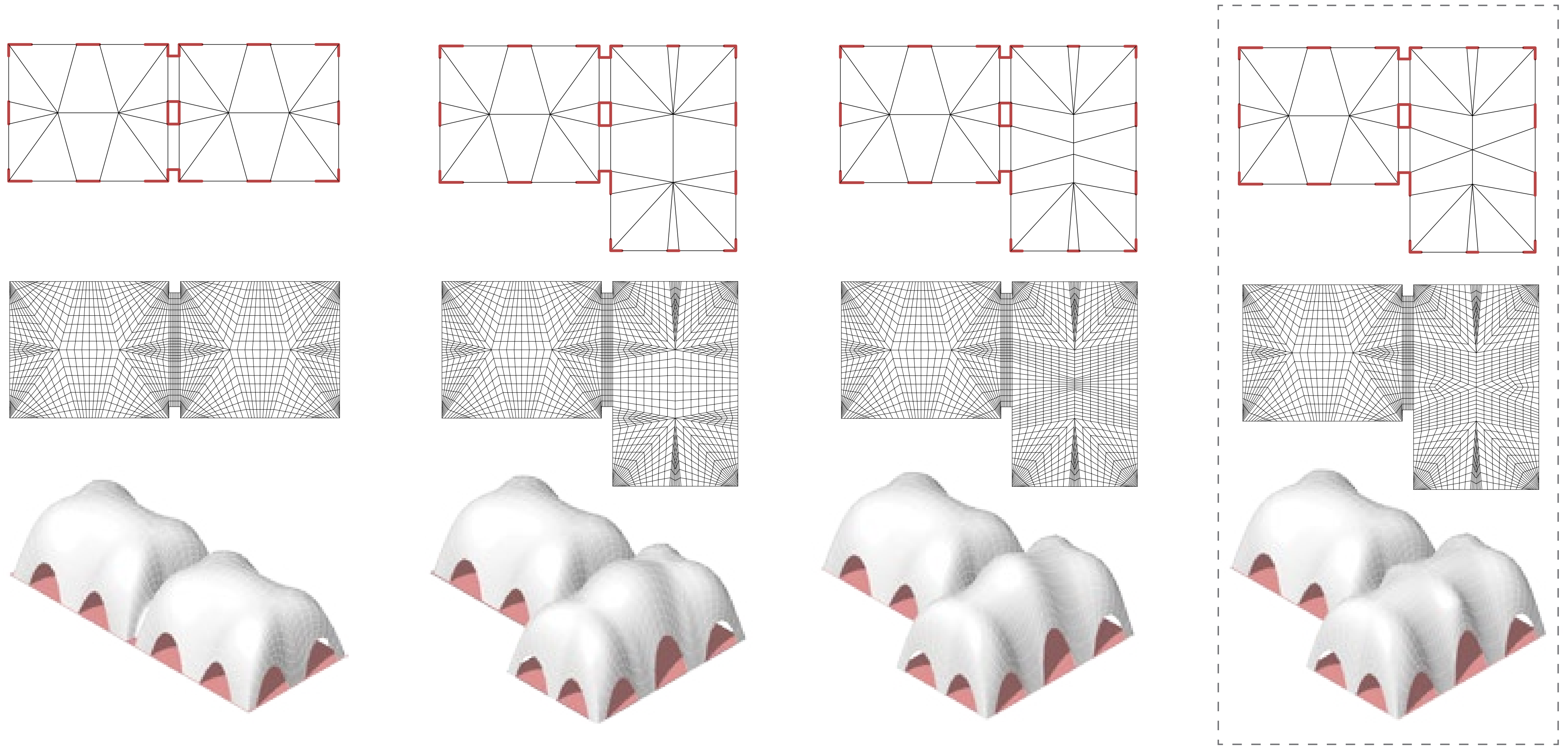
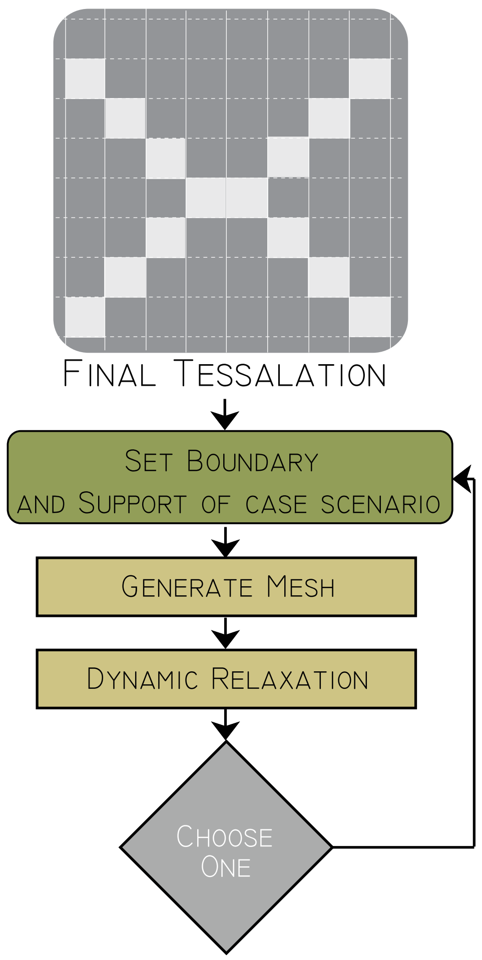


Figure 65. Final Tessalation for connected rooms

FORMING



FINAL TESSALATION APPROACH FOR UNIT

Next, the tessellation was done for two connecting rooms. The ceiling of two adjacent rooms were connected through established openings. The tessellation was tried on different combination of room shapes.

For the longer rectangular room, the tessellation had to be adjusted through trial and error to reduce the bump in the central portion of the ceiling. The length of the central ridge line of the ceiling caused the unwanted bump. This was altered by creating a central crisscross point to achieve the desired form.

After finalizing the ceiling tessellation for the two adjacent rooms, the tessellation was ready to be repeated for the chosen unit.

Finally in the final step of forming, the decided tessellation is drawn on a unit of the scenario cluster. The tessellation is made for both the ceiling and the roof level. In the roof level, the same tessellation as the ceiling is applied for a continuous surface including the support points but eliminating the wall thickness. Thus the roof and the ceiling layer work together to create a homogeneous dynamically
relaxed form (fig.66) .

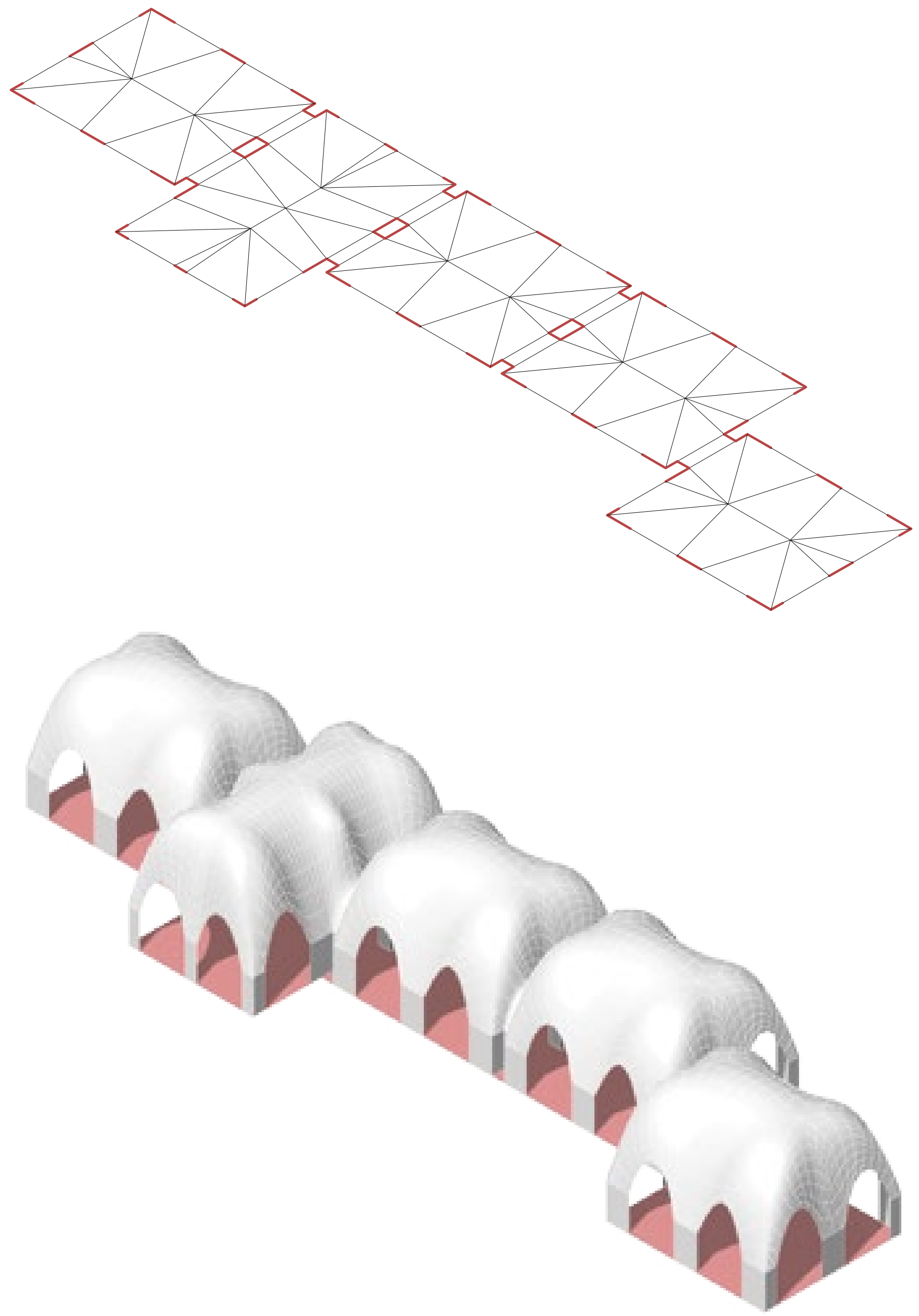
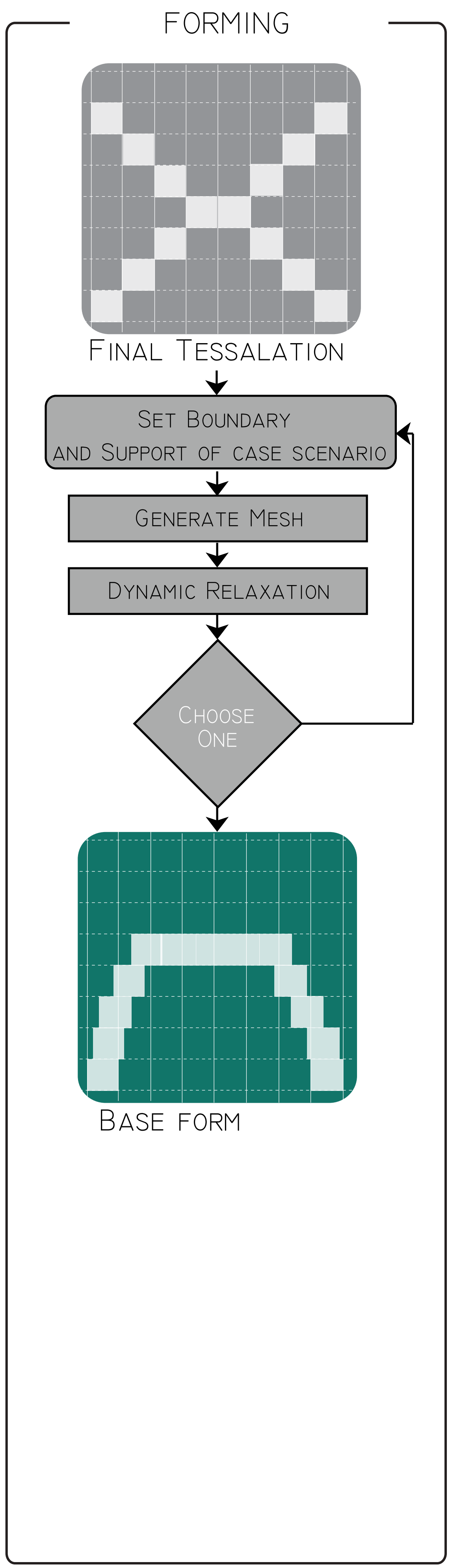


Figure 66. Final Tessalation and dynamic relaxation for unit



5 Unit Form

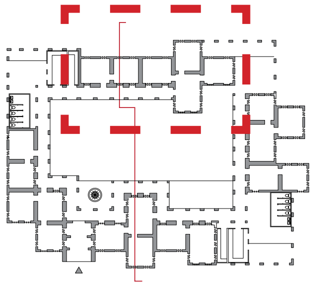


Figure 67. Key plan

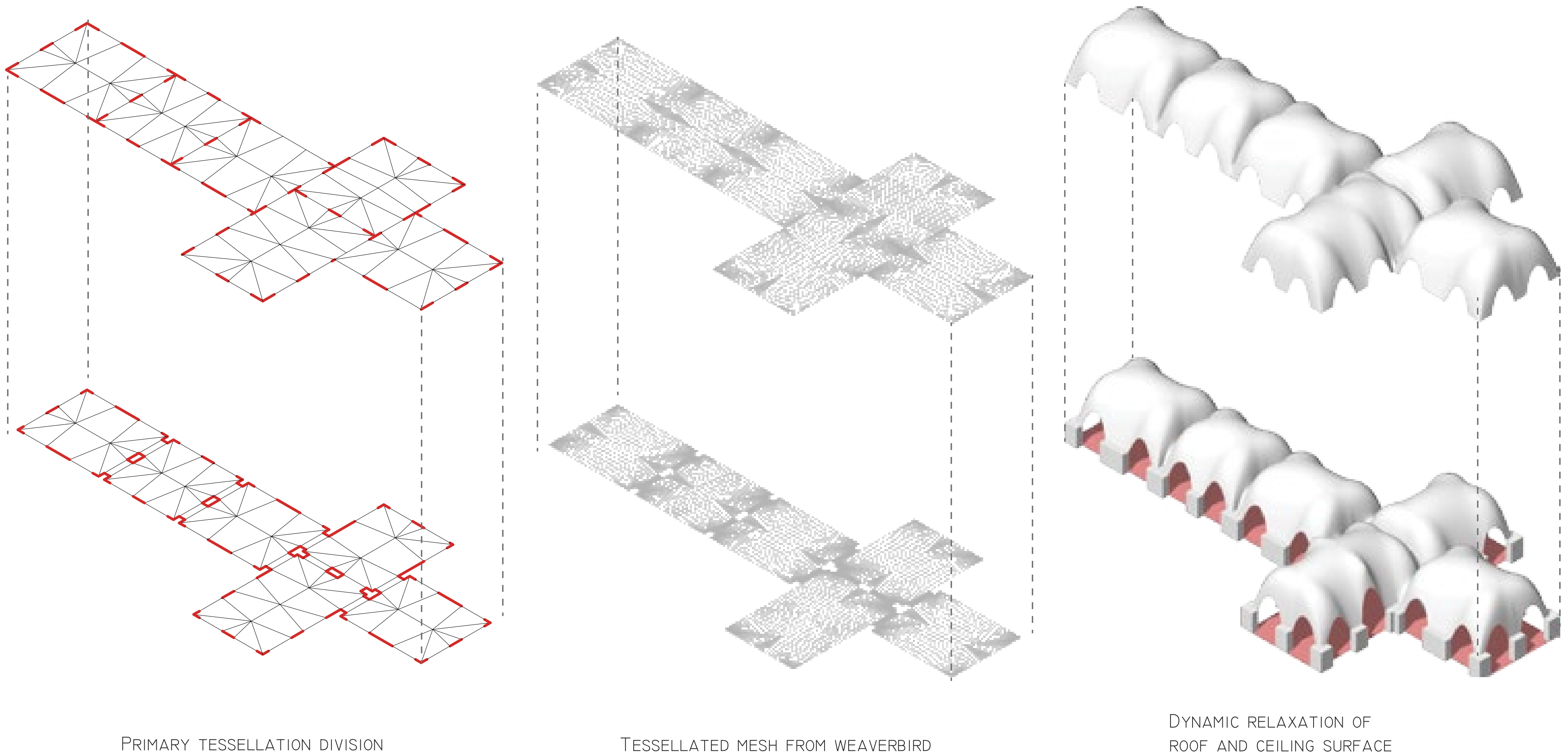


Figure 68. Final Tessalation and dynamic relaxation for the scenarop unit

08 Srtucturing

The first step to start the structuring of the unit was to define the material proprieties, this gave the materials inputs and limit values.
With this, the structural analysis was made.

As set of steps were taken so the structure and the bricklaying process would be feasible. The simplification of the structure was a key step to an easy constructability, which is needed for the proposal. The programme demanded a easy and fast replicability and with the last simplification was reached.

The main rules of structuring were set and the form for every room configuration was structurally analysed and the structural variations needed were defined.

Finally, a structural challenge was taken for the entrance forming. A cantilever was design and structurally tested to push the adobe design, and to research how adobe can work in a tensile structure.

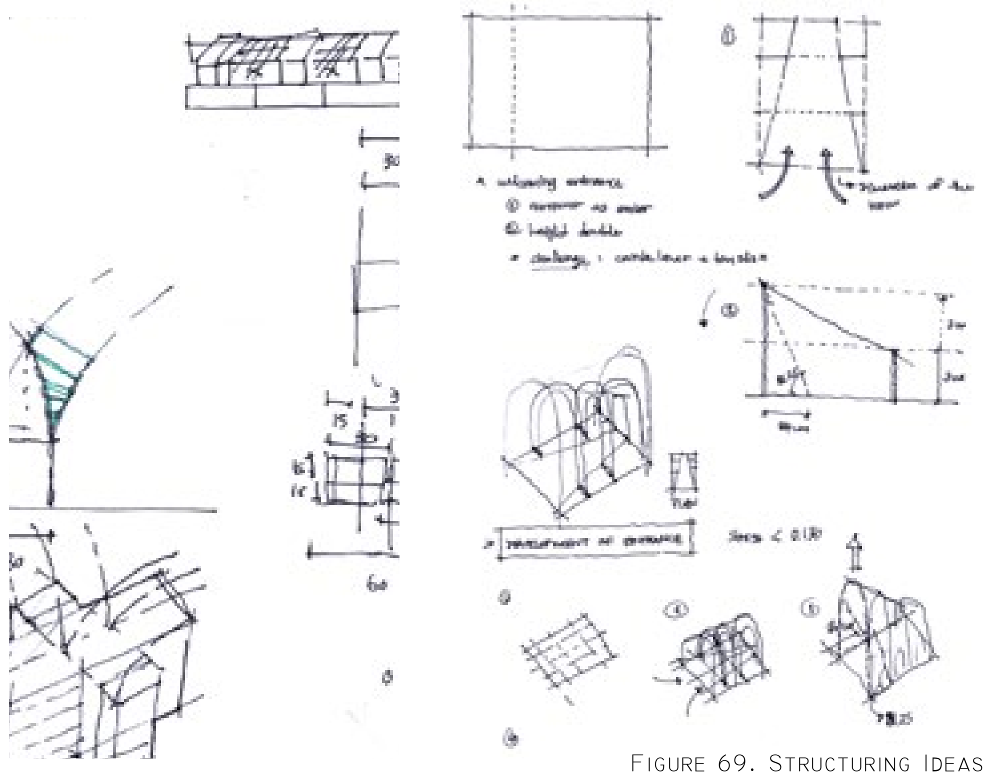


Figure 69. Structuring Ideas

| Material Propieties

The brick experiment was carried out with different types of material added to the standard adobe mixture. The results of the compressive strength showed wider variation between the different material composition. The specimen types chosen for the construction of the design were made with wood chips and straw.

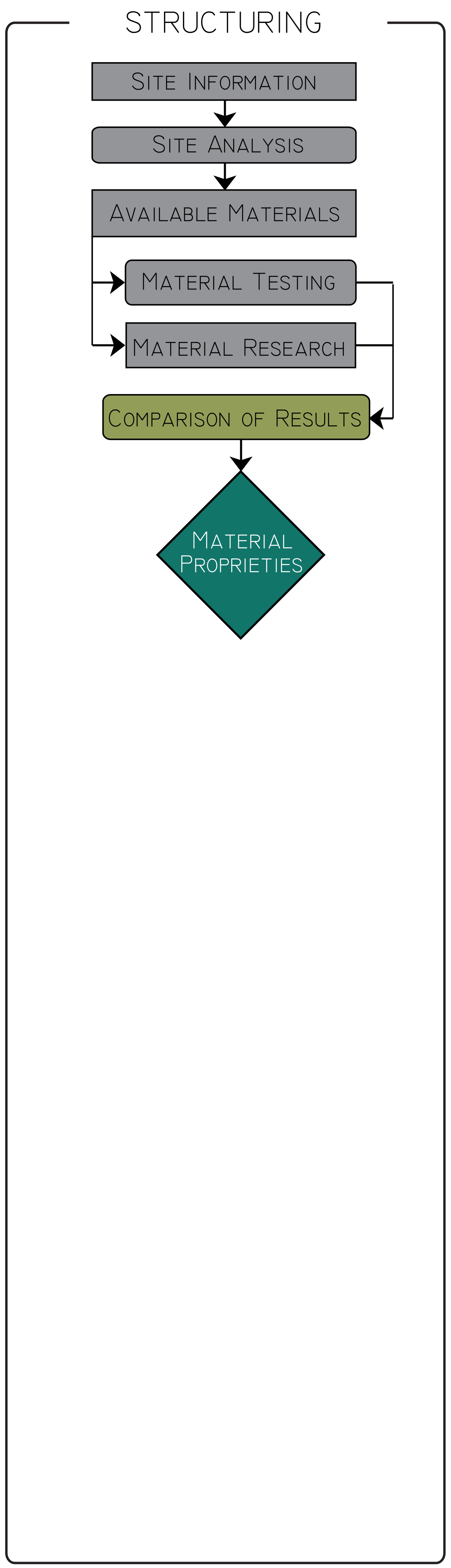
As both these specimen types were made in same size and showed similar mechanical behaviour, the limit values were set based on the lower value of the woodchip and straw adobe brick results.

The results of the brick workshop were also compared with those of the literature review. The comparison showed similarity between the results, validating the reliability of the experiment. Thus the compressive strength limit for the adobe bricks were set to 2.6 N/mm2, considering the lower limit of the specimens with straw and woodchips.

In the experiment the young's modulus values were too low due to some experimental errors, thus the value found from the literature was chosen to be used for the structural analysis. The young's modulus value was set to 150 N/mm2 to achieve a more practical structural outcome.

According to a literature study, with a safety factor of 2.5, the compressive strength of the adobe should have a minimum value of 0.34 N/mm2 (Clifton, J. R., & Davis, F. L., 1979). In table 3, the values of compressive strength for the bricks made, lies between 2.61-7.43 N/mm2 (except for the large bricks), that are well above the limit mentioned in the literature. Thus, a safety factor of 1.5-2 is feasible to be considered.

Also, the absence of the 1st floor and the absence of any snow load on the roof eliminates the need for a higher safety factor for the limited compressive load on the structure. Based on the safety factor of 2, the allowable compressive strength was calculated to be 1.3 N/mm2. The value for the allowable tensile strength is taken as 1/10th of the allowable compressive strength.



Specimen Type	Area(mm2)	Avg. maximum force (N)	Avg. maximum deformation (mm)	Young's Modulus(E) (N/mm2)	Compressive strength (N/mm2)
Large adobe	17325	11341.382	7.366	35.01	0.65
Small adobe	8800	58312.17	12.48	54.02	6.63
Wood chip	12150	31682.28	11.66	33.37	2.61
Straw	12150	44592.73	13.63	36.44	3.67
Cotton	8800	65397.79	9.98	81.94	7.43
Plastic Mesh	8800	43408.75	9.98	54.41	4.93
Sponge	8800	18955.03	9.96	23.8	2.15

Table 3. Based on Annex C, Section 3.4

Literature study

Compressive strength (N/mm2)	Source
0.5 - 8	(Illampas R., Ioannou I., & Charmpis D., 2011)
2.88 (avg)	(Gubasheva S., 2017)
Young Modulus (N/mm2)	
98 - 211	(Gubasheva S., 2017)
117.3 - 138.3	(Martins, T.(2006)
Safety Factor	
2.5	
for Compressive strength limit of 0.34 N/mm2	(Clifton, J. R., & Davis, F. L., 1979)

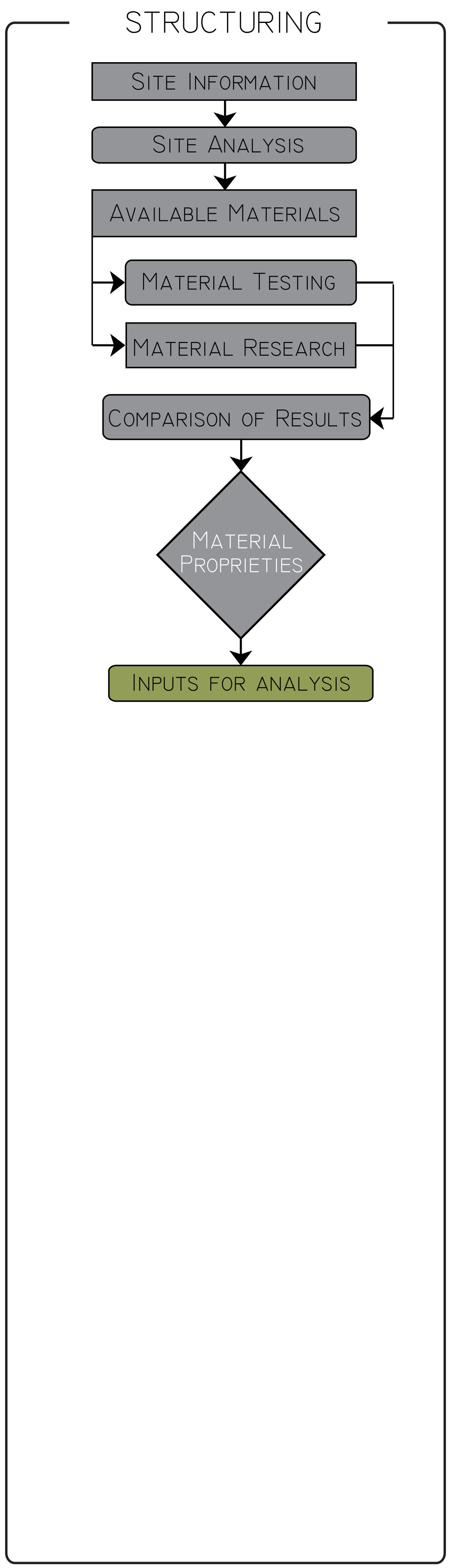
Table 4. Based on Annex C, Section 3.2 and 6

Chosen safety factor 2

Reasons:
- allowable compressive strength 2.6 N/mm2
- absence of 1st floor
- No external snow load

Young Modulus (N/mm2)	150
Compressive strength limit (N/mm2)	2.6
Safety factor	2
Allowable Compressive strength (N/mm2)	1.3
Allowable tensile strength (N/mm2)	0.13

Table 5. Material Propieties



Inputs for structural analysis

The structural analysis of the found geometry was carried out in Karamba 3D plugin in grasshopper. There were several inputs decided for the structural analysis.

Load:
Regarding the load-case, only self-weight was considered for the structural calculation. The calculated wind load was 0.06 KN/m2 (Highest wind speed in Al-Mafraq (closest city to Zaatari camp) = 35 kmph = 9.72 mps ≈ 10 mps = 60 pa = 0.06 KN/m2 [Wind Velocity and Wind Load], [Mafraq Monthly Climate Averages]). Since it was low and was affecting around 5% to the resul,t it was neglected for the calculations.

Supports:
All the supports are considered to be fixed in all directions.

Resolution:
Several mesh resolutions were tried to check the accuracy of the results. The considered mesh resolution was 0.1m because it was giving reasonably accurate results; comparing with mesh resolution of 0.05m, it was around 99% accurate. Thereby, the edge refinement factor was considered 0.667 which is 0.0667m because of the suggestion of Mesh Breps component to get the best result.

Validation of the computational model

After the assembly of the computational model, the verification of the model was done by comparing the results with hand calculation. The dynamically relaxed mesh of the chosen tessellation was analysed in Karamba with the inputs explained previously.

The sum of total reaction force in computational model = 149.66KN

Hand calculation

Surface area of the mesh = 27.72m2
Given thickness = 0.3m
therefore, volume of shell = 8.316m3

Here, the specific weight is 15KN/m3 and a safety factor for a load is 1.2.

therefore, total reaction force = 8.316 x 15 x 1.2
= 149.68KN

Thus, the computational model gives accurate results.

Material Inputs

Young's Modulus (N/mm2)	150
Yield Strength (N/mm2)	1.3
Shear Modulus (N/mm2)	60
Specific Weight (KN/m3)	15

Young's Modulus:
As Mentioned in previous page

Yield Strength:
Considered same as allowable compressive stress limit.

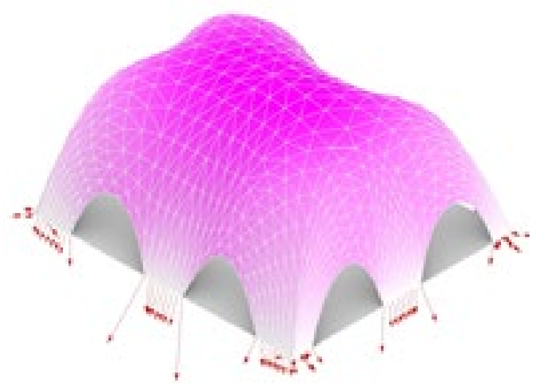
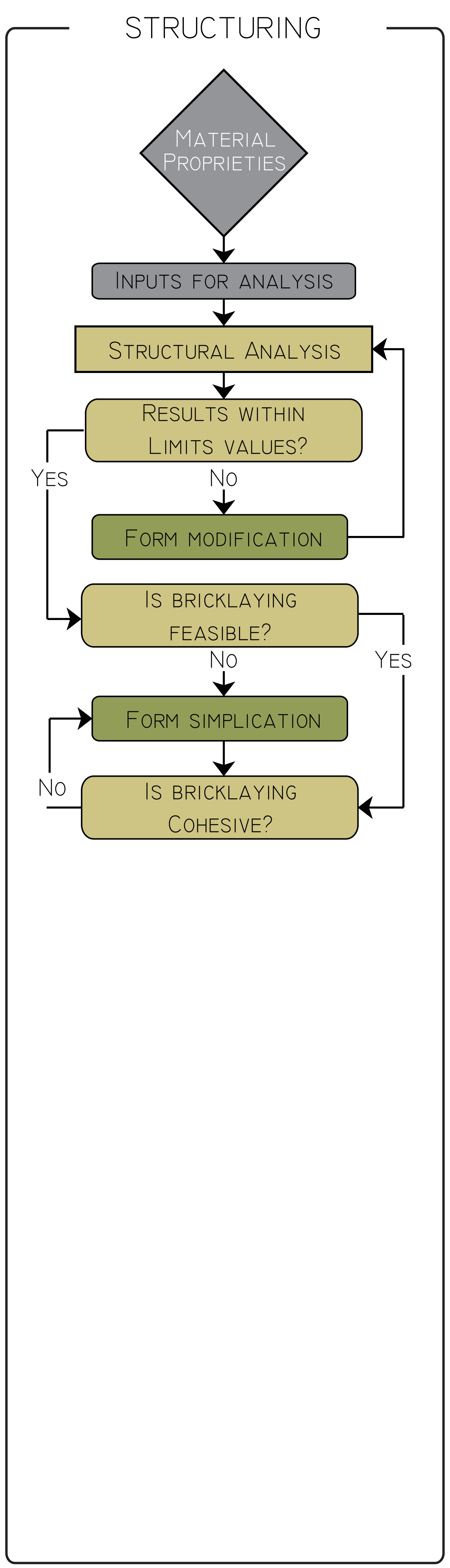


Figure 70. deflection in dynamically relaxed surface

Shear: Modulus:
As per (R. Illampas, 2011) the poisson ratio for adobe is 0.35. Therefore,
Shear modulus G = E/(2(1+v)) [Convert Elastic Modulus Constants]
= 150/(2(1+0.35))
= 55.55
≈60 N/mm2 = 60000 N/m2

Specific Weight:
According to (ABCs of Making Adobe Bricks) the weight of dry brick of 4 x 8 x 16 is 28lbs. Converting it to the specific weight **gives 14.81 KN/m3. Thus, 15 is chosen for calculation.**



2 Structural Analysis Process

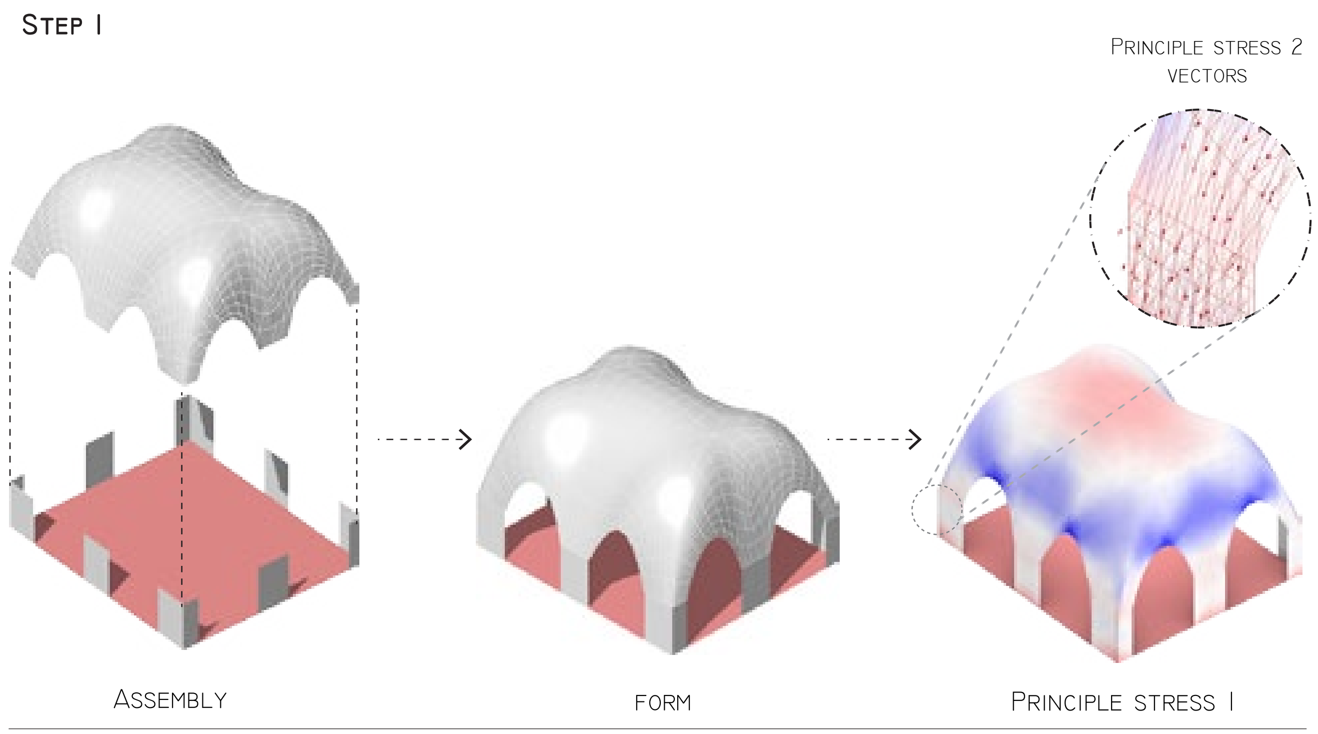
Step 1: For the chosen dynamically relaxed mesh, the initial structural analysis was performed by placing the mesh to a vertical base. Though results were within the limit, the stress vectors were significantly out of the plane. There was tensile stress observed at the base wall.

Step 2: To avoid the sharp angle at the base to mesh join, the 3d tessellation was generated and dynamically relaxed form was generated. The structure was performing uniformly. However, the mesh is complex to construct.

Step 3: For the ease of constructability, the form was simplified by drawing catenary arches on both sides and get the form through extruding them. The results of the structural analysis were unformed and within the allowable range.

	Deflection (cm)	Max. Compressive stress (MPa)	Max. Tensile stress (MPa)
Step 1	0.25	0.077	0.093
Step 2	0.22	0.039	0.033
Step 3	0.32	0.075	0.084

Table 6. Results for the different steps



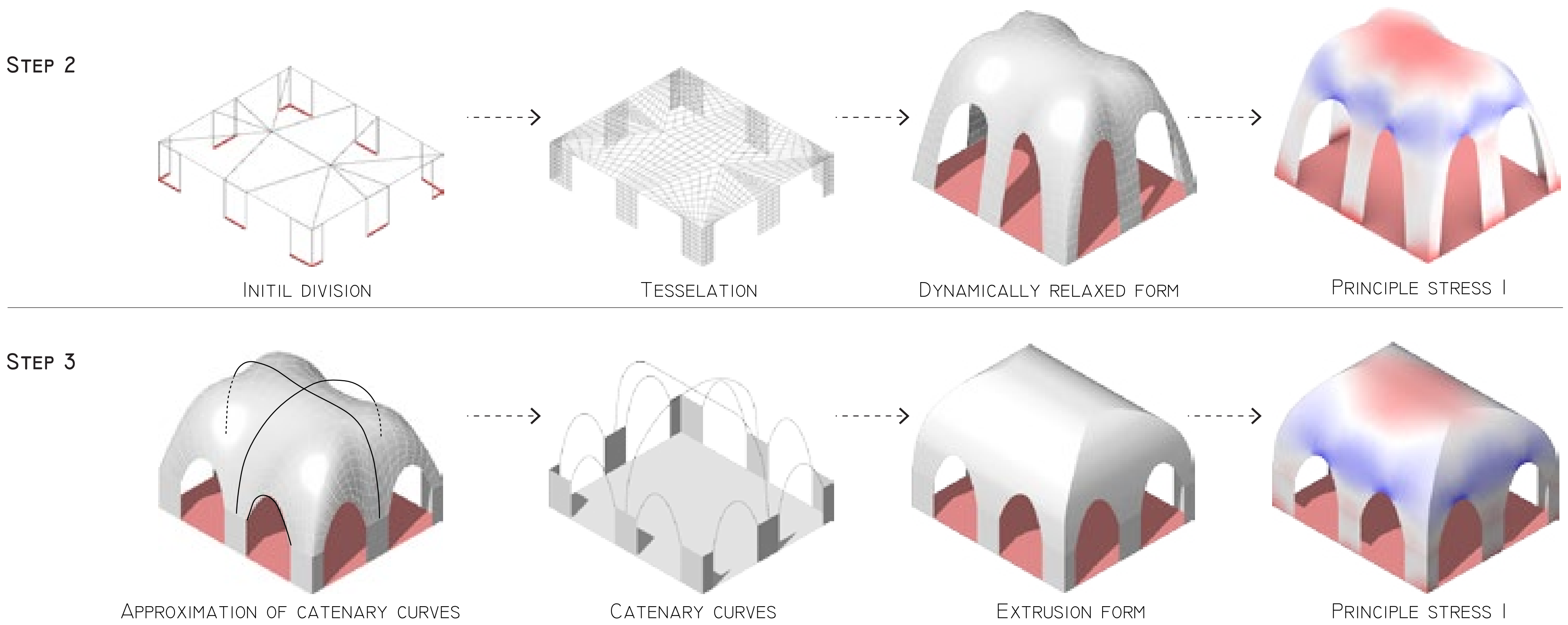
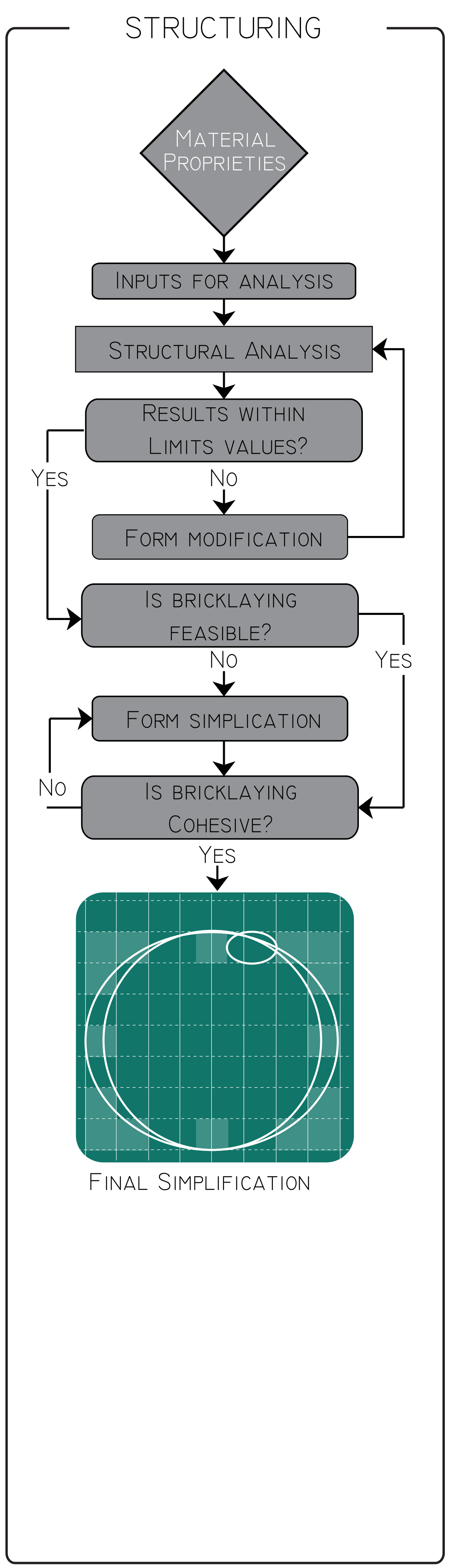


Figure 71. Phases of structual design and shape development



After the simplification of the dynamically relaxed form, the form was further refined under a specific geometry in order to ensure accuracy in construction. Each curve of the form was redrawn to the closest ellipse. Four different ellipses were made. One ellipse was made for the central arch, diving the top ridge line into half.

Second, two more ellipses were drawn for both ends of the top ridge, creating slight curvature on the smaller sides of the ceiling. Third, each of the corner rib arches were refined with its closest ellipse and lastly the opening arches were also drawn to the closest ellipse. The final form wes made with a set of pure ellipses, which provided the accurate numbers to create a clear and easy construction process.

3 SIMPLIFICATION

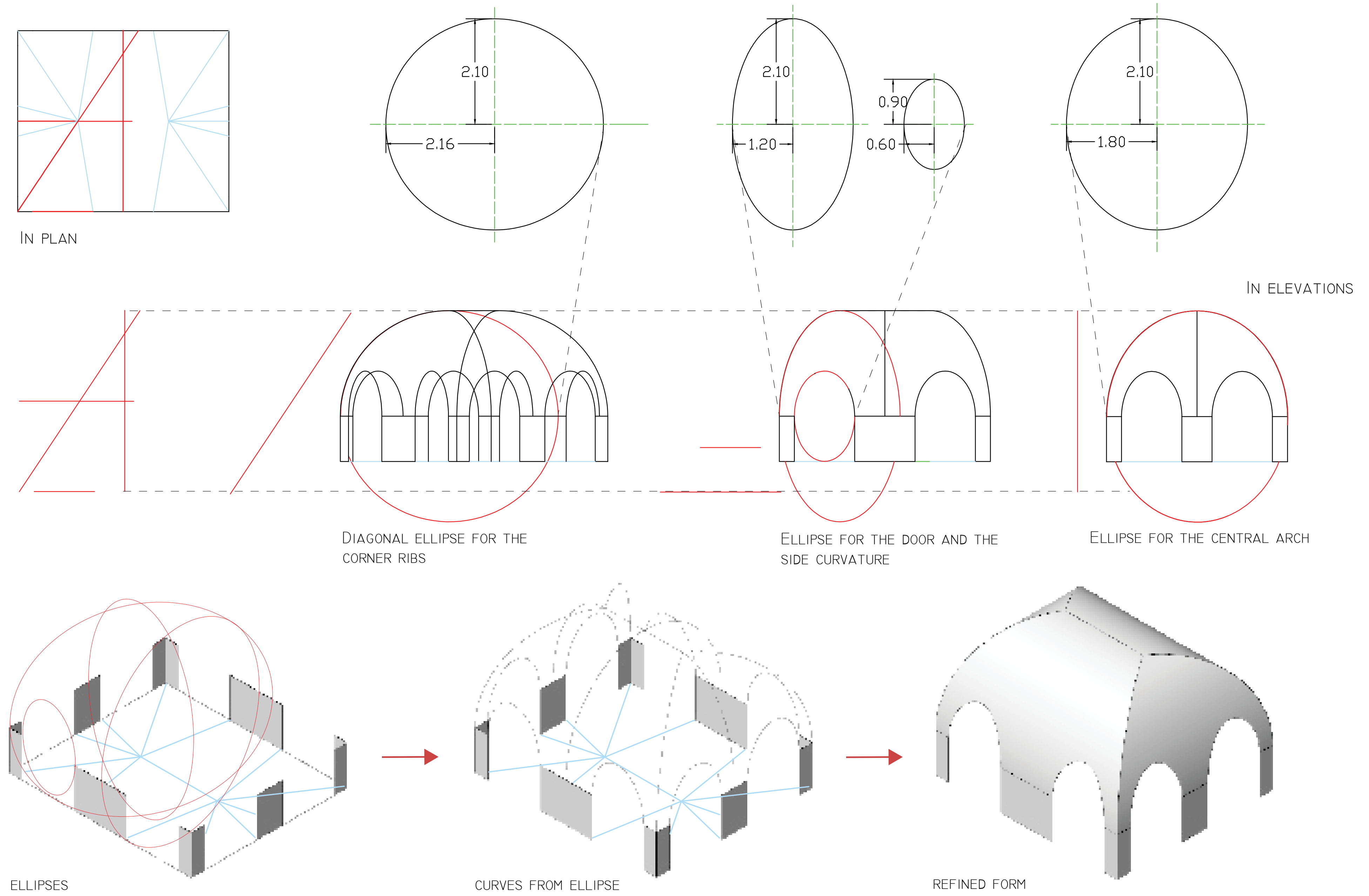
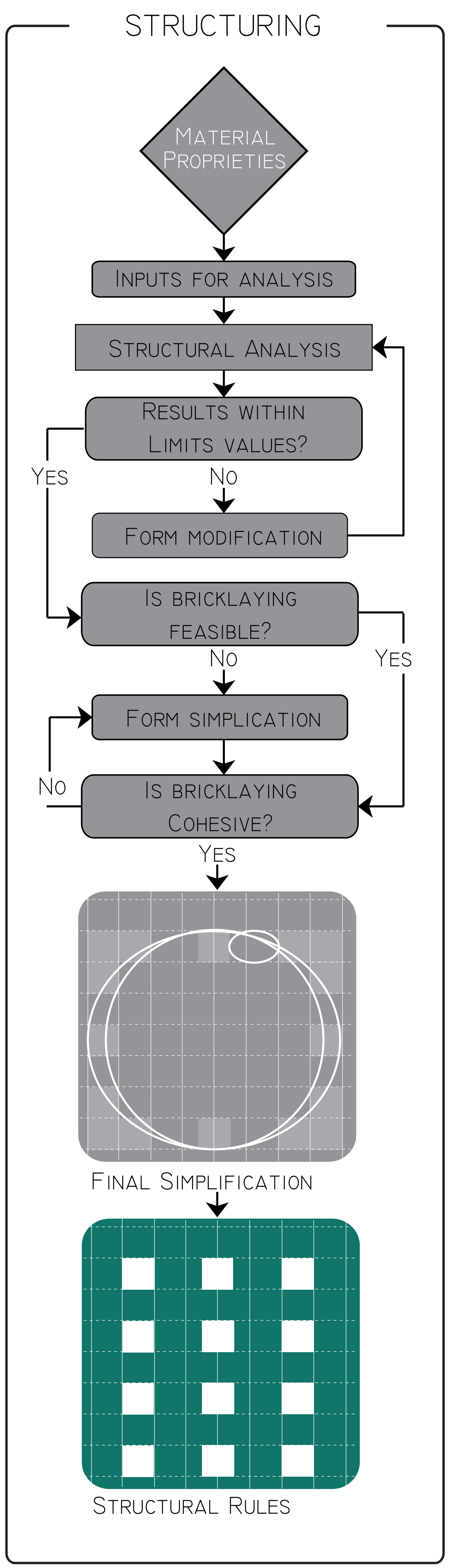


Figure 72. Translation of form to Ellipses



4 Structural rules

Based on the module size of 0.6, the room configuration is derived through module multiplication.

For the smallest room size of 3.6 X3.6, an opening of 1.2 with adjacent wall of 0.30 on both sides of the opening is created. This section is mirrored to create the inner length of the room. The length is again mirrored to get the 3.6X3.6 room.

For the 3.6X4.2 room size, the 0.3-1.2-0.3 section is mirrored at a distance of 0.60. Thus keeping the opening size same but contributing to a larger length of the room.

For the 3.6X4.8 room size, the section 0.3-1.2-0.3 is mirrored at 2X0.6 distance, resulting to a longer length with the same opening size.

For the 3.6x5.4 room size, the mirrored distance being 3x0.6= 1.8, resulted to repeat the 0.3-1.2-0.3 section introducing a third central opening for this room size.

Thus the process could be further repeated for larger room sizes, maintaining the module of 0.6x and the section 0.3-1.2-0.3.

The systematic room generation, created greater possibility for different unit configuration, thus providing the desired freedom and flexibility in cluster formation.

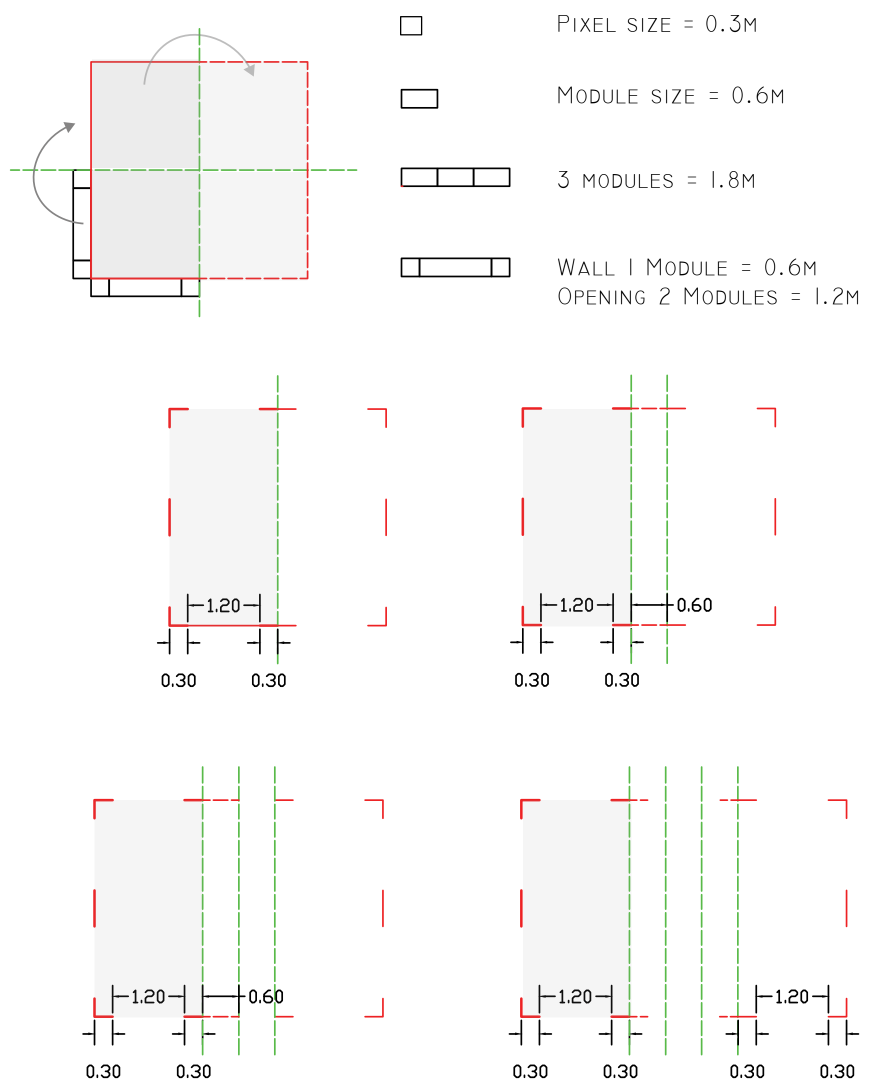
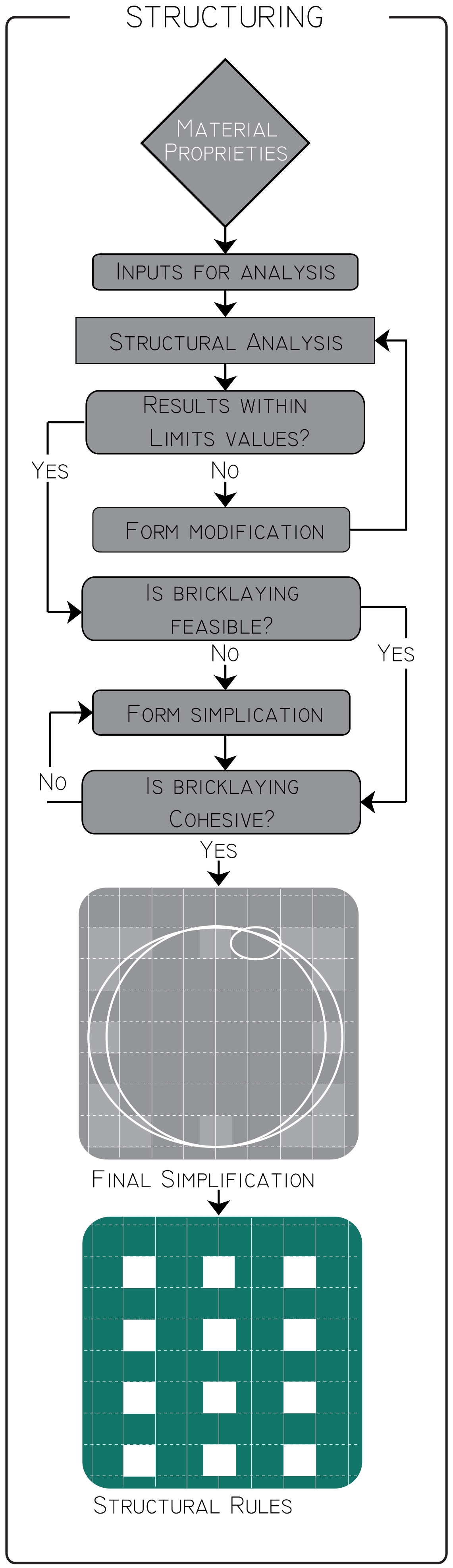
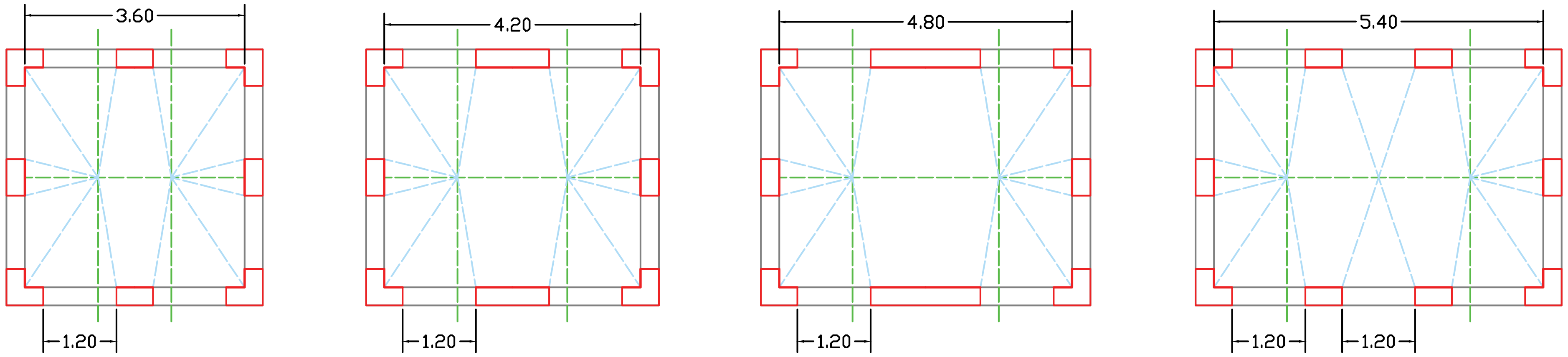
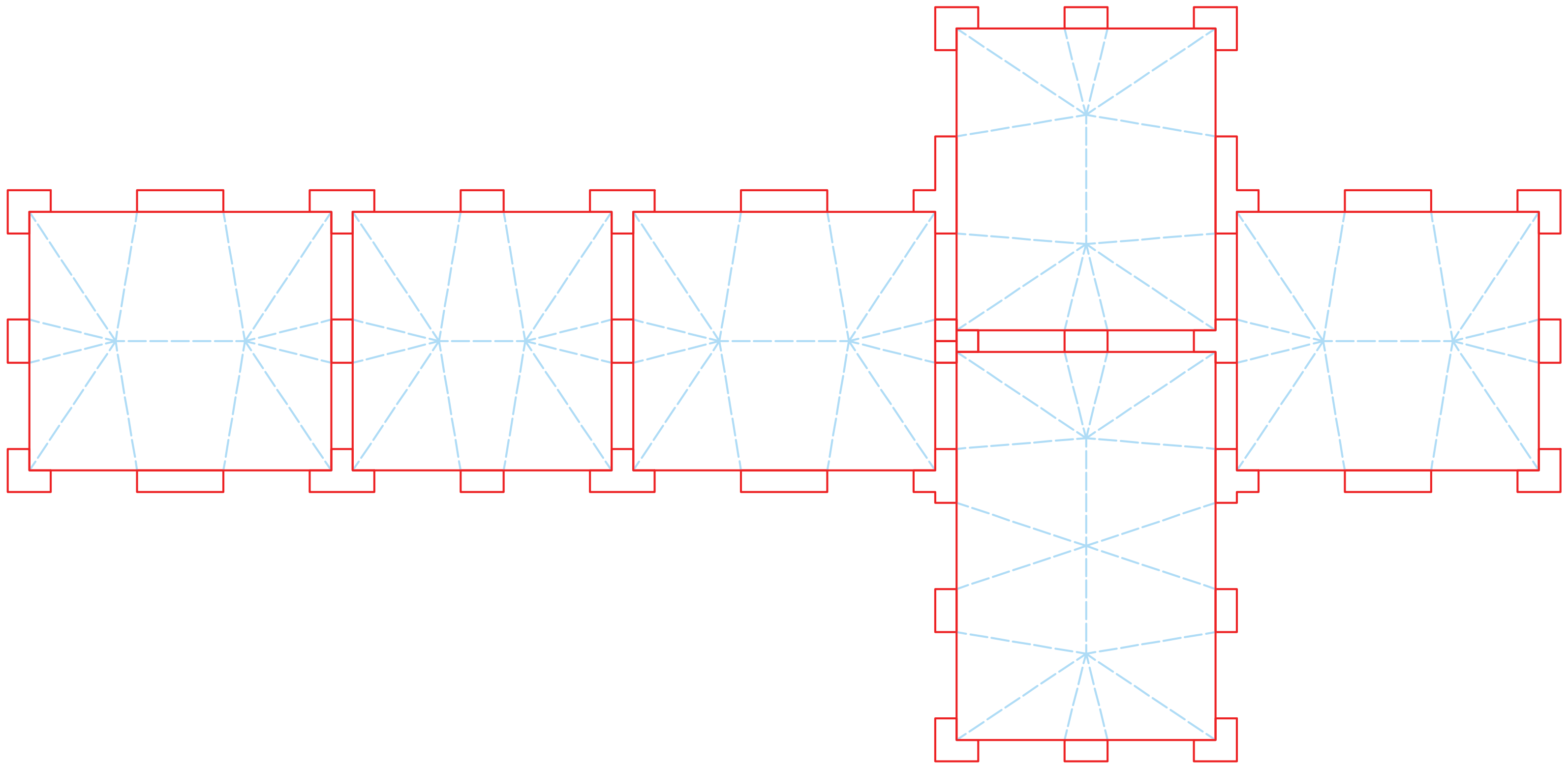


Figure 73. Room structural system generator



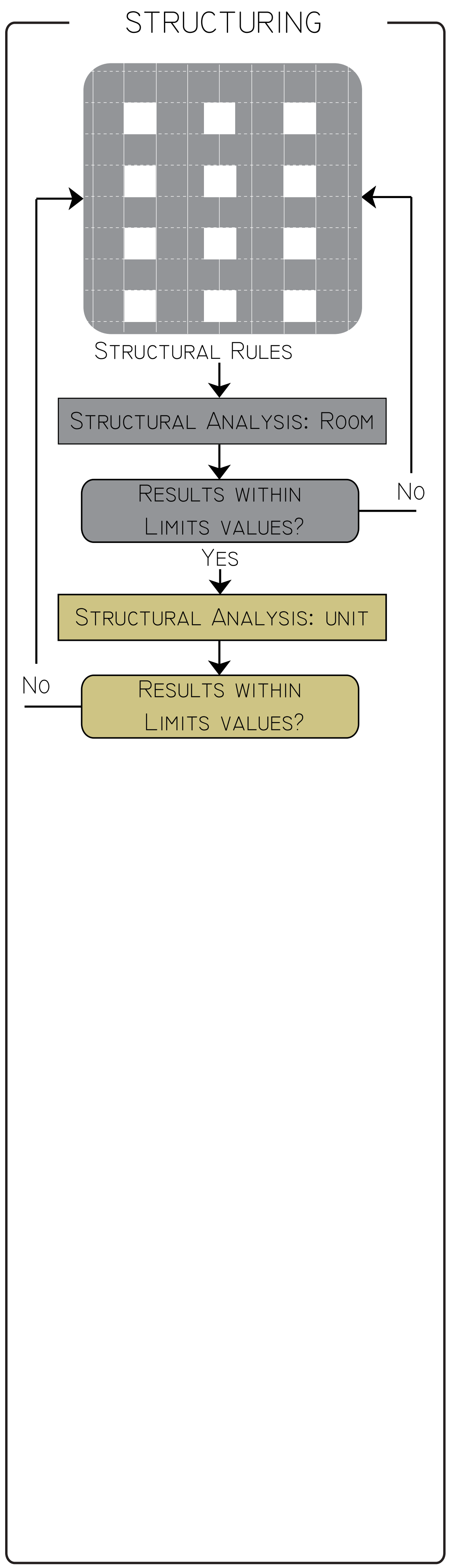


OPENNING PROPORTIONS



UNIT ARRANGEMENT

FIGURE 74. ROOM AND UNIT STRUCTURE



5 Final analysis

Room type (m)	Deflection (cm)	Max. compressive stress (N/mm2)	Max. tensile stress (N/mm2)
3.6x3.6	0.25	0.063	0.103
3.6x4.2	0.28	0.058	0.106
3.6x5.4			
Step 1	0.45	0.087	0.129
Step 2	0.3	0.136	0.112

Table 7. Results for different room configurations

The structural analysis is done for the final form of the three room types as shown in table 7.

For the 3.6x3.6m and the 3.6x4.2m room sizes, the deflection and the stress values were within the desired limit, validating the stability of the form.

For the 3.6x5.4m room type, the initial form showed higher deflection and tensile stress values owing to the longer length of the room.

Through some trial and error, two curved beams were added to the central section of the form, which significantly reduced the stress values.

However, to maintain a smooth inner ceiling. The height of the beams was reduced while the width was increased to the full width of the support walls, resulting to two central arches of each 0.6m width.

The arches provided the required stability to the length of the form and created the main skeleton for efficient construction process.

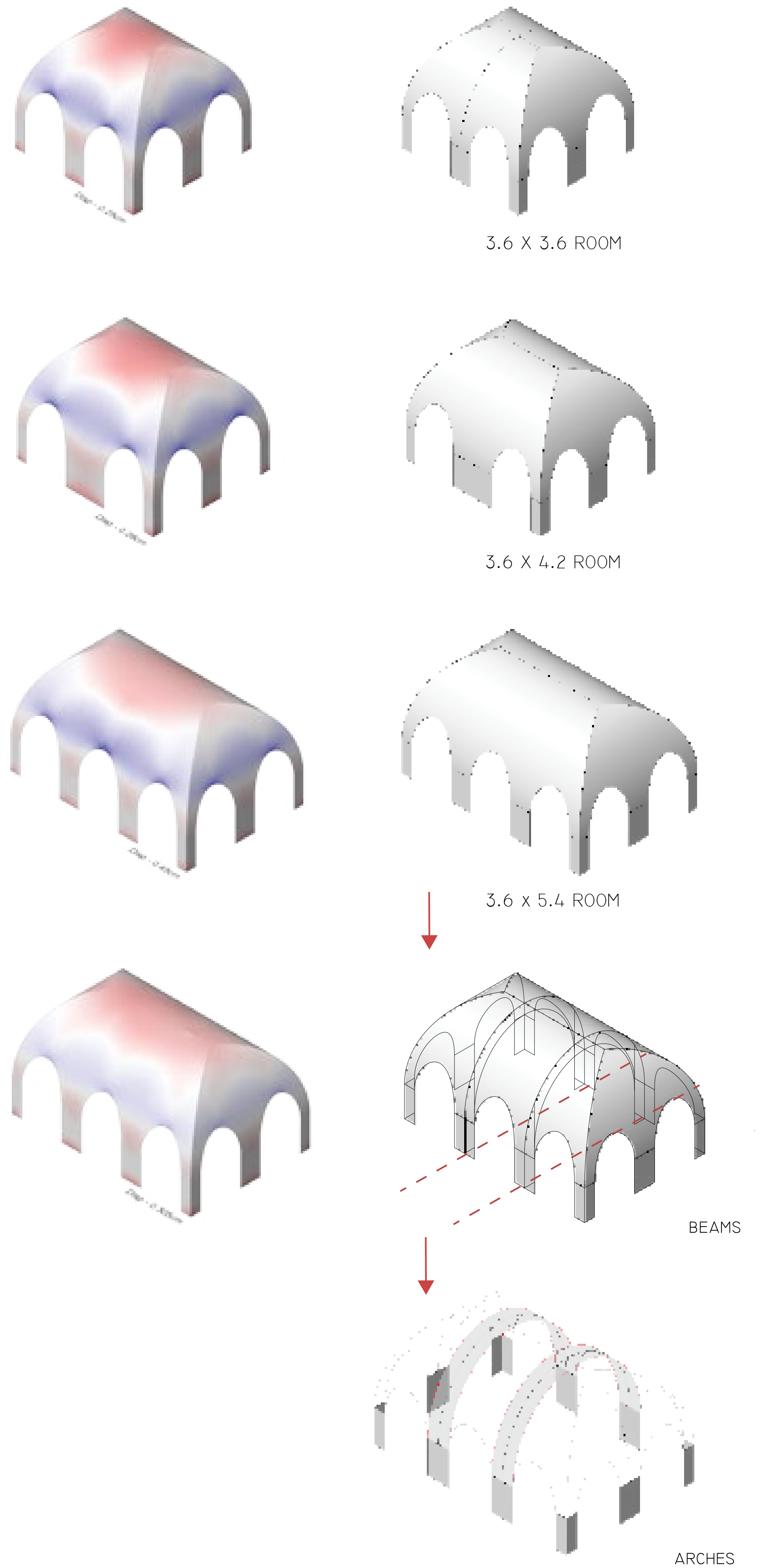
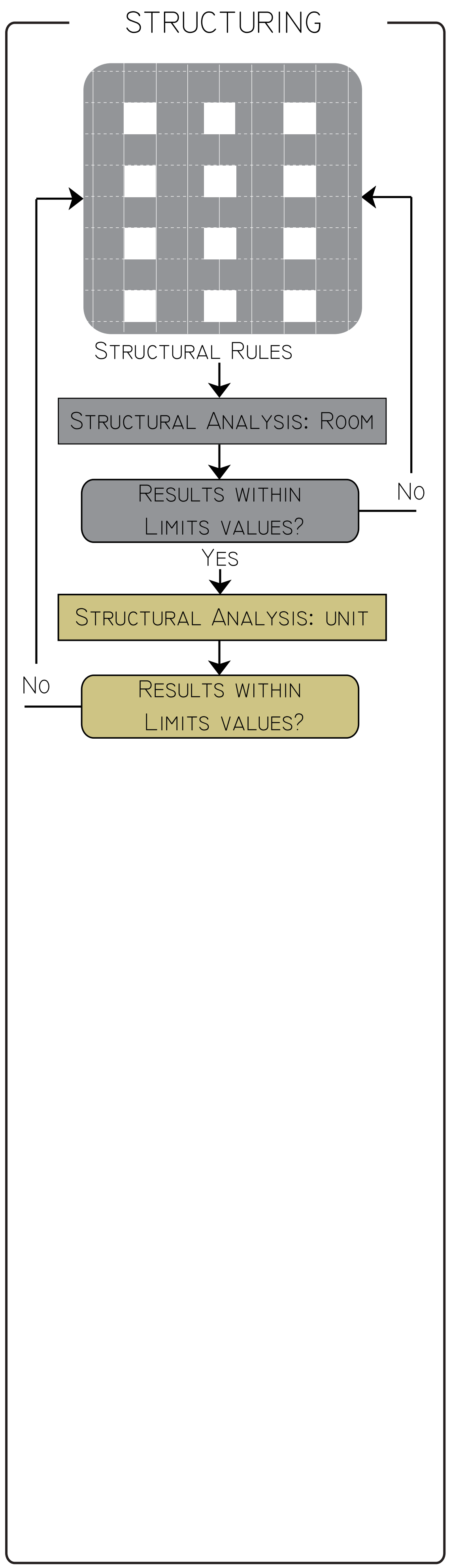


Figure 75. Room variation analysis



Structural analysis of the unit

While applying the room design to unit the process was to generate the dynamically relaxed form for roof and ceiling and simplify further to replicate the actual construction. Considering that there will be a variation of the thickness of the shell at the ceiling and joint, the non-uniformly distributed mesh load was applied. It was done by calculating the volume covered per mesh point and multiplied with a specific weight.

In step 1 the results of the structural analysis was showing tensile stress higher than allowable. This was because of the lateral force generated by push of room to adjacent ones. Thus, in step 2, the base of the last room in all directions was extended like buttress (fig.77). It gave results within the allowable range. Thus, the addition of buttress was proposed as a rule for construction.

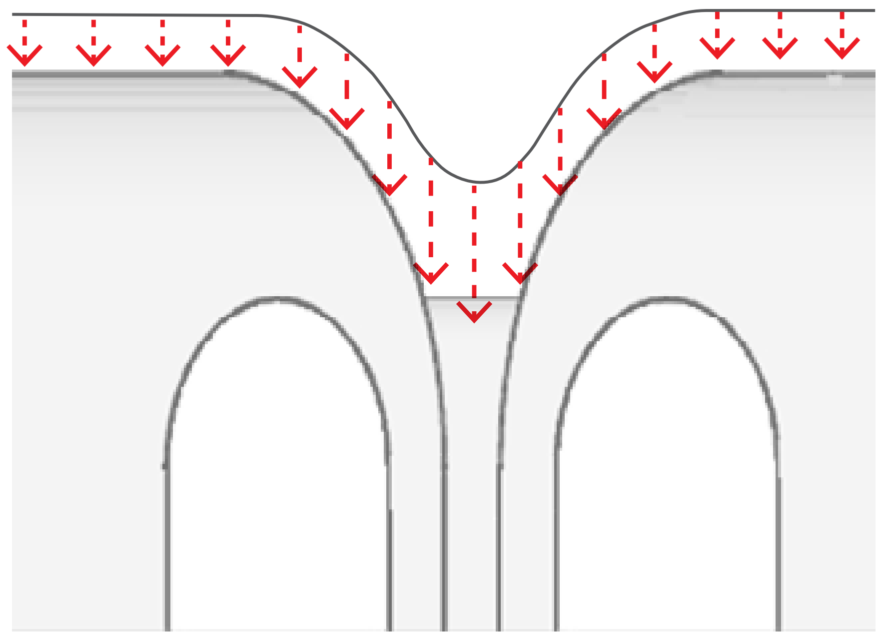
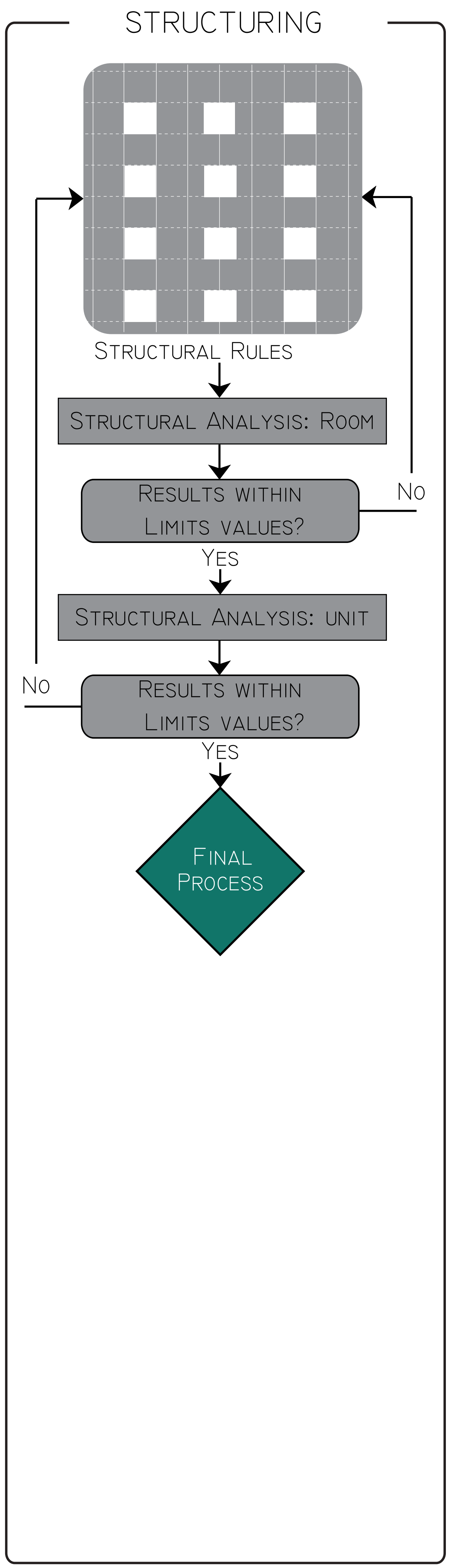


Figure 76. Non-uniform load distribution

	Deflection (cm)	Max. Compressive stress (N/mm2)	Max. Tensile stress (N/mm2)
Step 1	0.33	0.068	0.14
Step 2	0.3	0.092	0.112

Table 8. Structural results of the unit



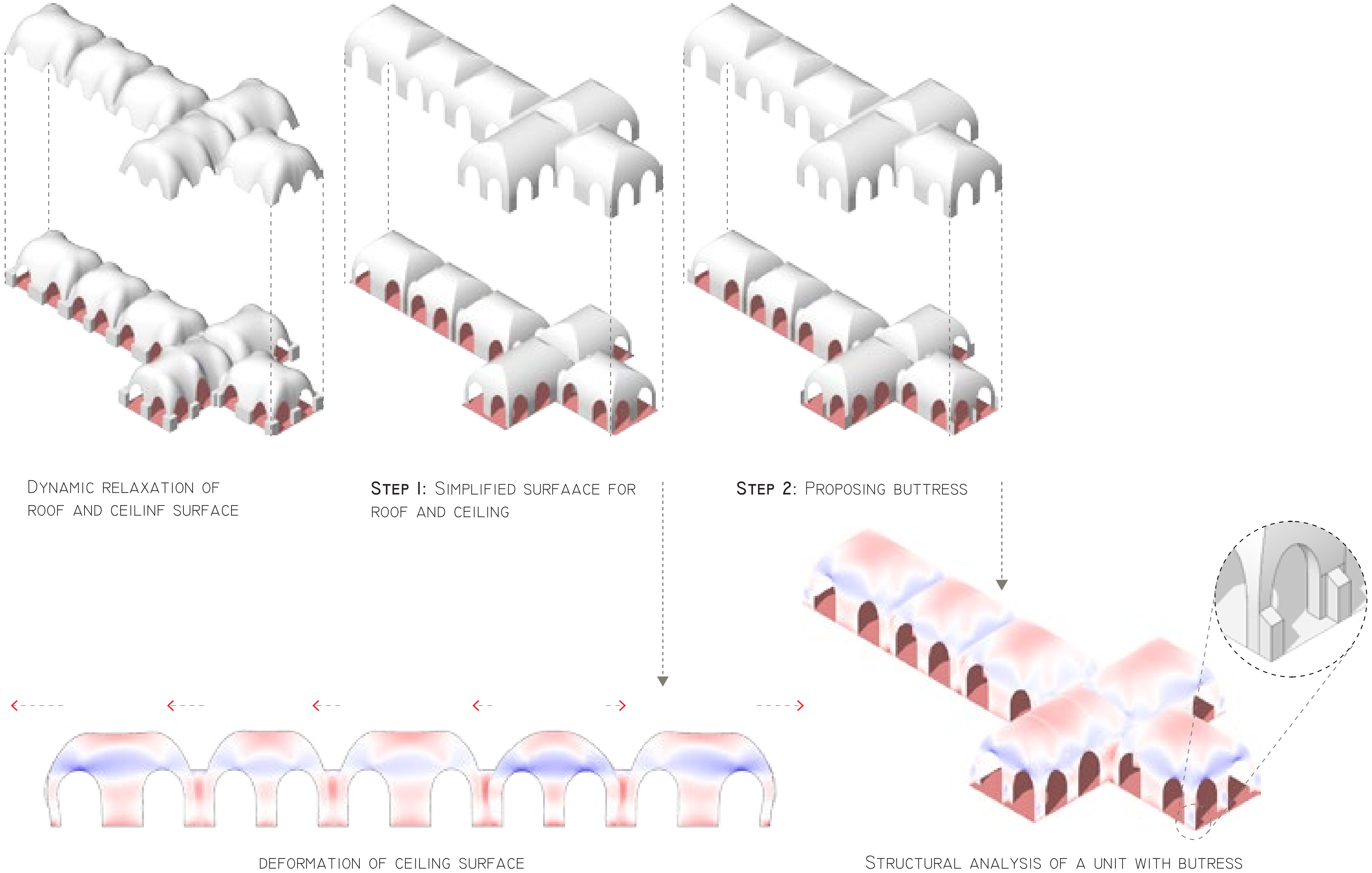
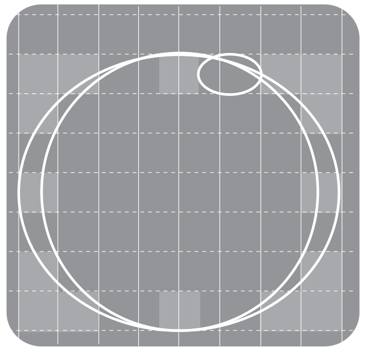


Figure 77. Unit structural analysis

STRUCTURING



Final Simplification

Forming Process

6 Adobe 2.0: Bustan Entrance

The entrance of the cluster was developed based on the pre-design modular system with the idea of hierarchy in mind and with the goal of inviting through a distinctive form and structure.

To adopt a challenge, the idea of dealing with the poor tensile property of the adobe by managing a cantilever, was announced.

The initial design of the entrance was developed based on the dimension of medium size room (3.6 x 5.4 m). Its distinct form and structure were created through the hierarchy in size and height of the arches.
This also create an illusion of depth, leading into the cluster; hence creating a sense of inviting. The cantilever structure was added in order to provide shaded spaces, and finally, the openings were made one both side of the walls.

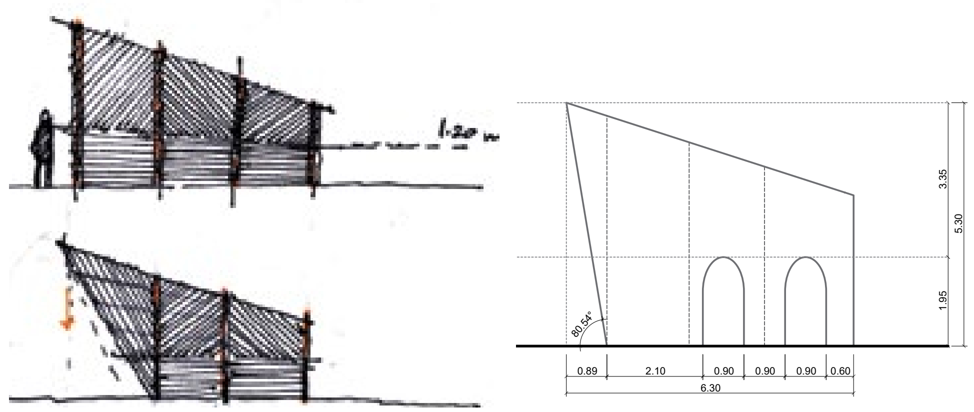


Figure 78. Concept of entrance

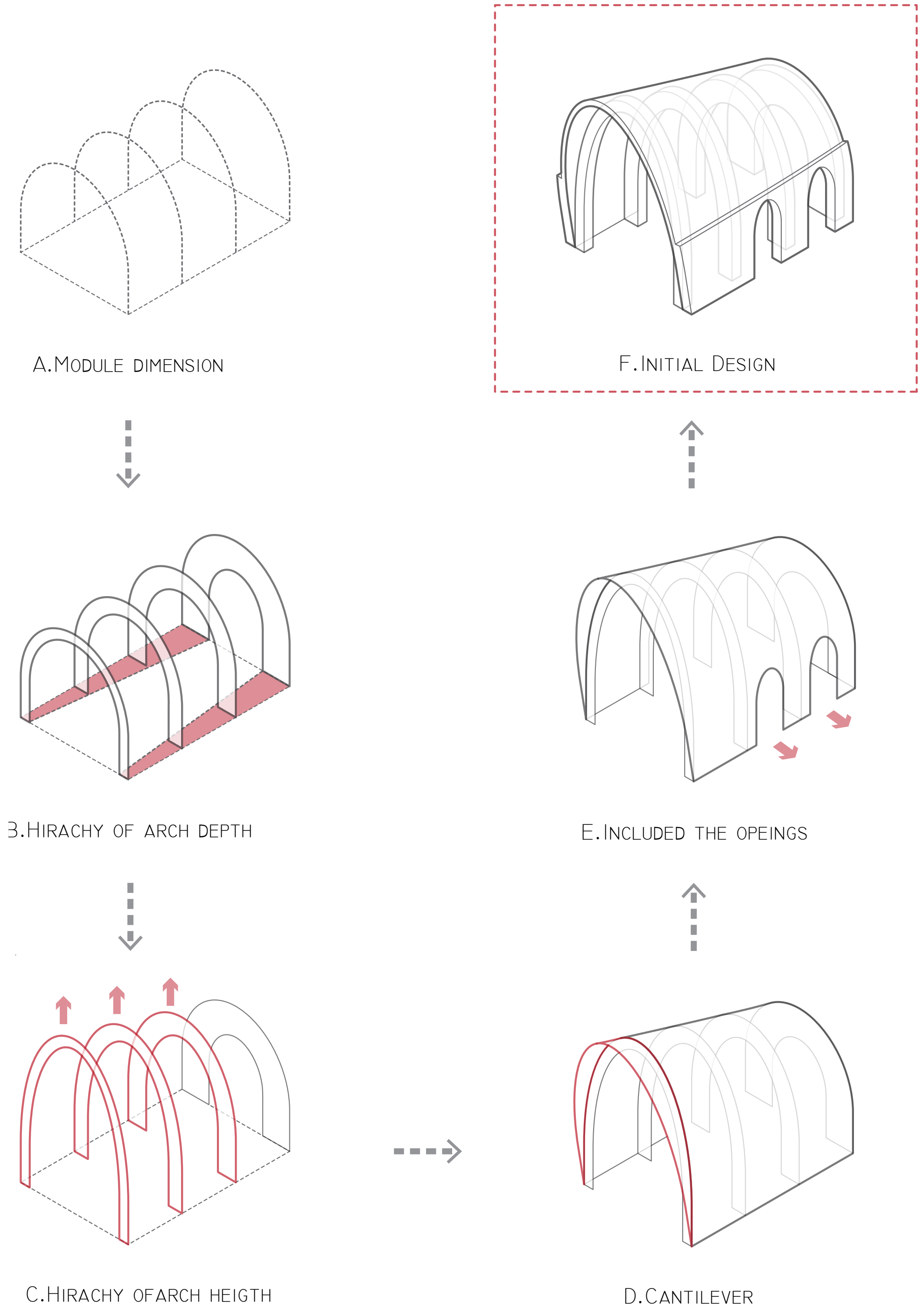
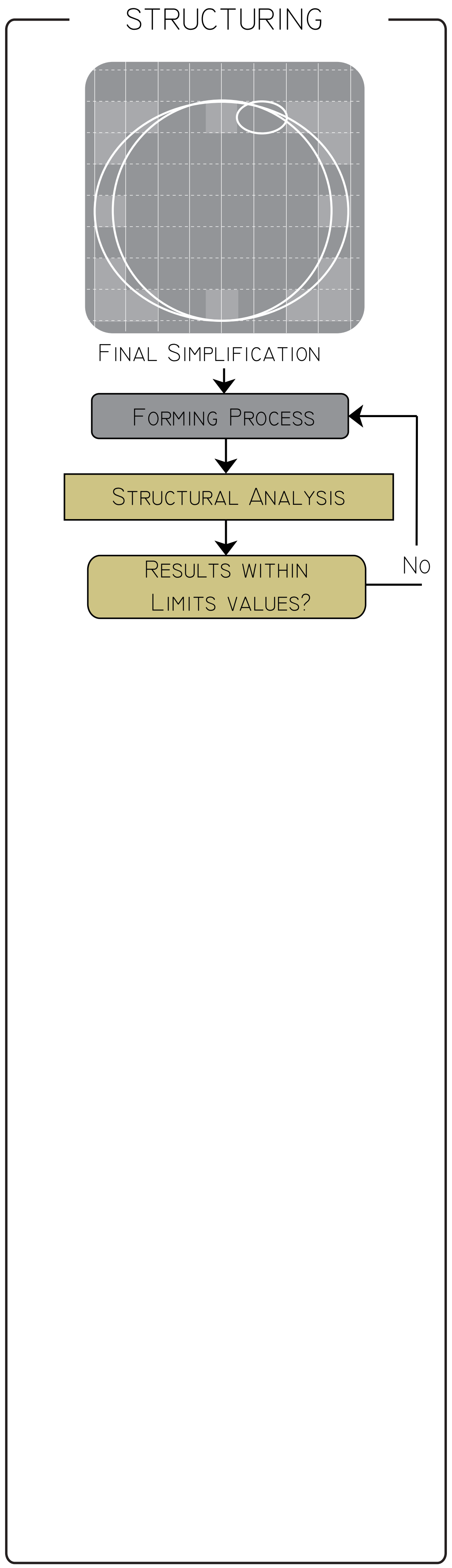


Figure 79. Forming process of the entrance



Structural analysis of the entrance

Step 1:

The structural analysis performed on the initial design showed that the structure was infeasible. As the tensile stress at the peak of the first structural arch was higher than the desired limit. This excessive stress was caused by the cantilever structure and the disproportion between the small cross section of the arch and its height.

Step 2:

To neutralize the stress, the depth of the cross section of the first arch needed to increase from 30 cm to 45 cm, as both compressive and tensile stress were reduced and within the desired limit. While the method provided the required stability to the form, it lessened the intended effect of depth due to the increased in depth of the first arch.

Step 3:

To preserve the intended effect of depth, the first arch structure was removed. This caused the tensile stress on the top of the vault and the second arch to increase dramatically, due to the elongated in the cantilever span. As the result the shape of the entrance deformed drastically due to the excessive load of the cantilever structure.

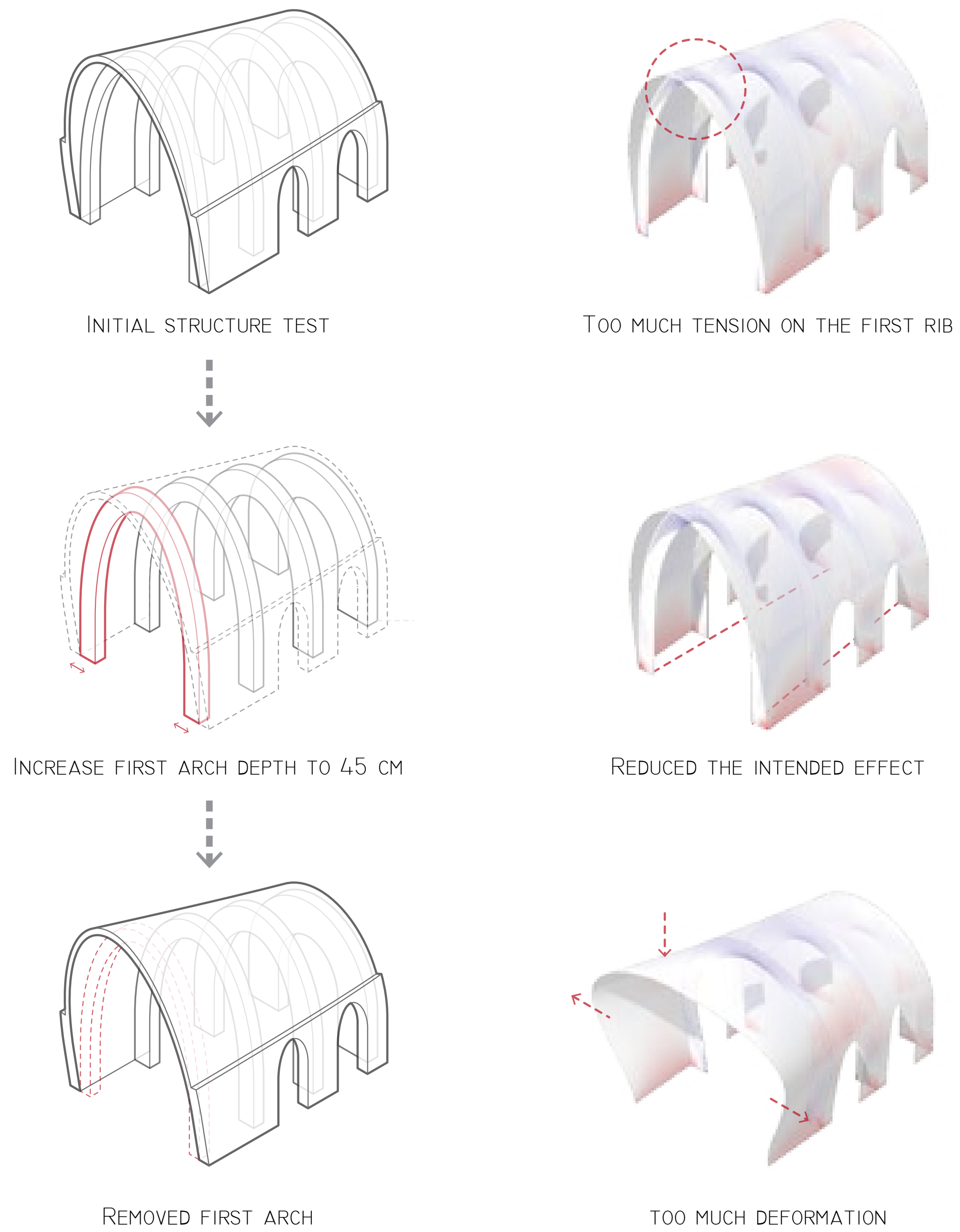
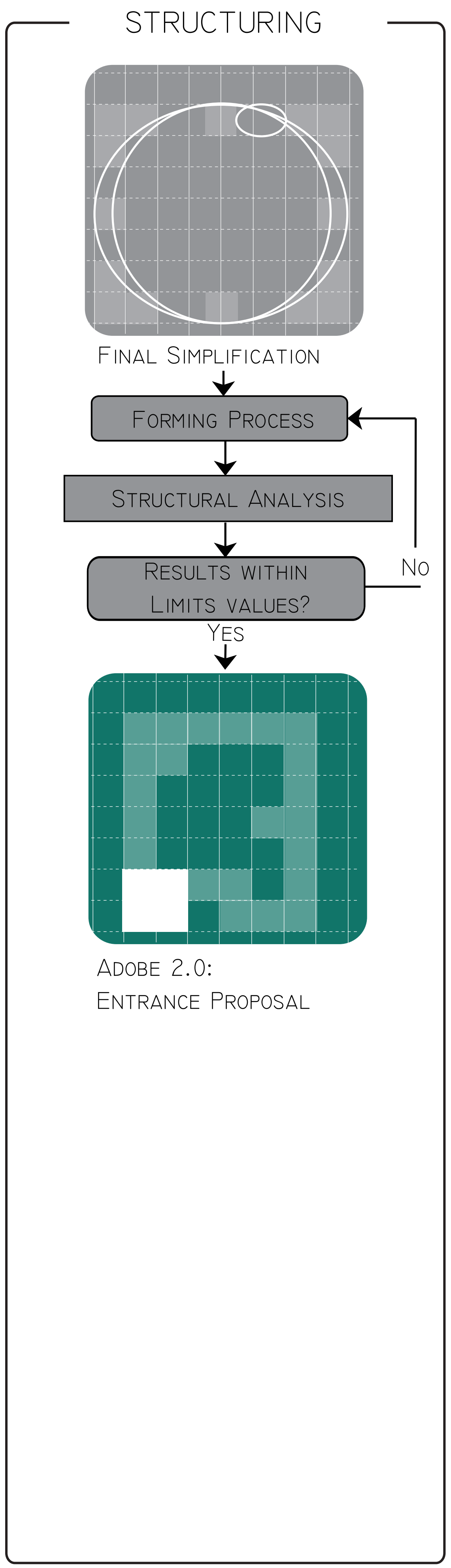


Figure 80. Structural analysis phases

	Deflection (cm)	Max. Compressive Stress (N/mm2)	Max. Tensile Stress (N/mm2)
Step 1	0.56	0.070	0.134
Step 2	0.42	0.066	0.112
Step 3	0.95	0.073	0.176

Table 9. Structural analysis results



	DEFLECTION (CM)	MAX. COMPRESSIVE STRESS (N/MM2)	MAX. TENSILE STRESS (N/MM2)
OPTION 1	0.82	0.069	0.129
OPTION 2	0.78	0.067	0.134
OPTION 3	0.78	0.054	0.135
OPTION 4	0.55	0.043	0.121
OPTION 5	0.54	0.042	0.117

TABLE 10. STRUCTURAL ANALYSIS FINAL RESULTS

Five different structural adjustments were proposed to solve the previous mentioned problem:

Option 1: increase the thickness of the structural arches from 0.30 m to 0.45 m. This resulted in a big improvement on the tensile stress; however, the deflection of the structure comparatively high.

Option 2: increase the depth of the second and third structural arch by 0.30 m. While the result shown a reduction in the deflection of the structure, the tensile stress is still above the desired limit of 0.130 N/mm2.

Option 3: the increased the thickness of the wall from 0.30 m to 0.45 m proved to be ineffective, as it yielded similar result as option 2.

Option 4: increase the thickness of the base of the cantilever from 0.30 m to 0.60 m. This show a great improvement in all the deflection, compressive and tensile stress of the structure

Option 5: similar to the previous option, however the cantilever structure has a gradual change in its thickness, from 0.60 m to 0.15 m. The perforation pattern is also added to the vault to further decrease its overall load. The analysis showed similar result to the previous option with an extra improvement on tensile stress. Hence, the most suitable option.

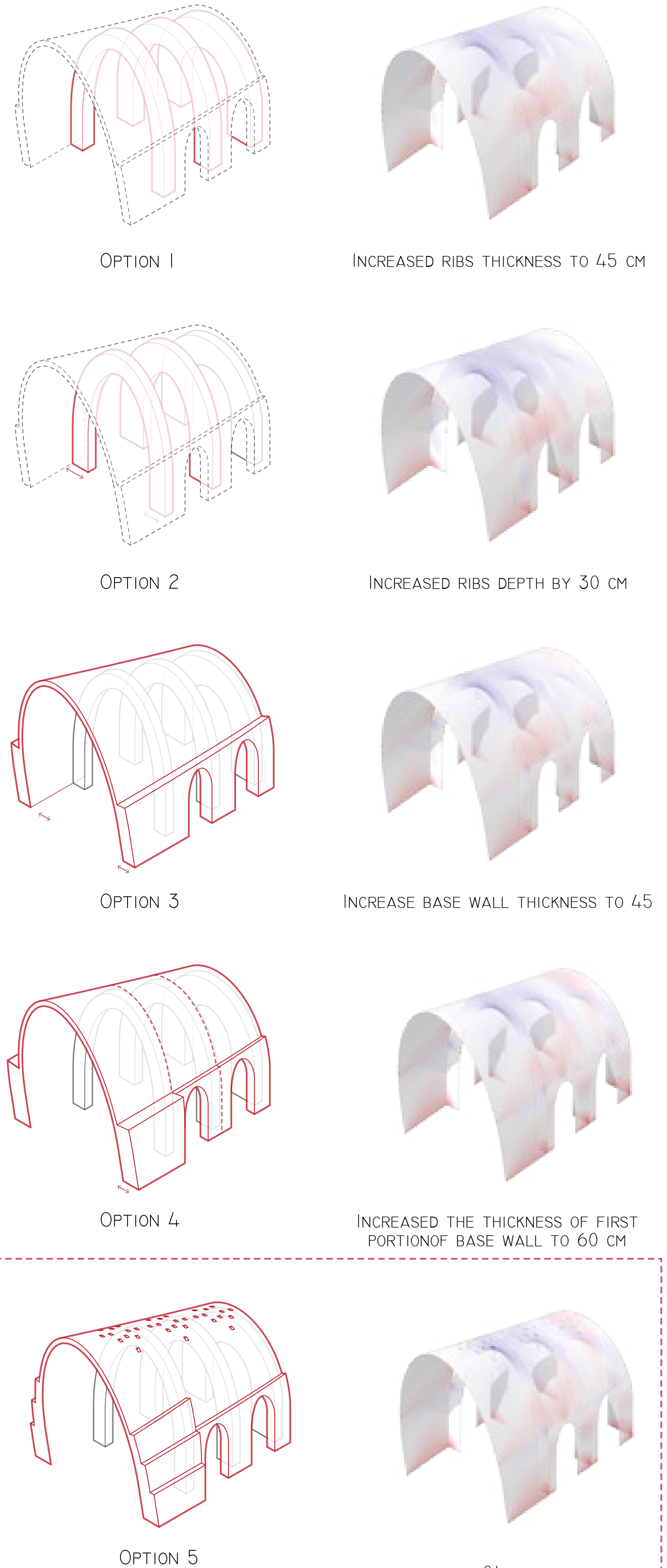


FIGURE 81. FINAL STRUCTURE

09 Construction

First the construction phases for both the entrance and the room configuration were set, Each phase of construction of the room was structurally analysed to ensure a proper and safe construction process.

After the results of the structural analysis were validated, the bricklaying was made with the help of a grasshopper script. After, the detailing process began in order to simplify the construction process for the users. This step gave us guidelines on how to position the bricks in the construction.

The materials and the sizes of adobe bricks were defined, considering the main configuration module and pixel sizes. And later the tool needed for the construction was detailed.

Finally, the opening design was made. With this, a catalogue can be made, and the refugees can choose their design considering

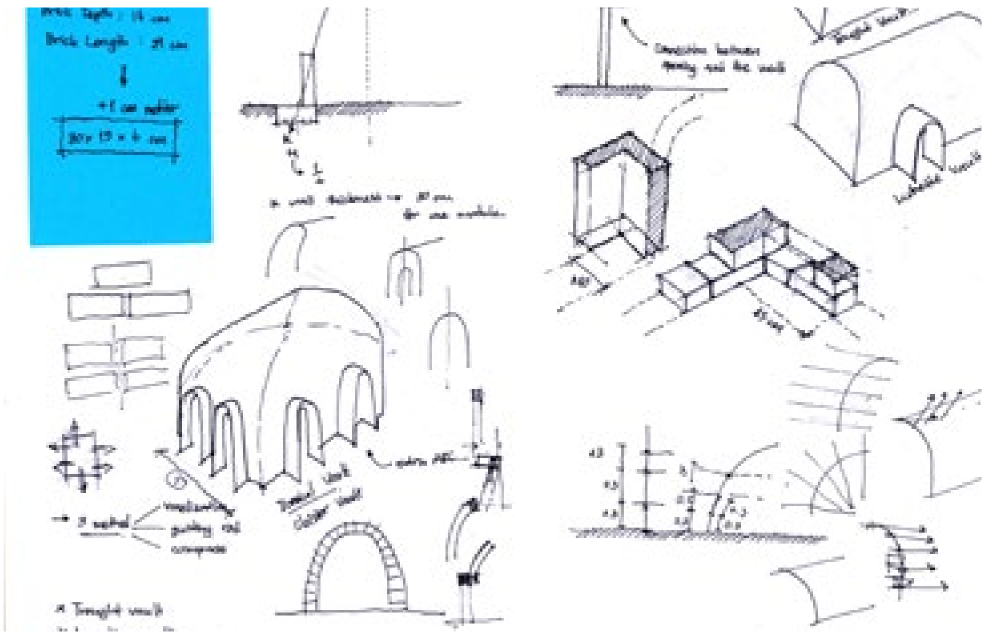


figure 82. Construction Ideas

I Construction Phases

Entrance

Step 1. The bricks are laid until the sill level. Note that the different in the wall thickness between the first 2.10 m (0.60 m thickness) portion and the rest (0.30 m thickness). This thick wall prevents the vault from deforming outward due to the load of the cantilever structure.

Step 2. The opening arches are constructed with the help of the compass, explained in the next chapters.

Step 3. Continue to lay the horizontal bricks until the top of the opening arches to provide binding stability to the wall and a stable footing for constructing the vault. Note again, the different in the thickness of the first portion of the wall (0.45 m thickness) and the rest (0.30 m thickness).

Step 4. Three structural arches, which vary in cross section and height, are constructed with the compass. Starting from the front to the back of the structure.

Step 5. The first 16 layers of bricks for the lower vault wall are constructed, with the thickness of 0.30 m. The bricks are laid in the horizontal manner that slightly rotate along the curvature of the vault.

Step 6. Two vaults between the second and third arches are constructed.

Step 7. In this final step, the cantilever structure is constructed.

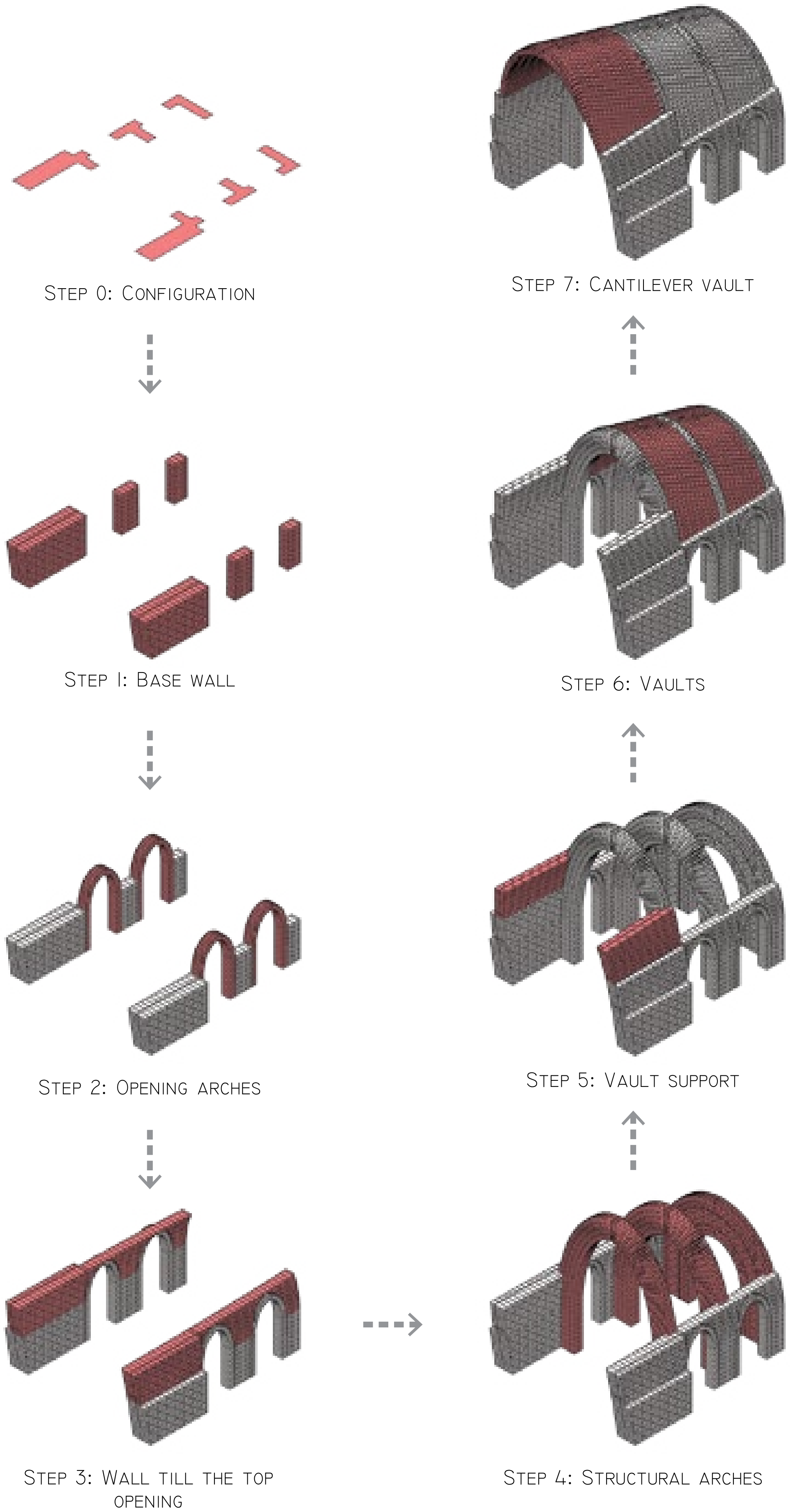
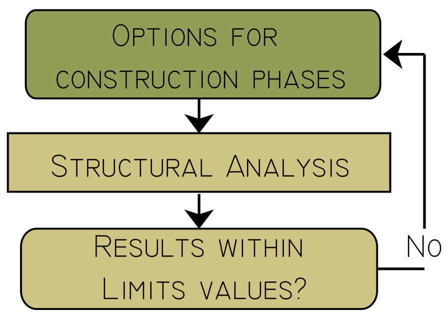


Figure 83. Entrance construction phases

CONSTRUCTION



I Construction Phases

Structural analysis of rooms

Young Modulus (N/mm2)	150
Compressive strength limit (N/mm2)	2.6
Safety factor	2
Allowable Compressive strength (N/mm2)	1.3
Allowable tensile strength (N/mm2)	0.13

Table 11. Inputs of material propieties

Limit values were set based on the brick report (annex C) and the literature review. As shown in table 11, a standard value for young's modulus of 150N/mm2 is considered for a well-made adobe brick. An allowable compressive strength of 1.3 N/mm2, with a safety factor of 2 is considered, as discussed earlier.

The value for the allowable tensile strength is taken as 1/10th of the allowable compressive strength. The structural analysis is carried out in relation to the steps of construction for one room with wall thickness of 30cm and compared for the shell thickness of 30cm and 15cm.

At first the analysis is carried out for the wall and shell thickness of 30cm as shown in table 2. Considering the limit value of 0.13 N/mm2 for tensile strength, it is found that the step 5, 6 and 7 of the construction process gives stress values above the limit. Also due to the higher weight of the roof, some of the reaction forces flip to upward direction creating unwanted tensile stresses, questioning the proper load transfer to the ground.

Following the problem with the shell of 30cm, the analysis is repeated with a lower shell thickness of 15cm as shown in table 3. The stress values are found to be within the limit value of compressive and tensile strength.

However, in few of the steps of the construction process the reaction forces are still in the opposite direction to that desired. Therefore, the last few steps of construction are altered to ensure no tensile stress and even load transfer to the ground.

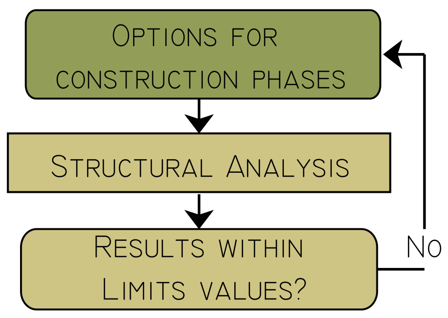
Steps	Deflection (cm)	Max. Compressive stress (N/mm2)		Max. tensile stress (N/mm2)		Reaction direction
		Principal stress 1	Principal stress 2	Principal stress 1	Principal stress 2	
step 1	0.0086	0.00568	0.0243	0.0007	0.0005	Downward
step 2	0.0746	0.0083	0.0594	0.01	0.0002	Downward
step 3	0.41	0.0349	0.159	0.0836	0.021	Downward
step 4	0.47	0.0576	0.233	0.0954	0.0336	some upward
step 5	0.54	0.0668	0.27	0.146	0.0371	some upward
step 6	0.54	0.0694	0.28	0.125	0.0451	some upward
step 7	0.37	0.0527	0.214	0.147	0.0454	Downward
One whole unit	**0.27**	**0.0557**	**0.186**	**0.082**	**0.0338**	**Downward**

Table 12. Results for 30 cm thickness shell

Steps	Deflection (cm)	Max. Compressive stress (N/mm2)		Max. tensile stress (N/mm2)		Reaction direction
		Principal stress 1	Principal stress 2	Principal stress 1	Principal stress 2	
step 1	0.0086	0.00568	0.0243	0.0007	0.0005	Downward
step 2	0.0746	0.0083	0.0594	0.01	0.0002	Downward
step 3	0.57	0.0339	0.149	0.081	0.016	Downward
step 4	0.63	0.0429	0.171	0.094	0.0399	Downward
step 5	0.73	0.0487	0.197	0.114	0.0473	Some upward
step 6	0.68	0.0496	0.241	0.11	0.0522	Some upward
step 7	0.38	0.0357	0.178	0.104	0.0436	Downward
New steps						
Step 4	0.5	0.0489	0.275	0.0486	0.0083	Downward
Step 5	0.47	0.0442	0.146	0.0832	0.038	Downward
Step 6	0.38	0.0361	0.228	0.0901	0.0423	Downward
One whole unit	**0.25**	**0.0473**	**0.129**	**0.071**	**0.0324**	**Downward**

Table 13. Results for 15 cm thickness shell

CONSTRUCTION



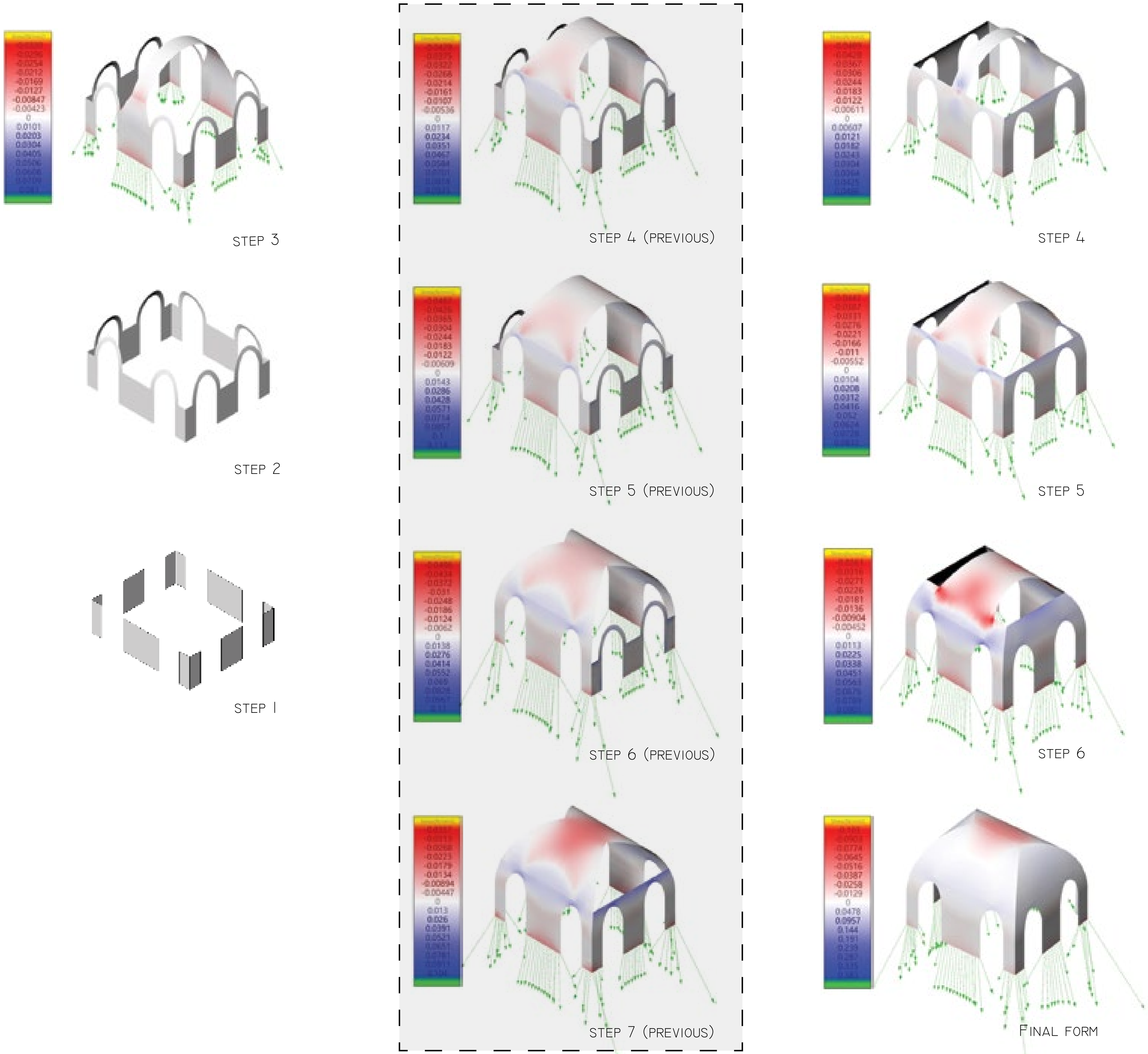
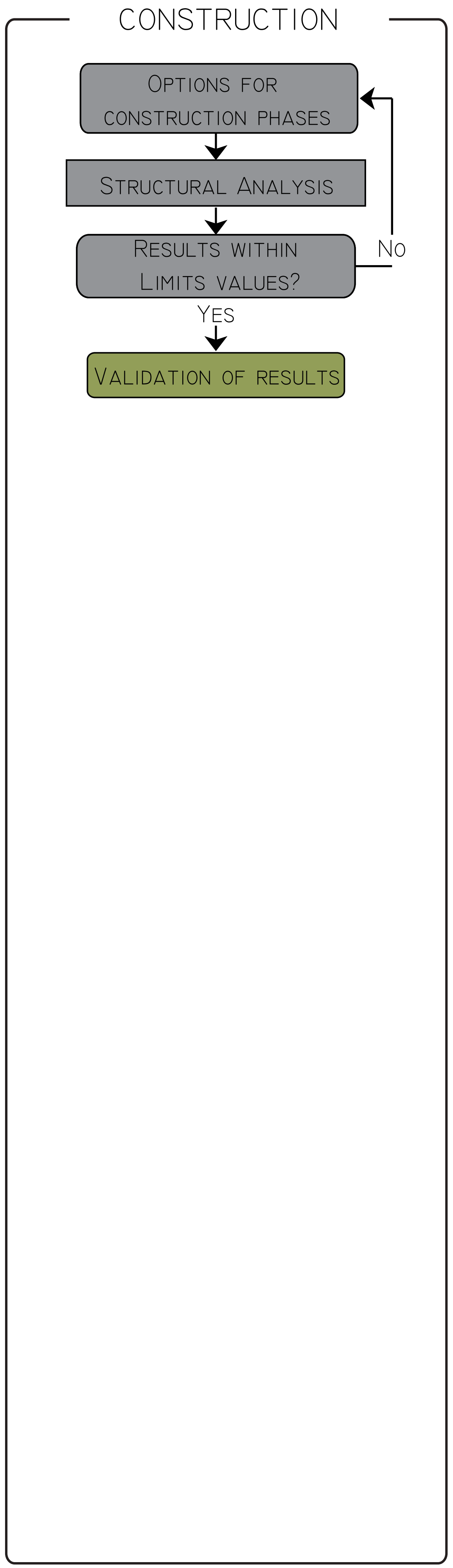


TABLE 14. STRUCTURAL ANALYSIS OF CONSTRUCTION PHASES

Through trial and error according to the structural results the construction is carried out in 6 steps. The process ensures tension free structure and the use of minimum number of tools.



STRUCTURAL ANALYSIS VALIDATION

The exercise was to hand calculate the vertical reaction force and compressive stress of the first arch on the base wall.

Since the arch is symmetric and load distribution is symmetric, the calculation is for half arch. The volume of half arch,

at Upper part 2.36 x 0.15 x 0.3 = 0.106 m3
at lower part 0.71 x 0.3 x 0.3 = 0.064 m3
Total volume = 0.170 m3

Here the specific weight of adobe is considered 15 KN/m3.
Thus, Total reaction = V = 0.17 x 15 = 2.55 KN

Surface area of the base of arch = A = 0.09 m2

Thus, Compressive stress on base wall = V/A
= 2550 N / 9e5 mm2
= 0.03 N/mm2

The Karamba results for the final steps of construction with a 15cm thick shell is shown in table X. To justify the results, the compressive strength result in principal stress 1 direction is cross-checked with hand calculations.

The previous hand calculation was done for step 3 of the construction process. In the same way, the Karamba results and the hand calculation results were compared and validated for all the steps of construction.

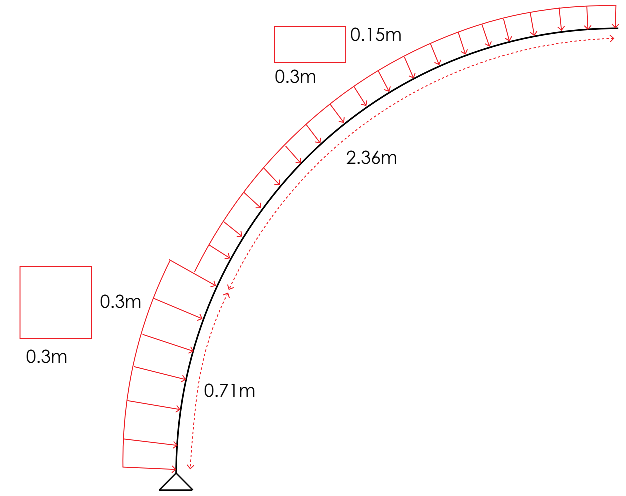


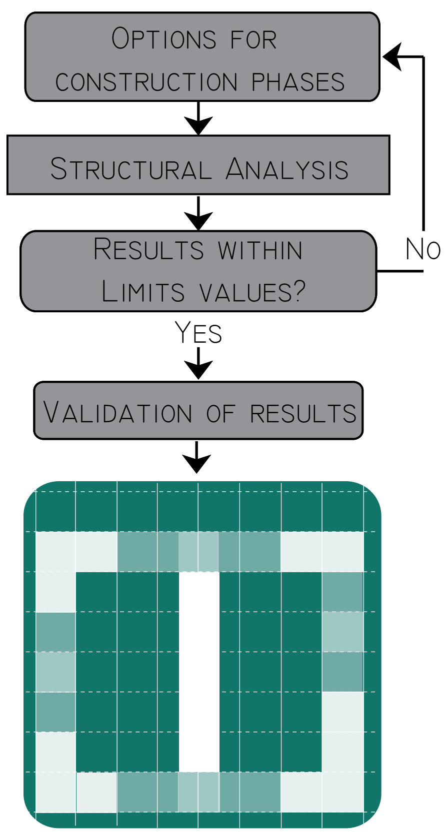
Figure 84. Validation through hand calculation


Figure 85. Validation of results

Steps	Deflection (cm)	Max. Compressive stress (N/mm2)		Max. Tensile stress (N/mm2)		Reaction direction
		Principal stress 1	Principal stress 2	Principal stress 1	Principal stress 2	
Step 1	0.0086	0.00568	0.0243	0.0007	0.0005	Downward
Step 2	0.0746	0.0083	0.0594	0.01	0.0002	Downward
Step 3	0.57	$\boxed{0.0339}$	0.149	0.081	0.016	Downward
Step 4	0.5	0.0489	0.275	0.0486	0.0083	Downward
Step 5	0.47	0.0442	0.146	0.0832	0.038	Downward
Step 6	0.38	0.0361	0.228	0.0901	0.0423	Downward
One whole unit	0.25	0.0473	0.129	0.071	0.0324	Downward

Table 15. Results for 15 cm thickness shell

CONSTRUCTION



Construction Phases

In step 1, the bricks are horizontally laid till the sill level to make up the wall until sill level.

In step 2, the arches for the openings are made using the compass to achieve the exact curvature and height

In step 3, the central arch is created with the compass replacing the compass arm for the desired focal length

In step 4, the wall is made till the top of the opening arches to provide the binding stability of the structure. The laying is done at an inward tilt of 10 degrees from the vertical as a base for the roof form.

In step 5, The Nubian vault is built without any formwork or compass by reclining the adobe bricks against the central arch till the edge of the rib arch.

In step 6, the Corner rib arches are made using the compass till the height of the vault.The junction of the two adjacent rib arches are closed with a triangular brick.

Finally the remaining bricks are laid to close off the vault.

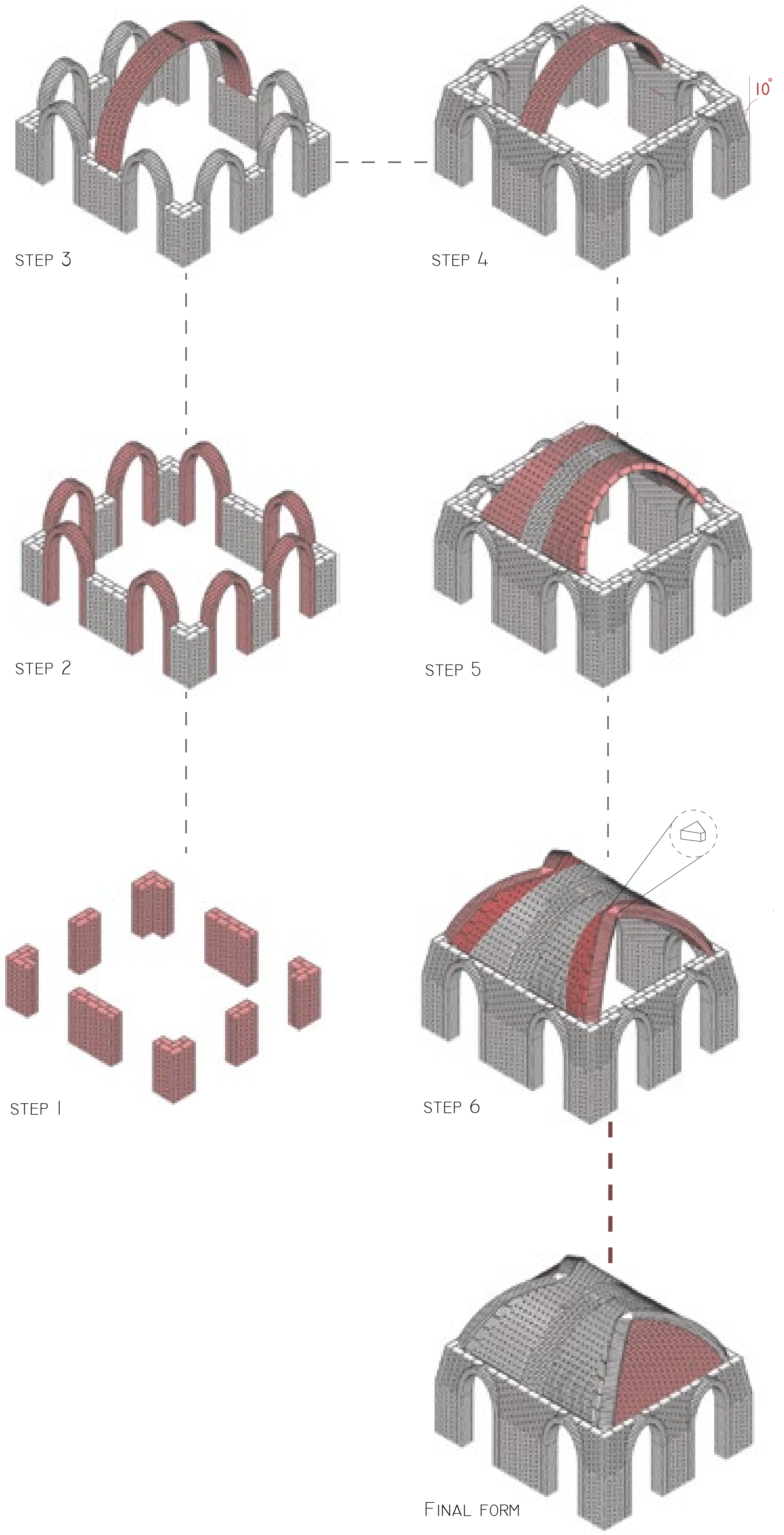
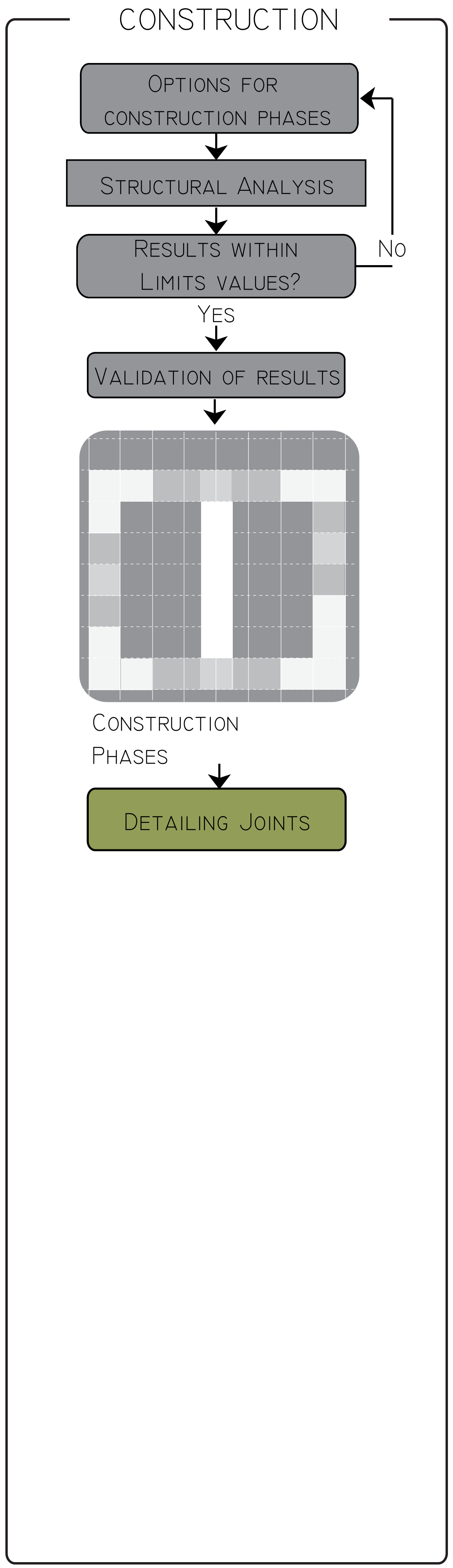


Figure 86. Construction phases



2 Detailing

The detailing of the project was made in order to understand better its constructability: how to build each base, each arch and the brick laying of every phase and the quantity of bricks.

This step was key for building the construction manual. First the grid was drawn as a background with the module and the pixel measurement to keep the construction with the same language of the configuration.

Various tries of bricklaying were made to make the constructability it was decided to put a base brick, every time an arch is built so the levelling of the construction remains the same after the base construction.

To finish the Nubian vault, it was decided to make a unique key brick to make the construction strong and the constructability feasible.

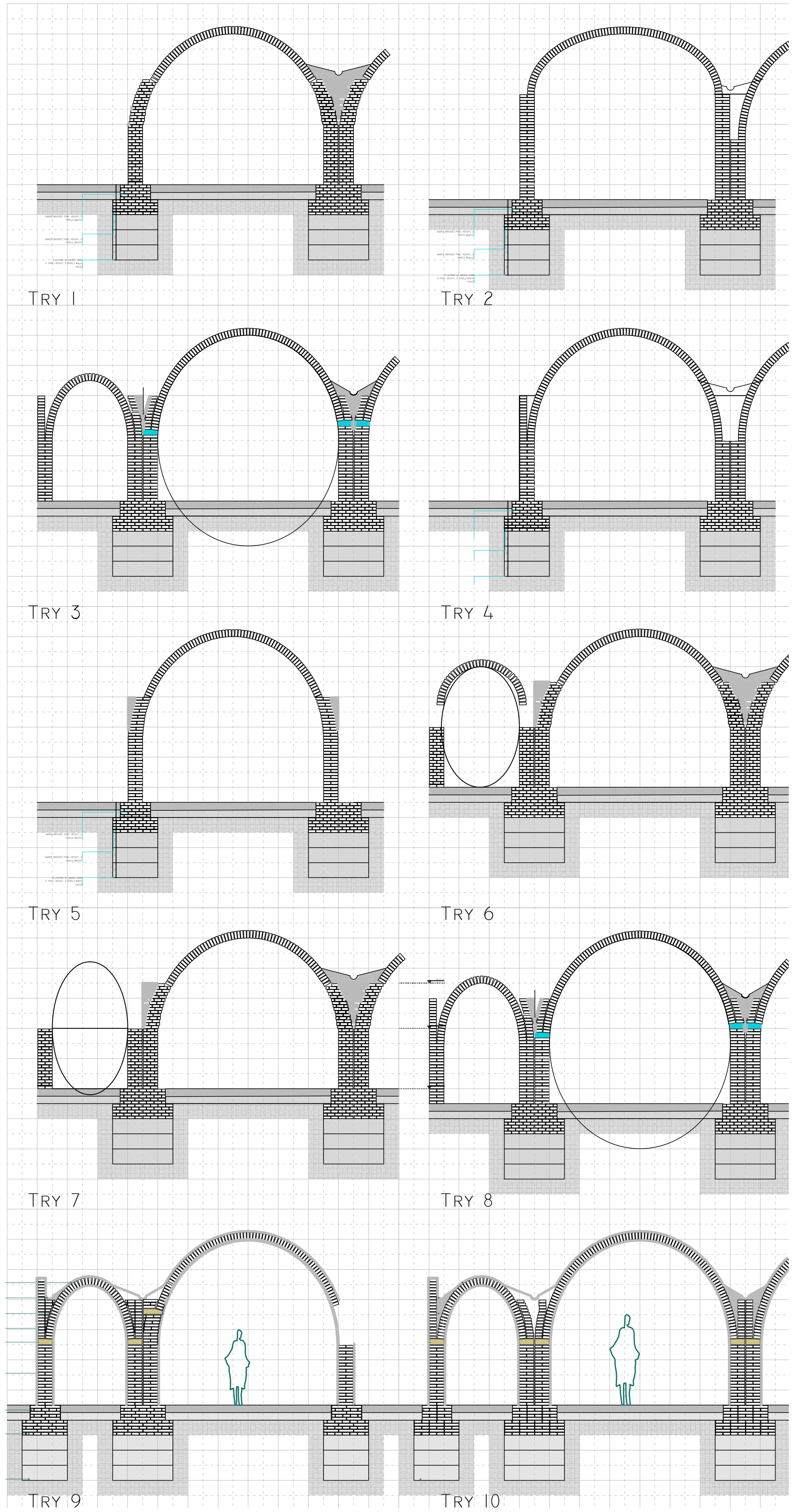
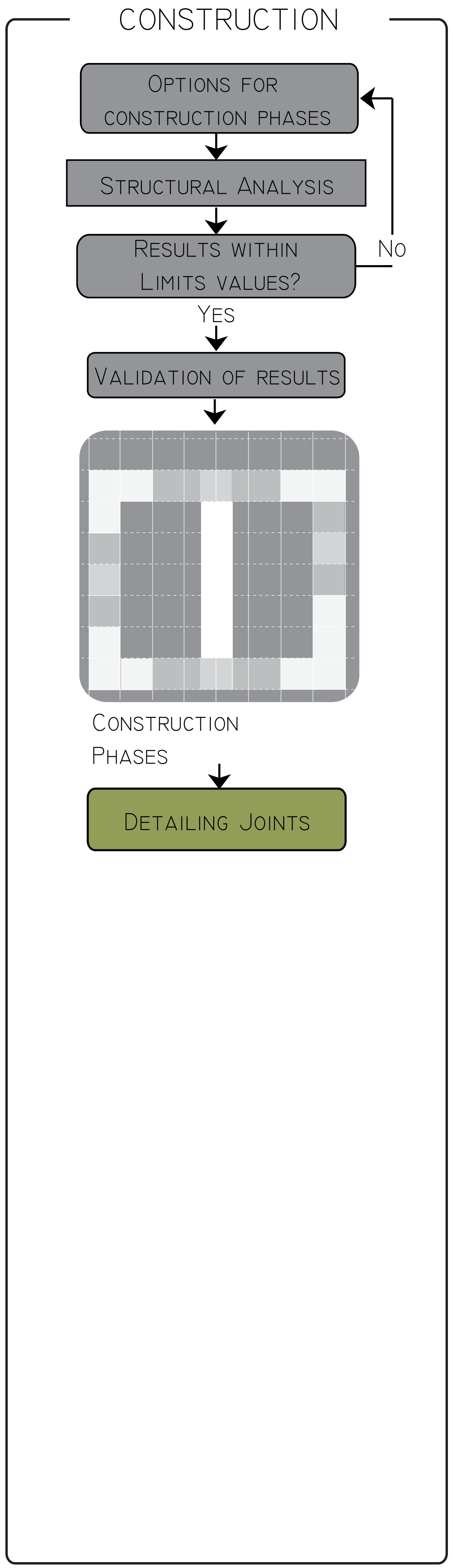


Figure 87. Process of detailing



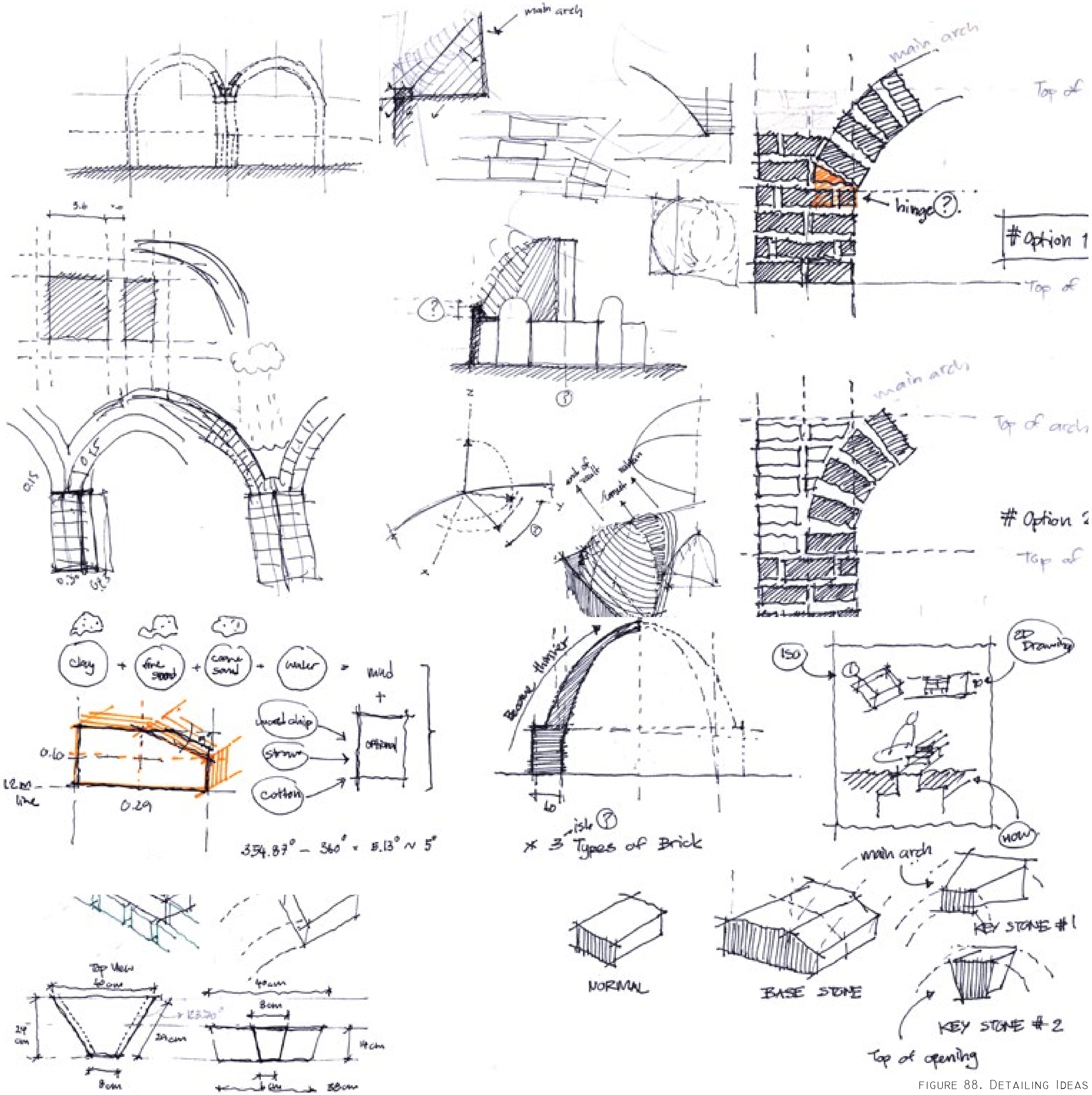
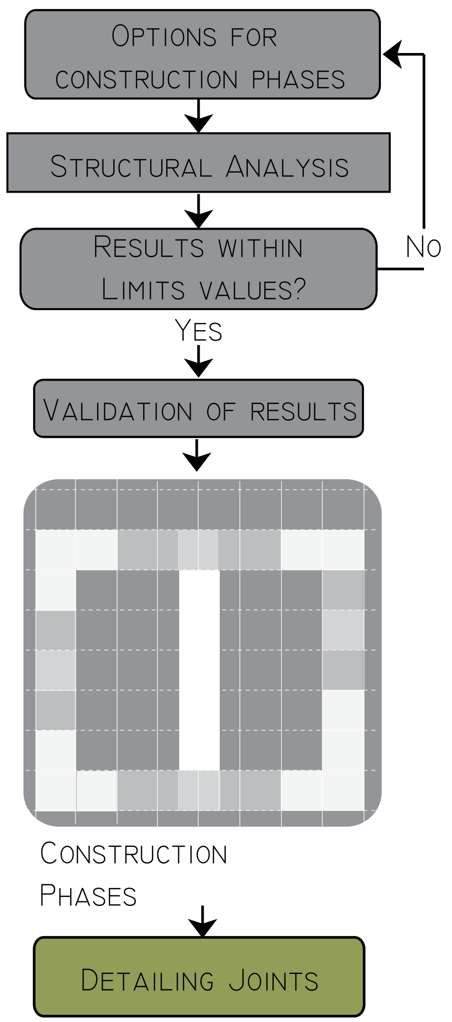
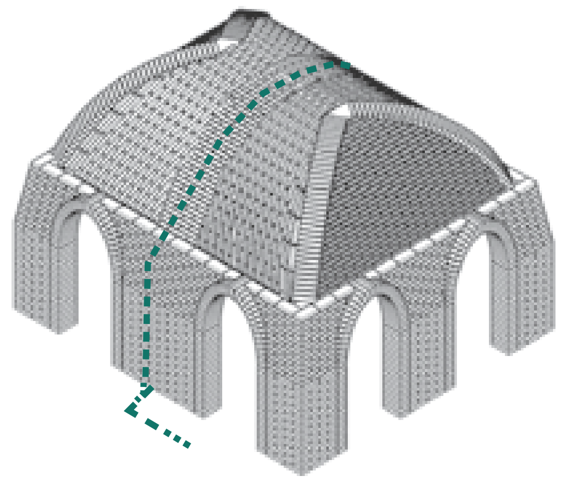


FIGURE 88. DETAILING IDEAS

CONSTRUCTION





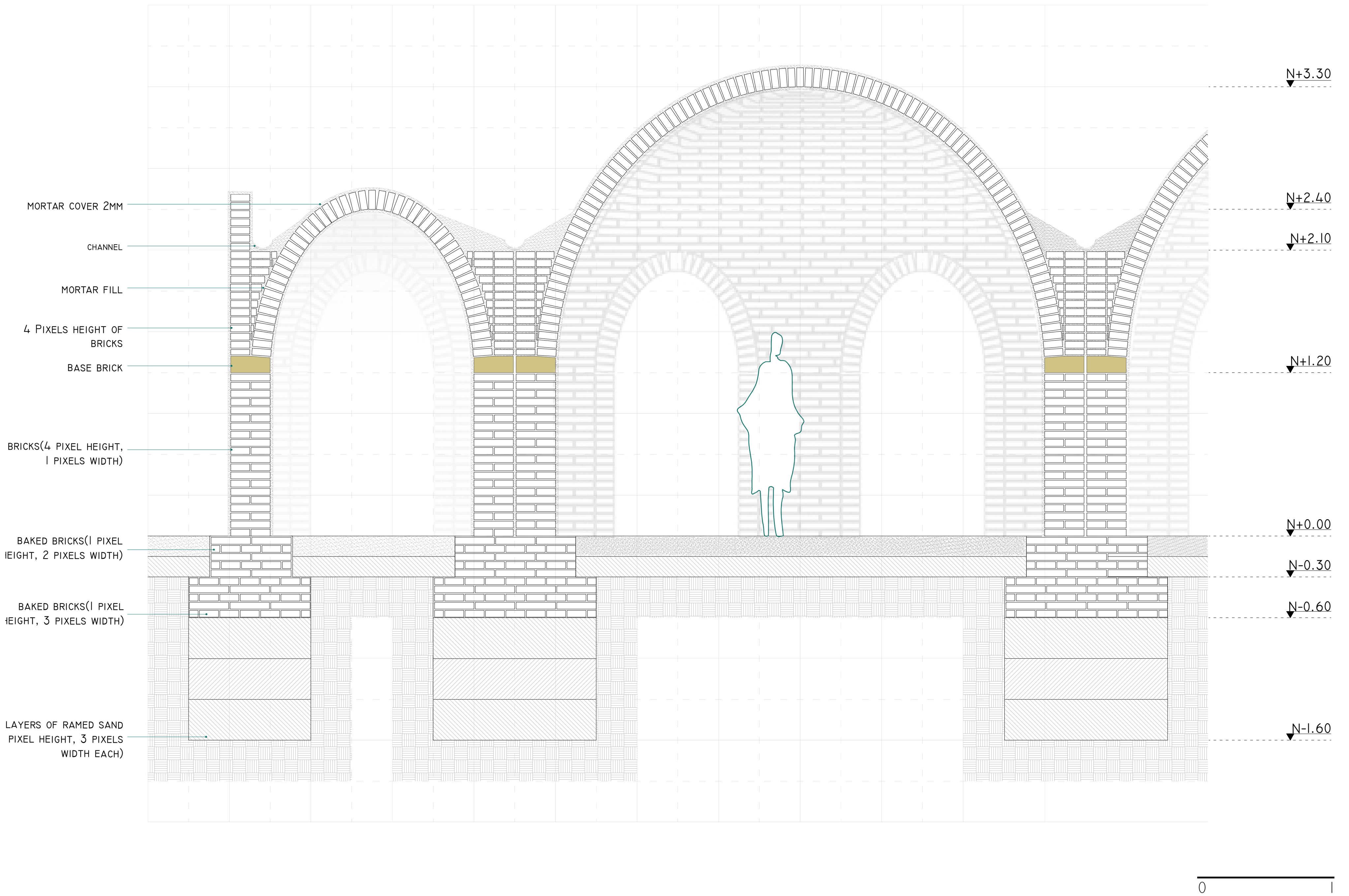
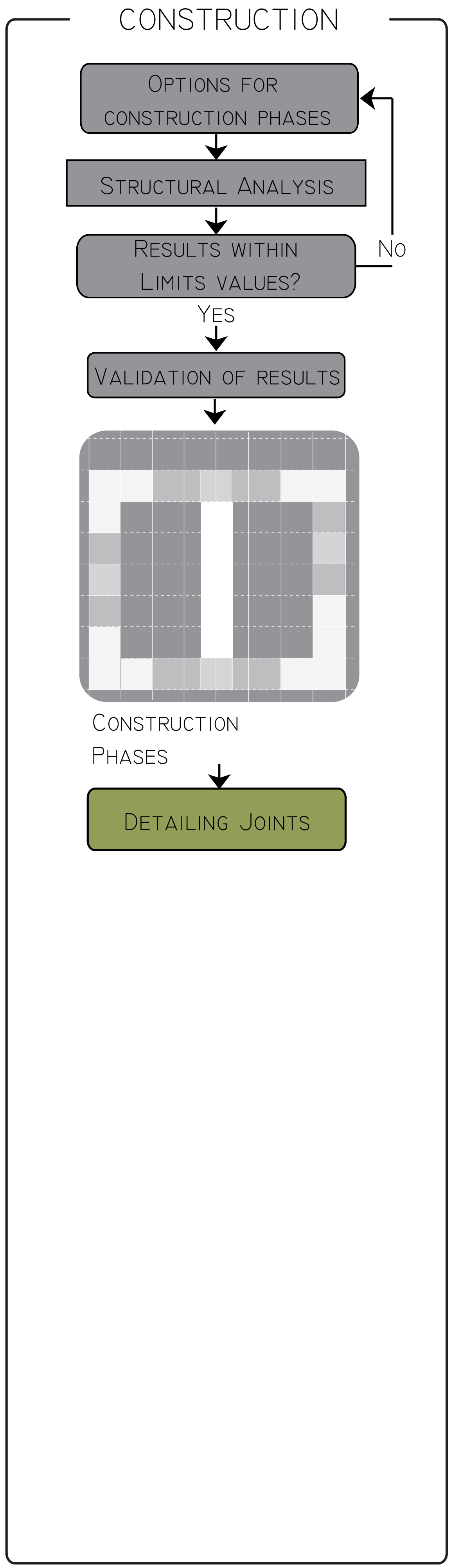
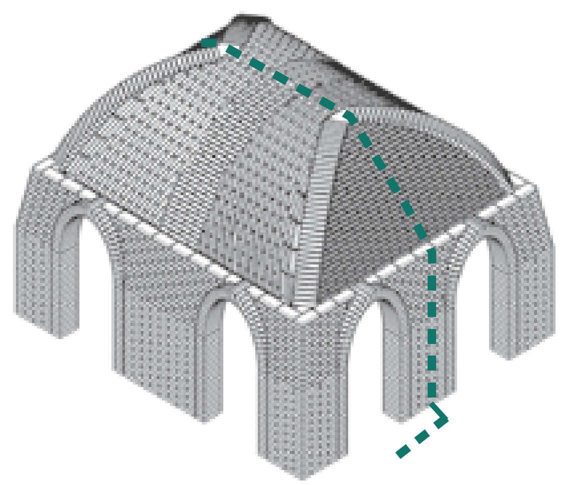


FIGURE 89. SECTION 1-1





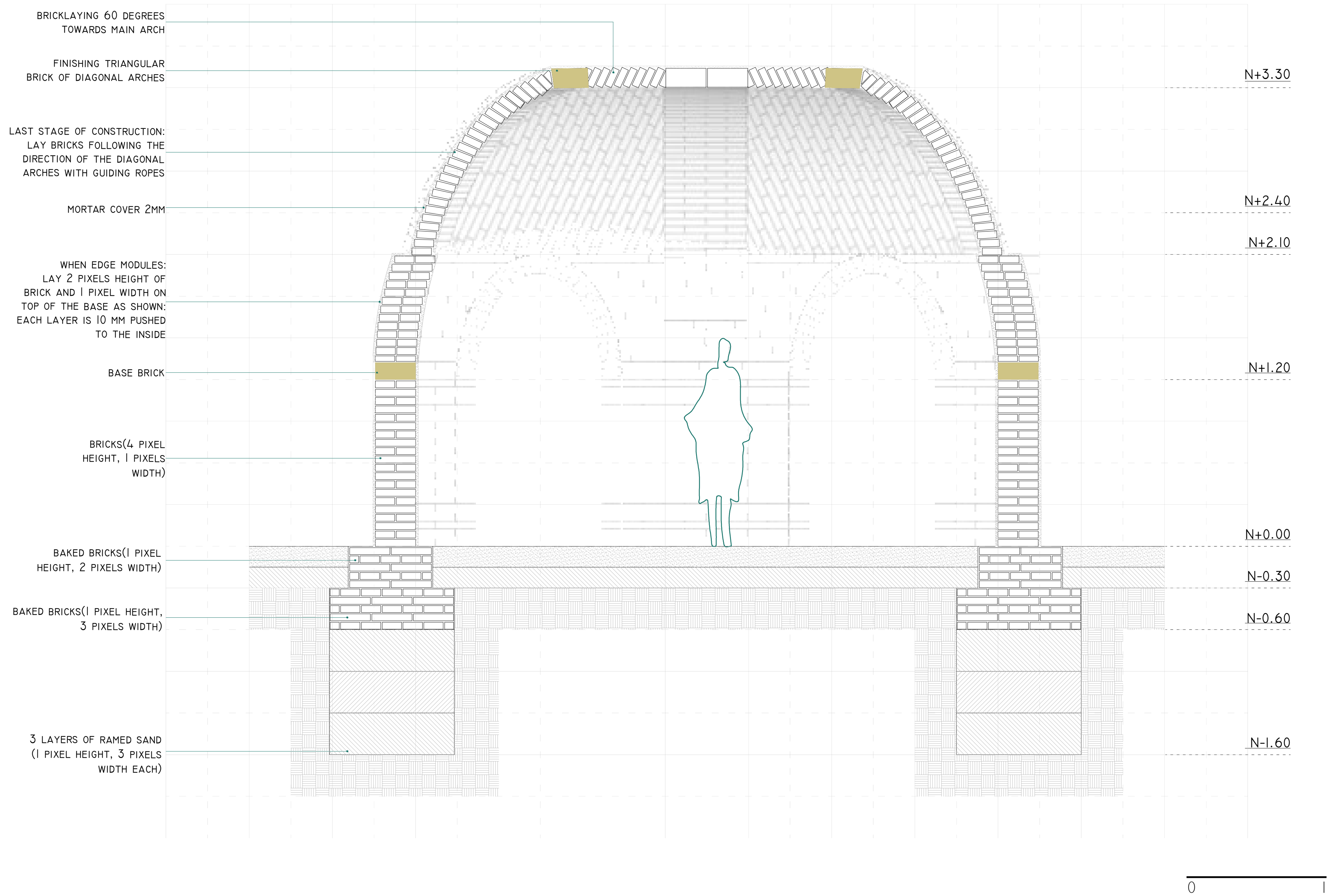
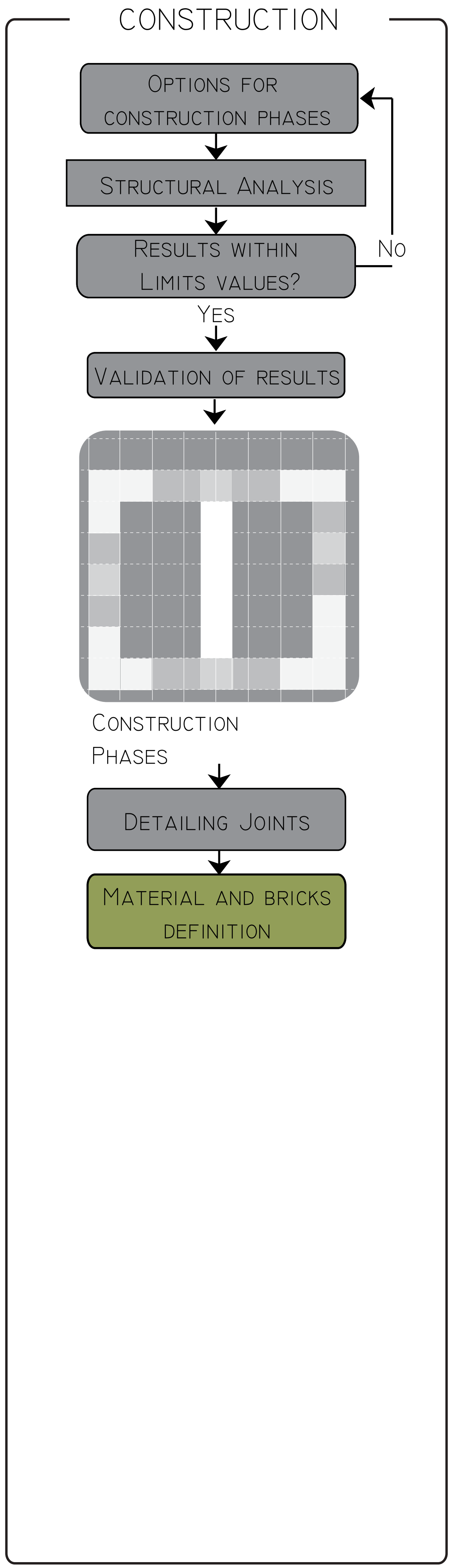


FIGURE 90. SECTION 2-2



3 Materilas

For the construction of the designed form, three different types of bricks were needed. The base brick for the transition from the vertical to the ellipse, the triangular brick as the key stone and the basic bricks for the rest of the construction. Measurements of these types can be seen in figure x.

The adobe bricks should be made by the refugees at the camp site with the available materials. The recipe for the standard brick composition were 30% clay, 30% fine sand, 40% coarse sand and 10% water of the total weight of the dry ingredients.

As additional material straw was chosen for its tensile quality. The straw was added in the percentage of 10% of the total mixture. The final mixture was then placed in the required moulds and allowed to dry to make the bricks. The mortar was also prepared with the same basic composition with higher percentage of water as required to make the sticky paste.

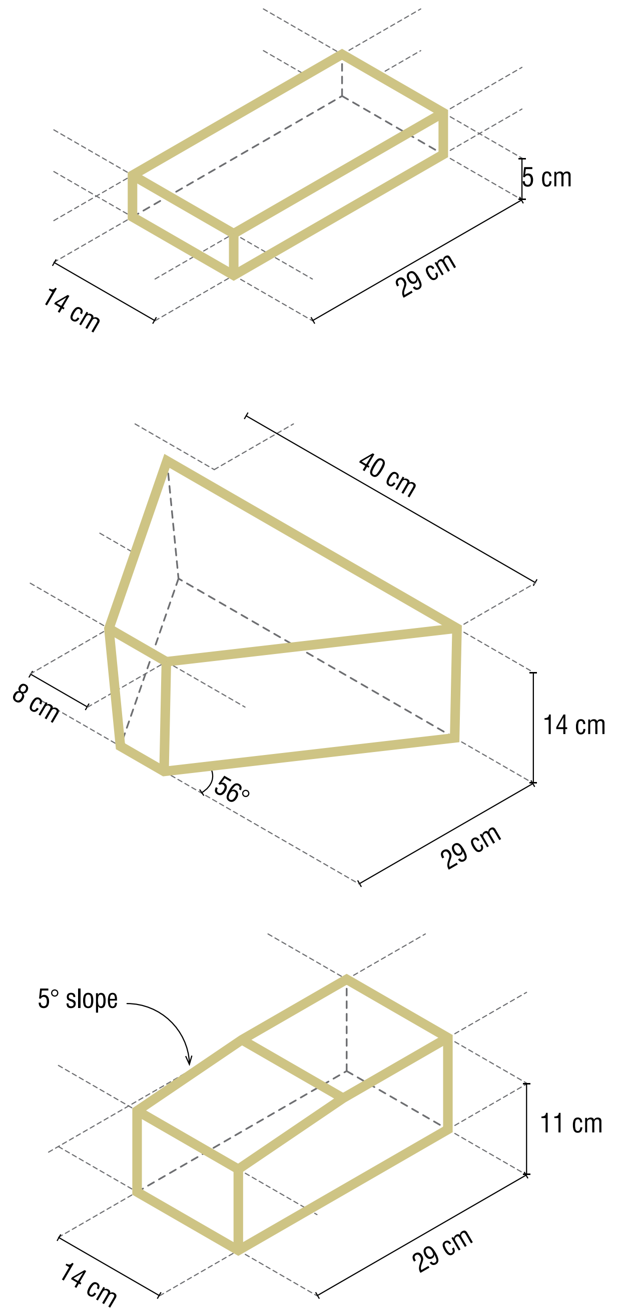
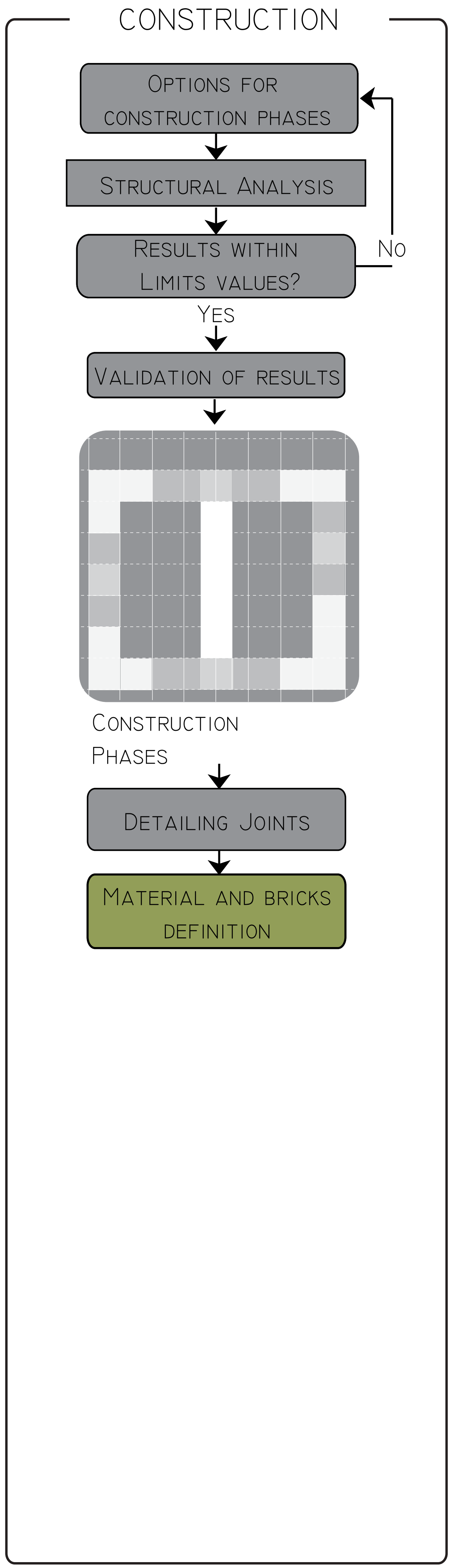


Figure 91. Types of bricks needed for the project



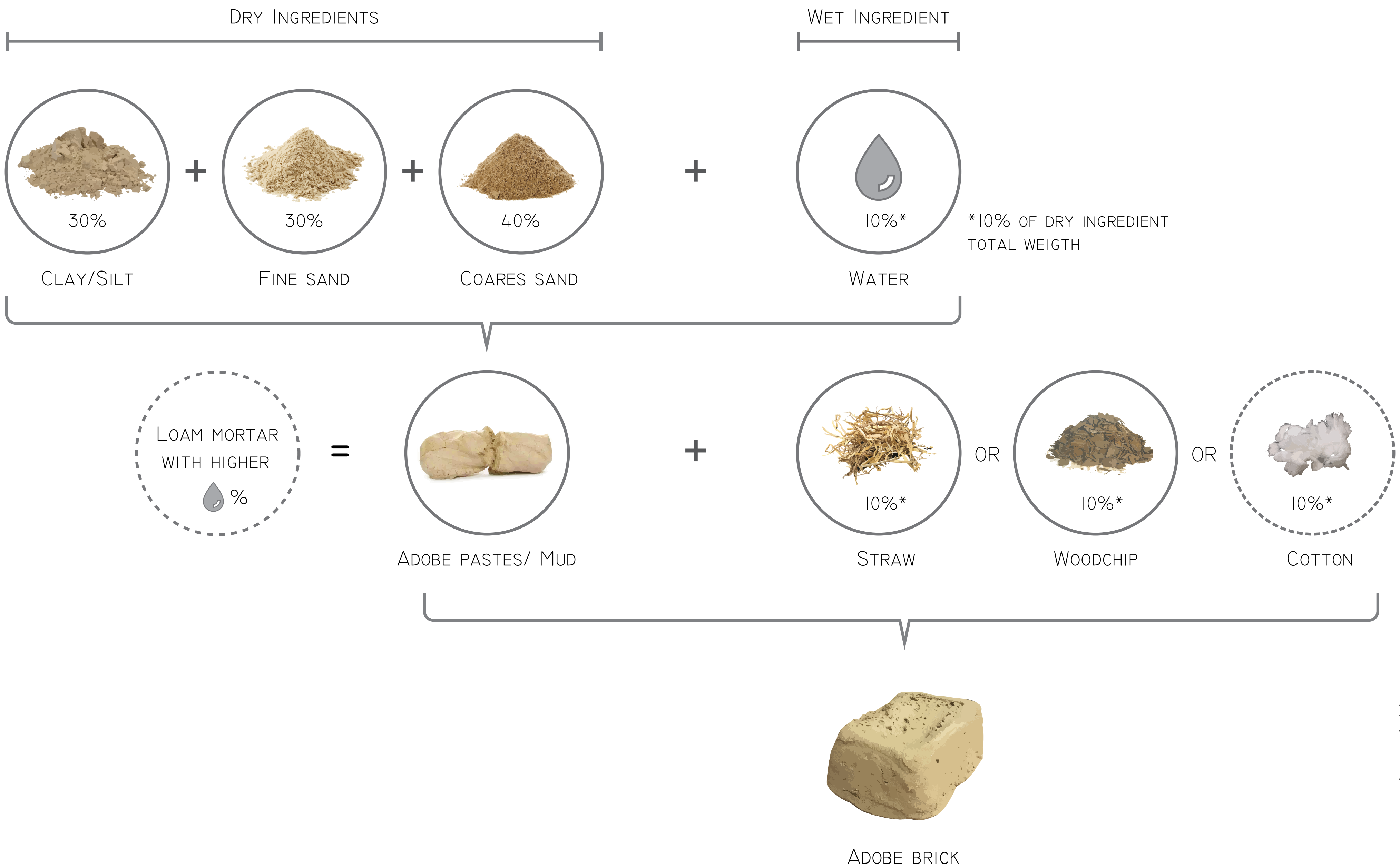
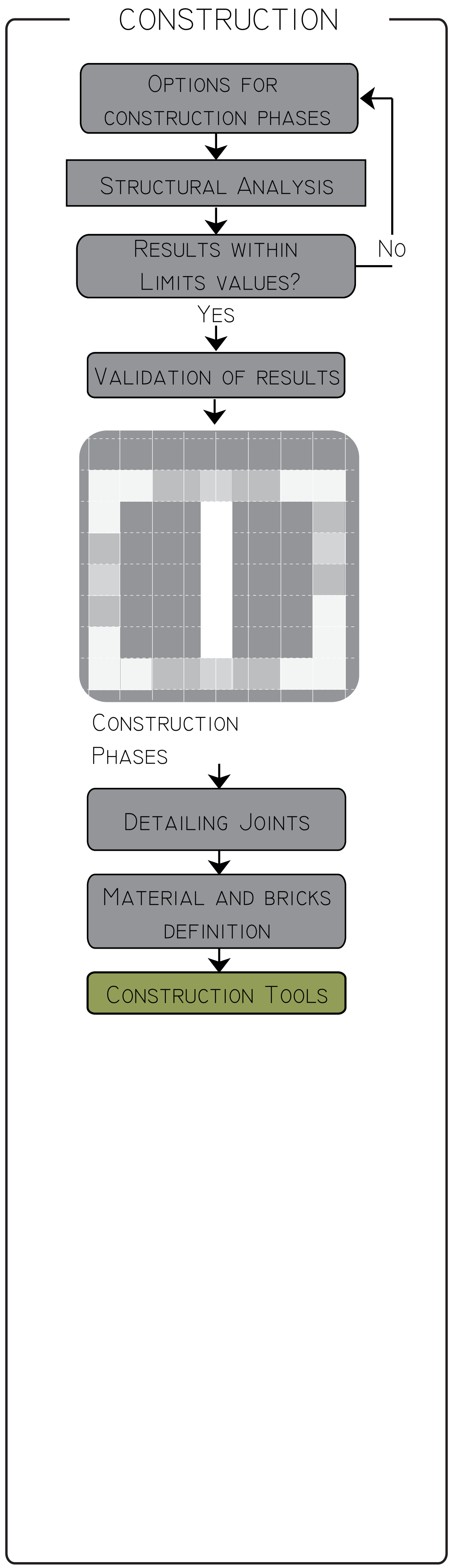


figure 92. Adobe Making



4 Tools

A compass was designed to create the arches in the different phases of construction. The compass can be made with wood and was designed to be able to be disassembled. it had three sets of beams to make the different arch types with the same tools.

The large two beams (2.10 meters long) were used for the main central arch, the medium beams (1.20 meters long) were used to create the arch for the corridor and the small (0.9 meters long) beams were used for the window, door and corridor openings.

The compass followed a simple mechanism where the two beams could move along a track to achieve the desired curvature for the arch. The beams could be used simultaneously to build the arch from the two sides. Each of the beams had a plate of 0.30m width to place two adjacent bricks, holding the previous one in place as it dries while the next brick could be placed beside it.

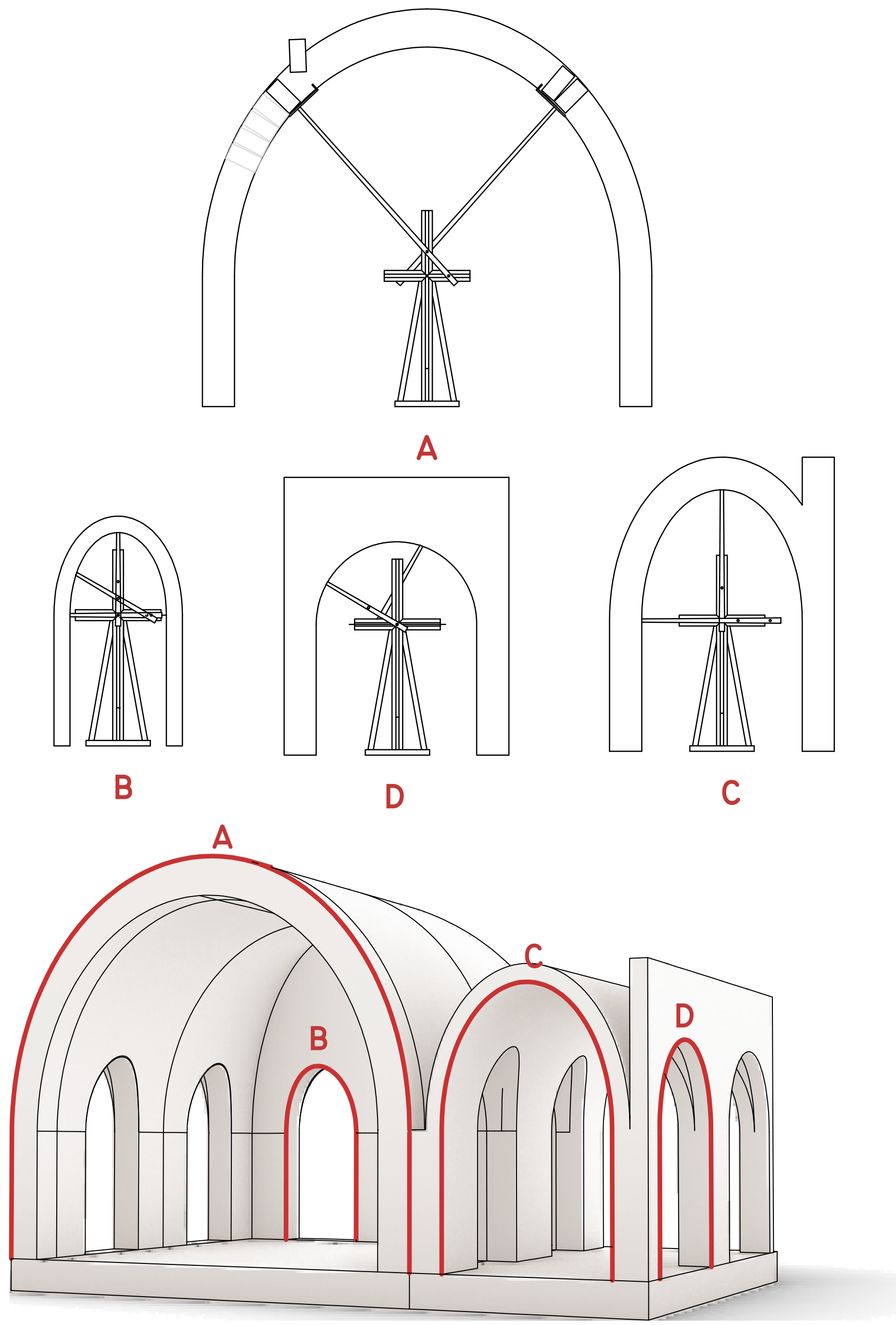
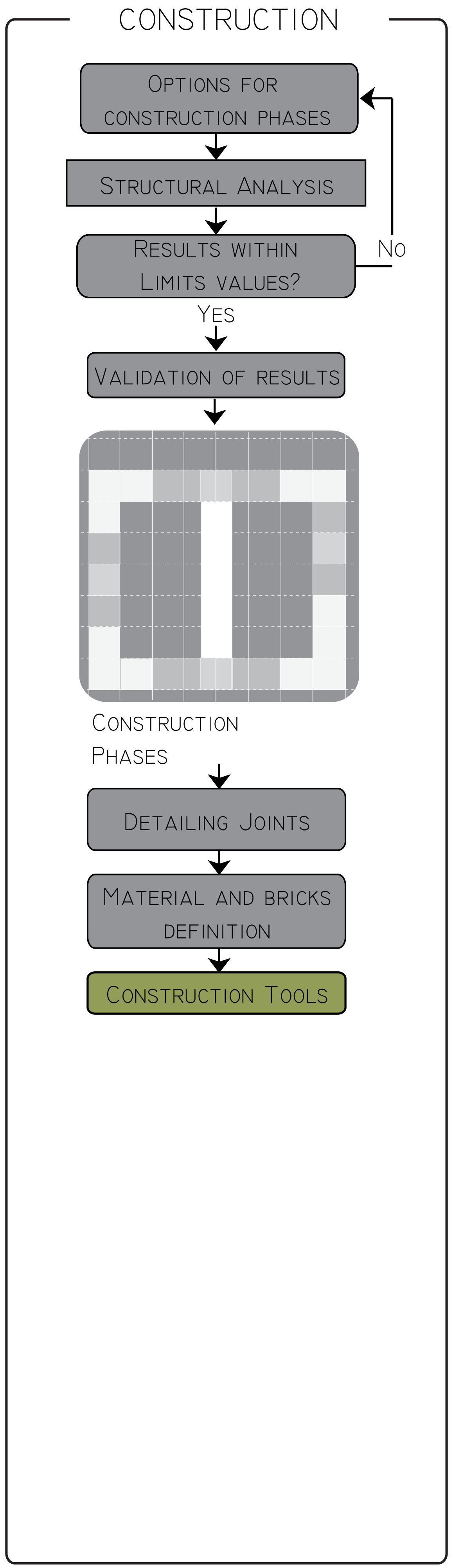


Figure 93. Types of arches



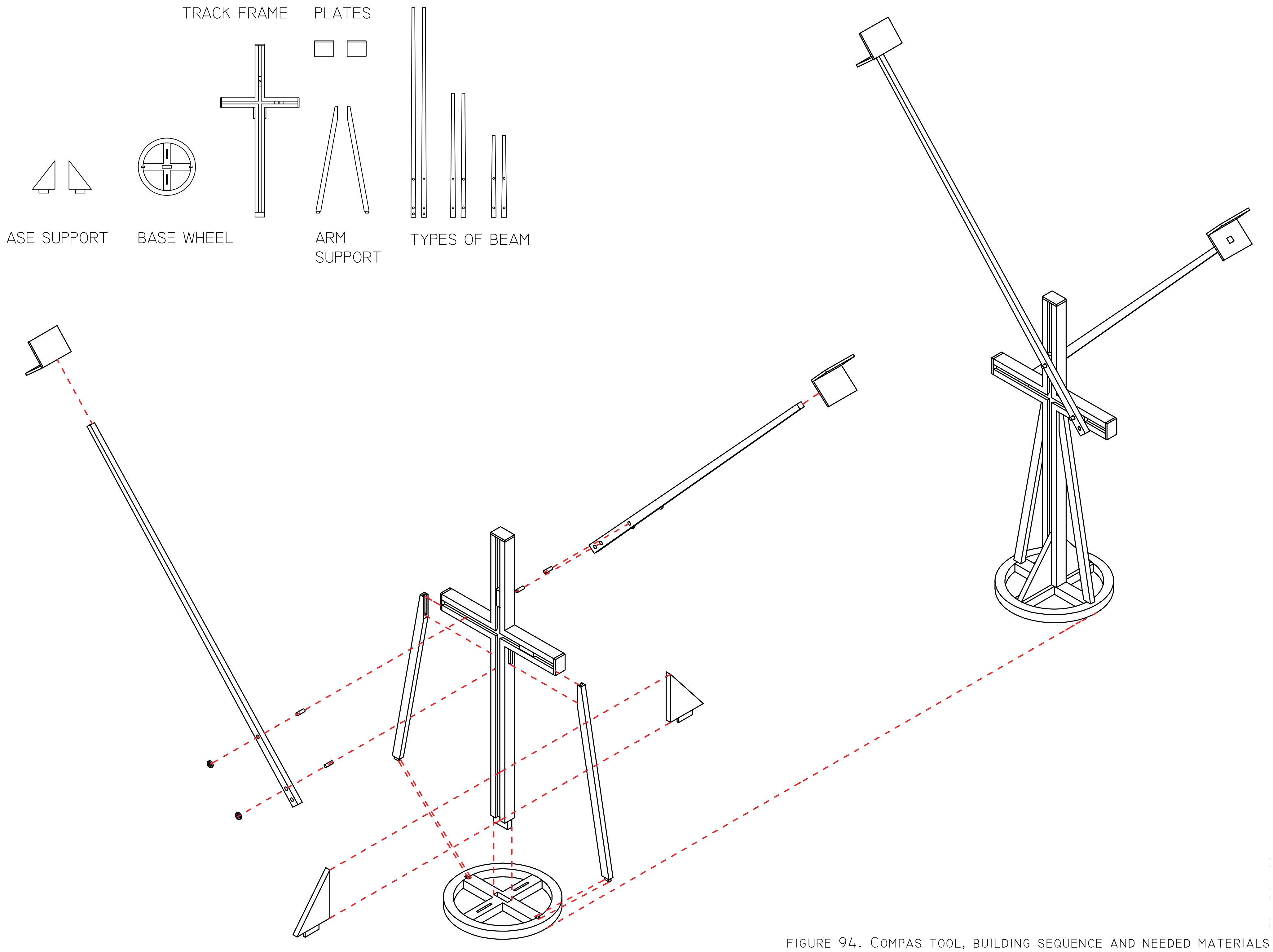
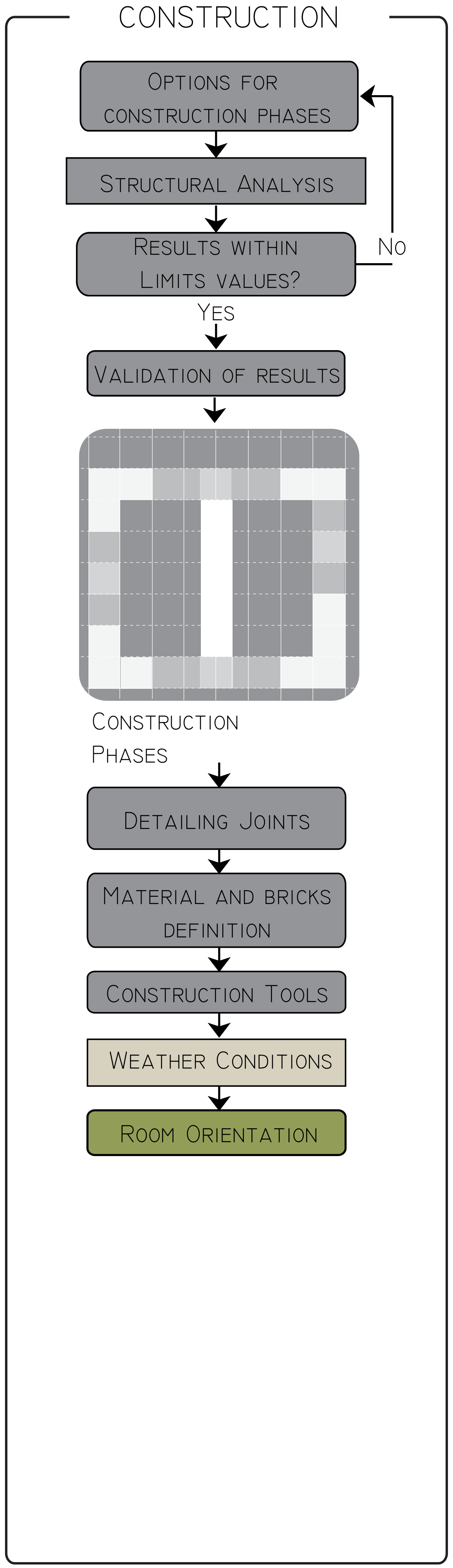


Figure 94. Compas tool, building sequence and needed materials



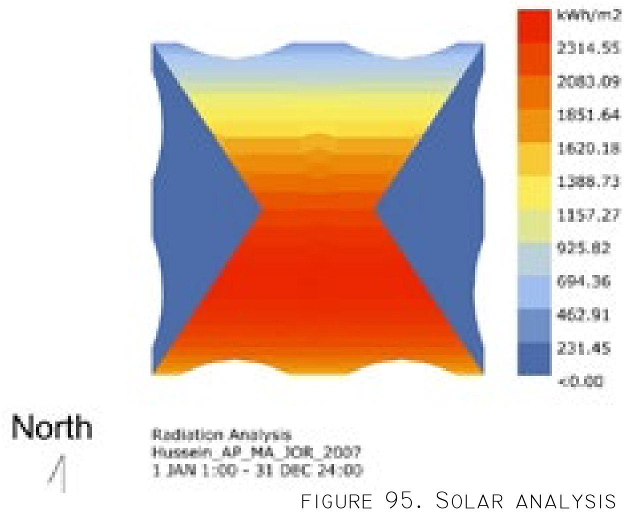


Figure 95. Solar analysis

5 Opening Design

A solar radiation analysis of the Zaatari Camp in a scenario room was conducted to start the opening design process, with the help of the ladybug plug-in for Grasshopper.

The weather file for the Jordan region was obtained from ladybug achieve. The results obtained were an average of the whole year solar radiation.

Once this was analysed the decision to focus the openings below the arch of the doors was done to avoid excess heat to enter the dwellings.

Another decision was that four different types of openings were needed for a typical room. These should include the door, and three different window iterations to allow different levels of lighting depending on the orientation and the desires of each family.

Various brick layout compositions were explored to find these solutions as it can be seen, first, in the sketches above, and later, in a 3D schematic view to have a clearer idea.

Some references were consulted to find inspiration on how the brick could be arranged to achieve the desired daylight inside the room with enough solar protection for the residents within.

The decision to create a pattern for jalousie was made to take advantage of the structural freedom in this part of the rooms and to allow the refugees to give their own touch to their own living space. So even if at the end a suggested catalogue of four opening options was done, the owner of the room could decide what to do with it.

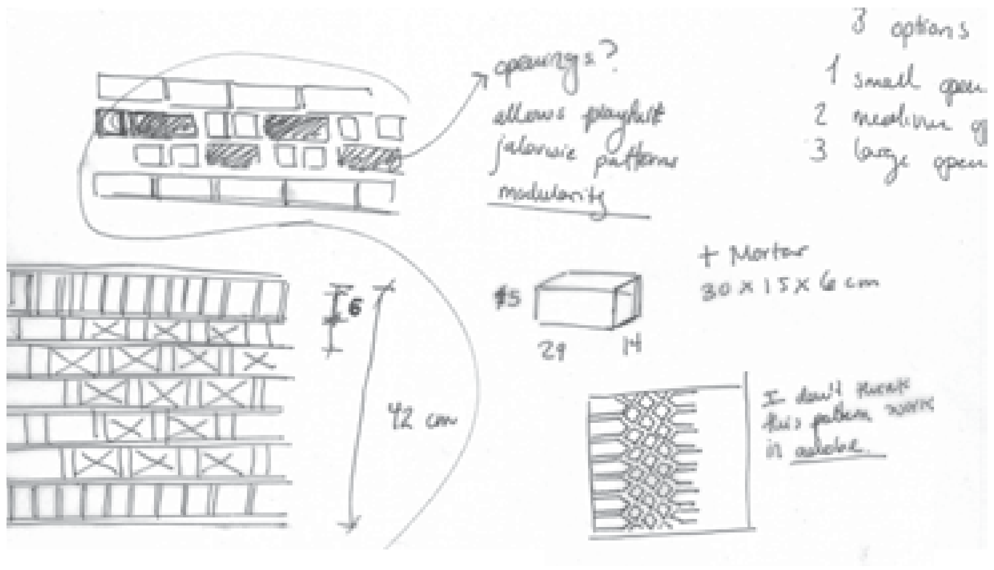


Figure 96. Opening Design

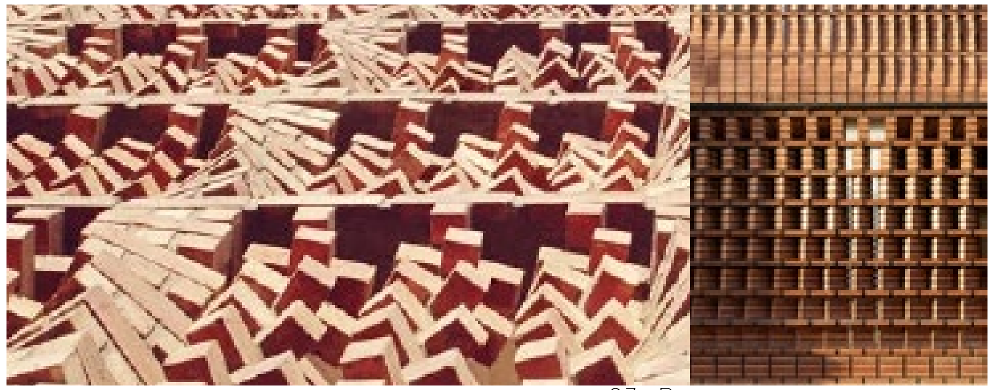
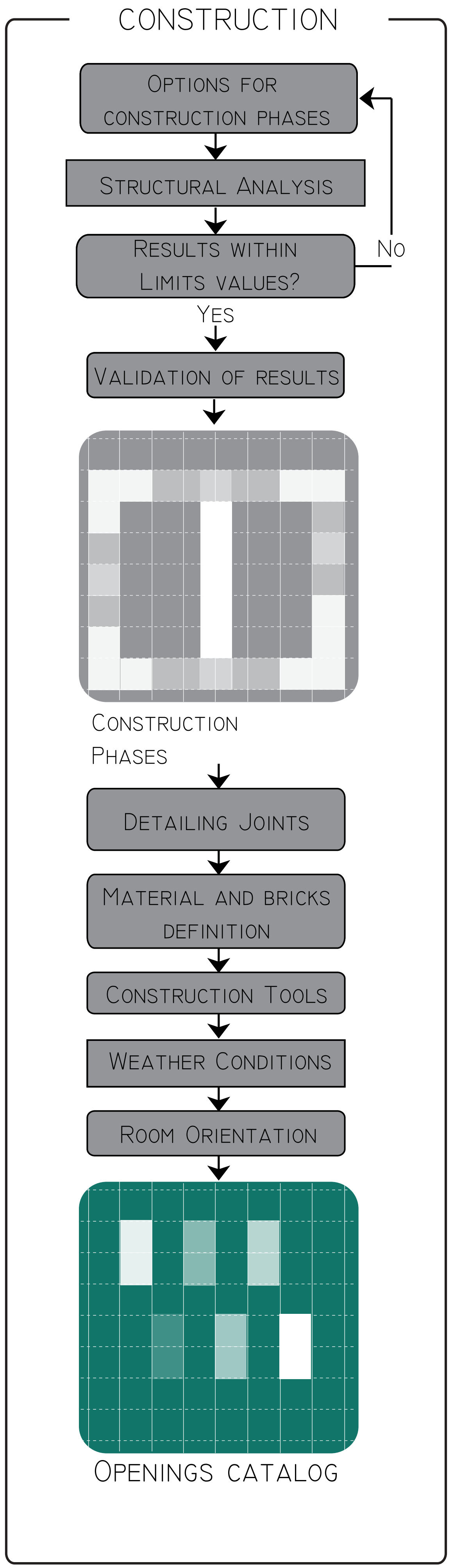


Figure 97. References for bricklaying



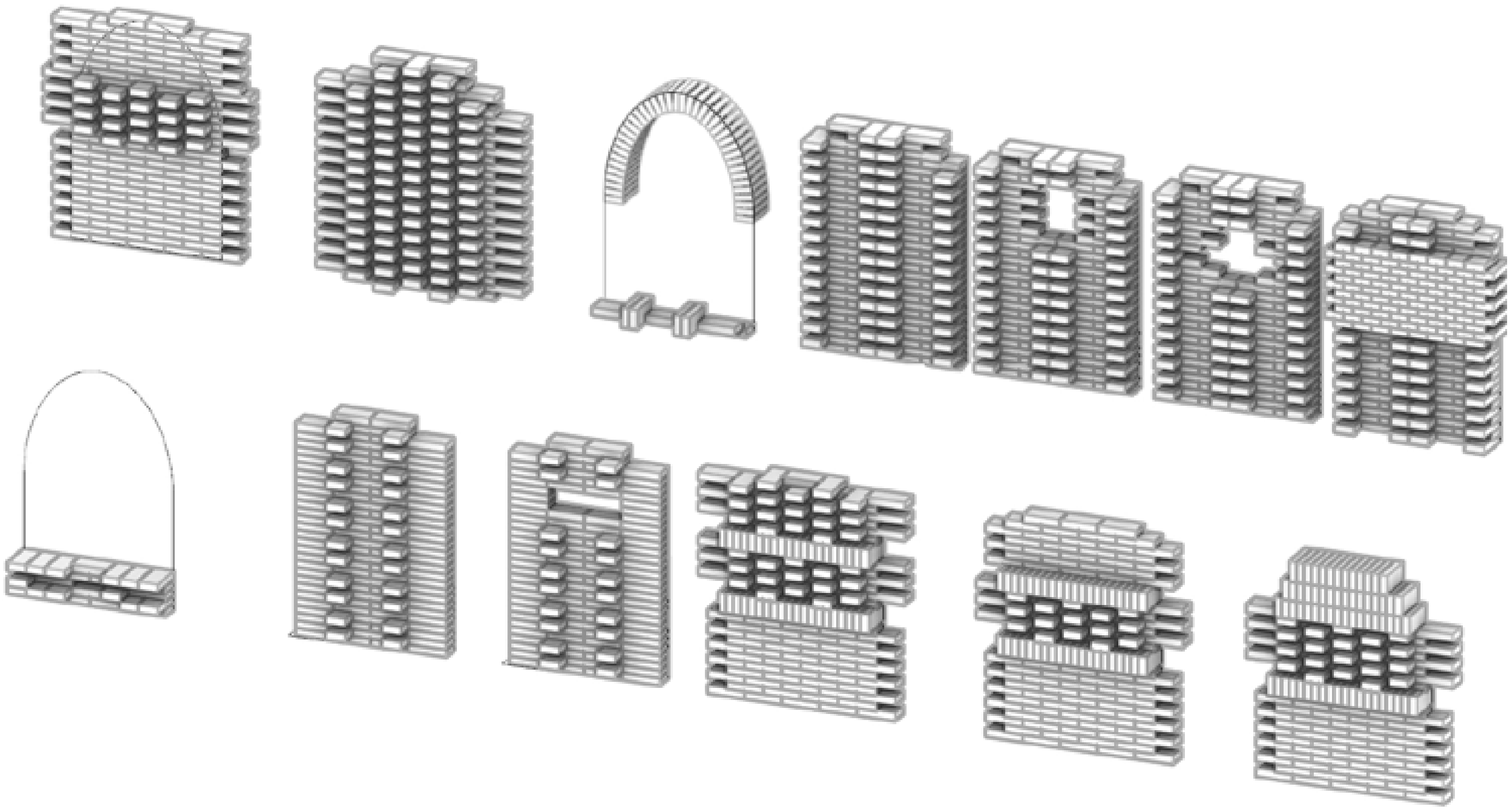
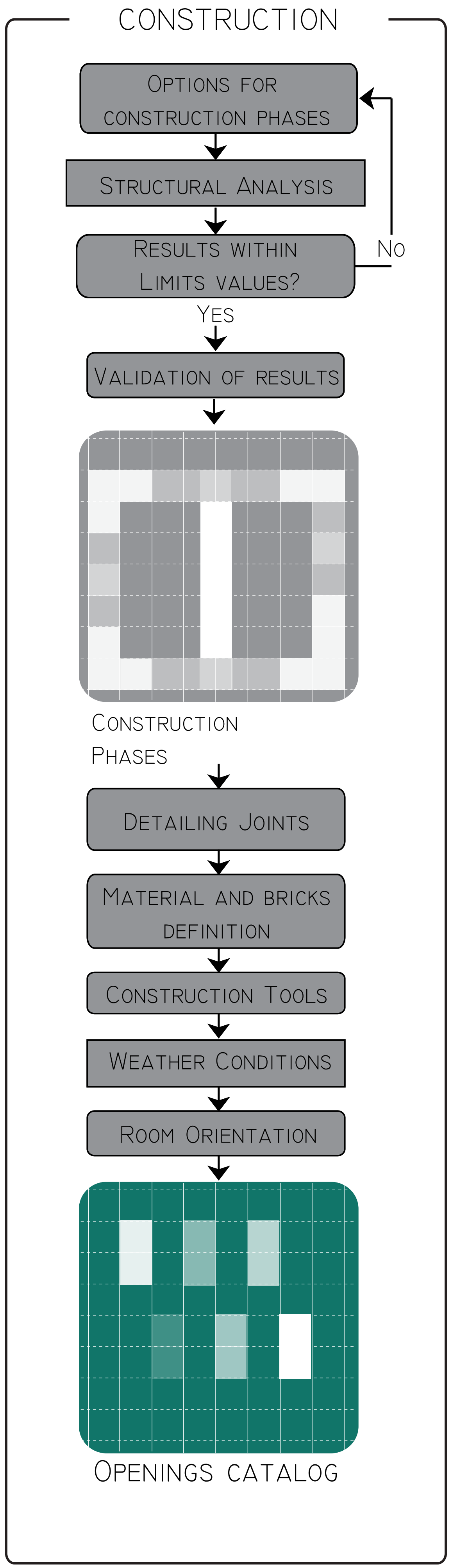


FIGURE 98. BRICKLAYING PROCESS EXPLORATION FOR OPENINGS



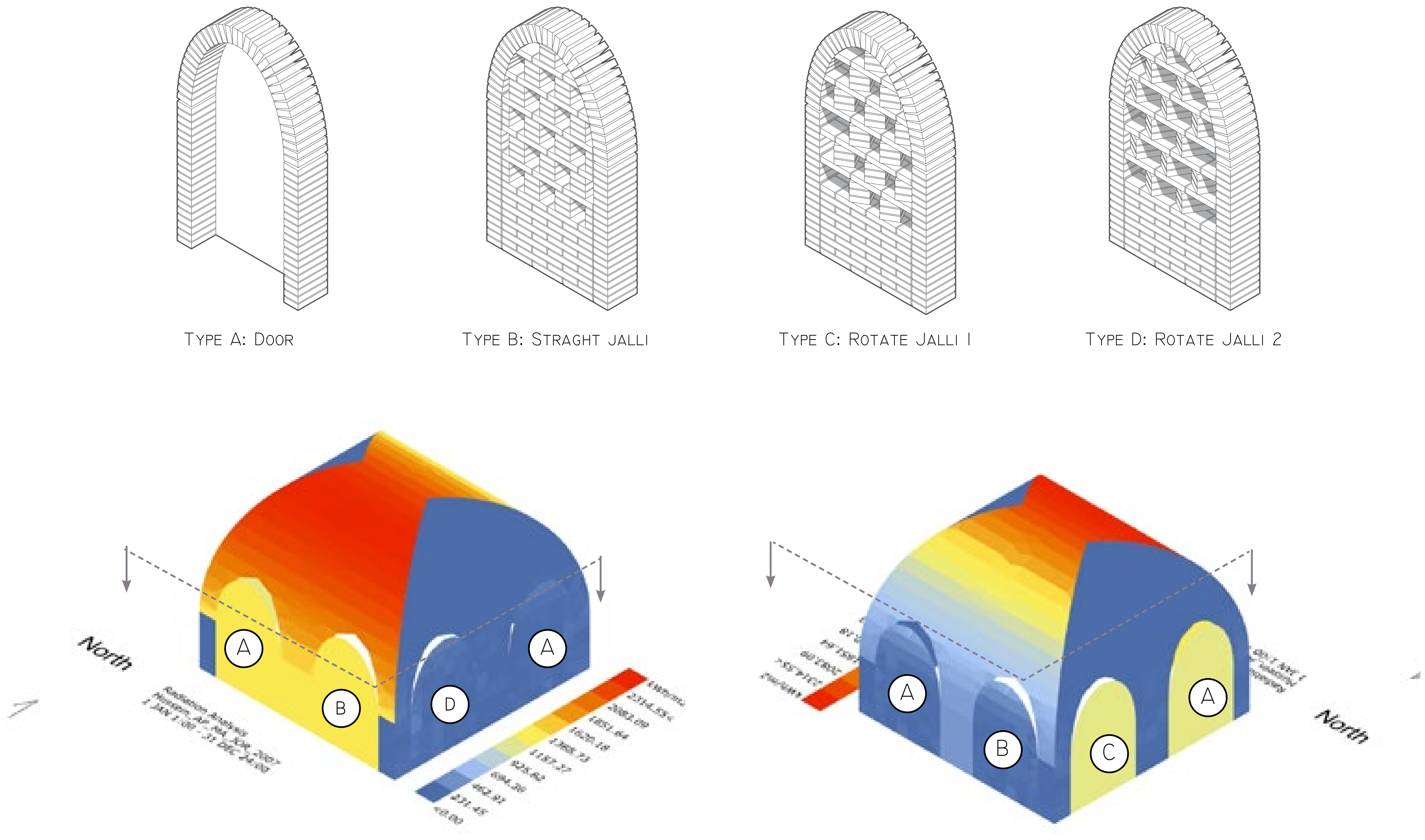


Figure 99. Opening options regarding orientation

Type A: Door, meant for privacy and entrance.

Type B: Possible if looking towards the courtyards, if there is protection from other units within the clusters, or the orientation if the room faces north(allow maximum daylight) or south (allow maximum solar radiation in winter)

Type C: Maximum privacy with enough opening size to allow cross ventilation. Rotation to protect from midday and afternoon sun (west).

Type D: Maximum privacy with enough opening size to allow cross ventilation. Rotation to protect from morning sun (east).

10 Bustan: the result

To improve the refugees' life by creating a co-housing system that adds value to the land, enhances living conditions and economic development through agriculture, we created BUSTAN.

BUSTAN means agricultural garden - a farm near the house and comes from basic rural traditional Syrian houses.

BUSTAN is composed in a set of guidelines and systems that allows the refugee enough modularity in their construction whilst maintaining the flexibility and identity each family needs and possesses. Its modular, brings back their traditional courtyards, groups services and communal spaces and allows for organic growth in an urban context.

BUSTAN develops all the way from the smallest component, the earth brick, to the largest, their makeshift city. The project goes through the family size, considers a unit as families living together, creates a cluster of units that protect a farm and recreates a whole community that thrives on culture and a sense of belonging.

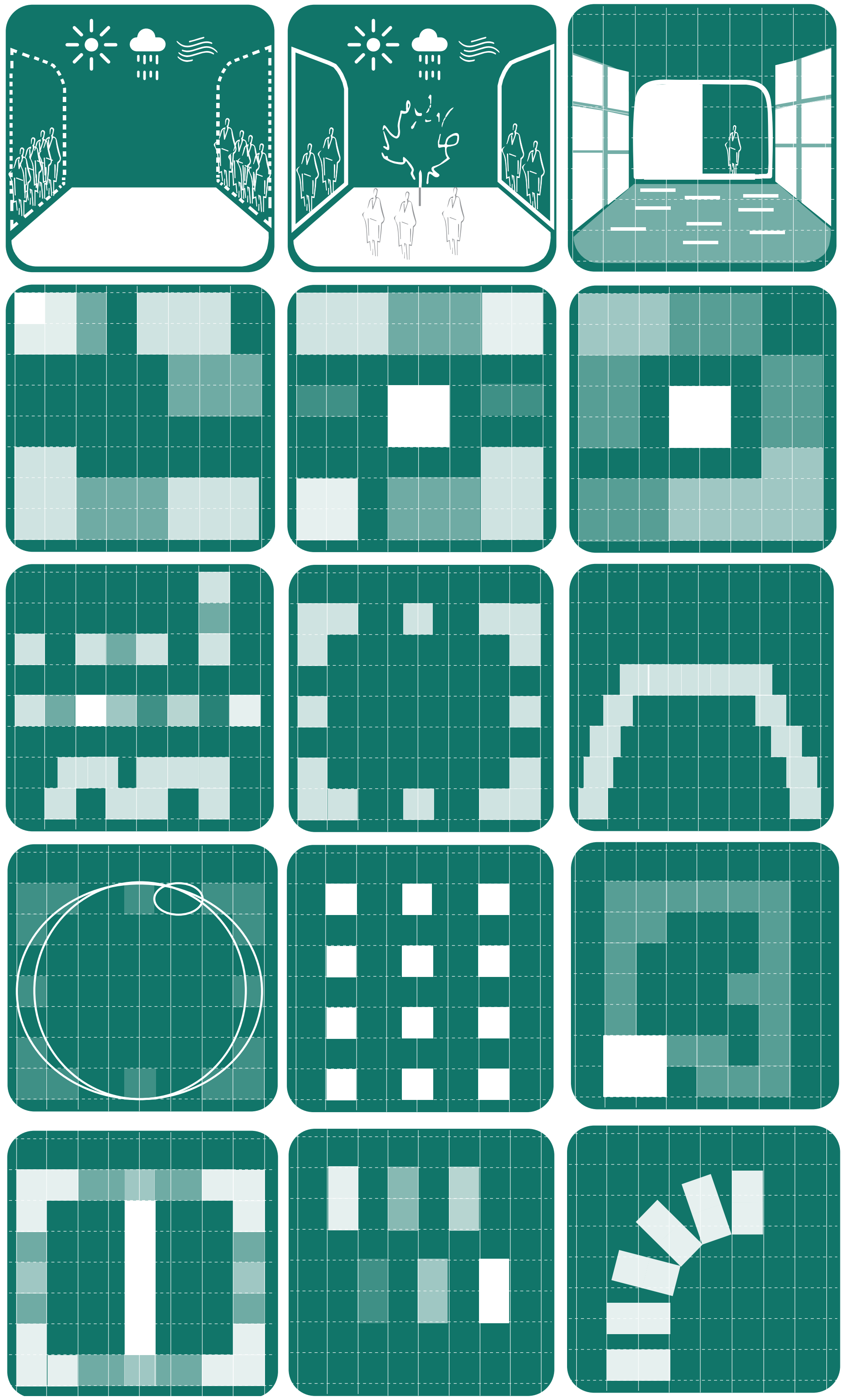
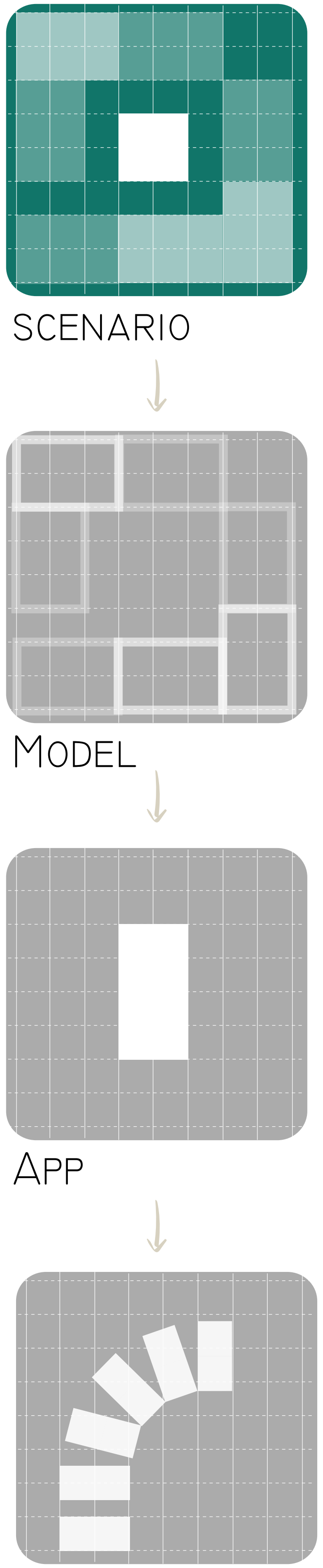


Figure 100. Bustan: the result

BUSTAN



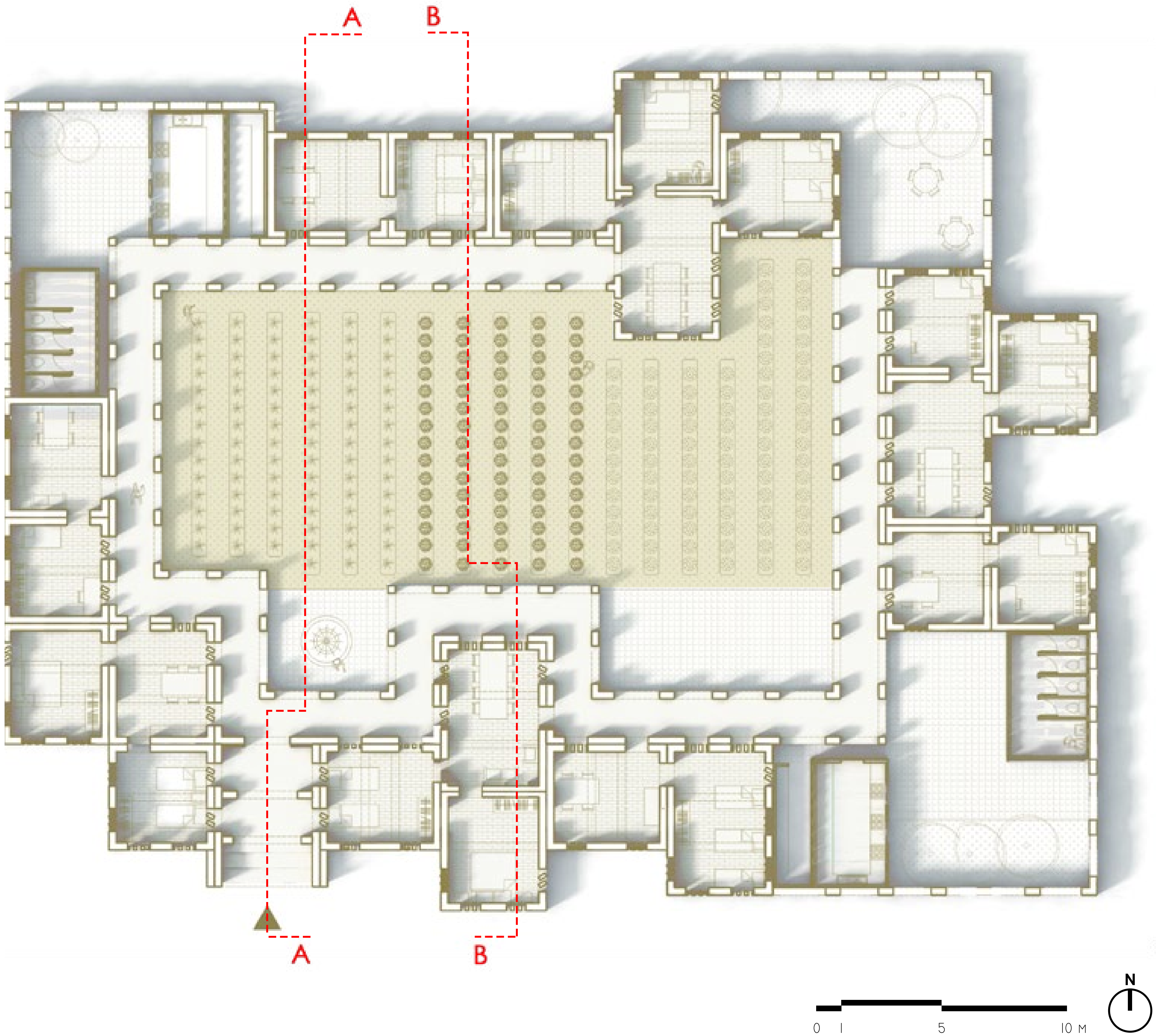
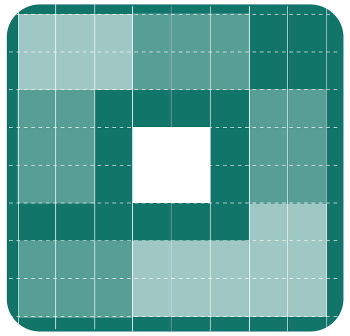
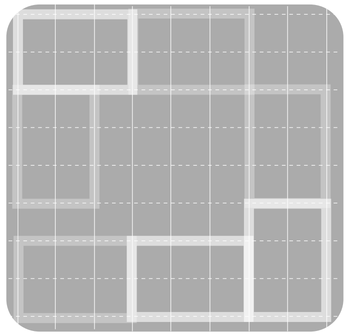


FIGURE 101. PLAN OF CASE SCENARIO (7 FAMILIES, 21 PEOPLE)

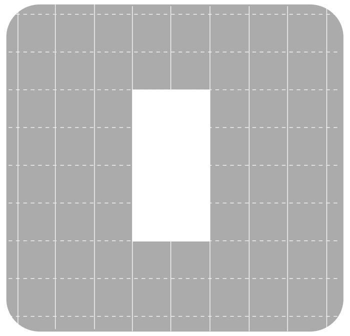
Bustan



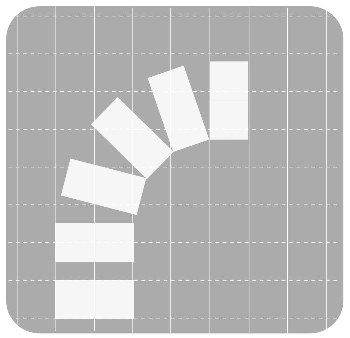
SCENARIO



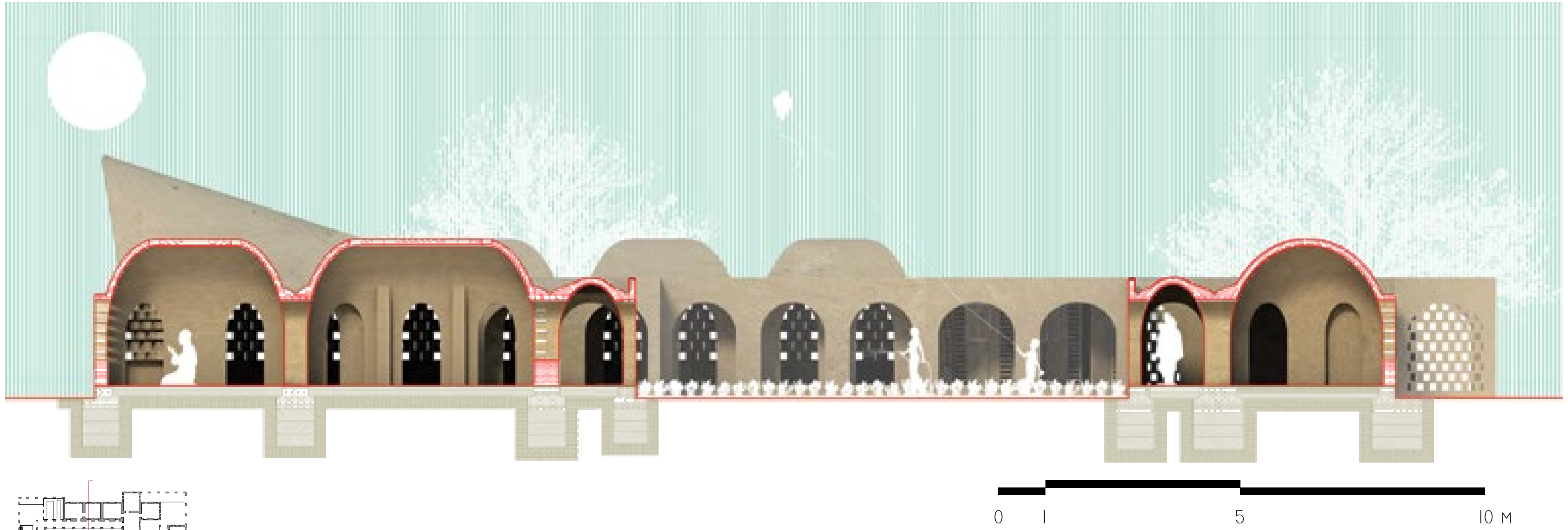
MODEL



APP



CONSTRUCTION MANUAL



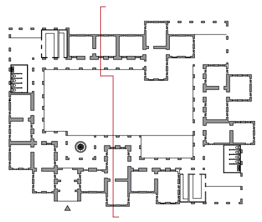


FIGURE 102. SETION 1-1'

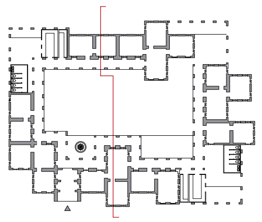
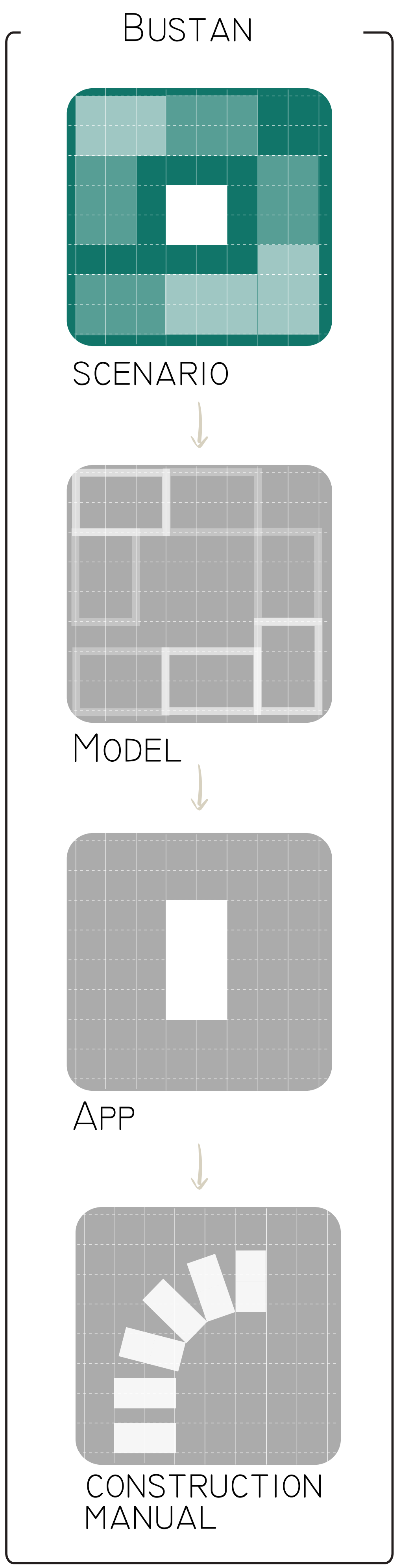


FIGURE 103. SECTION 2-2"



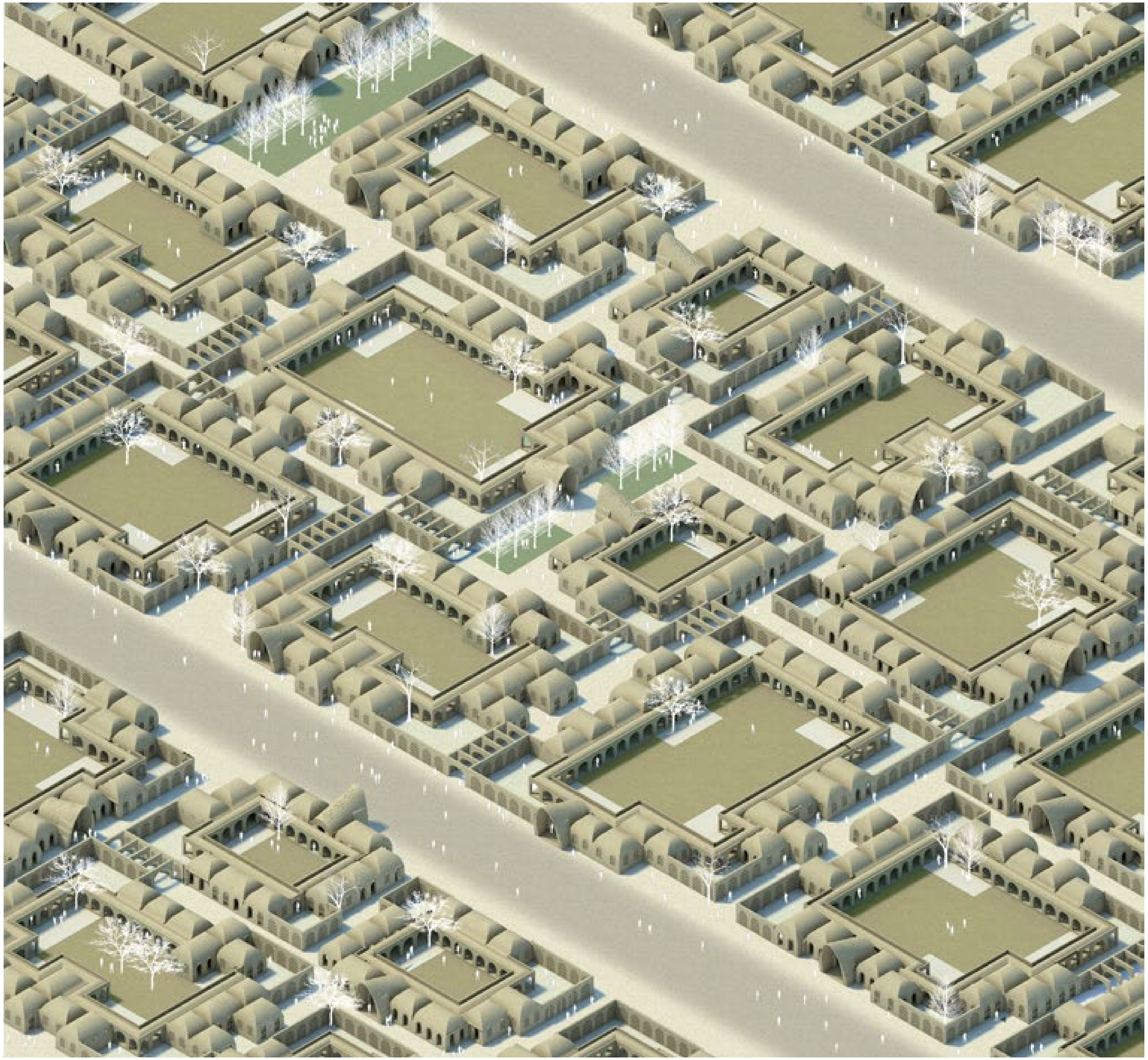


Figure 104. Bustan Project in Zaatari context

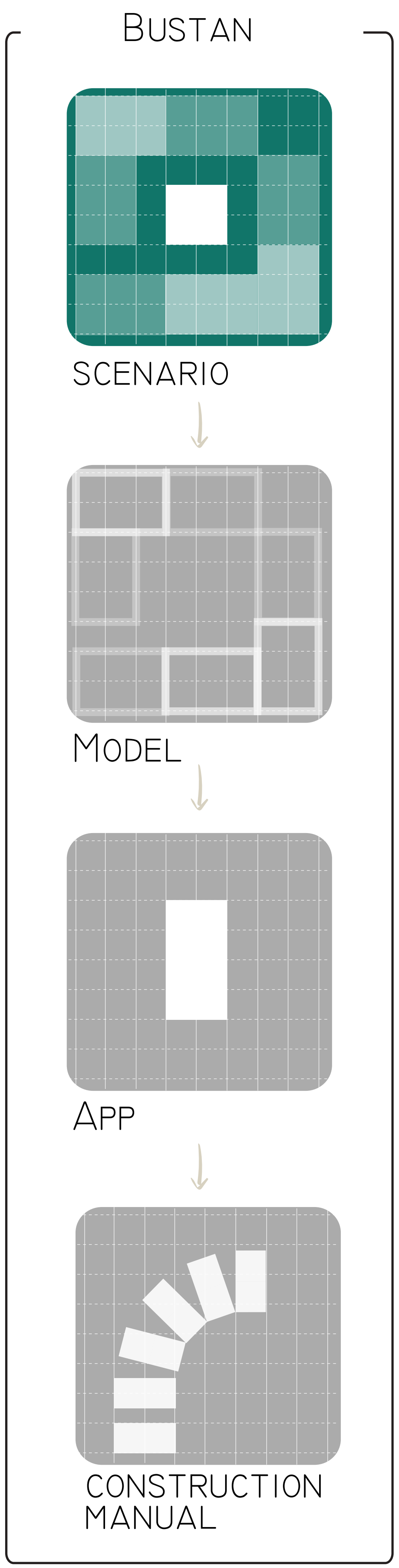


Figure 105. Bustan Sabat

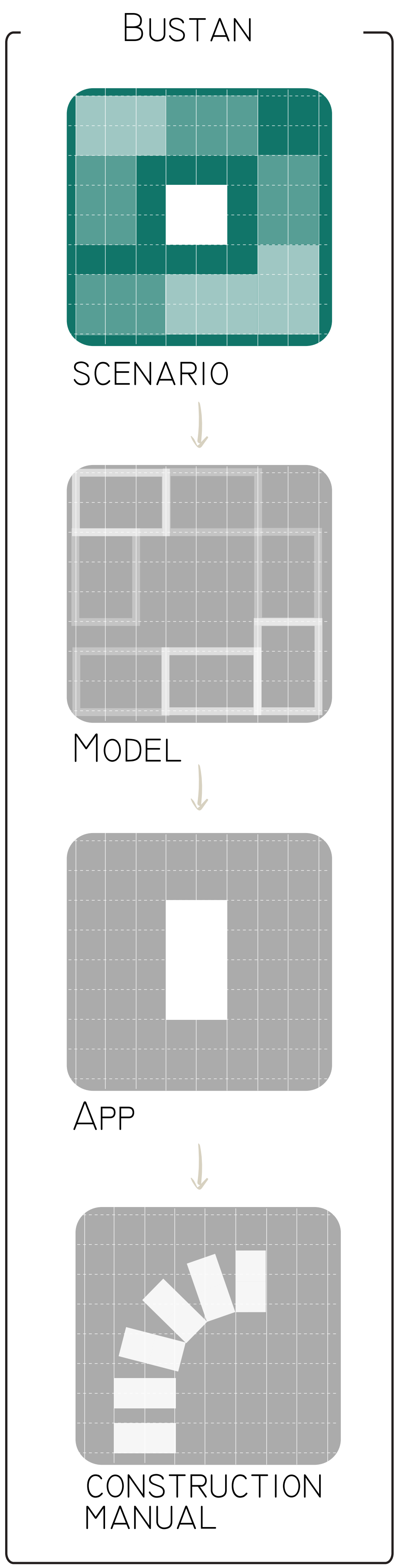


Figure 106. Bustan Entrance

Bustan

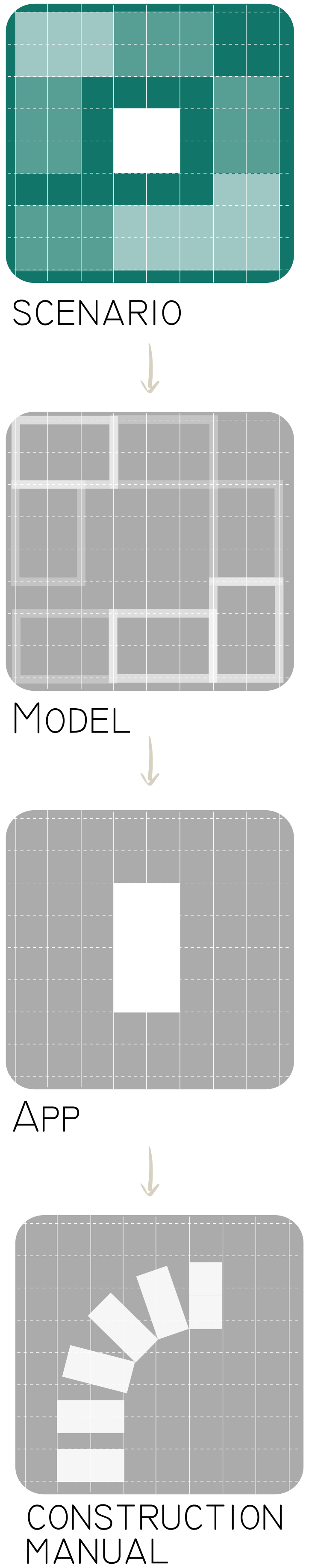


Figure 107. Bustan cluster

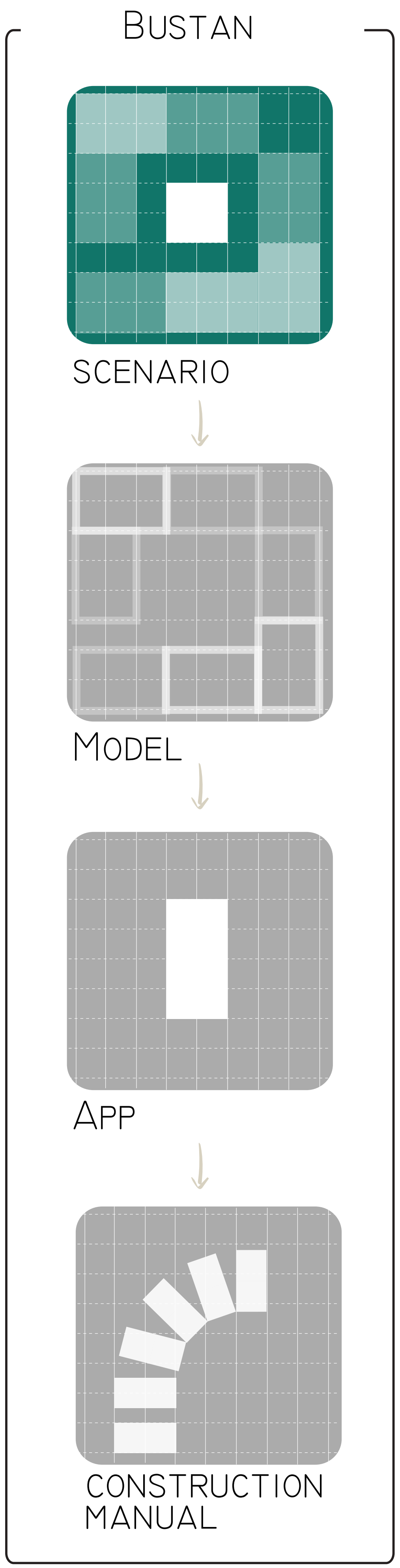


figure 108. Bustan varanda

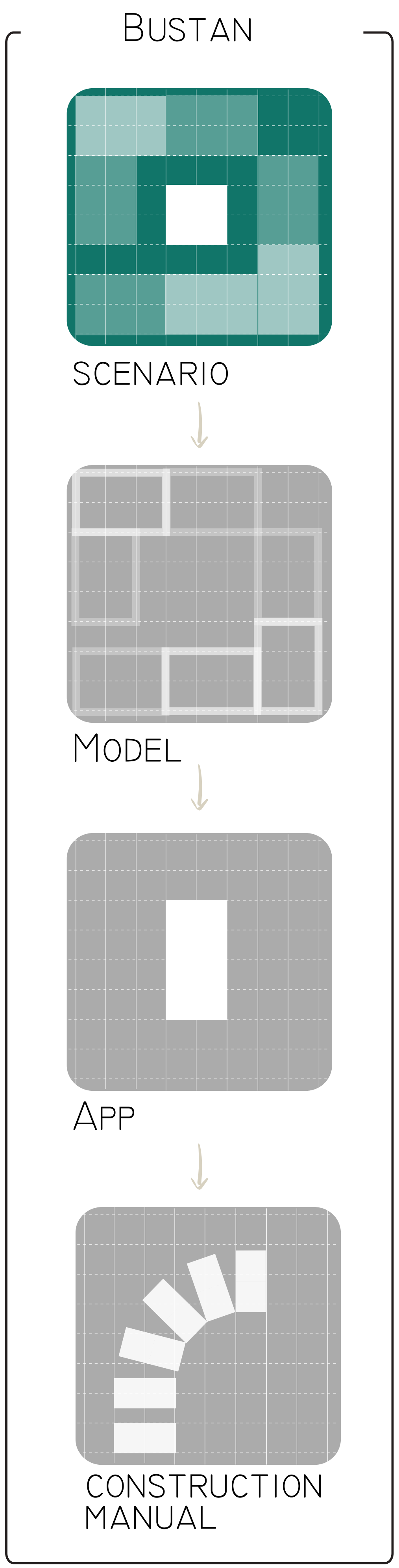


Figure 109. Bustan Service Courtyard

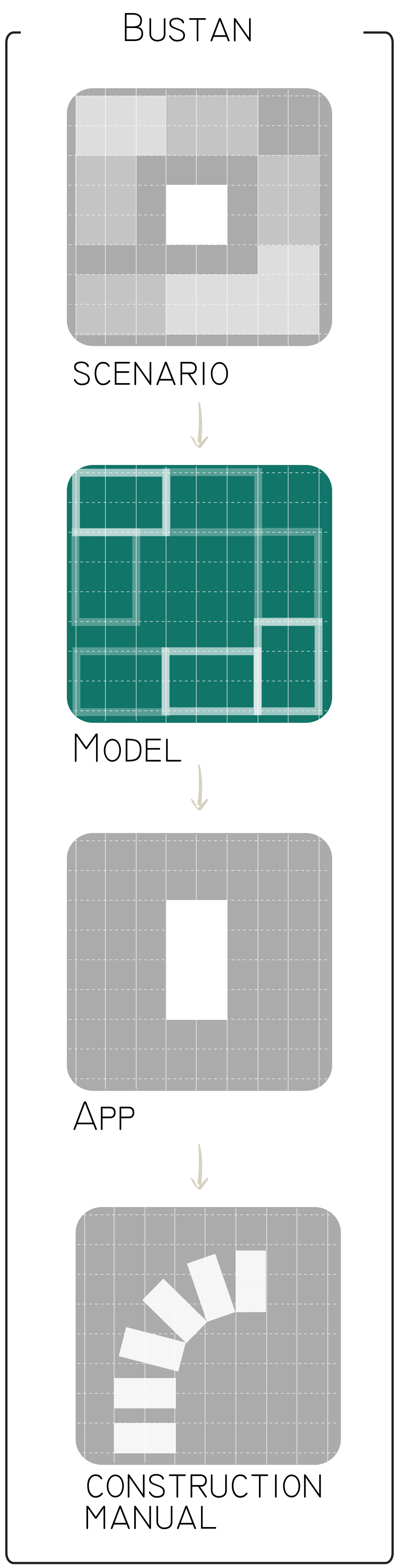
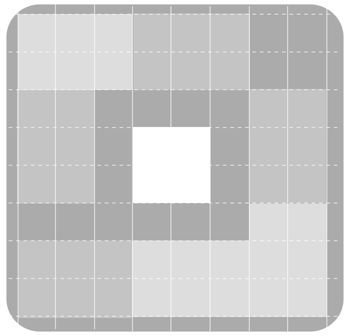
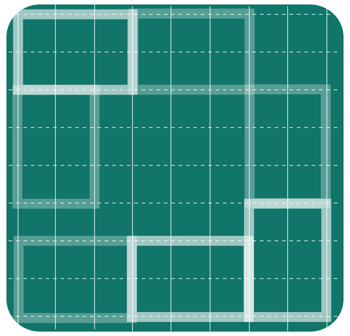


Figure 110. Bustan Living Module

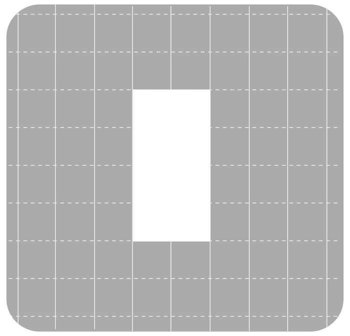
Bustan



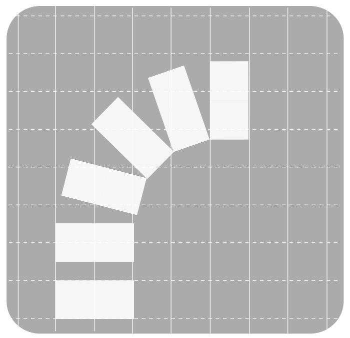
Scenario



Model

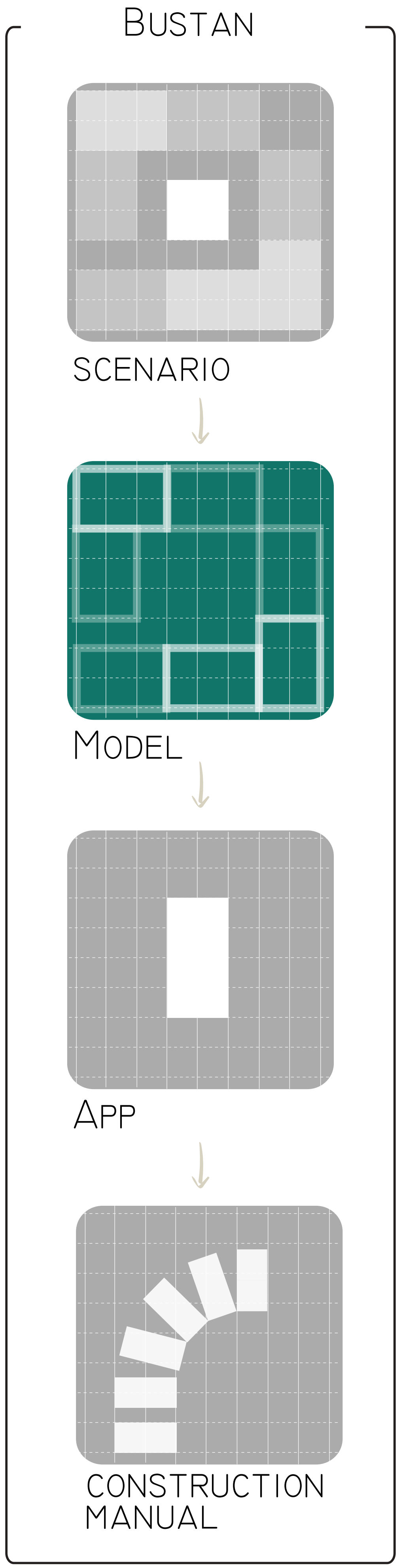


App



Construction Manual

Figure 111. Bustan transition living to courtyard



A unitless configuration model game that includes the configuration rules was built. In such a way that the user can better understand how the system of BUSTAN works. A preliminary mock-up was done to see the possibilities of the game and then implemented for the wooden game. The board has small squared holes to fix the elements (bedrooms and living rooms) in a certain position.

To play with the board size decided, 1 out of the 4 case scenario families can be chosen and from there the game begins. Depending on the number of persons in the family chosen, the different rooms are taken checking the back side of the room to see the amount of people that each room fits. After this, the amount of farm modules and caravans can be taken.

Once this is done, the placement in the boardgame can start following the design guidelines written next to the board.

When building the configuration game model, some small problems were also found such as some residual spaces appearing between the units. This happened because the squared wholes that fix the rooms had to be done every two modules instead of one, since the laser cutting would be troublesome in such a small size. A simplification had to be done, and so these small mistakes were present.

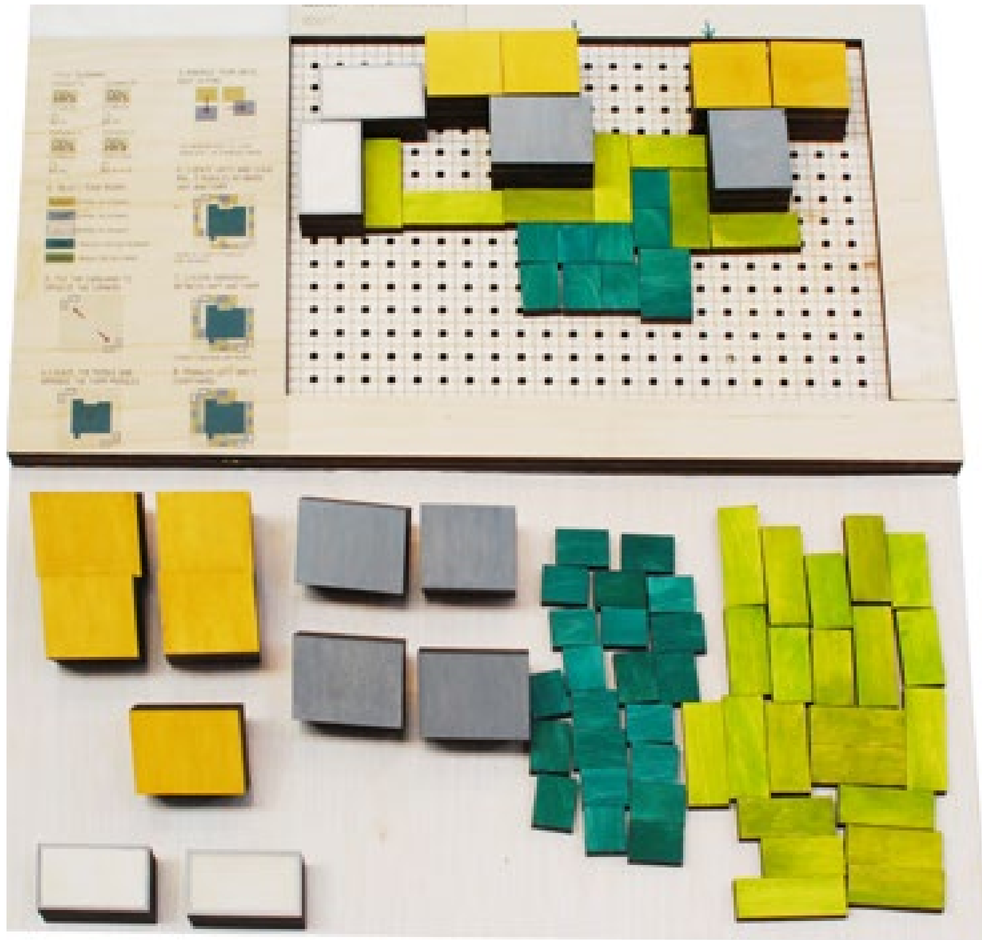
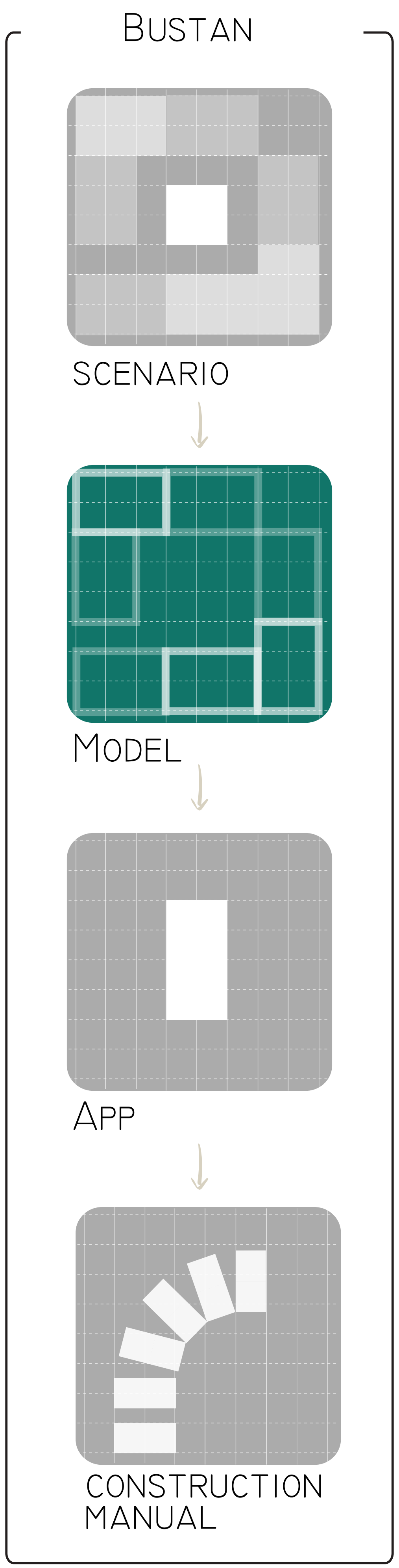


FIGURE 112. BUSTAN BOARD GAME



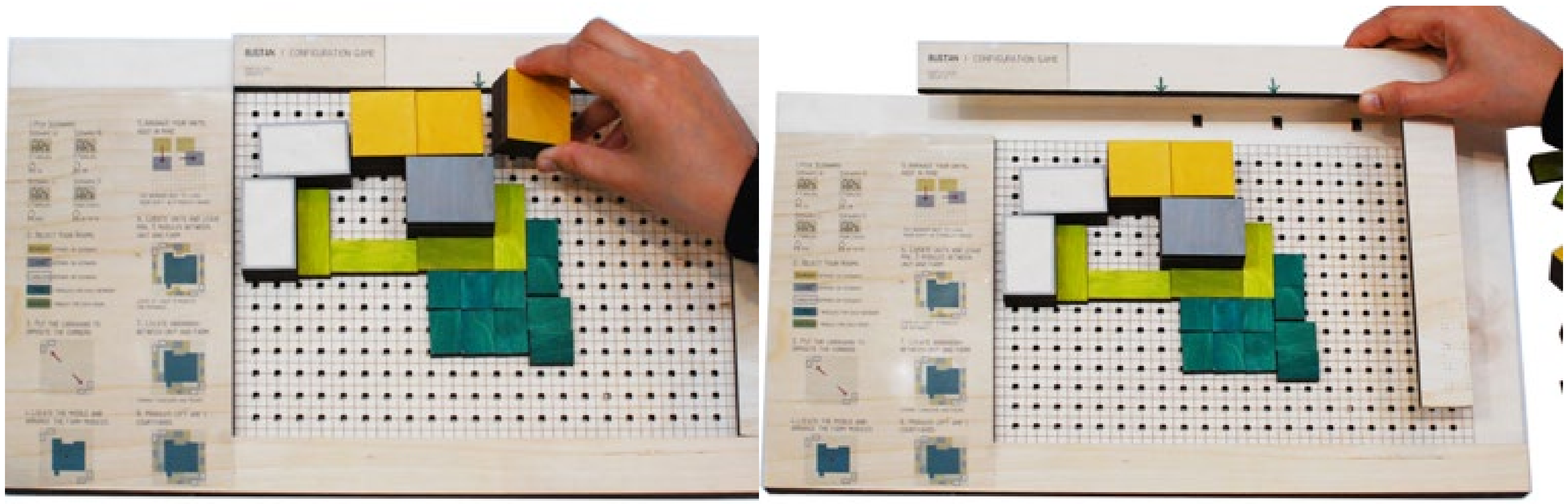
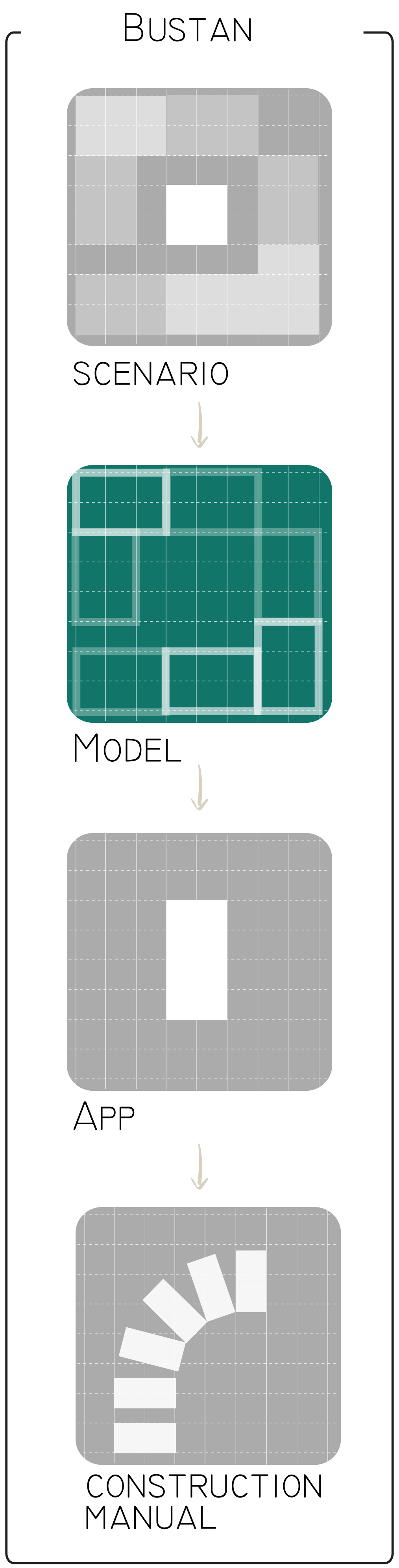


FIGURE 113. BUSTAN BOARD GAME



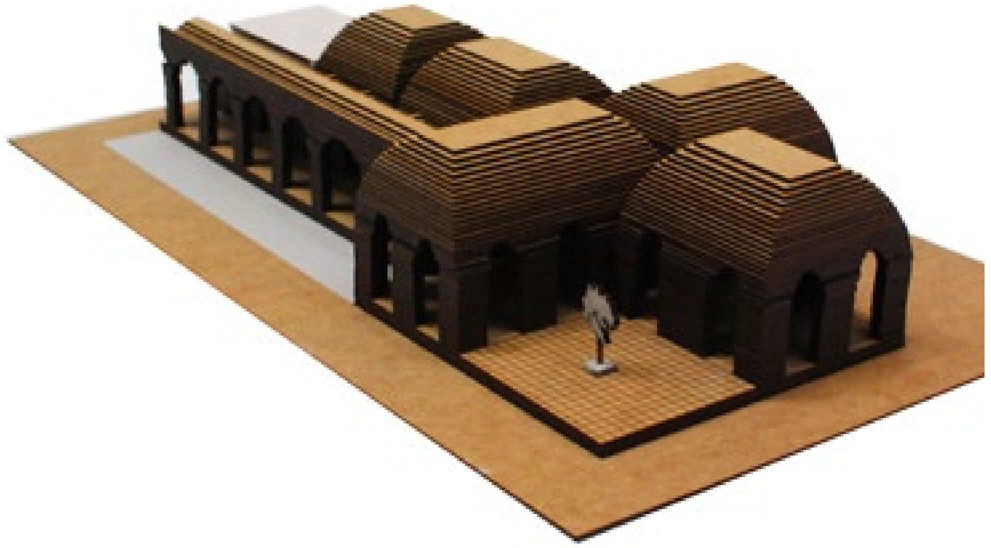


FIGURE 113. BUSTAN UNIT 1.50

A scenario unit model was done in 1: 50 scale. The scenario shows the different types of connections with different room sized, as well as the interaction of the unit with a caravan, farm and courtyard.

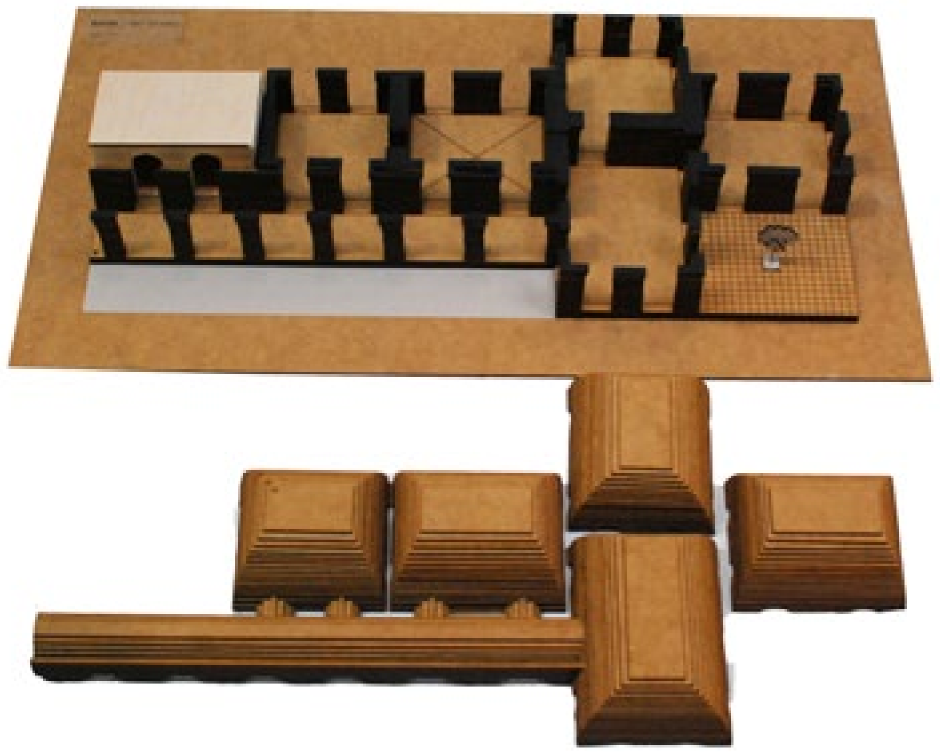


FIGURE 114. BUSTAN UNIT 1.50 : CONFIGURATION

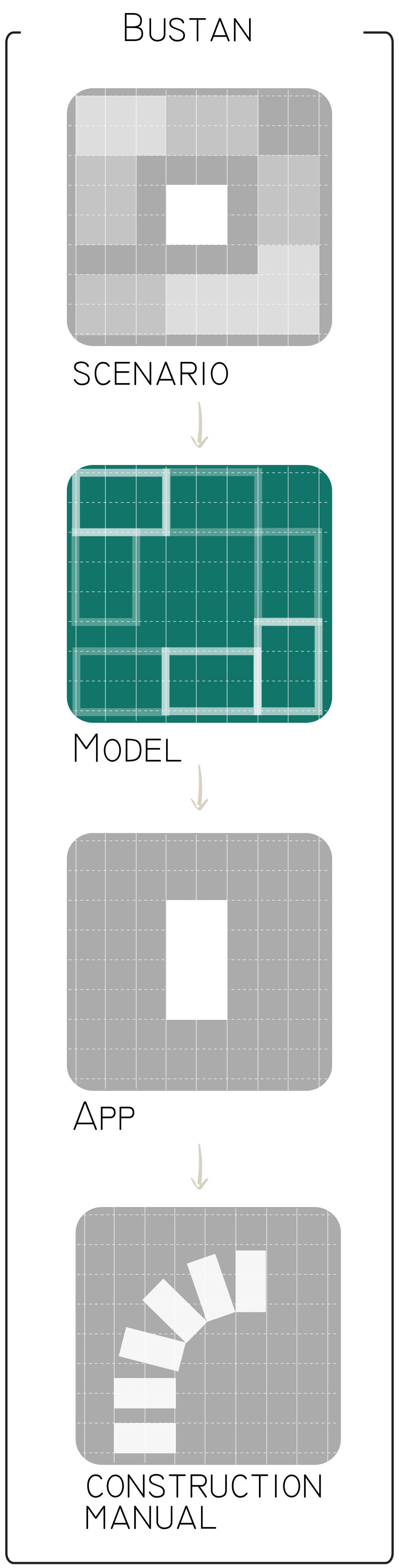


Figure 115. Bustan Construction 1.25

The construction process model was done in 1:50 scale. The base was done with laser cutting. A layer of clay was added to simulate a working progress o a room with a verandah.

Figure 116. Bustan Construction Process 1.25

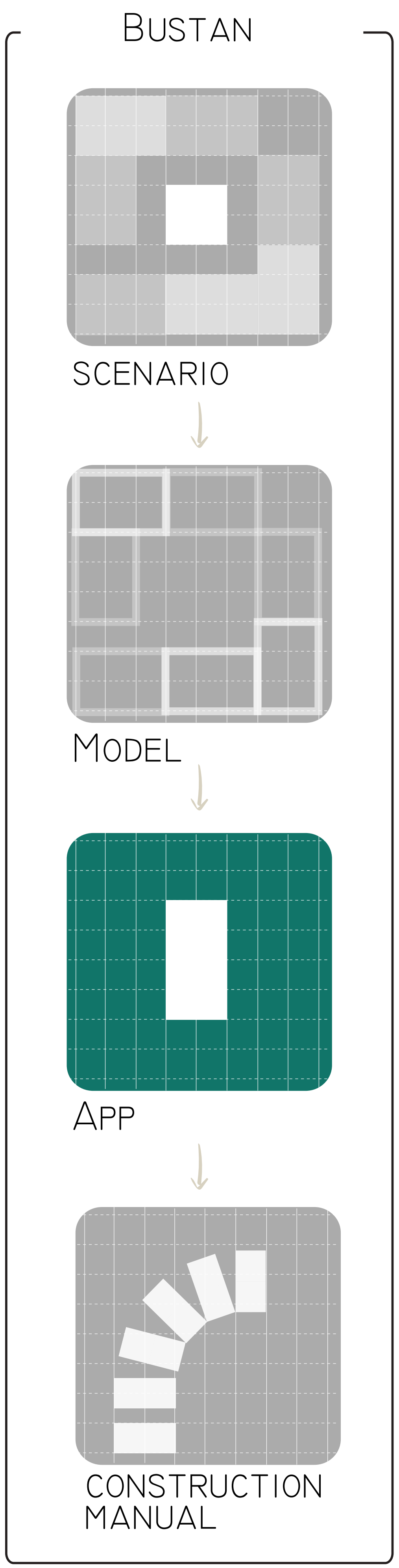
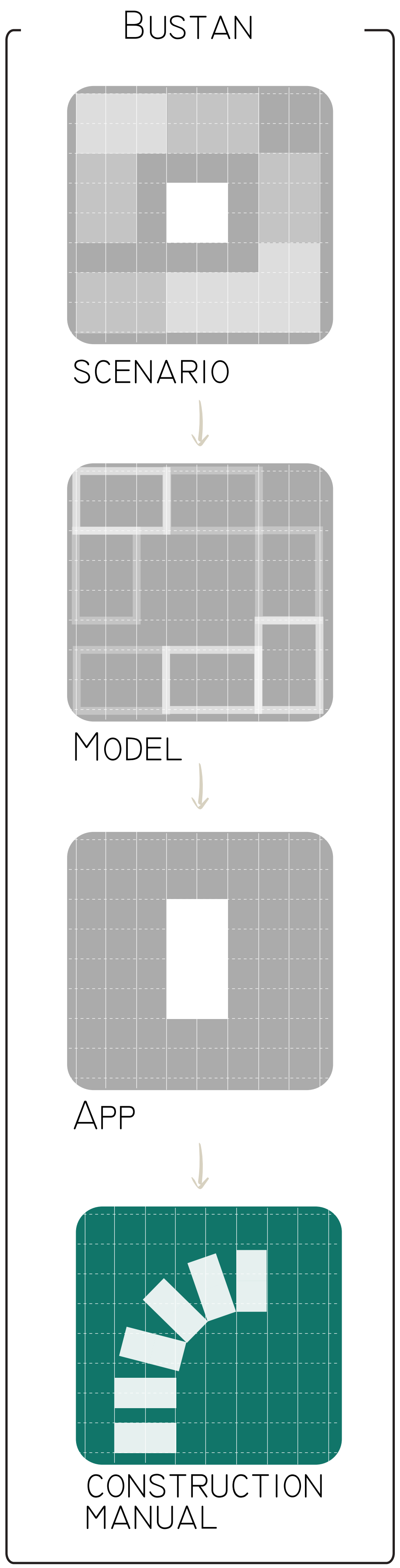
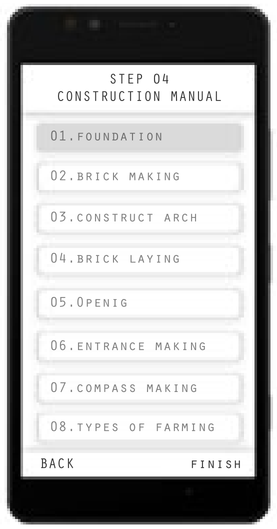


Figure 117. Bustan App Mock-Up





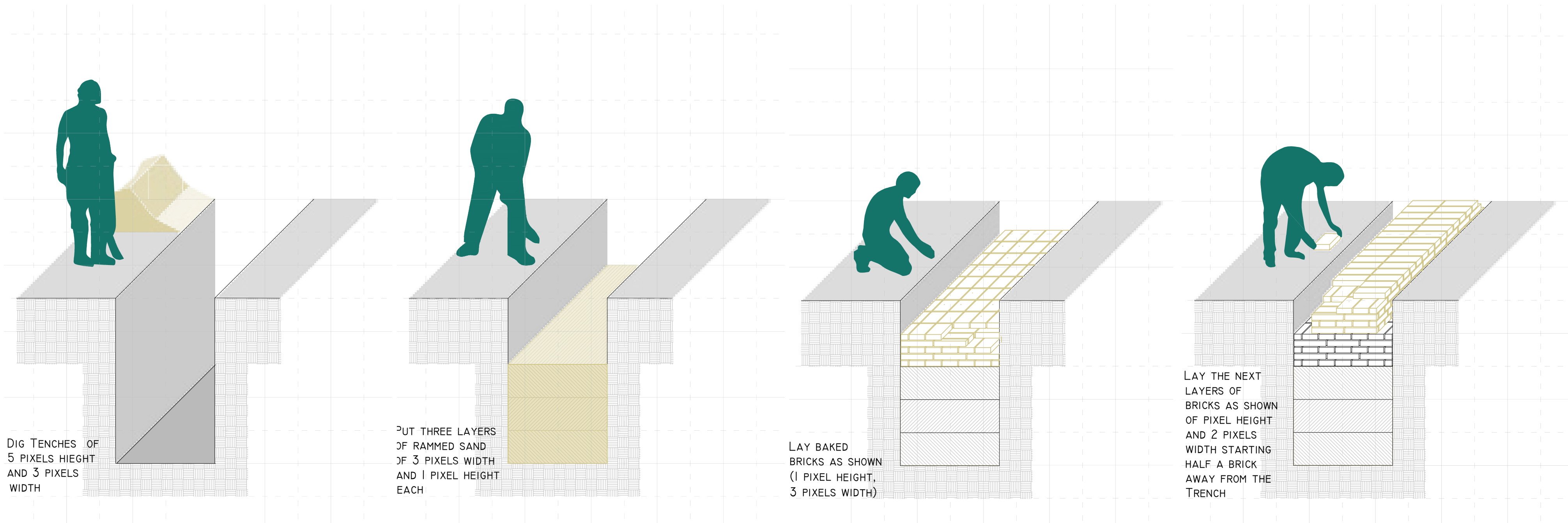
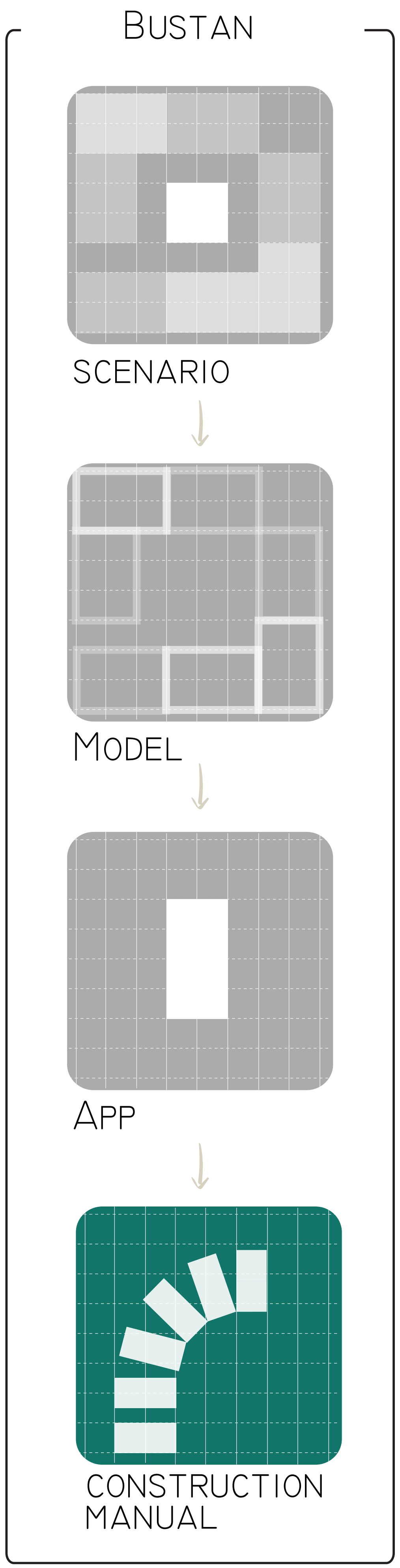
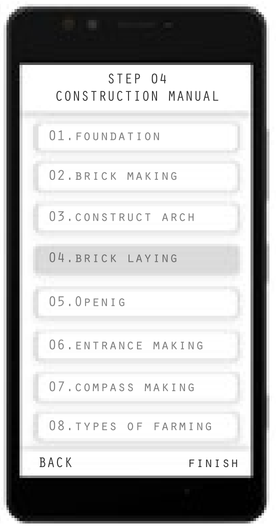


Figure 118. Foundation





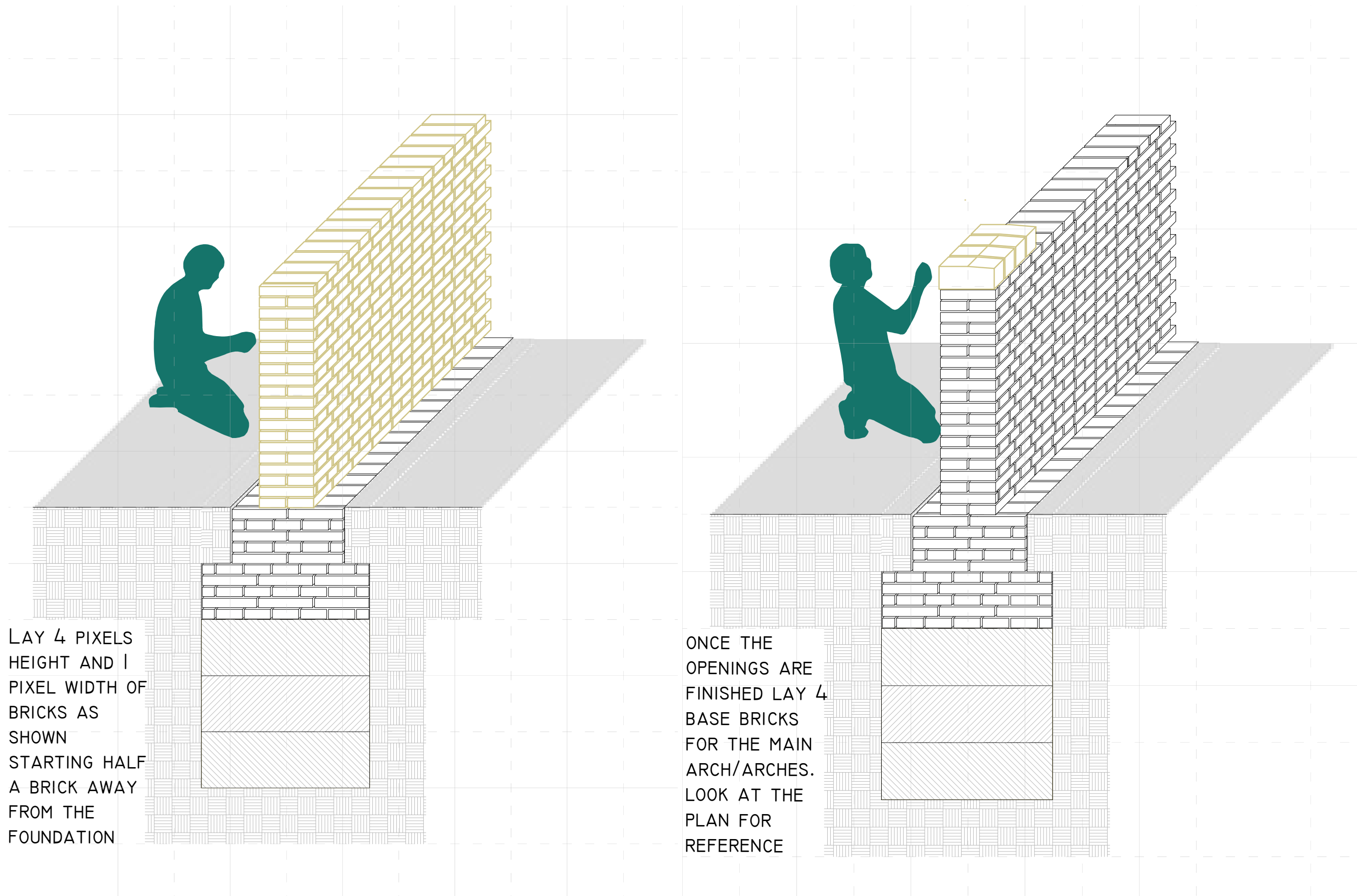
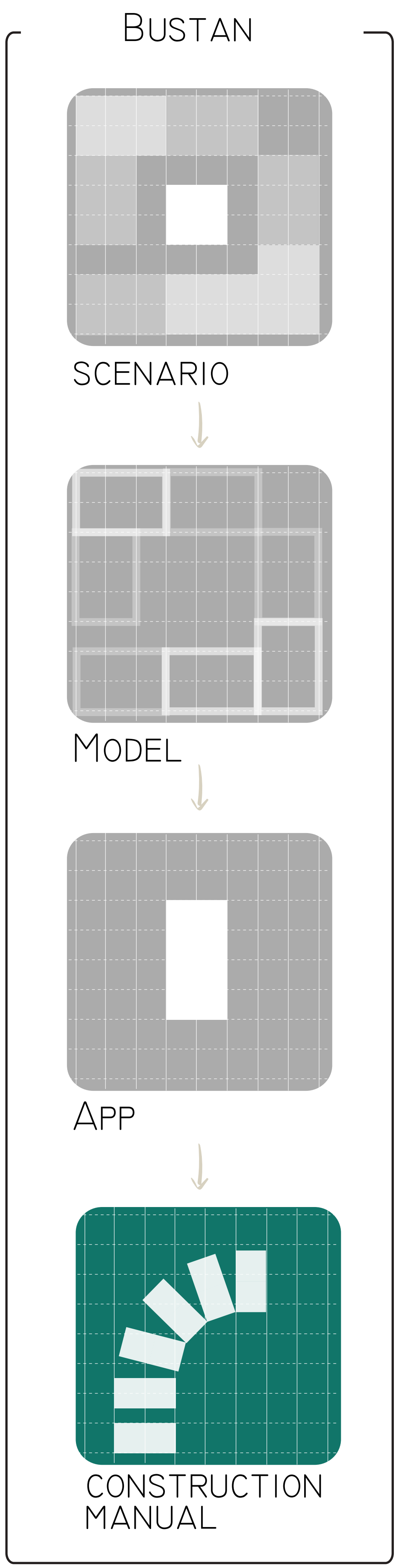
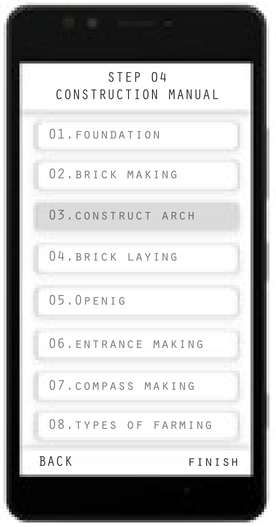


Figure 119. Brick Laying, Wall





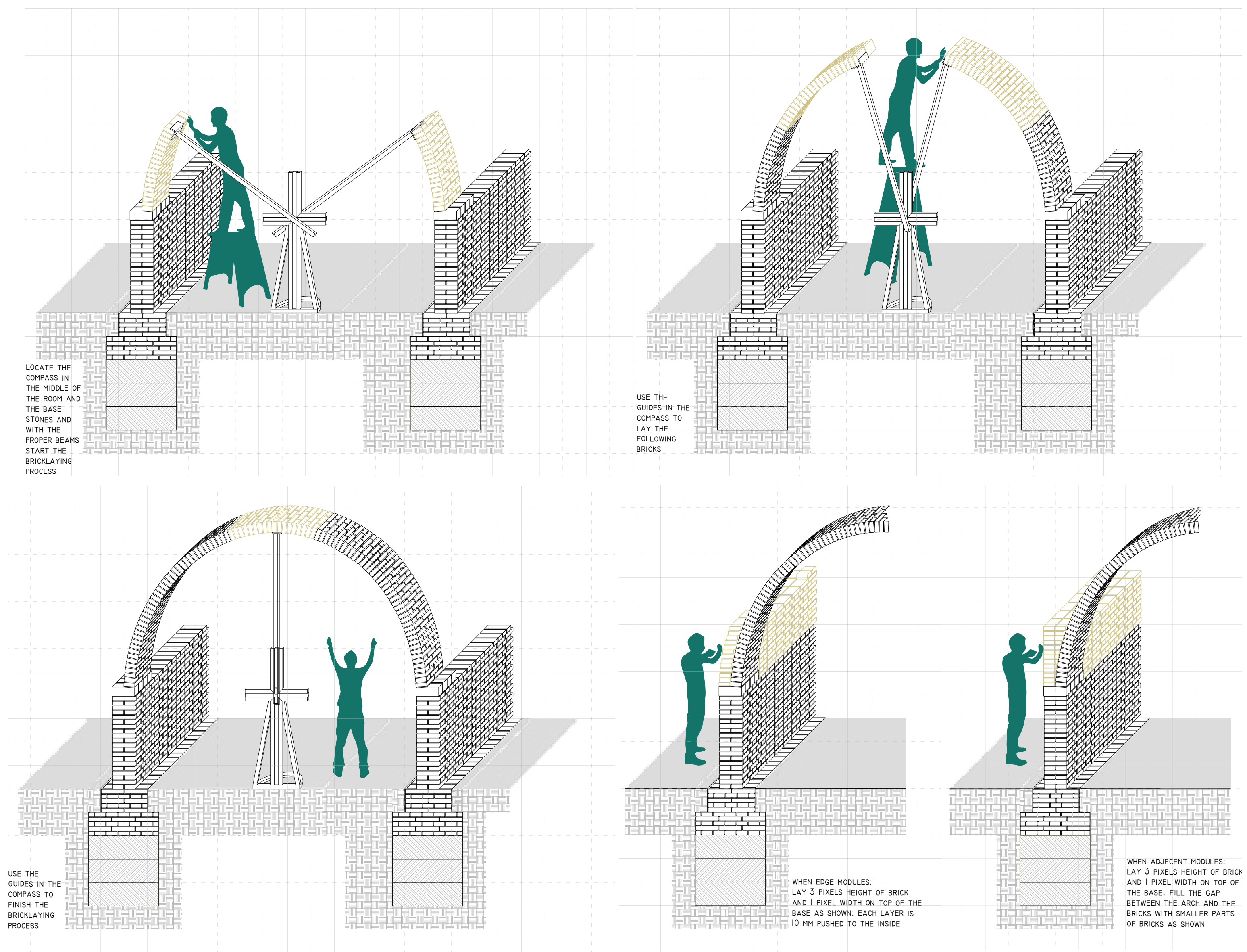
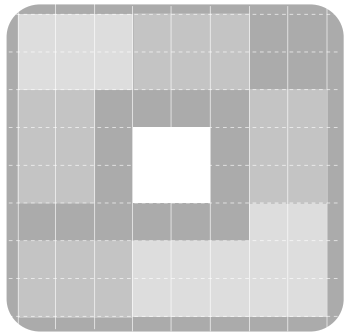
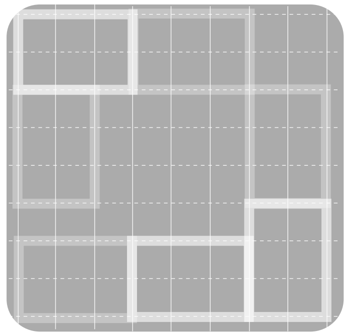


FIGURE 119. ARCH

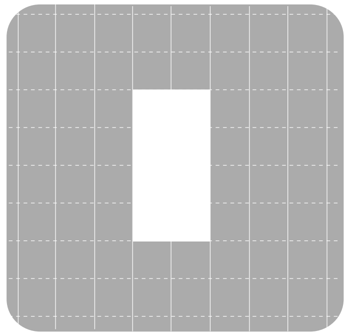
Bustan



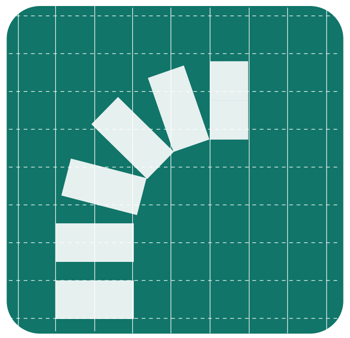
Scenario



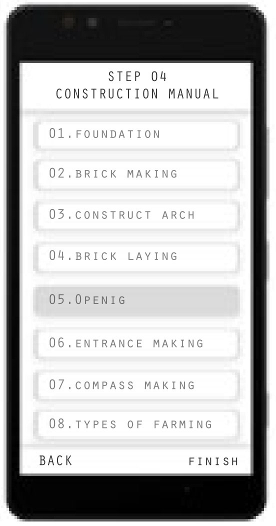
Model



App



Construction Manual



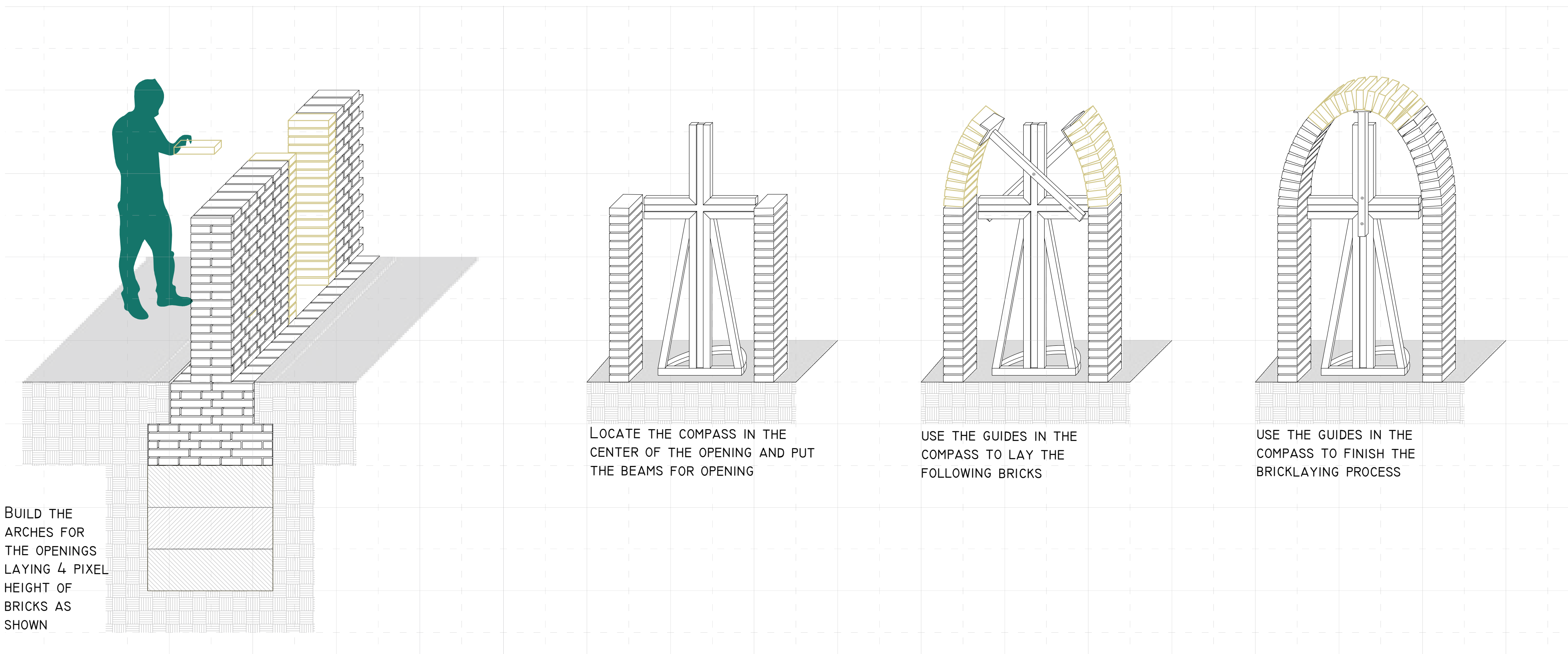


Figure 119. Openings

11 Conclusions

1 Limitations

As it is in every project and research, there are always things that could be improved. For this reason, a detailed recount of elements within our project that should be improved will be listed for every step of the process.

A set of definitions for all the elements in the project was needed (refer to pixel, module, unit, etc). These many elements could make the construction of a cluster a tad confusing for the refugee. To make things easier, the pixel is only used in the structural parts. At the room level, the options designed were mostly as a reference for the number of modules a family would need to create their own rooms (the room matrix), which ultimately could give the families too much freedom when building their own rooms. For this problem, some structural constraints were also applied to allow this modularity and flexibility to work.

At the cluster level, the amount of families that want to live together is asked and from there the cluster is composed. When the space needed for the cluster is bigger than the allowable within the context (thinking in an existing refugee camp), the families need to redefine the amount that will be living together to fit in this place. Doing this manually could be troublesome, so the proper development of the app/computational tool would help this easier, but it's a limitation in our project.

Another limitation of the manual configuration of the clusters was during the large cluster construction. To develop this cluster following all the rules and desires of the different families could prove to be troublesome and time consuming. It would also be suggested the implementation of the computational configuration when working with larger amounts of people.

There could have been more steps from the dynamically relaxed form to the simplified one. The optimal dynamic relaxation found was not taken literally for the construction, since it was a much complex geometry and we wanted to focus on the constructability. Geometries that the refugees could handle easier and faster. Nonetheless, this form was taken as the base to find the correct proportion for the heights needed for the doors and ceiling.

All the structural analysis was done in the same software, Karamba, so although the validations were also done with hand calculations, further validation with another software could have helped our results.
We took some decisions during the structural analysis based on the literature research, and this could no be corroborated with the brick making tests we did.

figure 120: Group Picture

figure 121: Inspiration and mood (source: google)

In the computation development of the rooms and units, the limit of both scripts is that they don't work together yet. A further development would be to combine them.

In the computational development of the clusters with the Magnetizing-Floor Generator plug-in, the configurations obtained had some dead ends and some empty spaces. These configurations should later be tweaked manually for them to actually work.

In the computational development of the urban configuration, not all the rules were applied, such as the reaction of the clusters with other facilities. The main distances were considered, but the plaza implementation required in some cases was not added to the set of rules due to time and skill constraints. The selection of the streets and placement of the reference point remains as manual inputs. Another constraint of the urban script is that it was developed unitless, when actual values or larger numbers were applied the system would crash due to the computer's capacity.

figure 122: one day before mid-term last group to leave the studio

2 Reflection

This report explained the design process and the final result of BUSTAN, a co-housing system that adds value to the land, enhances living conditions and economic development through agriculture. BUSTAN was developed from the refugees' perspective since the beginning of the project, taking their traditional housing typologies and united culture as inspiration for all we designed.

The course AR3B011 EARTHY at TU Delft, Building Technology Master programme encompassed a diversity of topics, ranging from programming to the construction and structural design. One major challenge of the course was its emplacement in an actual context with limited resources to build from. Although construction with adobe comes a long way back, there is little to no documented building codes, granting the perfect challenge for a master's course.

Diving into scripting and programming with python was also a major challenge for us, but we still pushed ourselves to construct a system that could later be implemented in a complete code. As a result, the course required more time and work than it was accounted for.

Nonetheless, we are very happy with our final result. We learnt a lot with the design of BUSTAN and the process we followed. The experience of teamwork was amazing since we all gave our best and continuously searched for improvement. Everyone had different set of skills that complemented each other, and we made them work together by creating BUSTAN.

figure 122: Group's first earthy dinner

figure 122: Group's Last earthy Dinner

THANK YOU !

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FIGURES

Figure 3. Zaatari Camp (Rasmussen, B. 2014) Retrieved on 4 Sept., 2019, from: https://www.kickstarter.com/projects/michaelfrib-erg/by-the-olive-trees-stories-of-syrian-refugees

Figure 4: Zaatari Maps (Krujit, R. 2014) The Rightful Landscape

Figure 6: Zaatari Camp Information based on UN High Commissioner for Refugees, 2014 Retrieved on 4 Sept., 2019, form: https://www.unhcr.org/

Figure 7: Camp density and Family size by UN Children's Fund (2015) Zaatari Population. Retrieved 4 Sept., 2019, from: https://www.unicef.org/

Figure 9: Average wind speed and direction in Al Mafraq, Jordan. Retrieved on 4 Sept., 2019, from: https://www.meteoblue.com/en/products/historyplus/windrose/al-mafraq_hashemite-kingdom-of-jordan_250582

Figure 10: Average temperature in Al Mafraq, Jordan. Retrieved on 4 Sept., 2019, from: https://www.worldweatheronline.com/mafraq-weather-averages/al-mafraq/jo.aspx

Figure 11: Average rainfall in Al Mafraq, Jordan Retrieved on 4 Sept., 2019, from: https://www.worldweatheronline.com/mafraq-weather-averages/al-mafraq/jo.aspx

Figure 12: Average humidity in Al Mafraq, Jordan. Retrieved on 4 Sept., 2019, from: https://www.worldweatheronline.com/mafraq-weather-averages/al-mafraq/jo.aspx

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Figure 15: Traditional Syrian Houses (Caso, 2004).

Figure 17: Working in Zaatari (New York Times, 2012). Retrieved on 4 Sept., 2019, from: https://www.nytimes.com/2012/11/01/world/middleeast/market-rises-at-zaatari-camp-for-syrian-refugees.html

Figure 18: Activities in Zaatari (Kloosterman, 2014). Retrieved on 4 Sept., 2019, from: https://www.greenprophet.com/2014/10/secret-gardens-planted-by-syrian-refugees-in-jordan/

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Figure 21: Living Developmant in Zaatari based on Stromme L. (2013)

Figure 22: Chain of loss, Framgard. L. (2015) Retrieved on 4 Sept., 2019, from: https://issuu.com/3xnarchitects/docs/intheinterim

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TABLES

Table 1: Zaatari in Number (Kruijt, 2014)

Table 2: WFP, 2018 Working in Zaatari. Retrieved on 4 Sept., 2019, https://www.wfpusa.org/stories/10-facts-about-the-syrian-refugee-crisis-in-jordan/

13 Appendix

Annex A
Configuration Process - Phase I

Unit scale - 3 families (ONE UNIT)			
Constraints	**Input**	**Rule**	**Output**
#Less than 3 families, won't be enough to create a courtyard, and we want to do the exercise with a courtyard	**NF=** Number of families	When FS is less than 6, two modules of 3mx3m will be provided #living/sleeping space When **FS** is 6 or more, three modules of 3m x 3m will be provided	
Members per family	**FSize =** **Type of family**		**NM=** Total number of modules
NM= Total number of modules NM * 2 m^2 = courtyard size			**CSize=** Courtyard size
W= Width of the module (3mx3m) **H=** Height of the module (2.5m)	**T**=Thickness of the wall (range from 0.25m-0.80m)	A wider distance (**mt**) will increase every time T gets thicker while W and H will remain constant.	**MT**=Whole program and structural module
Max distance to services in X = 8 MT **Max distance to services in Y** = 4 MT		#Maximum distance between the living and service areas (kitchen, toilet and storage)	**SGrid=**Grid that established the working space for the computer to

Design Parameter

Unit scale - 3 families (ONE UNIT)			
Constraints	**Input**	**Rule**	**Output**
#Less than 3 families, won't be enough to create a courtyard, and we want to do the exercise with a courtyard	**NF=** Number of families	When FS is less than 6, two modules of 3mx3m will be provided #living/sleeping space When **FS** is 6 or more, three modules of 3m x 3m will be provided	
Members per family	**FSize =** **Type of family**		**NM=** Total number of modules

Configuration Process - Phase I

Design Parameter

Unit scale - 3 families (ONE UNIT)			
Constraints	**Input**	**Rule**	**Output**
#Less than 3 families, won't be enough to create a courtyard, and we want to do the exercise with a courtyard	**NF=** Number of families	When FS is less than 6, two modules of 3mx3m will be provided #living/sleeping space When **FS** is 6 or more, three modules of 3m x 3m will be provided	
Members per family	**FSize =** **Type of family**		**NM=** Total number of modules
NM= Total number of modules NM * 2 m^2 = courtyard size			**CSize=** Courtyard size
W= Width of the module (3mx3m) **H**= Height of the module (2.5m)	**T**=Thickness of the wall (range from 0.25m-0.80m)	A wider distance (**mt**) will increase every time T gets thicker while W and H will remain constant.	**MT**=Whole program and structural module
Max distance to services in X = 8 MT **Max distance to services in Y** = 4 MT		#Maximum distance between the living and service areas (kitchen, toilet and storage)	**SGrid**=Grid that established the working space for the computer to

Configuration Process - Phase 2

Redefined RULES for Housing

Working module	**Demographic/Family**	**Context (Climate boundaries)**	**Functional boundaries**
0.3m brick size with mortar Working module = 1.2m	**Sleeping modules** 1P = 9 modules 2P = 9-10.5 modules 3P = 10.5- 12 modules 4P = 12 - 18 modules 5P = 21- 22.5 modules 6P = 21- 27 modules 7P = 22.5 - 30 modules 8P = 24 - 36 modules 9P = 31.5 - 36 modules **Living modules** 1P= 9 modules 2P = 9 modules 3P= 9 modules 4P= 9 modules 5P=12 modules 6P = 12 modules 7P= 14 modules 8P= 14 modules 9P= 14 modules	Wind direction = North west = **Dictates openings orientation** **Dictates direction of rooftop**	9 living +bedroom modules = 3 modules for **courtyard** **1 living + bedroom modules = 1 modules for farmland** (Taking the 15 m2 per family of 6 will mean 0.5 modules of farm per module of living, but we want to allow them to sell part of the crops so an extra 0.5 module is added to the total farming area) research
1.5 modules Corridors/Walking module	**Services / Common areas** 100 modules = 1 kitchen caravan, 1 toilet caravan	Min Temp = 7 °C = **Min. wall thickness of 0.30 m**	**B** = Bedroom **L**= Living room **K**= Kitchen **T** = Toilet **V** = Veranda **C** = Courtyard **F** = Farmland **V connects to L** **L connects to B** **K and T connects to V and C** **F connects to C**
3.6 x 3.6 room size	Urban distribution- Clusters come together to form a central playground for children	Max Temp = 32 °C Cold-semi arid climate = **Semi-open space towards courtyard**	2% of the farmland will be farm storage

Redefined RULES for Housing

Working module	**Demographic/Family**	**Context (Climate boundaries)**	**Functional boundaries**
0.3m brick size with mortar Working module = 1.2m	**Sleeping modules** 1P = 9 modules 2P = 9-10.5 modules 3P = 10.5- 12 modules 4P = 12 - 18 modules 5P = 21- 22.5 modules 6P = 21- 27 modules 7P = 22.5 - 30 modules 8P = 24 - 36 modules 9P = 31.5 - 36 modules **Living modules** 1P= 9 modules 2P = 9 modules 3P= 9 modules 4P= 9 modules 5P=12 modules 6P = 12 modules 7P= 14 modules 8P= 14 modules 9P= 14 modules	Wind direction = North west = **Dictates openings orientation** **Dictates direction of rooftop**	9 living +bedroom modules = 3 modules for **courtyard** **1 living + bedroom modules = 1 modules for farmland** (Taking the 15 m2 per family of 6 will mean 0.5 modules of farm per module of living, but we want to allow them to sell part of the crops so an extra 0.5 module is added to the total farming area) research
1.5 modules Corridors/Walking module	**Services / Common areas** 100 modules = 1 kitchen caravan, 1 toilet caravan	Min Temp = 7 °C = **Min. wall thickness of 0.30 m**	**B** = Bedroom **L**= Living room **K**= Kitchen **T** = Toilet **V** = Veranda **C** = Courtyard **F** = Farmland **V connects to L**

Annex B

Urban Configuration - Phase 1

Unit scale - 3 families (ONE UNIT)			
Constraints	**Input**	**Rule**	**Output**
#Less than 3 families, won't be enough to create a courtyard, and we want to do the exercise with a courtyard	**NF=** Number of families	When FS is less than 6, two modules of 3mx3m will be provided #living/sleeping space When **FS** is 6 or more, three modules of 3m x 3m will be provided	
Members per family	**FSize =** **Type of family**		**NM=** Total number of modules
NM= Total number of modules NM * 2 m² = courtyard			**CSize=** Courtyard size

Urban Configuration - Phase 2

URBAN SCALE- CONFIGURATION RULE (in working process)

Type	Situation	Rule	Output
Protection	Relation to typical street	• Min 2 modules for cluster safety • Plus 4 modules of pedestrian area	Distance
	Relation to main street with bazaar	• Min 2 modules for cluster safety distance • Plus 6 modules of pedestrian area (more traffic)	Distance
	From wind/sand storm	• Clusters located at North west and west districts should not have jollie towards the outside (North west and west) • If windows are desired, they should be operable to protect	Type of wall
	Passage safety	Distance from cluster to cluster should be min 4 modules	Sabat or Pocket plaza
	Cross junction street	• Min 6 modules distance	
Connection to amenities	Relation with school	• Min 4 modules of offset • One side should be 10 modules to allow for a proper entrance • Windows towards school to increase connection and sense of security	Distance and plaza
	Relation with hammam	• One side Min 4 modules of offset • Two sides with 10 modules (open plaza/religious) • One side dependant	Distance and plazas

Annex B

Urban Configuration - Phase 2

URBAN SCALE- CONFIGURATION RULE (in working process)

Type	Situation	Rule	Output
Protection	Relation to typical street	• Min 2 modules for cluster safety • Plus 4 modules of pedestrian area	Distance
	Relation to main street with bazaar	• Min 2 modules for cluster safety distance • Plus 6 modules of pedestrian area (more traffic)	Distance
	From wind/sand storm	• Clusters located at North west and west districts should not have jollie towards the outside (North west and west) • If windows are desired, they should be operable to protect	Type of wall
	Passage safety	Distance from cluster to cluster should be min 4 modules	Sabat or Pocket plaza
	Cross junction street	• Min 6 modules distance	
Connection to amenities	Relation with school	• Min 4 modules of offset • One side should be 10 modules to allow for a proper entrance • Windows towards school to increase connection and sense of security	Distance and plaza
	Relation with hammam	• One side Min 4 modules of offset • Two sides with 10 modules (open plaza/religious) • One side dependant	Distance and plazas

Annex C

Strength of Adobe bricks

Influence of different additional materials on the strength of a standard adobe brick

Date:

14-10-2019

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Content

1. Introduction

This report explores the results of the measured strength of adobe bricks made with different material compositions and dimensions. The experiment was carried out in two sessions: the first session consisted in the manual preparation of the adobe bricks. After left to dry for seven days, the bricks were broken one by one on the second session. The results of the series of measurements is reported in this document in order to compare the strength of the different mixtures in the adobe bricks.

1.1. Research objective and question

The main objective of the research is to identify the influence on the strength of a standard composition of adobe bricks mixture in addition to other materials. Afterwards a comparison will be drawn, based on the strength of each brick type with sourced standard strength values according to their different compositions and their dimensions.

Based on the research objectives, two main research questions were formulated: What is the standard strength of the adobe brick in addition to different material additives? How does the dimension of the brick affects its strength?

2. Methodology

2.1. Equipments and software used

The equipment used in the brick making process are a large bucket, weighing machine, a mixing drill and a masonry trowel. Image 1 shows the equipment in the sequence of use from left to right. For testing the strength of the bricks, Zwick z100 testing machine is used and the data is recorded using the testXpert software.

Image 1: *Equipments used in the brick making process*

2.2. Procedure for Brick making

To start with the brick making workshop, materials and the standard recipe to make the bricks were provided by the professor. The recipe for the standard brick

Image 3: *Steps in brick making*

2.3. Additional materials

The first brick type was made with the standard adobe ingredients. For better comparative results five bricks were made in large size and five in small size.

The second type and the third type of bricks were made adding 10% straw and 10% wood chips respectively to the original mixture. The use of the natural fibers like straw fibres and wood chips into the mixture can improve the binding quality of the mixture, reducing shrinkage and resulting in better compressive strength of the bricks (Mohammed, A. & Bahobail, M., 2011).

For the 4th, 5th and 6th brick type, experimental ingredients like cotton, plastic thread and sponge pieces were used respectively for each batch of three specimens. Cotton is chosen to be experimented with, due to its cultivation possibility within the Zaatari camp. Cotton fibers also have a moderately good tensile strength and it absorbs water easily and is breathable (Zupin, Z., & Dimitrovski, K., 2010).

Synthetic fibers like plastic thread and sponge is chosen due to its cheap price and easy availability. Table 1 shows a cumulative data of the different brick types produced with the different materials.

Brick Type	Standard Composition	Size	Dimension	No. of Specimens	Additional Materials 10%
1	Clay 30% Fine Sand 30% Coarse Sand 40% Water 10% of total dry mixture	Large	16.5 x 10.5 x 6.5	5	N/A
		Small	11 x 8 x 3	5	
2		Medium	13.5 x 9 x 4	5	 Straw
3				5	 Woodchips
4		Small	11 x 8 x 3	3	 Cotton
5				3	 Plastic
6				3	 Sponge

***Table 1**: Different types of bricks produced*

2.4. Method of Strength test

The strength test was conducted at the material test laboratory at the Faculty of Mechanical, Maritime and Material Engineering (3ME) of the Delft University of Technology. All the bricks were arranged in order according to the composition. Each dried brick was placed on a wooden plank and levelled with a metal plate on top for even load distribution. The metal plate was used only for the bricks with an uneven surface.

The initial state of the brick was photographed. The piston of the Zwick z100 was slowly lowered on the brick with a gradual acceleration in force until the brick breaks, as shown in Image 4. The final state of the bricks was photographed and the maximum load before breakage and the maximum deformation of the brick was recorded using the software testXpert. The process was repeated for all the brick types.

Brick Type	Standard Composition	Size	Dimension	No. of Specimens	Additional Materials 10%
1	Clay 30% Fine Sand 30% Coarse Sand 40% Water 10% of total dry mixture	Large	16.5 x 10.5 x 6.5	5	N/A
		Small	11 x 8 x 3	5	
2		Medium	13.5 x 9 x 4	5	 Straw
3				5	 Woodchips
4		Small	11 x 8 x 3	3	 Cotton
5				3	 Plastic
6				3	 Sponge

***Table 1**: Different types of bricks produced*

2.4. Method of Strength test

The strength test was conducted at the material test laboratory at the Faculty of Mechanical, Maritime and Material Engineering (3ME) of the Delft University of Technology. All the bricks were arranged in order according to the composition. Each dried brick was placed on a wooden plank and levelled with a metal plate on top for even load distribution. The metal plate was used only for the bricks with an uneven surface.

The initial state of the brick was photographed. The piston of the Zwick z100 was slowly lowered on the brick with a gradual acceleration in force until the brick breaks, as shown in Image 4. The final state of the bricks was photographed and the maximum load before breakage and the maximum deformation of the brick was recorded using the software testXpert. The process was repeated for all the brick types.

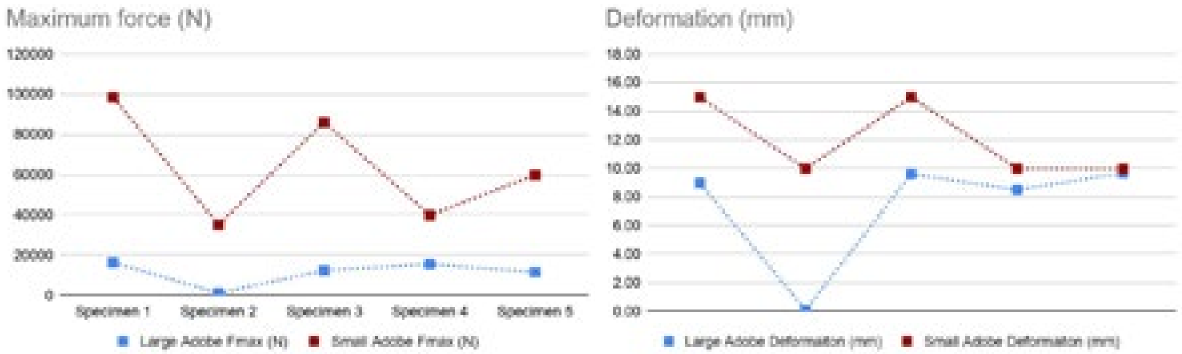
***Image 4**: Steps for strength test*

3. Results (of testing for each category)

3.1. Estimation of ultimate strength per category

a. Large adobe brick vs. small adobe brick

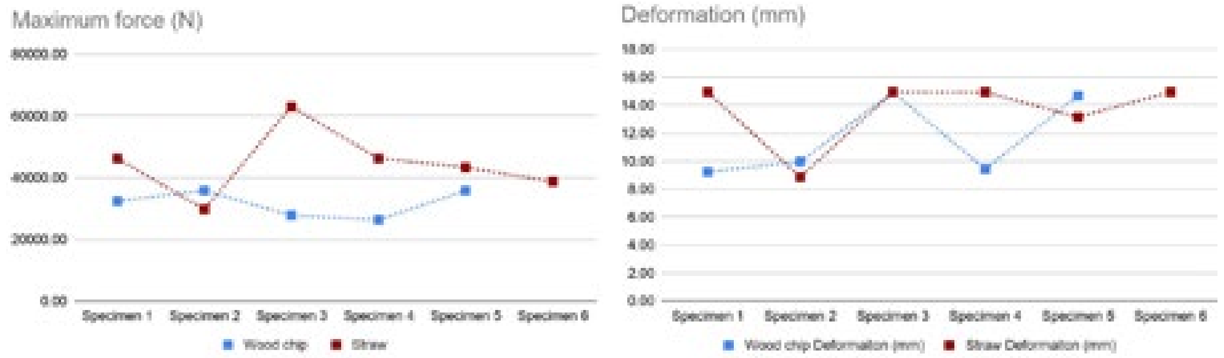
The standard adobe bricks were made in two sizes, five of the specimens in small size and five in large size. The strength of the bricks was tested in terms of the maximum force (N) and the maximum deformation(mm).



***Graph 1:** Maximum force on the different standard adobe bricks(left); Maximum deformation of the different standard adobe bricks(right).*

b. Medium adobe wood chip vs. straw

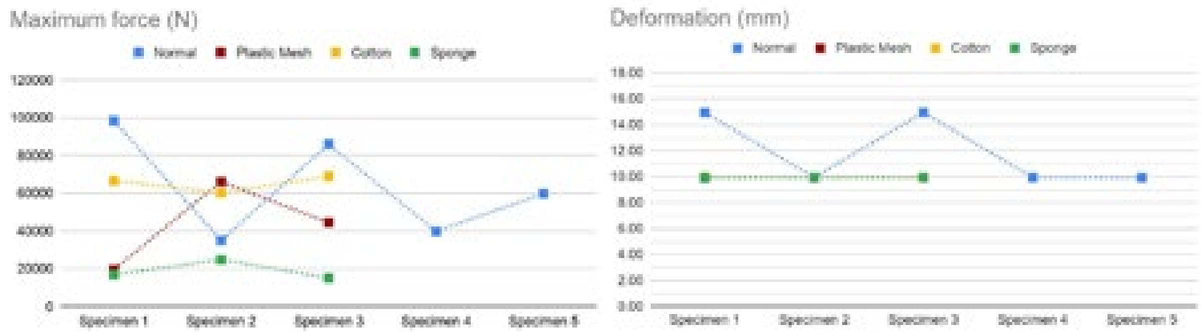
The medium size adobe bricks were made in two batches of five specimens each. The first batch was made with additional 10% straw fibers and the 2nd batch with additional 10% wood chips. The strength of the medium sized adobe bricks was tested in terms of the maximum force (N) and the maximum deformation(mm).



***Graph 2:** Maximum force on the adobe bricks with straw and wood chips(left); Maximum deformation of the adobe bricks with straw fibers and wood chips(right).*

c. Small adobe normal vs. plastic mesh vs. cotton vs. sponge

The last sets of adobe bricks were made in small sizes. Five specimens of normal adobe bricks were compared with bricks made of 10% additional cotton, plastic mesh and sponge respectively in batches of three. The strength of the small sized bricks was tested in terms of the maximum force (N) and the maximum deformation(mm).



***Graph 3**: Maximum force on the small adobe bricks with cotton, plastic mesh, sponge and standard adobe(left); Maximum deformation of these adobe bricks(right)*

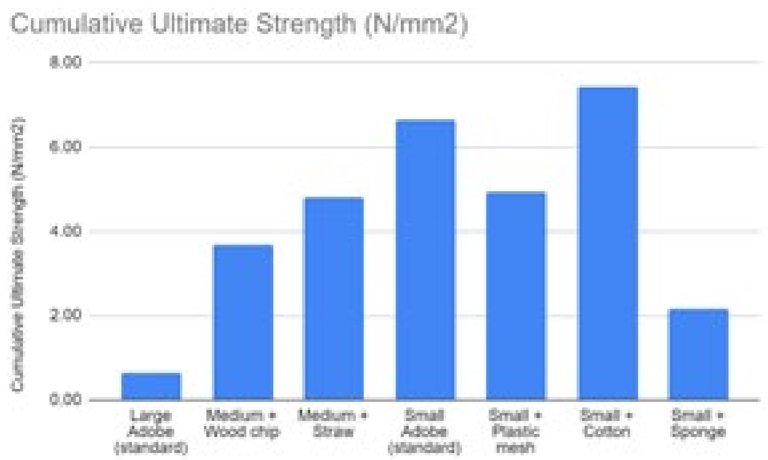
3.2. Estimation of safe design strength per category

The results of the brick breaking test show that most of the bricks undergo an instant breakage due to their brittle behaviour. For all the bricks, with the exception of two or three, the force and deformation at breakage could not be obtained from the experiment.

Thus, looking into the values of the maximum force and the deformation at the maximum force, a safety factor value was considered for obtaining a safe design strength value based on the literature review. As found, with a safety factor of 2.5, the compressive strength values should have a minimum value of 0.34 N/mm2 (Clifton, J. R., & Davis, F. L., 1979). From table 2, it can be seen that the values of compressive strength for the bricks made, lies between 2.61-7.43 N/mm2, that are well above the limit mentioned in the literature. Thus a safety factor of 1.5-2 is feasible to be considered. Also due to the absence of the 1st floor and the absence of any snow load on the roof eliminates the need for a higher safety factor for the limited compressive load on the structure.

3.3. Cumulative Ultimate strength results for the different compositions and dimensions

Graph 4 shows the comparison of the ultimate compressive strength of all the brick samples according to the material composition and different dimensions. The ultimate compressive strength was calculated for each brick type using the average value of the maximum force(N) for each type divided by the area(A) according to the dimension of the bricks, as shown in table 2.



***Graph 4**: Overall bar chart representing the ultimate strength of the different brick types*

3.4. Young's Modulus

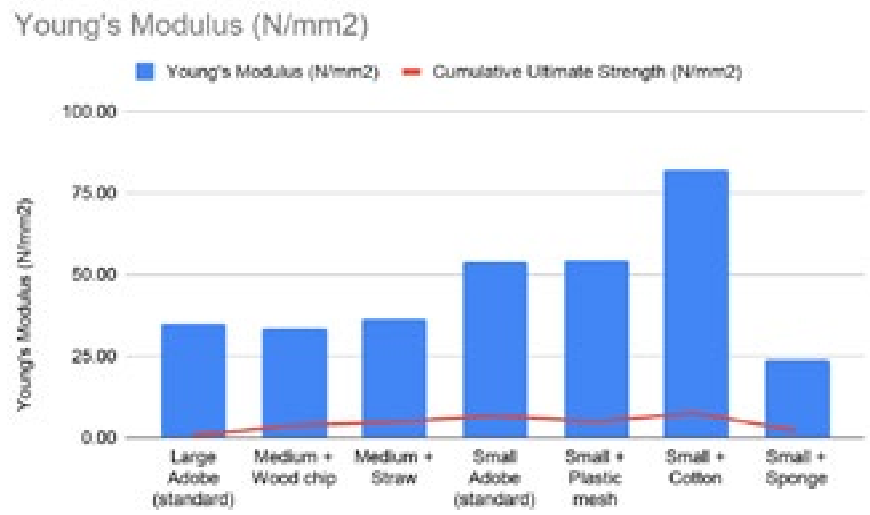
Young's modulus (E) is the material property to measure the change in length under compression or tension (Encyclopedia Britannica, 2019). The average maximum force (N) and average deformation (mm) according to the material composition of each specimen type was calculated.

The values are used to calculate the Young's modulus (E) with the formula E = stress/ strain = (FL) / (A * dL), where F is the applied force, L is the initial length, A is the area, dL is the deformation (Sciencing, 2018), as shown in table 2.

Specimen Type	Area(mm2)	Avg. maximum force (N)	Avg. maximum Deformation (mm)	Young's Modulus (E)(N/mm2)	Compressive strength(N/mm2)
Large adobe	17325	11341.382	7.366	**35.01**	0.65
Small adobe	8800	58312.17	12.48	**54.02**	6.63
Wood chip	12150	31682.28	11.66	**33.37**	2.61
Straw	12150	44592.73	13.63	**36.44**	3.67
Cotton	8800	65397.79	9.98	**81.94**	7.43
Plastic Mesh	8800	43408.75	9.98	**54.41**	4.93
Sponge	8800	18955.03	9.96	**23.8**	2.15

***Table 2**: The average Young's modulus and compressive strength values for the different brick types*

Graph 5 shows the graphical representation of the comparative young's Modulus values for the different brick types.



***Graph 5:** The graphical representation of the average Young's modulus for the different brick types*

4. Discussion of reliability of the data

4.1 Analysis of the result

In this section the results obtained of the brick making experiment will be discussed and compared as per the division established in the section before. The specimens were divided into three main groups, one as a control group with the normal composition of the adobe bricks, the second with the addition of straw and wood chips, and the third one with other experimental additions such as cotton, plastic fibers and sponge.

a. Large adobe brick vs. small adobe brick

The standard adobe bricks were made in two sizes, five of the specimens in small size and five in a large size to obtain a comparative result. Analysing the deformation recorded on both types of specimen, the large adobe specimens showed lower values.

The highest deformation being of around 15 mm and the lowest being 10 mm for the small bricks. The highest deformation for the large bricks being of around 9 mm and the lowest of 0.09 mm deformation. It should be noted that the specimen 2, with the lowest deformation of the large bricks had a low maximum force value, at 1100 N, and showed a brittle behaviour by breaking almost as soon as the test was applied to this specimen (Image 5), thus amounting to a relatively low deformation when compared with the other specimens of the same batch.

The large adobe bricks, as per observation in general showed brittle behaviour and the material seemed to be very dry in its composition.

Image 5. Specimen 2, of the large adobe bricks broke right in the middle.

On the other hand, when comparing the maximum force, the small adobe bricks showed significantly higher values. The Specimen 1 of the small adobe bricks had a maximum force of 98,500 N, being the highest value. While Specimen 1 of the large adobe bricks had its highest maximum force at 16,400 N.

The small specimens also showed the highest deformation, which could mean that other circumstances should be taken into consideration, such as the thickness to length ratio of the bricks.

It has to be considered that, some of the load during the experiment could have been distributed to the wooden slab, when the bricks were tested, due to the slenderness of the small bricks.

Another consideration is the final state of the bricks after the test was done. Both types of specimens (small and large) were completely destroyed by the end of each test as shown in the images below.

***Image 6**. Left, large adobe brick broken example. Right, small adobe brick broken example.*

b. Medium adobe wood chip vs. straw

The medium size adobe bricks were made in two batches of five specimens. The first batch contained additional 10% straw fibers and the second batch was made with additional 10% wood chips.

Looking at the deformation found in both types of bricks, the highest deformation was around 15 mm for both of them, and the lowest deformation was around 9 mm also for both of them.

Since they behaved in similar ways in the deformation, further analysis on the maximum force was done. The highest maximum force was obtained by the specimen 3 from straw, with 63,061 N, and the lowest at 26,408 N from woodchip.

On average the straw bricks had a better behavior than the wood chip bricks. Image 6 also shows the two bricks that performed the best at the end of the test, comparing the different types, the woodchip bricks crumbled into smaller pieces, whilst the straw bricks crumbled in thin slabs and stayed tighter and closer together when taken to their breaking point.

***Image 7**. Left, wood chips adobe brick broken example. Right, straw adobe broken example.*

c. Small adobe normal vs. plastic mesh vs. cotton vs. sponge

The last sets of adobe bricks were made in small sizes. Five specimens of normal adobe bricks were compared with bricks made of 10% additional cotton, plastic mesh and sponge respectively in batches of three.

During the testing of these smaller specimens, an unknown problem with the machine was encountered, meaning that not all the data was obtained and recorded for some of the specimens.

Comparing the deformation of the two available types of brick, the bricks with sponge showed lower deformation values (10 mm) than the control bricks with the normal composition (max. 15 mm).

Nonetheless, some discussion can be made by observing the image 7, once the test was applied. The least deformed brick was the cotton, followed by the sponge, then the plastic and finally the normal brick, which showed the most deformation of the four types.

The addition of different components caused a bridging effect that holds together the soil and so they still seem intact even after they've reached their failure point, probably amounting to a better ductile behavior.

Image 8. *Left to right: cotton, sponge, plastic and normal examples.*

On the maximum force the bricks could withstand, the highest values were obtained by the brick with the normal composition of adobe, though the three cotton specimens tested were also amongst the highest values and had a stable behaviour. As seen on Graph 3, both the cotton and sponge had more stable values, whereas the normal brick and the one with plastic mesh as additive had sudden jumps on values, depending on the test performed.

d. Comparison of all types of specimens.

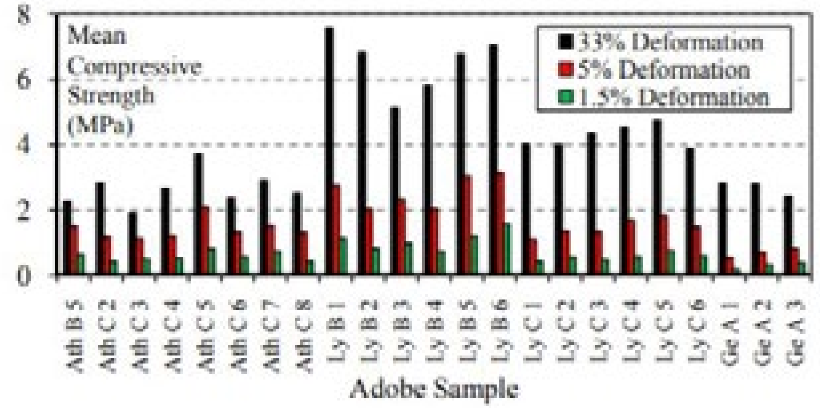
Comparing the performance of each type of brick depending on the size, as seen on Graph 4, shows that the smaller specimens had better results. The medium and small specimens had a cumulative ultimate strength of above 2.00 N/mm2. The large adobe brick had a cumulative ultimate strength of 0.66 N/mm2.

The greatest performance in terms of the Young's Modulus, compressive strength and ultimate strength were found in the small adobe bricks with the normal composition and the small brick with cotton addition, as well as the medium brick with straw addition.

Among these three types, the cotton brick showed the least average deformation, of 9.98 mm. The cotton bricks had an average Young's Modulus of 81.94 N/mm2 (table 2), relatively higher than the straw and normal bricks. On the other hand, it should be mentioned that the thickness of the small specimens could be crucial to these results, since part of their good performance could be awarded to the wooden slab where they were tested absorbing part of the loads.

4.2 Comparison with standard/other source strength values

In a study of the mechanical behaviour of adobe mansory of the University of Cyprus (Illampas R., Ioannou I., & Charmpis D., 2011), the specimens with higher deformation percentage also had the highest compressive strength. The compressive strengths varying from 0.5 N/mm2 to almost 8.0 N/mm2, similar to the values obtained and discussed previously, giving reliability to the results (These bricks had a 5 x 10 x 10 cm dimension).



Graph 6*. Mean values of compressive strength. At least four specimens from each brick were tested. (Illampas, R. , 2011)*

Another research that studies adobe's mechanical properties from the University of Aveiro tested two different types of walls with compressive strength ranging from 0.82 N/mm2 to 0.95 N/mm2. The average Young's Modulus was 117.3 N/mm2 and 138.3 N/mm2 for the two different types tested, much higher than the ones calculated from the specimens tested in this experiment.

In an experiment done by the Czech Technical University in Prague (Gubasheva S., 2017), the results on the compression test show a range in the Young Modulus from 98 N/mm2 to 211 N/mm2, also higher than the values obtained in the experiment, and an average of 2.88 N/mm2 of compressive strength . Other findings from this author shows that only the full earth large bricks visibly cracked even before doing the tests, and some further observations on the addition of other materials such as straw conclude that it helps in the behaviour of produced large bricks.

4.3 Reliability and Limitations

To ensure scientific rigour five specimens of each type were built so a proper comparison was possible. Comparison with values found in literature and other research papers was also conducted to evaluate the reliability of the results.

One of the limitations of this study was that the brick were measured when they were made and not after they got dry, which some studies explain that the shrinkage on the brick between this two steps affects it mechanical properties.

Another limitation was the sudden jumps on values could be due to inconsistencies by human error when mixing and doing the mix. Also the even distribution of the additives could be a factor affecting the results.

There was also a problem during the compression test of the small bricks, due to the small thickness, various times, the machine was not able to record the deformation value and only the failure strength was shown. So lack of reliability on the machine could compromise the results found. It is also possible that the wooden slab used for supporting the bricks absorbed part of the force applied to the bricks, amounting to higher values for the small bricks.

Finally, the amount of bricks tested were too little to be able to draw concrete conclusions from the specimens.

5. Conclusions

The test on the adobe bricks revealed that the mechanical properties of the material display great variation depending on the size of the brick and if additional materials are added to the original composition of the adobe mixture.

The larger bricks showed brittle behaviour and performed the worst when compared to the other specimens tested. Among the small bricks the one with sponge had the worst results and the one with cotton had the best results. On the other hand, among the medium bricks the straw ones had the least deformation and the highest Young's Modulus; these bricks also looked fairly intact by the end of the test. Comparing all these results, the use of straw as an additive could increase the overall performance of the adobe bricks if a larger brick is desired. For the application of these values on the structural analysis, the values found comparable with the literature were taken for a reliable structural performance. An average of 150 MPa for the Young's Modulus will be used, and a compressive strength limit of 2.6 N/mm2. The safety factor taken into account is 2 based on the literature as mentioned before.

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