GREENING THE BLANKS

Living streets for cooler cities

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Chalmers School of Architecture
Department of Architecture and Civil Engineering
Examiner: Emilio Brandao, Supervisor: Kengo Skorick

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Master's thesis at Chalmers School of Architecture
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CHALMERS
UNIVERSITY OF TECHNOLOGY

ABSTRACT

Temperatures all around the world are increasing as a consequence of global warming. In the future, heatwaves will occur more frequently and last for longer periods of time. Due to the urban heat island effect, increasing temperatures will be especially noticeable in urban environments which is a dangerous development for vulnerable groups living in cities and is the reason why it's so important to adapt urban environments to the warming climate. Greenery has the potential of cooling entire cities, however, finding space for greenery in densified city centres is becoming increasingly challenging. Urban green spaces are being built on to cope with rapid urbanisation which puts a strain on the ecosystem services we rely on to survive. Green spaces in urban environments, no matter how large or small, are therefore becoming increasingly important.

This thesis explores ways of adapting urban environments to the warming climate with the purpose of developing an intervention that helps regulate extreme summer temperatures in densely built urban environments. Climbing plants are used in combination with a supporting skeleton as a space making element for green rooms that provide a sanctuary for heat stressed urban dwellers. The logic from geometric experiments on enclosing space is translated into a logic for a structural system for living outdoor green rooms that can be squeezed in on a wide range of plots in densely built urban environments.

As the final outcome of this thesis, the logic for a structural system for living outdoor green rooms is tested on the urban geometry of a site in central Stockholm. The structure defines the spatial qualities of the green room and provides a frame for plants to climb on. The climbing plants act as a living envelope that strengthens the local ecosystem as well as providing shade and protecting from the elements.

STUDENT BACKGROUND

Bachelor in Architecture
Chalmers University of Technology

Master's Program: Architecture and Urban Design
Chalmers University of Technology

Courses:
Sustainable Development and the Design Professions
Material & Detail
Nordic Architecture
Housing Inventions
Architectural Competitions
Academic Writing

Independent courses:
Green Design in Urban Environment (University of Gothenburg, HDK)
Colour theory (University of Borås)

TABLE OF CONTENTS

BACKGROUND

During the 20th century, average temperatures have been increasing almost everywhere on earth. In the northern hemisphere, the last 30 years have been the warmest in at least 1400 years. This recent acceleration of climate change has been linked to an increase of greenhouse gasses in the atmosphere which is strengthening the greenhouse effect that is warming up our planet (Bernes, 2016).

High heat is dangerous to both plant and animal life and as average temperatures keep increasing, it is not only important to decrease greenhouse gas emissions but also to adapt built environments to the changing climate. Warmer temperatures will force us to alter our lifestyles, people will be spending more time outdoors which creates a need for more outdoor spaces that protect from heat. The effects of climate change combined with the urban heat island effect, in the future, will periodically create intolerable conditions and create a need for cooling not just indoor environments but also the outdoors in cities (Boverket, 2010).

Already more than half of the earth's population lives in urban areas, by 2050 that number is expected to increase to 70 percent. Urbanisation has led to an increasing densification of urban areas and green spaces are quickly disappearing in Sweden's rapidly expanding cities. Attractive locations in cities often collide with important green spaces which leads to green spaces being built away.

The green infrastructure of a city includes everything from large parks to private gardens. Greenery provides us with vital ecosystem services is therefore important for both our mental and physical wellbeing. Green spaces in urban environments, no matter how large or small, are becoming increasingly important. However, finding space for greenery in densified city centres is becoming increasingly challenging (WWF, 2015).

PURPOSE

The aim of this thesis is to explore ways of adapting cities to the warming climate. The purpose is to develop an intervention that helps regulate extreme summer temperatures in densely built urban environments.

CONCEPT

The concept is to shade the in-between spaces in cities from summer sun through living outdoor green rooms that cool their surroundings through greenery. The objective is to develop a logic for a structural system that can be used in combination with climbing plants as a space making element that provides a sanctuary for heat stressed urban dwellers.

METHOD

Knowledge on the temperature-related consequences of climate change and the ways extreme heat affects living beings is gathered through literature studies. Information on strategies for adapting cities to the warming climate is used to shape the design concept. The logic for the structural system for living outdoor green rooms is developed through a research by design process of geometric experiments of enclosing space. The strategy for selecting a site is based on information on the urban heat island effect gathered in the literature studies. The logic for a structural system for living outdoor green rooms is tested on a site in central Stockholm as the final outcome of this thesis.

DELIMITATIONS

This thesis focuses on finding solutions for increasing summer temperatures in urban environments as one specific negative consequence of climate change. The application of the logic of the structural system and the resulting design proposal is specific to the selected site.

THEORETICAL FRAMEWORK

A WARMING CLIMATE

Future emissions of greenhouse gasses will be shaped by technological, economic and social changes that have yet to happen. Looking too far ahead is difficult, so rather than predicting the future, researchers are making calculations based on different scenarios that take into account many different factors that could be affecting future atmospheric greenhouse gas concentrations (Bernes, 2016).

RCP8.5 is a climate model that is based on a future scenario where greenhouse gas emissions continue increasing while RCP4.5 is a model that is based on a future scenario with large reductions of greenhouse gas emissions. Both models calculate that by the end of this century, the Swedish average annual temperature will increase with a few degrees. RCP8.5 shows an increase of 4-6°C while RCP4.5 shows an increase of 2-4°C (Asp et al., 2015).

An increase of the average annual temperature with a few degrees might seem insignificant but a few degrees could have dramatic consequences. The warming in Europe is causing climate zones to shift. In Sweden, climate zones could move more than 50 kilometres north in a single decade. The northernmost parts of Sweden could by the end of this century have a temperature climate that is similar to the climate central parts of the country have today. Central Sweden would in turn take over the climate of the northern parts of Germany, while southern Sweden could get temperatures that are similar to those in today's central France.

Climate change does not only affect average temperatures but also the annual minimum and maximum temperatures. Annual maximum temperatures are going to go up just as much as summer average temperatures go up. The increase could possibly be even higher in Europe. A continued warming of the climate could, by the end of the century, lead to extreme temperatures occurring every year instead of once every ten years (Bernes, 2016).

ENDANGERED ECOSYSTEMS

Higher amounts of carbon dioxide in the atmosphere accelerate photosynthesis which is beneficial for plant growth. Plants don't have to keep the microscopic openings in their leaves open for as long to absorb the same amount of carbon dioxide. Plants also use these openings for transpiration and if they don't stay open for as long, the amount of water vapour that is emitted decreases which makes plants better at resourcing with water. Plant growth is therefore going to increase in the coming decades. In the long-term, the positive effects of an increased amount of carbon dioxide in the atmosphere will be outweighed by the negative effects. Slow growing species that are dependent on large amounts of light will eventually die off as they are not able to compete with faster growing species that due to the carbon dioxide fertilisation grow even faster. Increasing heat and summer droughts will eventually cause a decrease in the growth rate of plants.

Species that are negatively affected by climate change can survive by either adapting to the new climate or by moving. For many animals and plants as well as entire ecosystems, the speed at which the climate is warming doesn't give enough time for genetic adaption as different species of plants and animals within an ecosystem tolerate change to a different extent. In Sweden, biodiverse areas are often isolated as islands in intensively cultivated fields and forests that lack biodiversity. Fragmentised habitats make it difficult for species to move with shifting climate zones. The amount of species in Sweden might actually increase as a result of climate change but some ecosystems still risk changing beyond recognition due to disruptions in species compositions (Bernes, 2016).

Ecosystems provide services that are vital for our existence. Some examples are oxygen production, air and water purification, climate regulation, noise absorption and the binding of carbon dioxide. Climate change as well as other forms of human interference pose a threat to ecosystem services that regulate temperatures and purify air and water (Boverket, 2010).

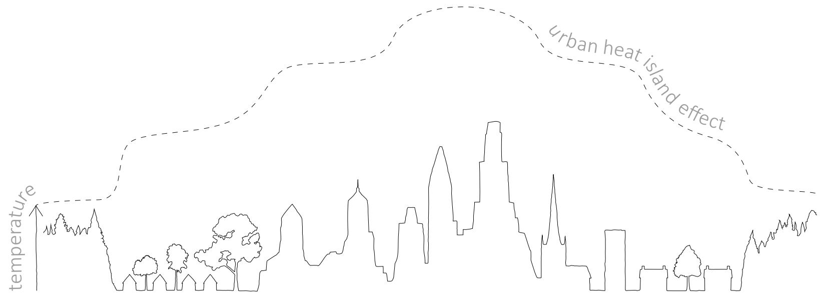
URBAN HEAT ISLAND EFFECT

Urban environments are especially vulnerable to the effects of climate change as their natural ecosystems are already being subjected to exploitation (Bernes, 2016). Cities are made up of hard, impervious surfaces that absorb heat. At night, when the air temperature falls, these surfaces start acting as radiators and emitting the heat they've absorbed during the day. Temperatures in cities are usually higher that in the surrounding countryside and the difference can sometimes be as high as 12 degrees Celsius. The ongoing shift of climate zones as a consequence of climate change means that the UHI effect will, in the future, become increasingly relevant in traditionally cooler countries such as Sweden (Boverket, 2010).

RISK GROUPS

Periods of prolonged hot weather can be very dangerous for both animal and plant life. The long-lasting heatwave of 2010 that affected a large area of the European parts of Russia shortened the lives of 55 000 people, 11 000 of them in Moscow. The heatwave of august 2003 that affected southern and western Europe led more than 40 000 people losing their lives.

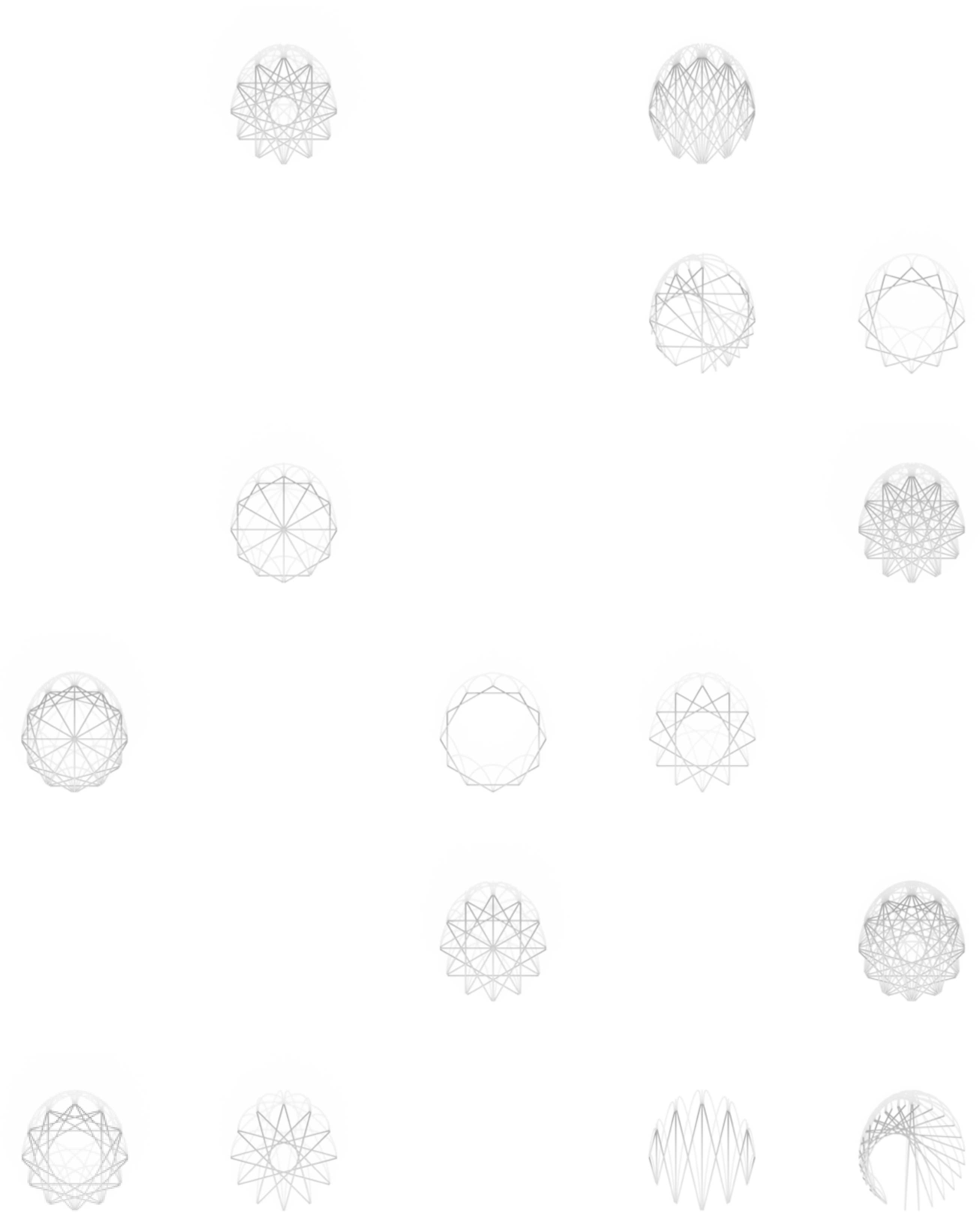
Those who already are sick, the elderly, and children are more likely to develop heat related health complications and the cause of death in these cases is often related to cardiovascular and respiratory diseases. In Sweden, for every degree that the daily average temperature exceeds 20–21°C, the mortality rate among people that live in cities and are over the age of 64 increases with 5%. Extreme heat is rarely a serious threat to the lives of the young and healthy but the discomfort heatwaves bring affects all age groups (Bernes, 2016).



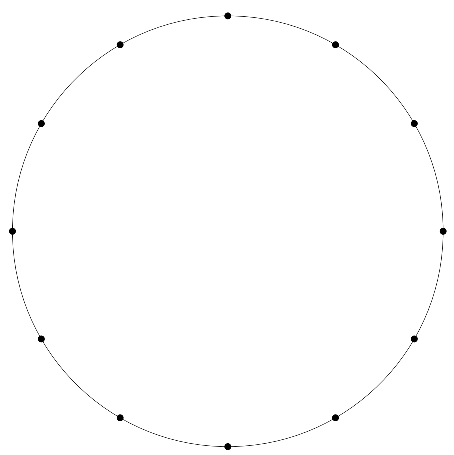
ADAPTING BUILT ENVIRONMENTS

The number of trees in an urban area has a direct effect on the number of temperature related deaths in that area during long periods of warm weather. During the European heatwave of 2007, the death toll was lower in areas with many trees compared to areas with very little trees. During a heatwave, the outdoor climate is often a safer environment for those that are vulnerable to high heat as temperatures outdoors are often cooler than those indoors. Areas with large amounts of trees offer their inhabitants a lot of shaded outdoor space which makes people more likely to go outside to cool off.

Trees cool their surrounding by physically blocking sunrays from being absorbed by the built environment around them and also through transpiration. Plants release water from their leaves into the atmosphere and as the liquid is turned into vapour, the surrounding air is cooled. Large trees are especially effective as microclimate regulators as they have a larger transpiration and provide more shade. Bushes and other vegetation with high plant mass all contribute to cooling. Greenery has the potential of cooling entire cities. A 10 percent increase of the amount of green spaces in an urban environment could bring local temperatures down with up to 4 degrees Celsius (Boverket, 2010).



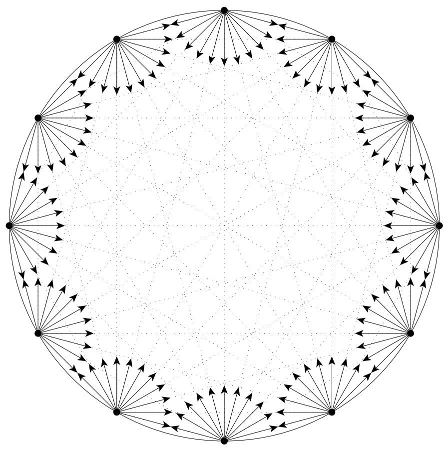
ENCLOSING SPACE



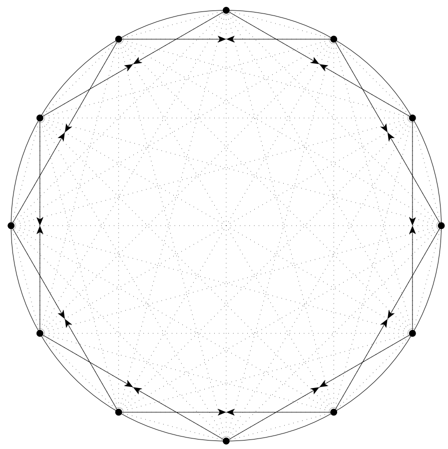
BOUNDARY
ANCHOR POINTS

ITERATION NO. 1

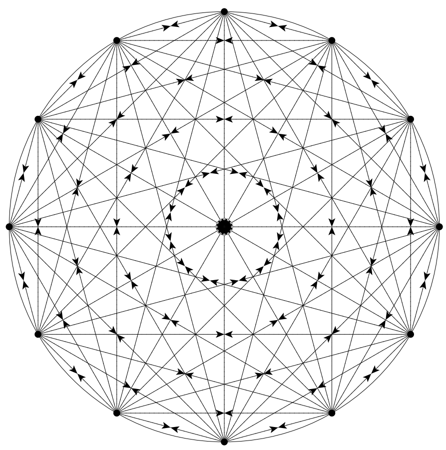
A circle is chosen as the boundary as it is a simple closed shape that has the same radius all around its circumference. The circle is divided into a number of points – the anchor points. Semi-circular arcs are sent out from every anchor point around the circle to create an enclosed dome. The pattern is varied by controlling the diameter of the arcs and also the number of arcs that is sent from every anchor point. Combining different oculus diameters with a different general openness / closeness of the structure gives a lot of control to vary the pattern and makes this system very versatile.



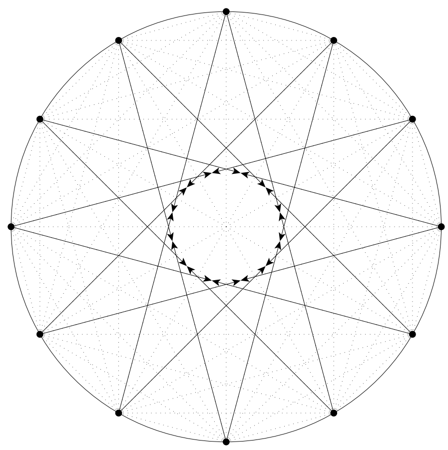
SYSTEM
LOGIC



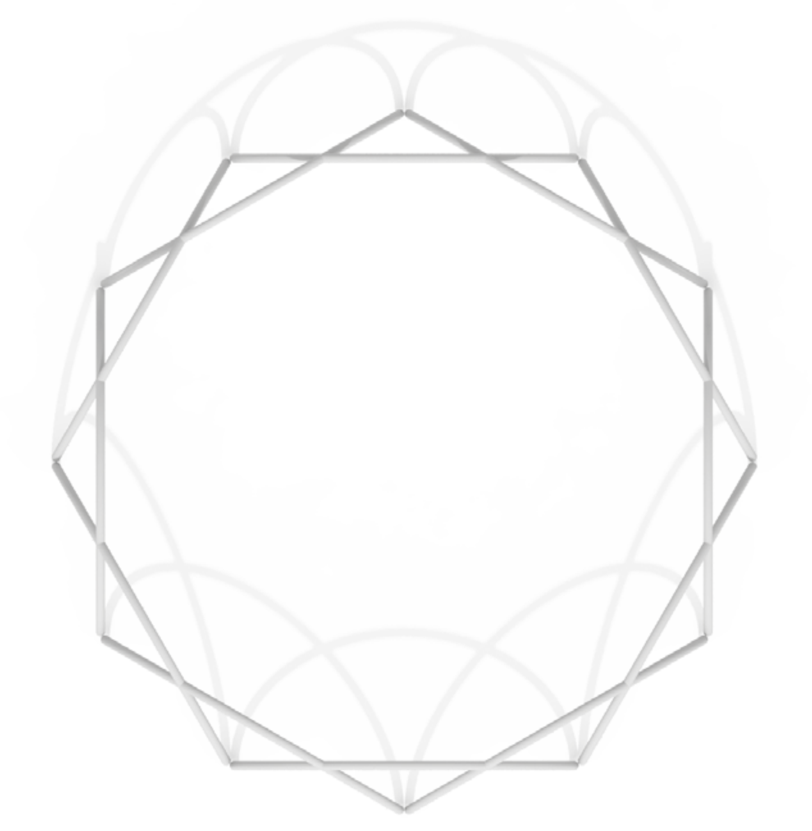
OPEN / LARGE OCULUS
short diameter of arcs, low number of arcs



CLOSED
maximum number of arcs



OPEN / SMALL OCULUS
long diameter of arcs, low number of arcs



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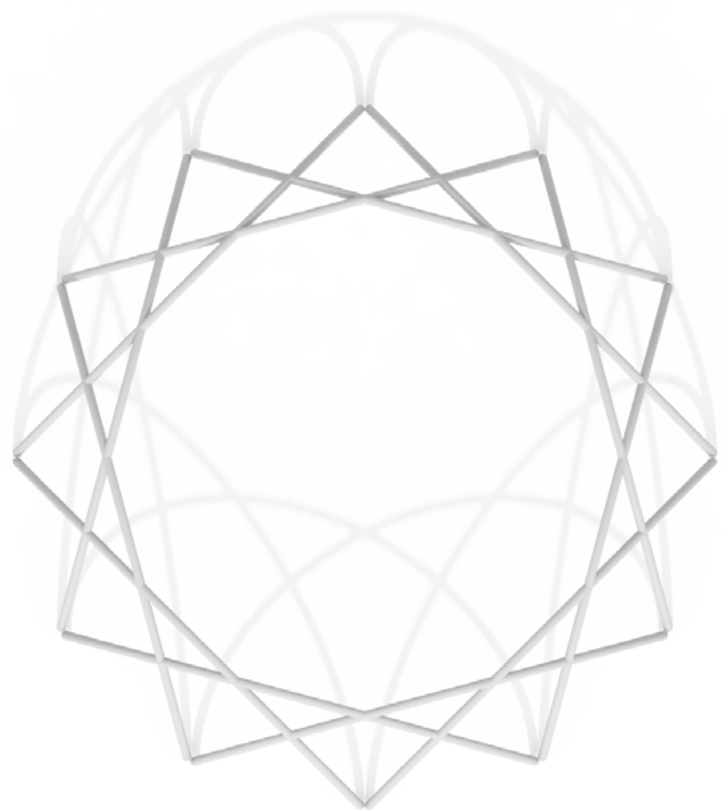

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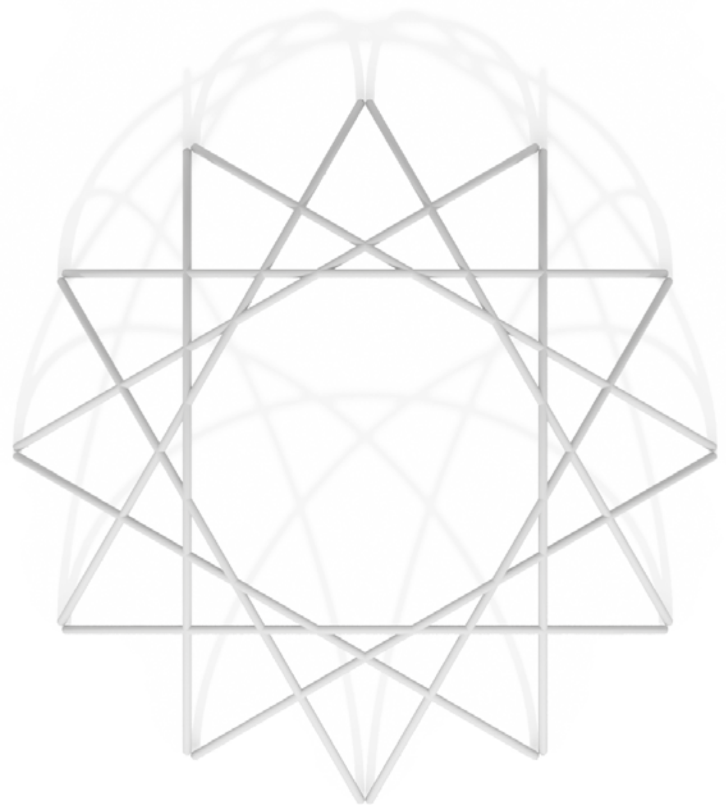

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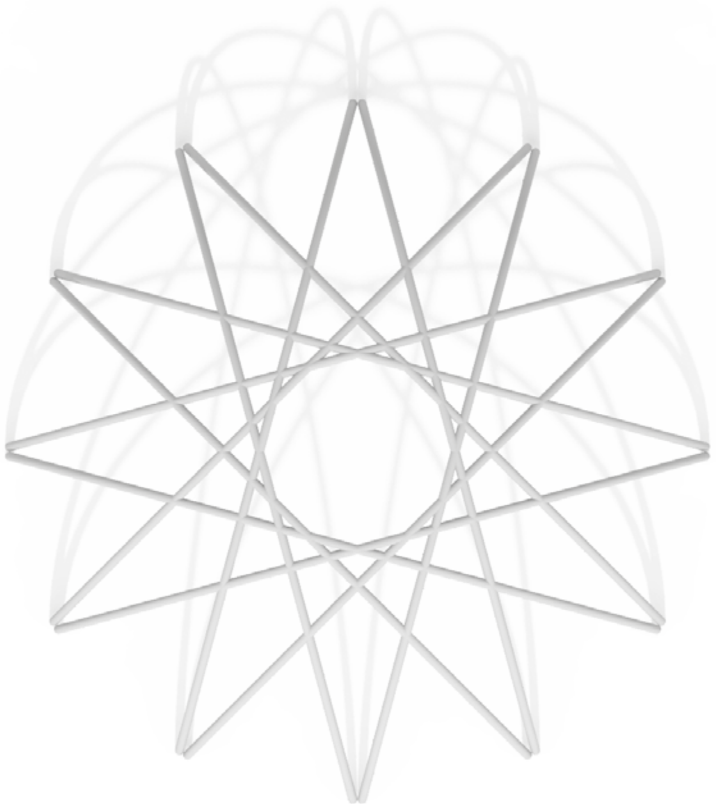

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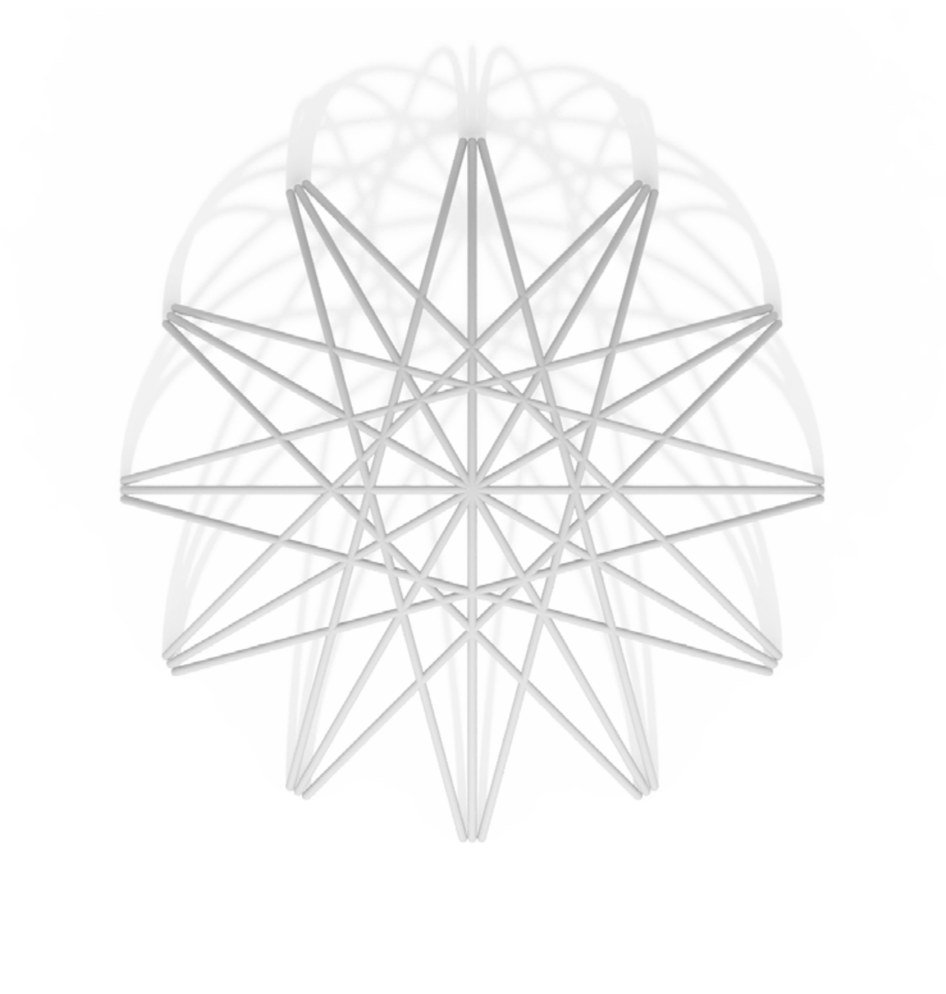

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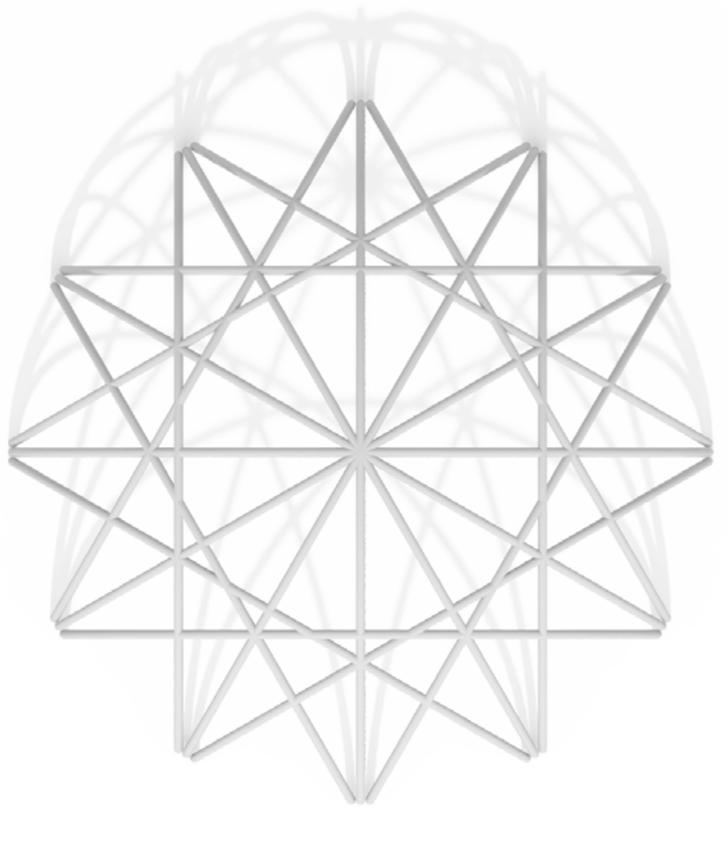

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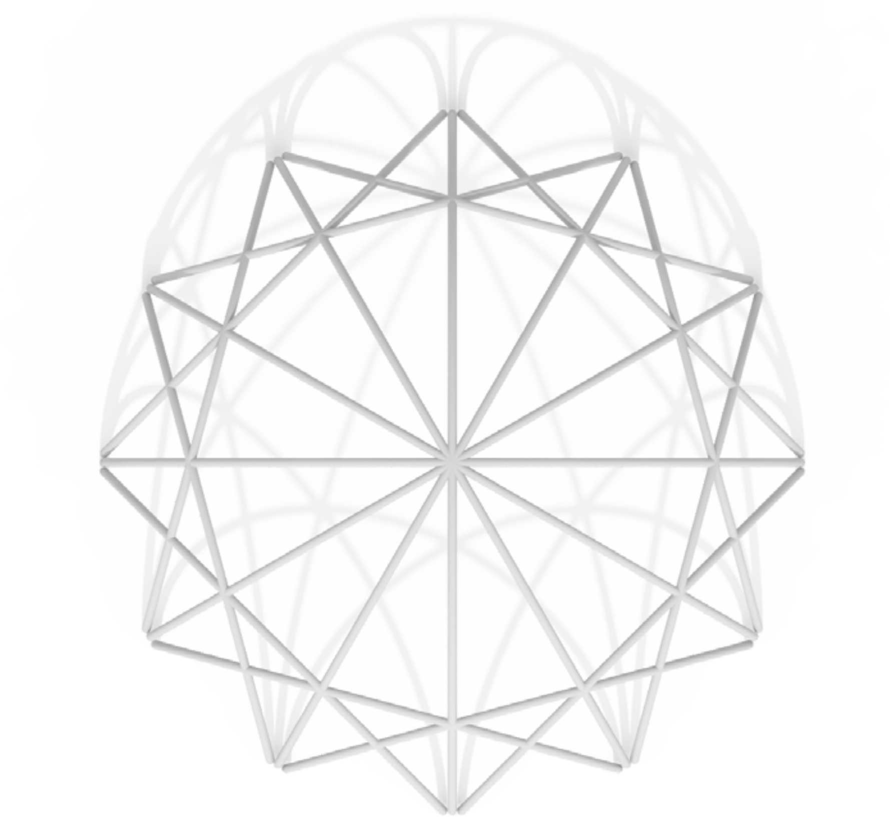

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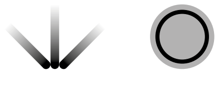

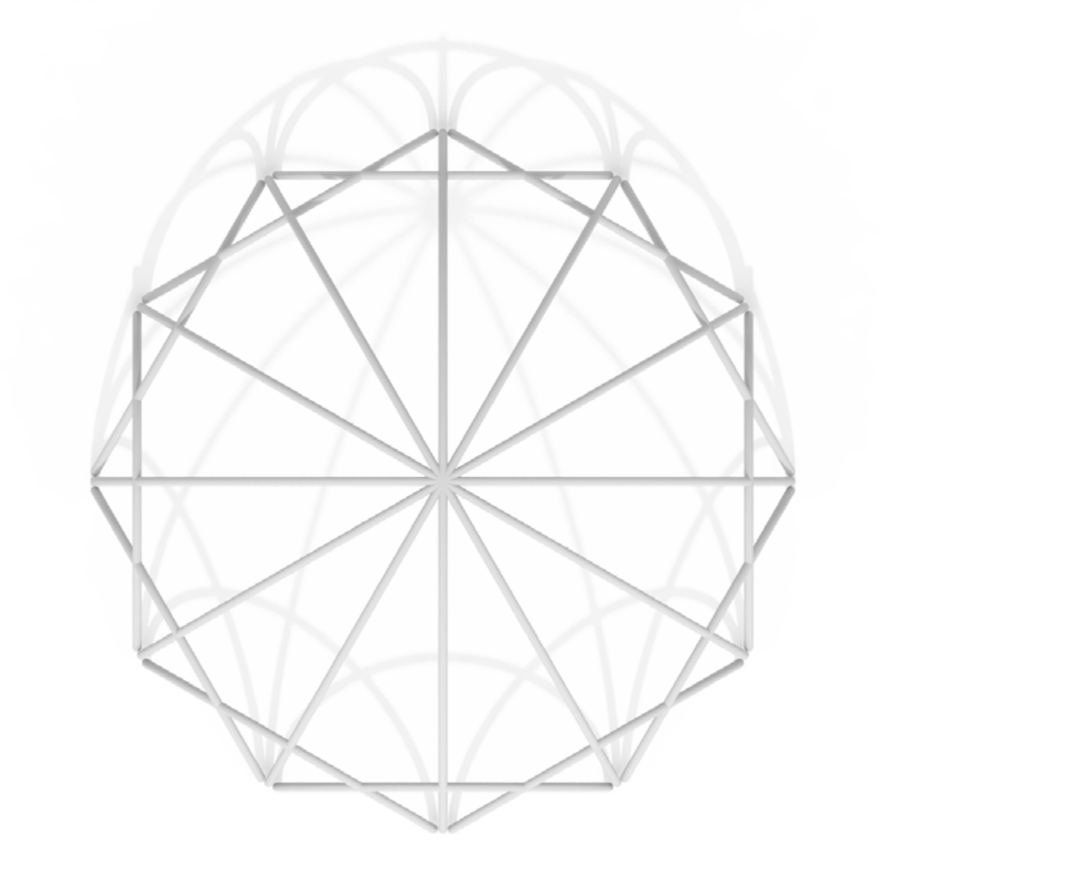

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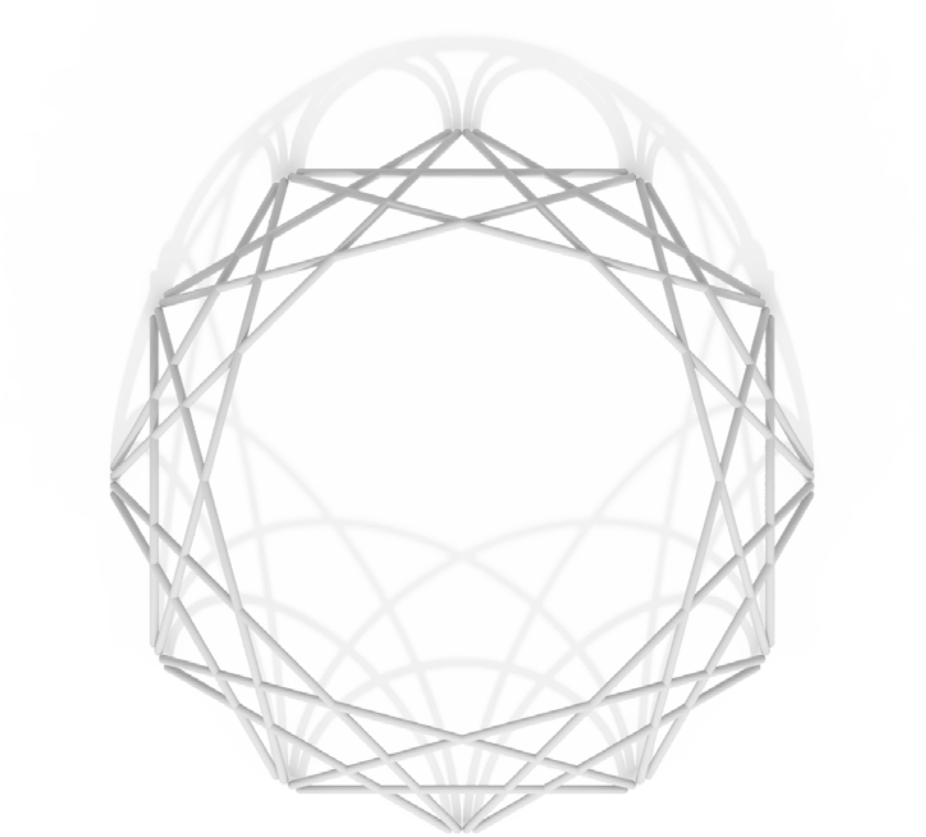

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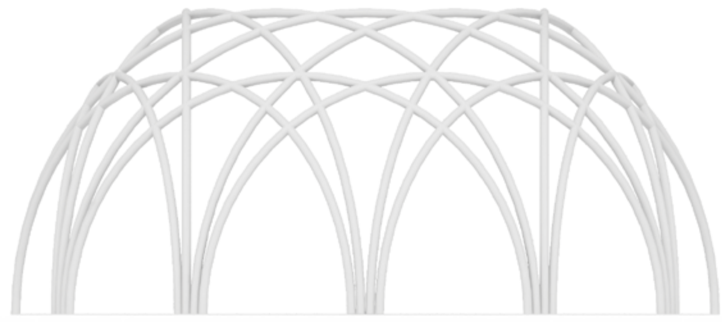

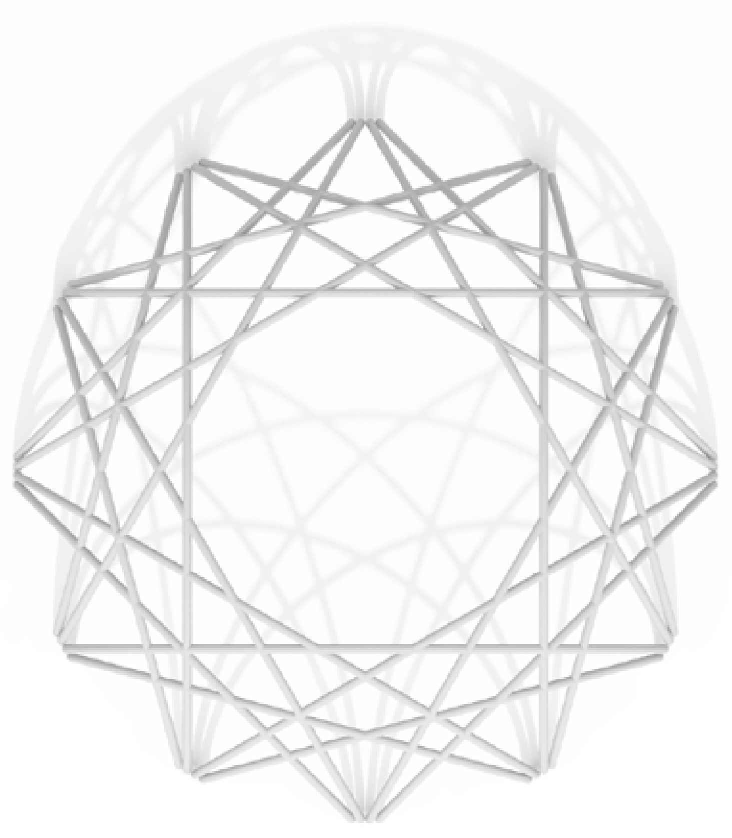

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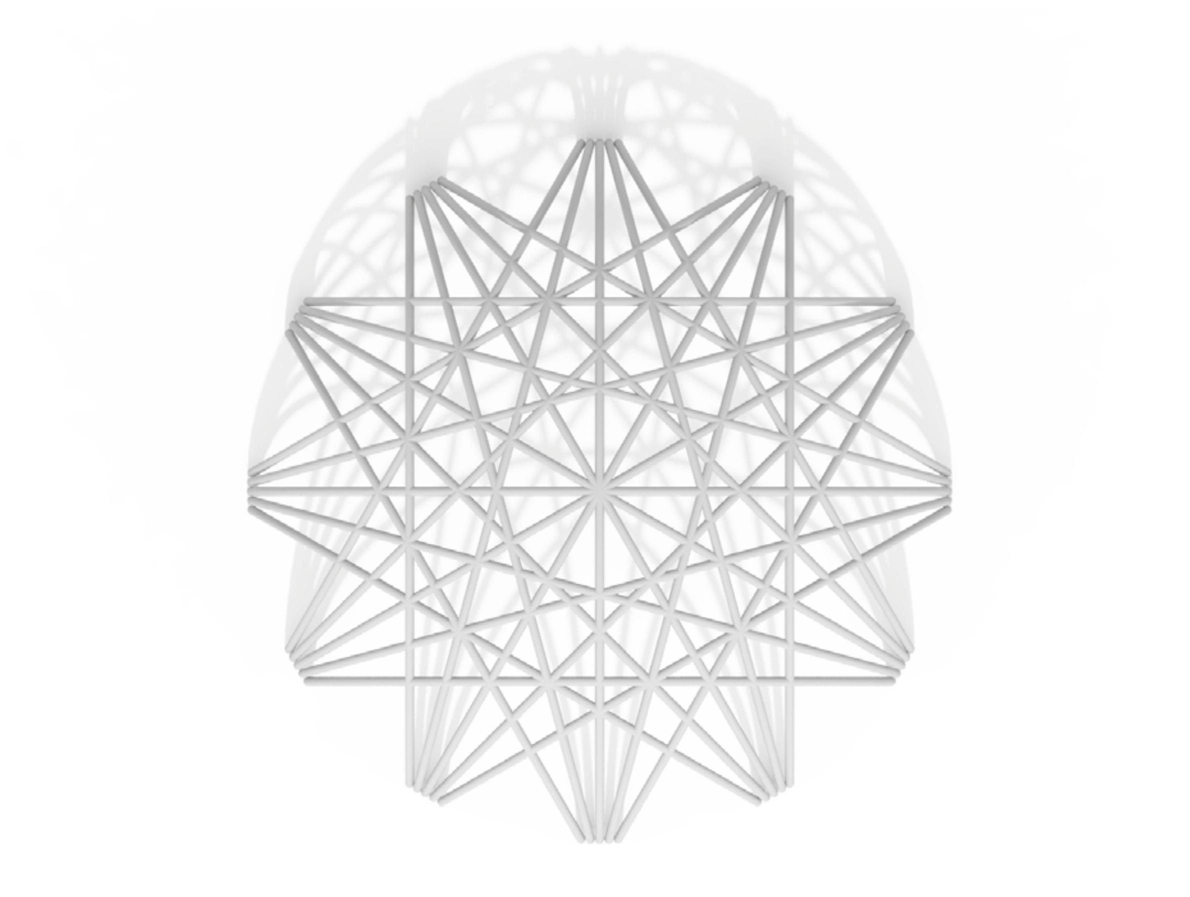

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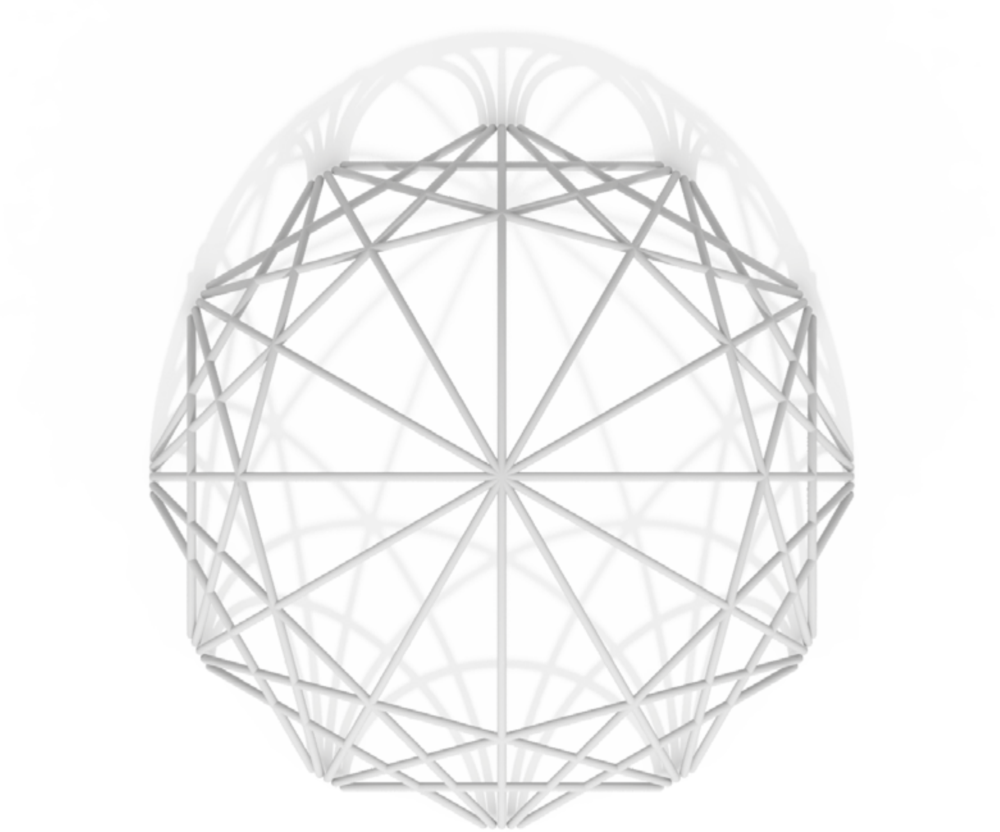

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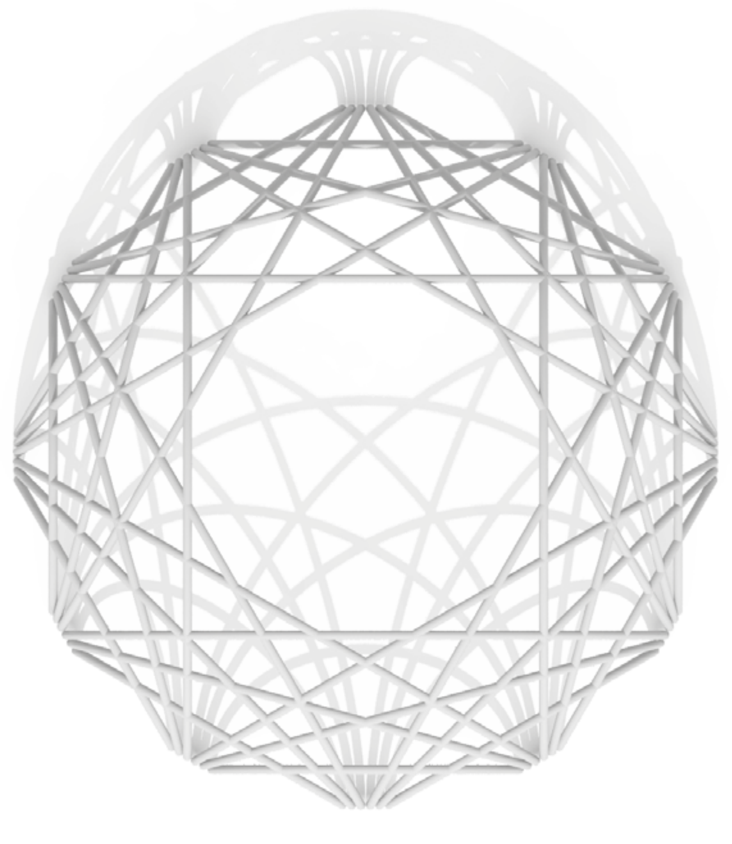

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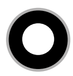

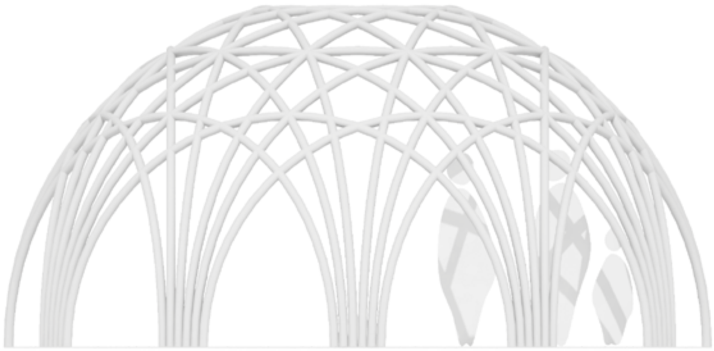

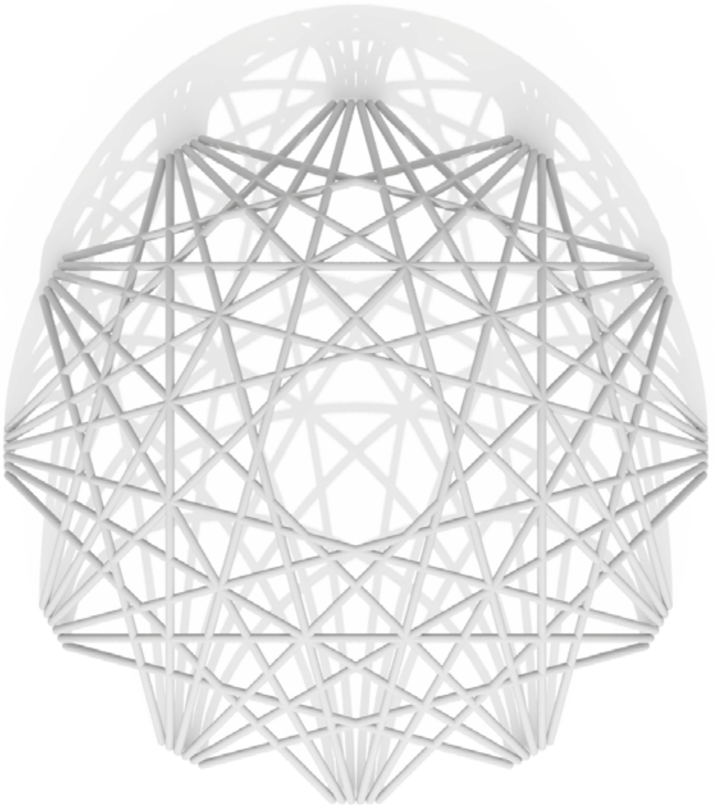

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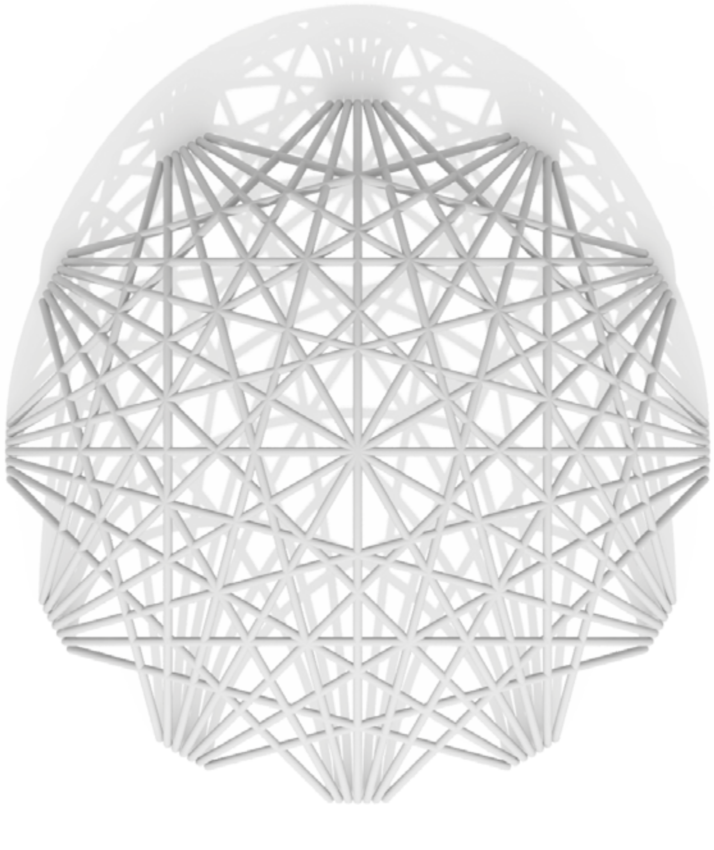

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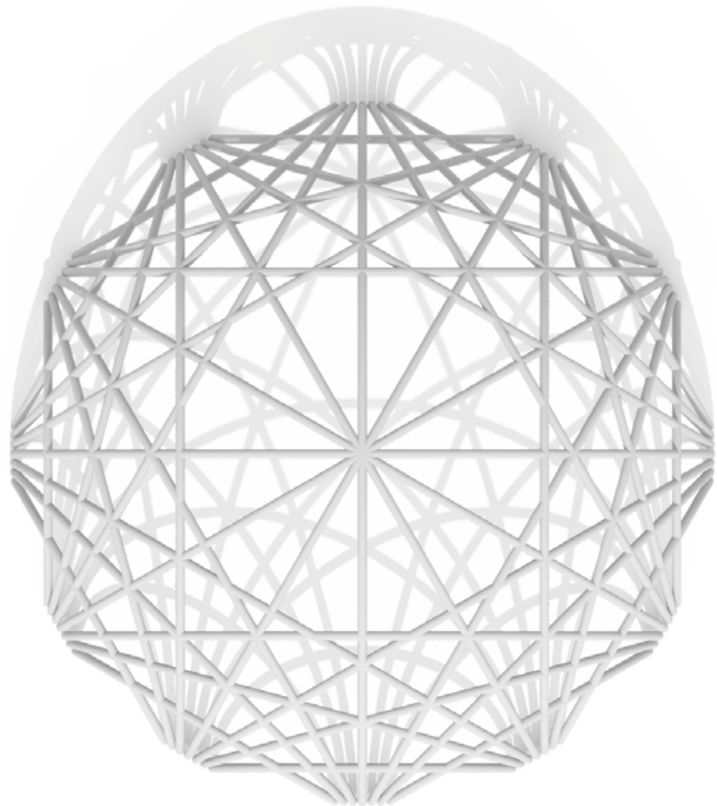

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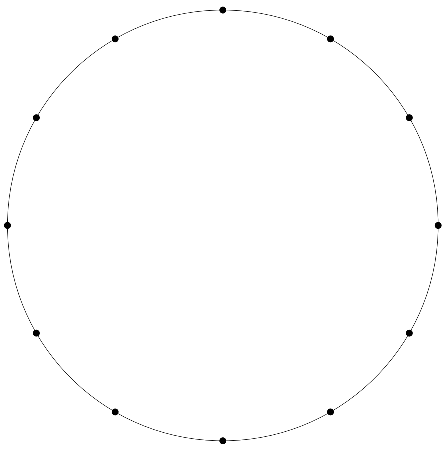
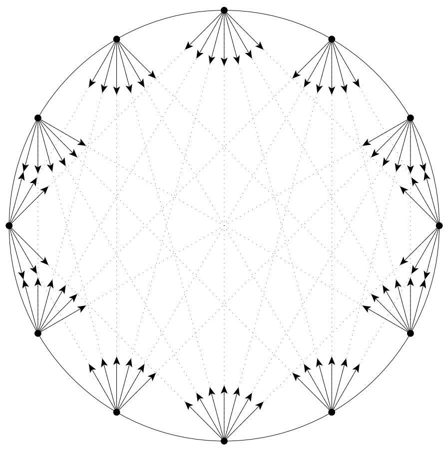
64% / 36%

ITERATION NO. 2

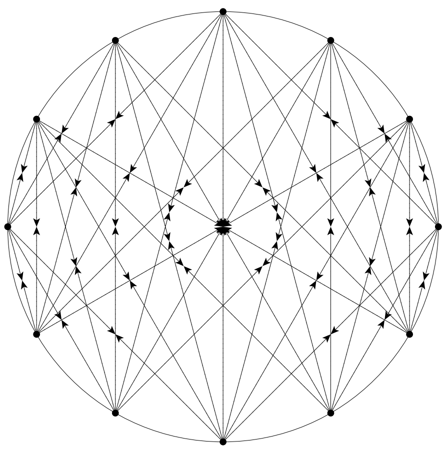
The boundary as well as the number of anchor points are kept the same as in the previous iteration. Semi-circular arcs are sent out from every anchor point across the circle in a top ↔ bottom direction to create an enclosed dome. The pattern is varied by controlling the number of arcs that are sent from every anchor point. This system does not give as much flexibility to generate patterns that are as versatile as in the previous iteration.



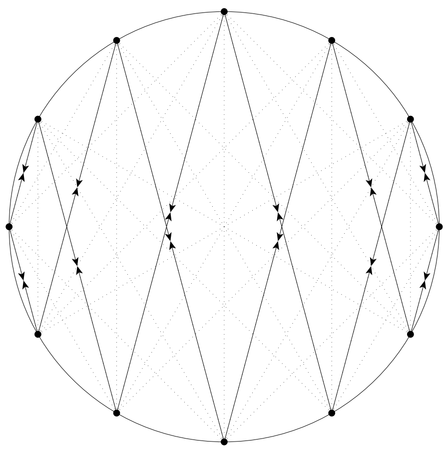
BOUNDARY
ANCHOR POINTS



SYSTEM
LOGIC



CLOSED
maximum number of arcs



OPEN
minimum number of arcs

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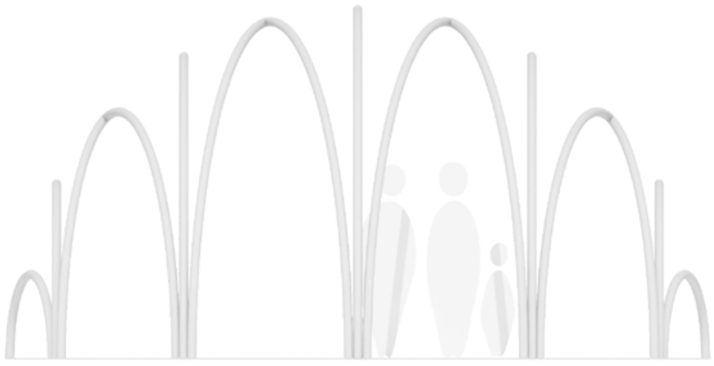

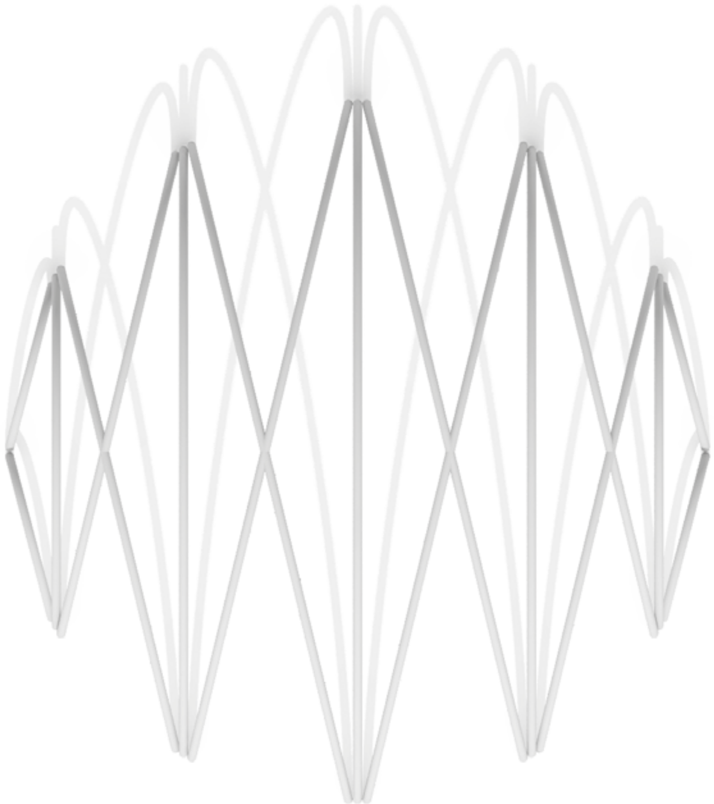

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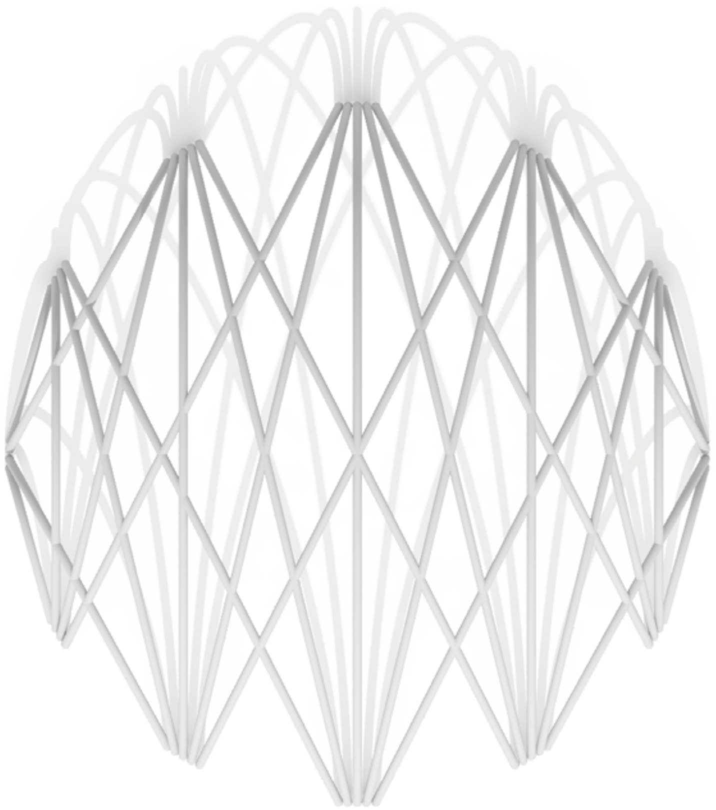

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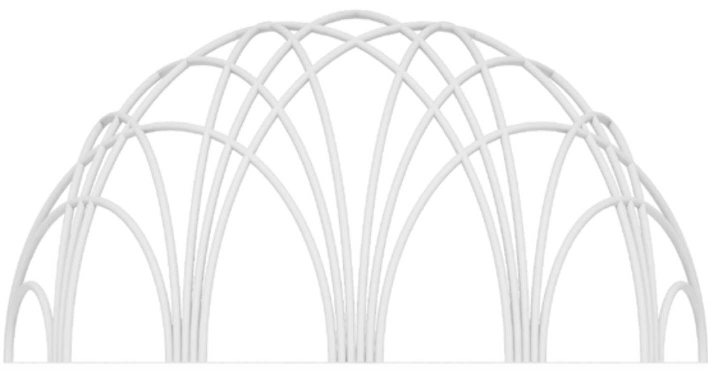

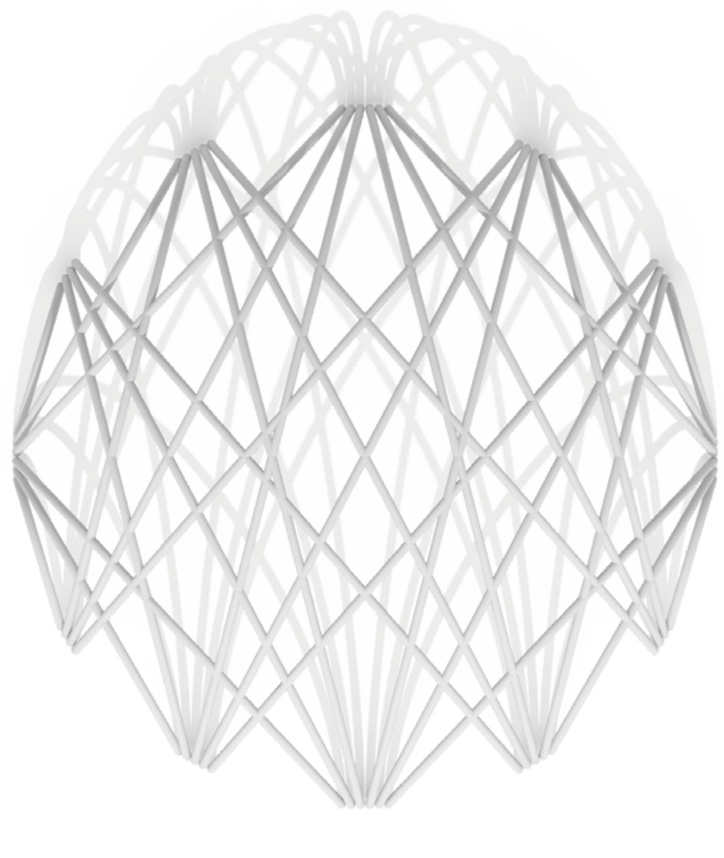

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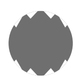

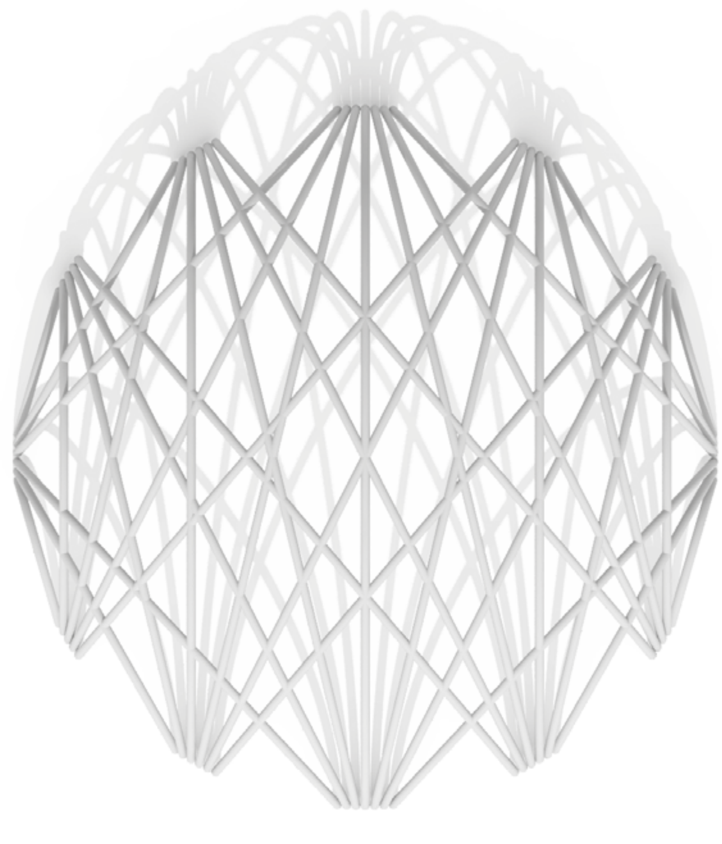

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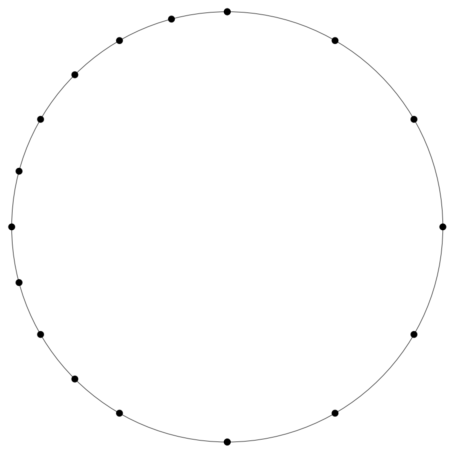
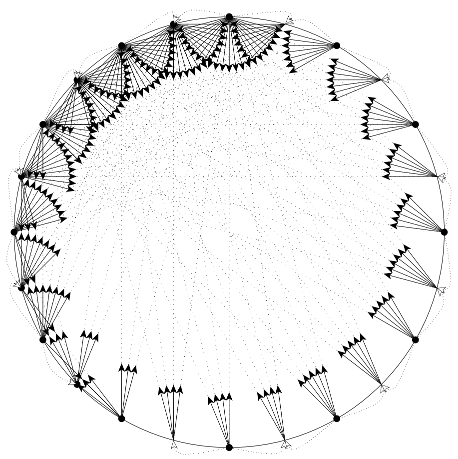


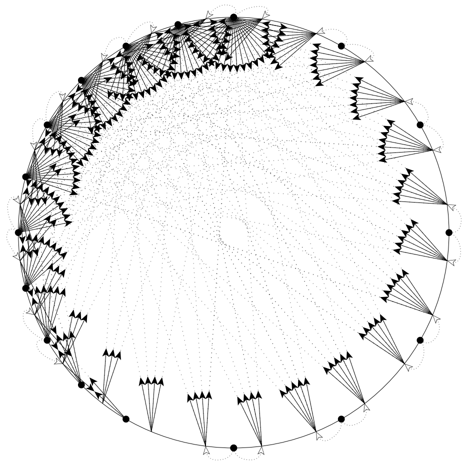
BOUNDARY
ANCHOR POINTS

ITERATION NO. 3

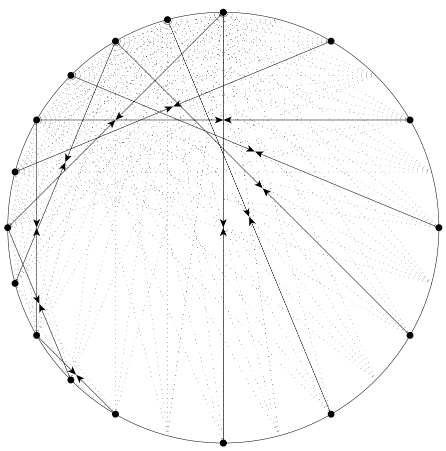
The boundary is kept the same as in previous iterations. The number of anchor points is doubled on the left side of the circle. Semi-circular arcs are sent out from every anchor point around the circle to create an enclosed dome. The resulting patterns are unsymmetrical. The pattern is varied by controlling the number of arcs that are sent from every anchor point and also by copying and rotating the pattern 180 degrees which completes the structure.



LOGIC
odd

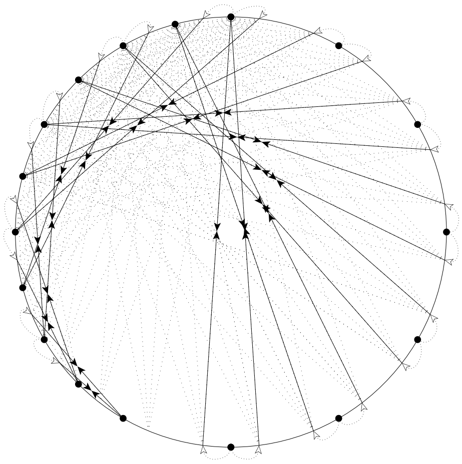


LOGIC
even



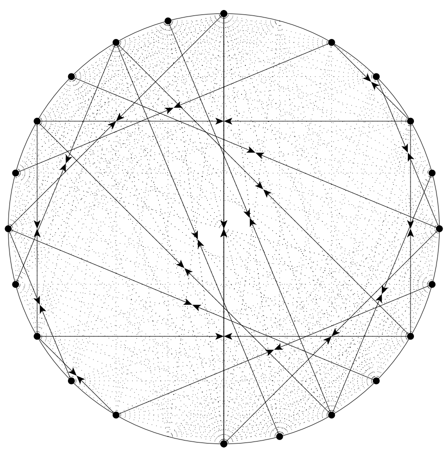
HALF

minimun number of arcs



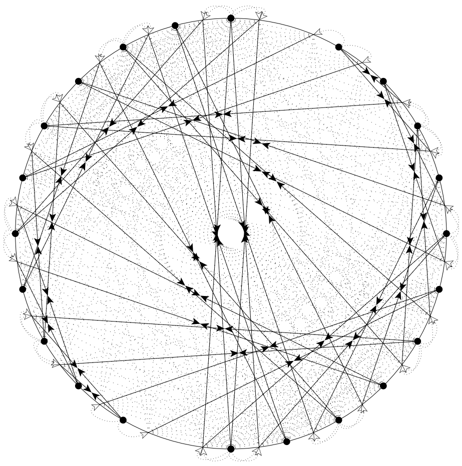
HALF

increased number of arcs



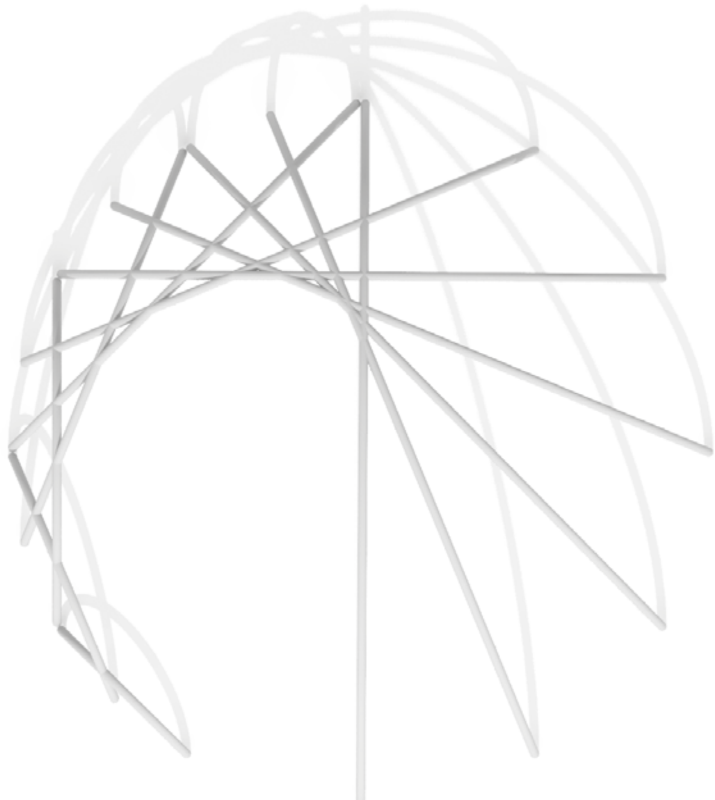
WHOLE

minimum number of arcs

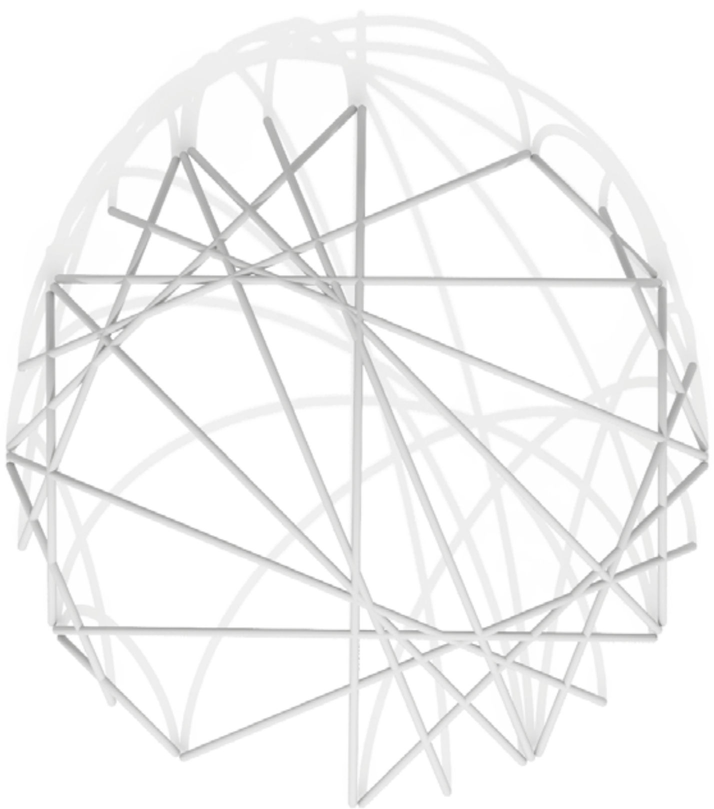


WHOLE

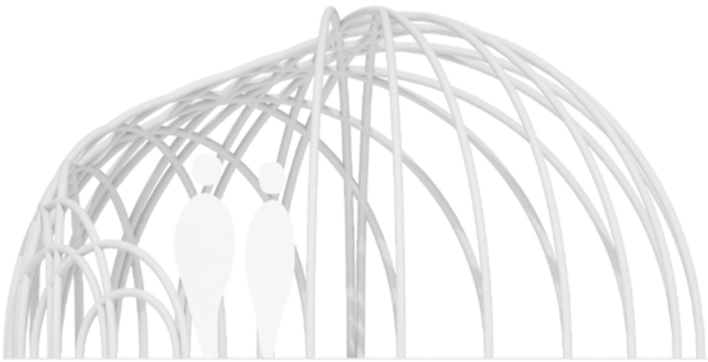
increased number of arcs

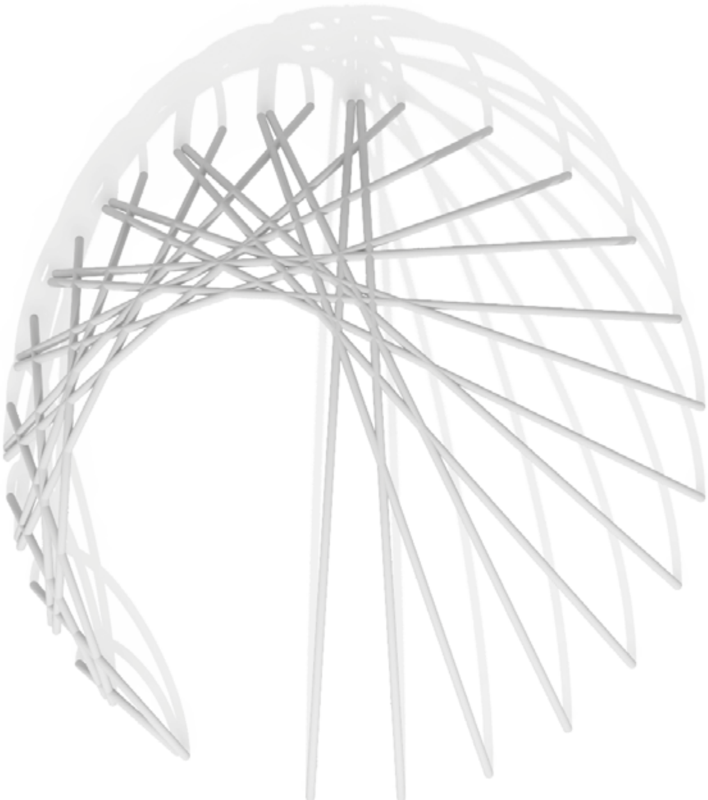


open/
c l o s e d
90% / 10%

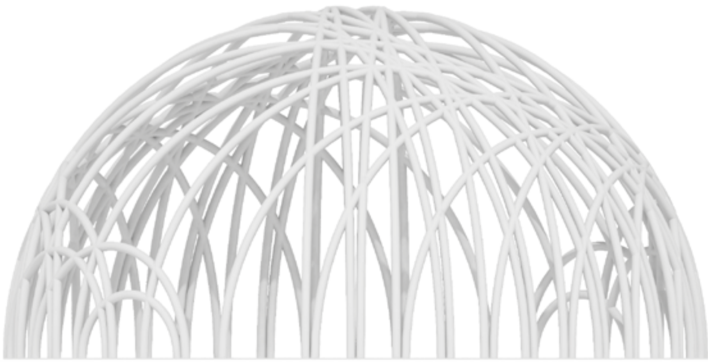


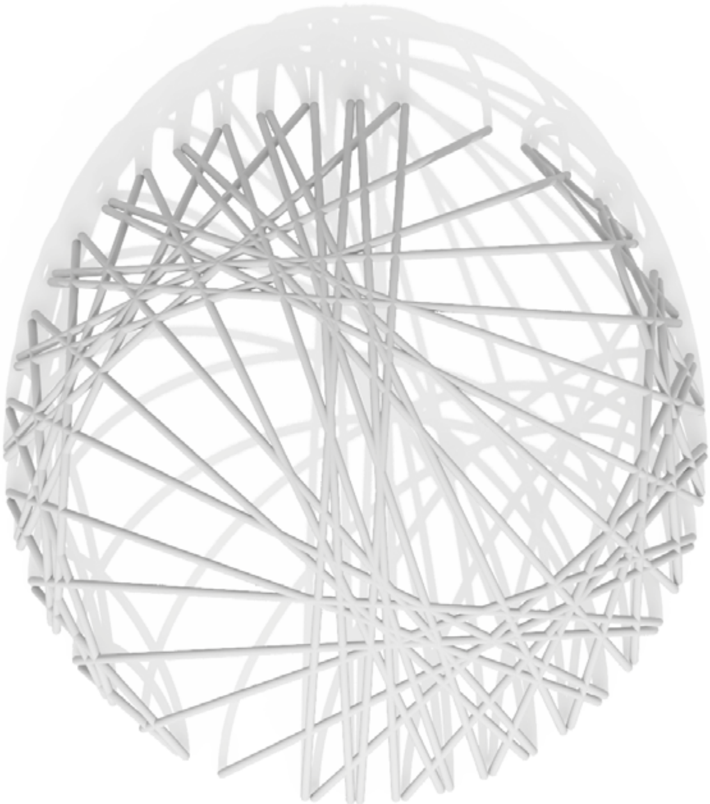
open/
c l o s e d
82% / 18%



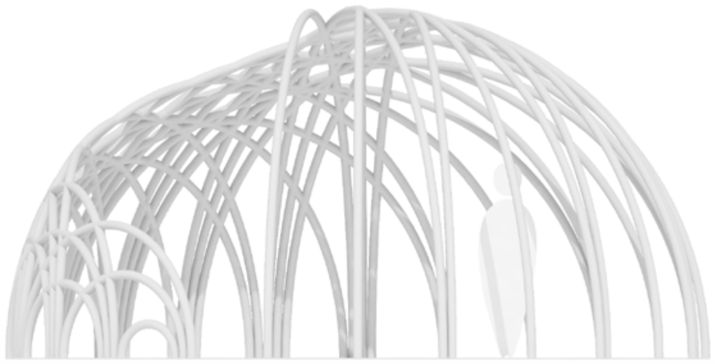


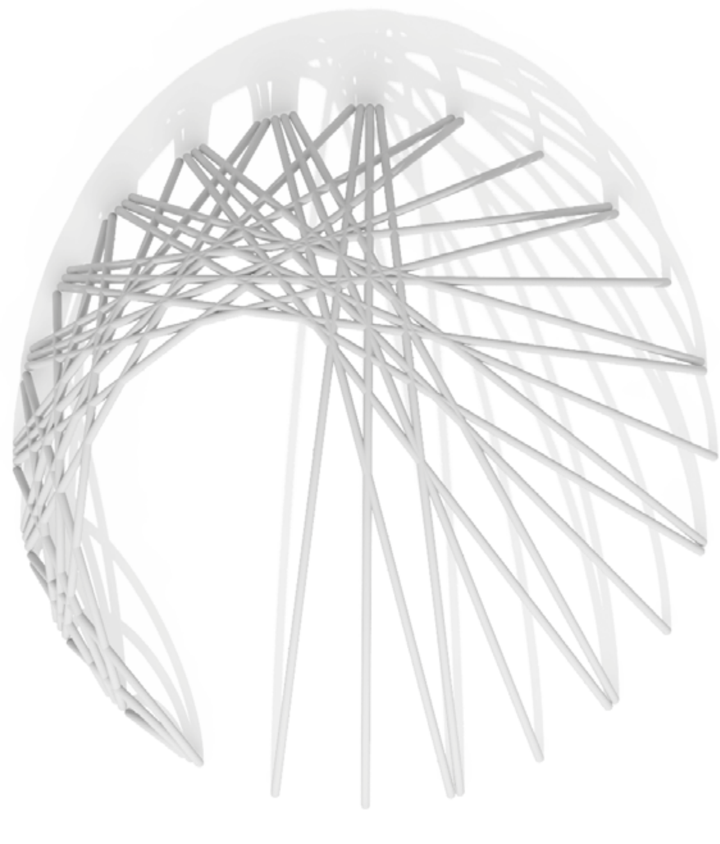
open/
c l o s e d
81% / 19%



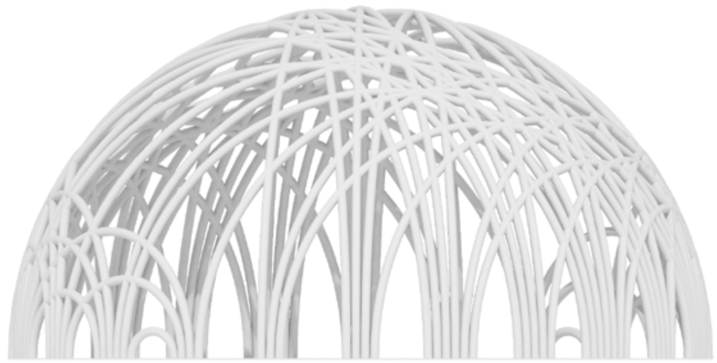


open/
c l o s e d
64% / 36%





open/
c l o s e d
72% / 28%

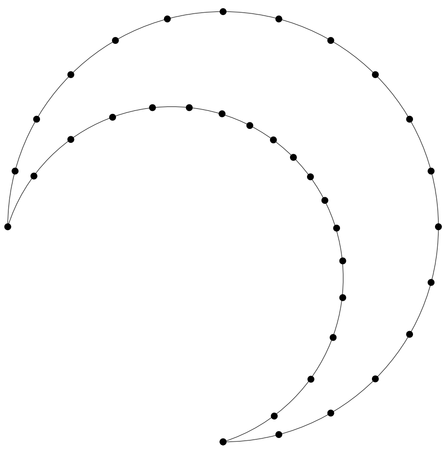


open/
c l o s e d
51% / 49%

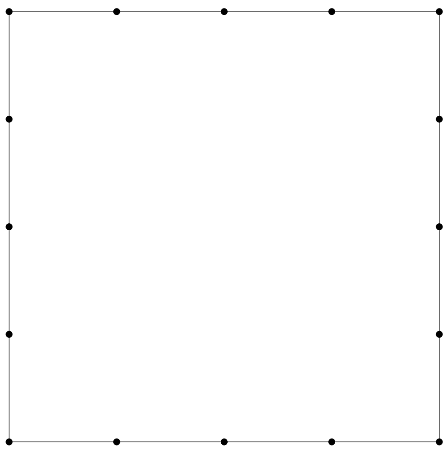

MODEL
bamboo
1:50

TESTING THE BOUNDARY

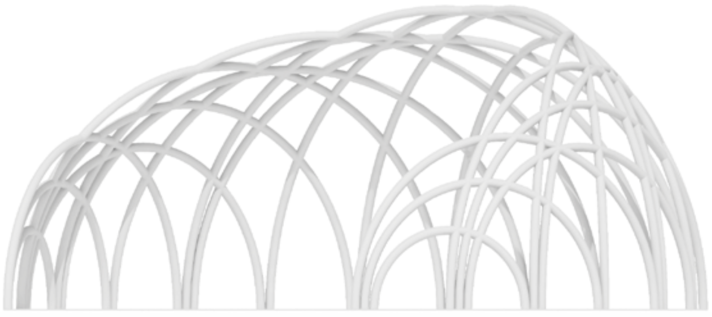
In the following pages, the three different iterations of systems for enclosing space developed in previous experiments are tested on new boundary shapes. The systems have previously only been tested on convex curves, the crescent boundary tests them with a concave side. The square tests the systems on a boundary shape that is very common in urban environments.

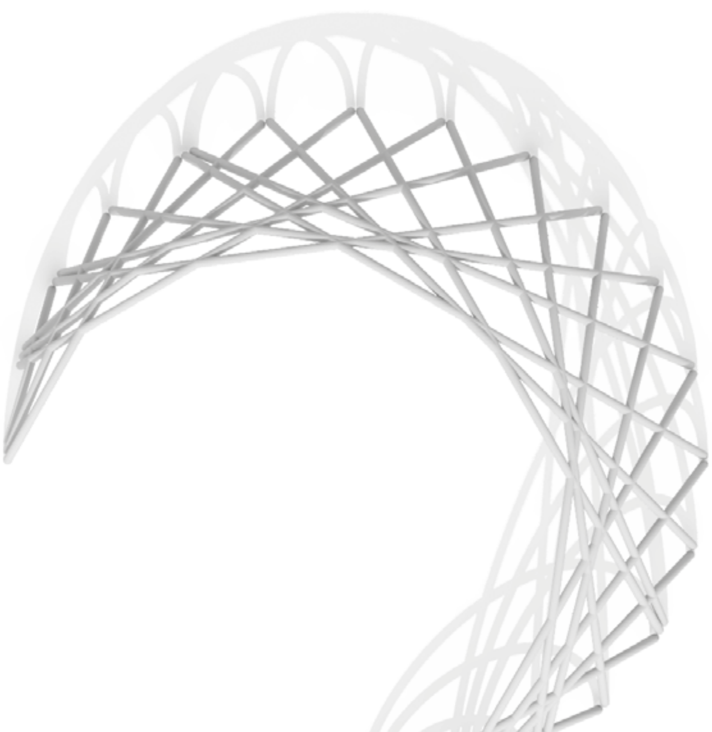


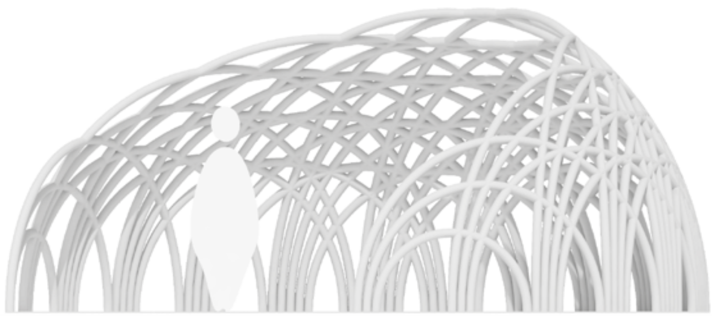
BOUNDARY
ANCHOR POINTS

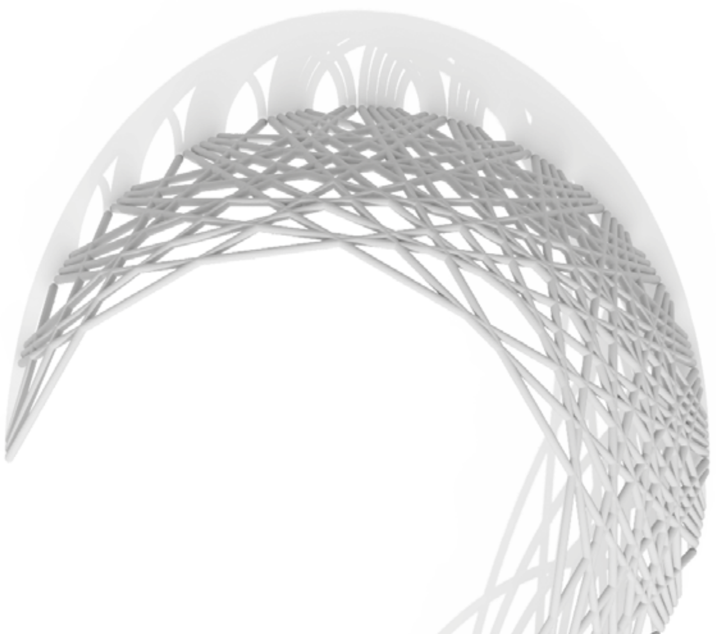


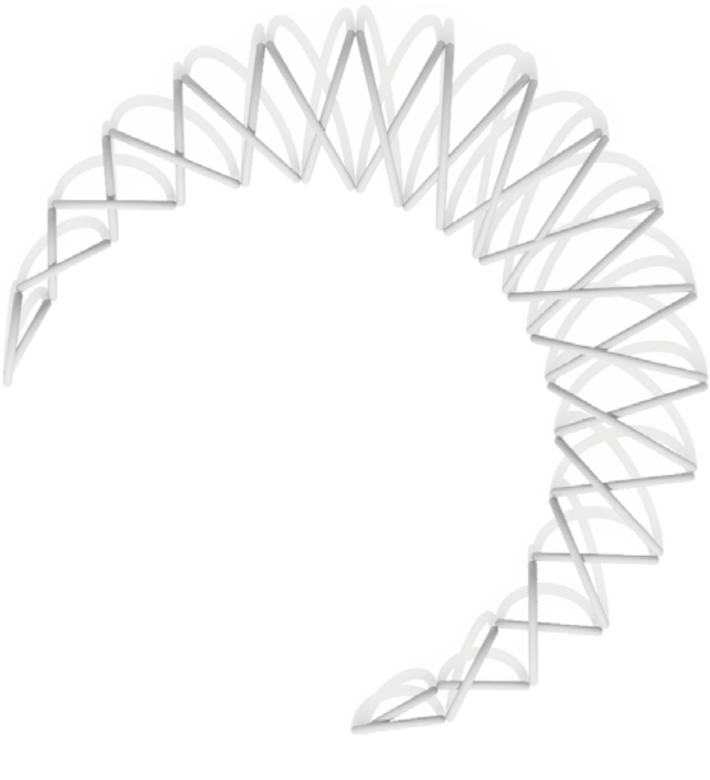
BOUNDARY
ANCHOR POINTS

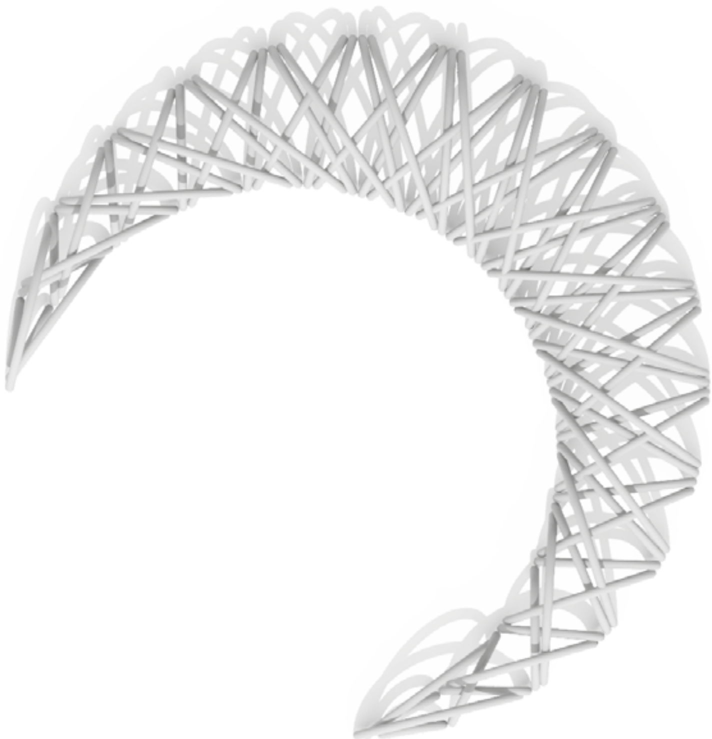


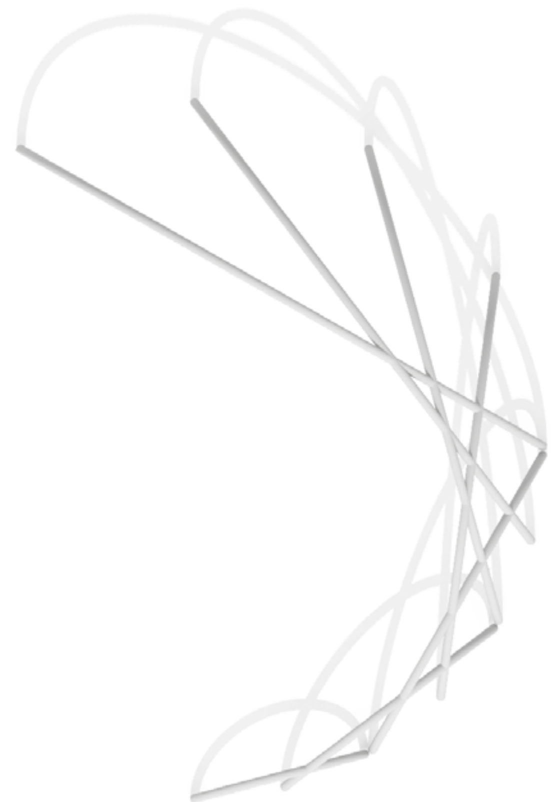


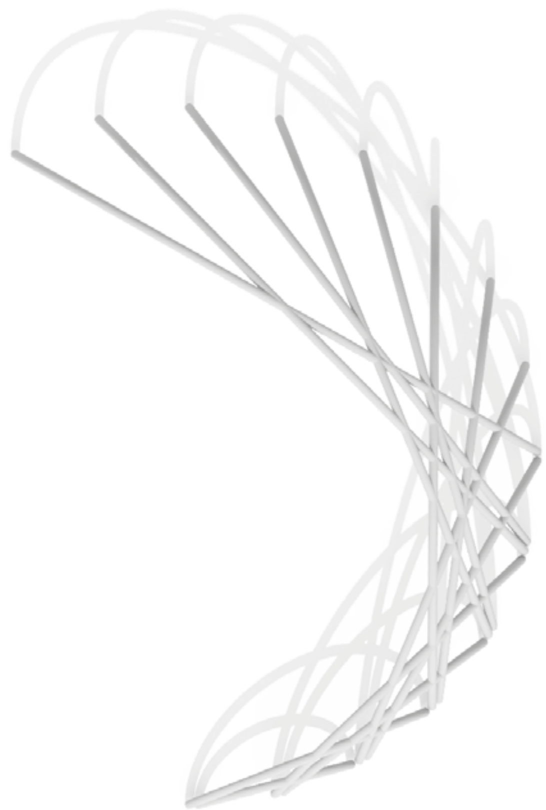


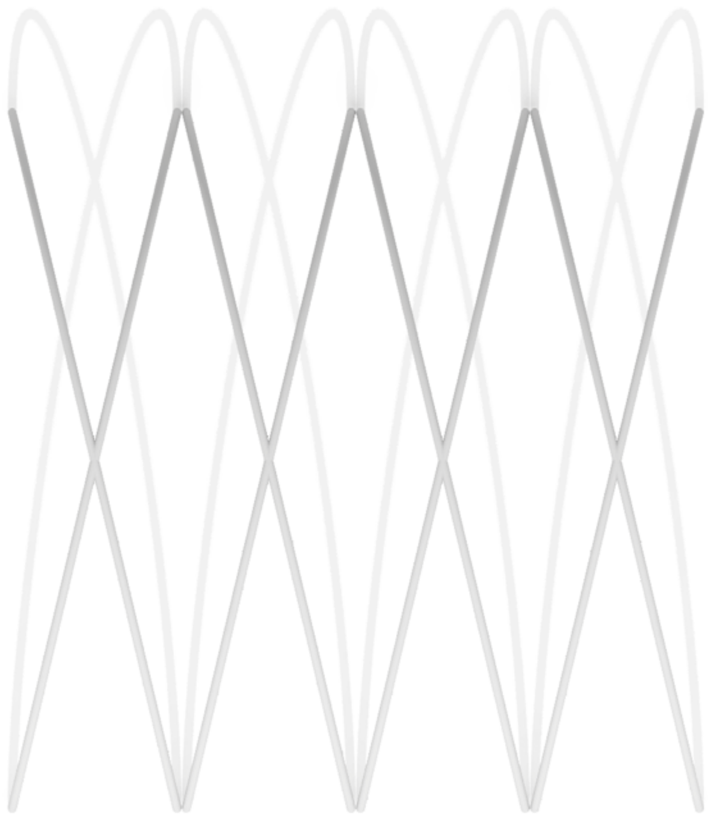


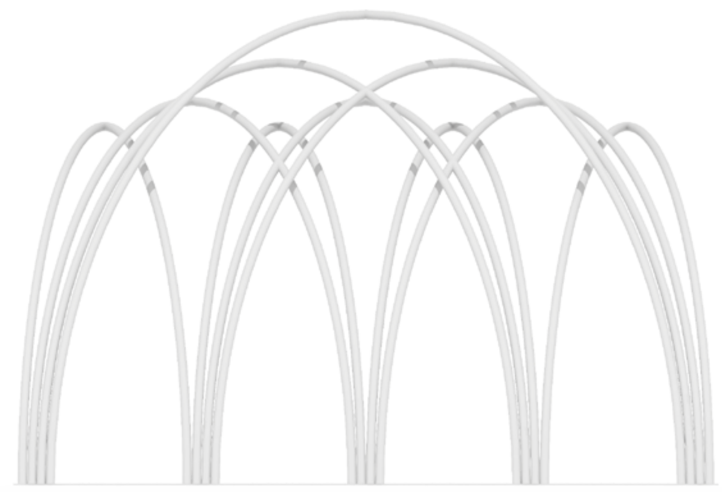


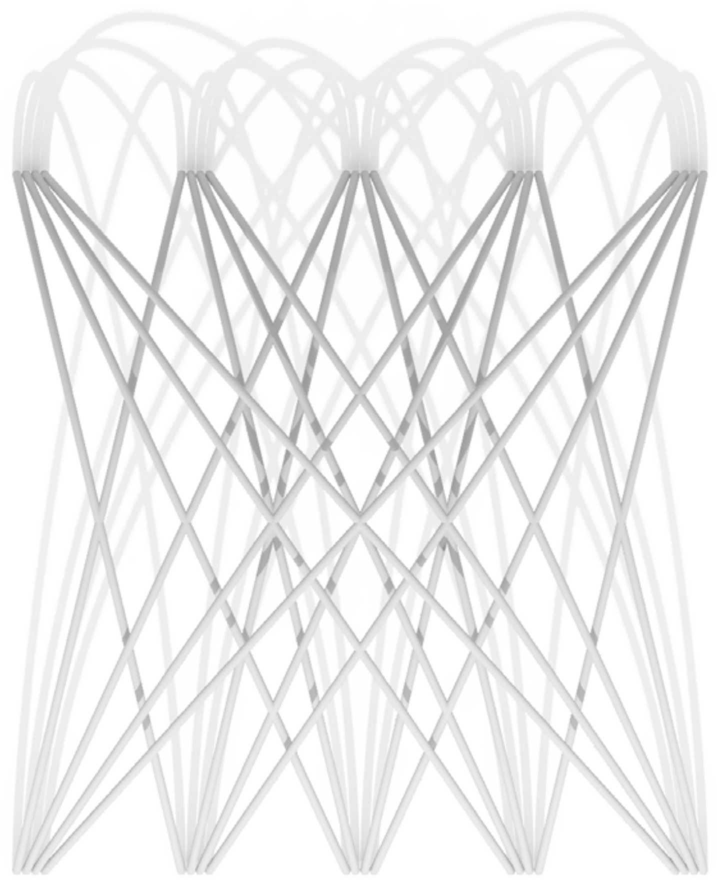


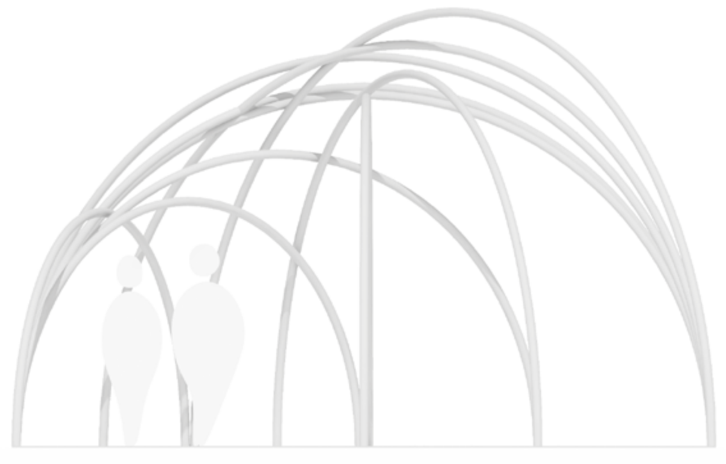


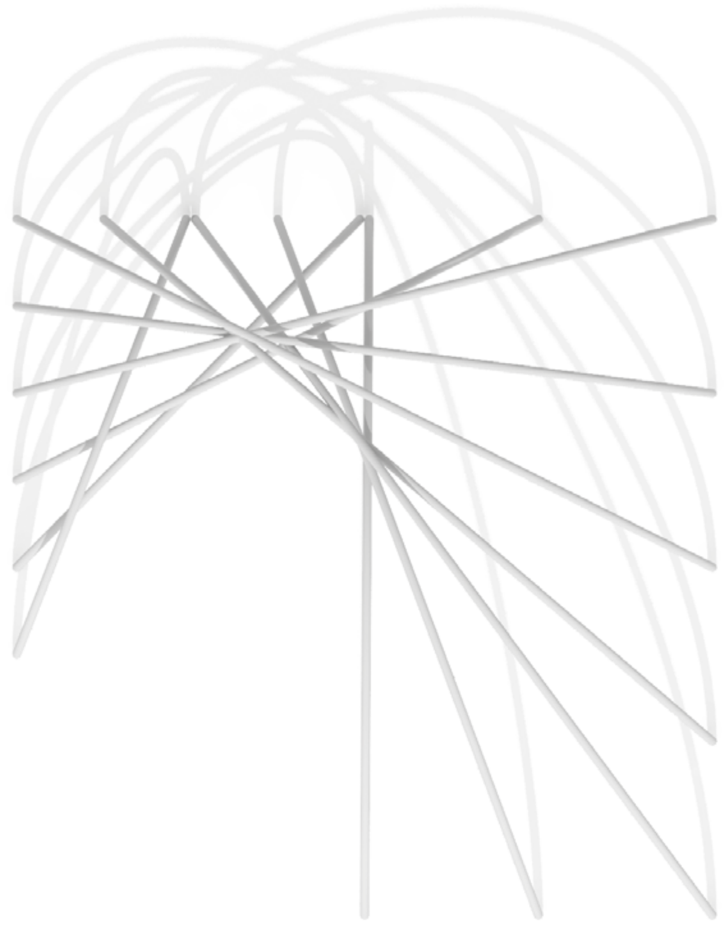


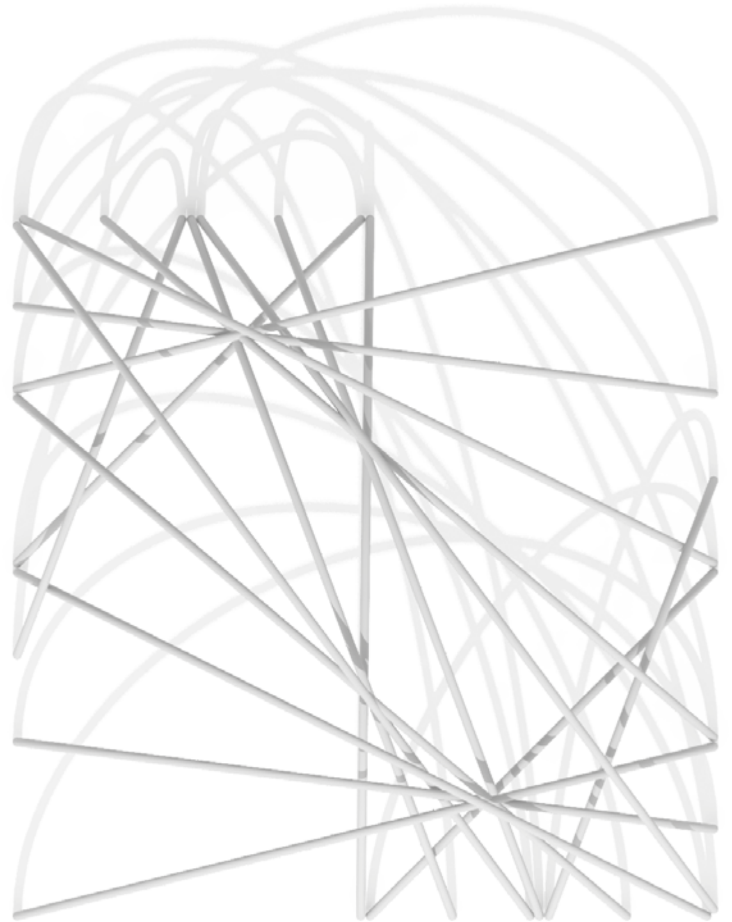








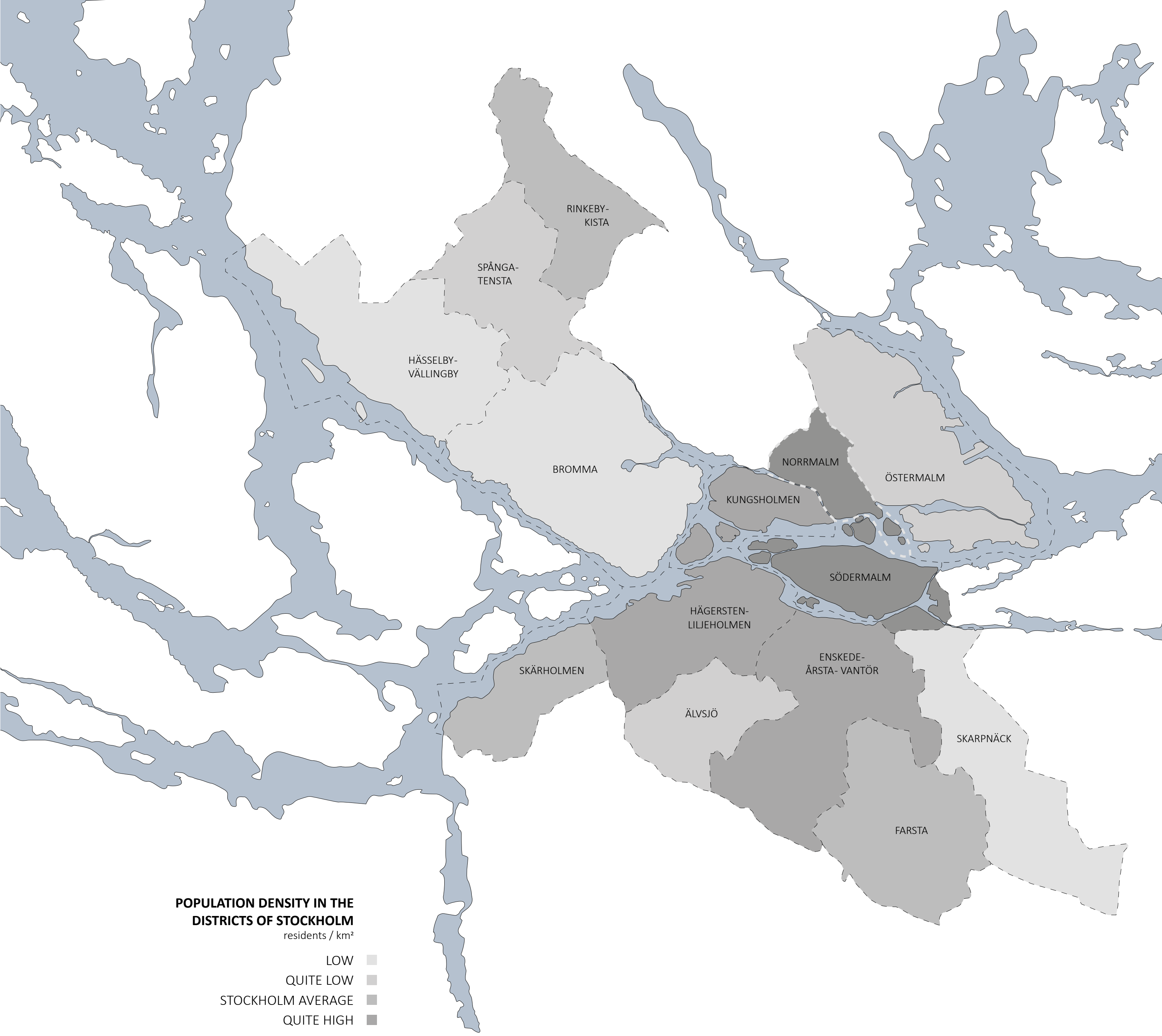




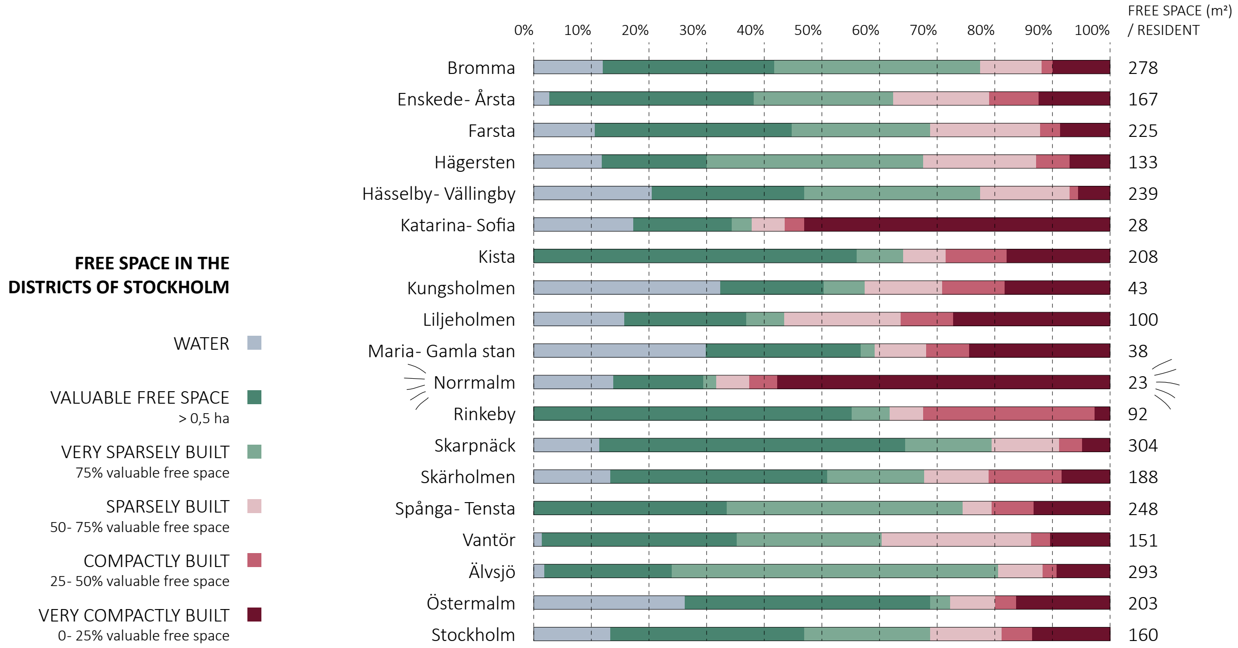
Orthophoto Stockholm
(Stockholms Stadsbyggnadskontor, 2017)

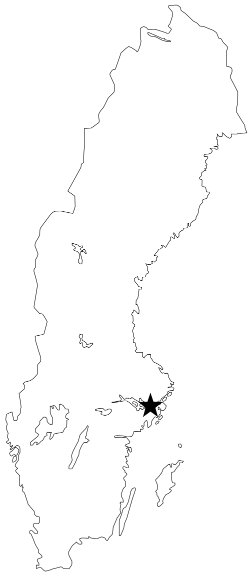
CHOOSING A SITE

POPULATION DENSITY IN THE DISTRICTS OF STOCKHOLM



FREE SPACE IN THE DISTRICTS OF STOCKHOLM



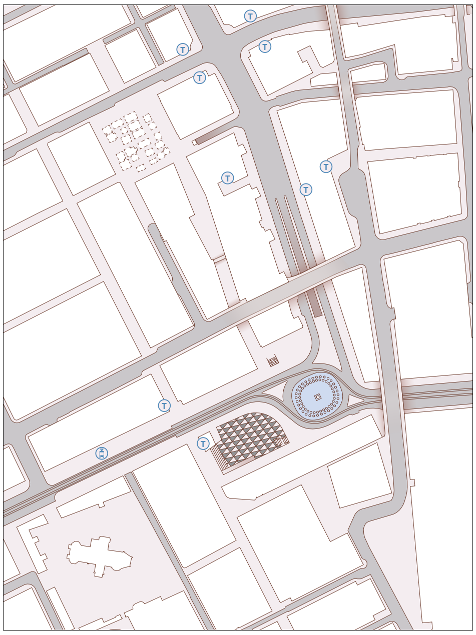


CITY CONTEXT

The strategy for selecting a site is based on a number of criteria that aims to identify urban areas that are in the risk zone of being affected by the urban heat island effect. The site has to be located in a city district that is both densely populated and compactly built which indicates that the built environment in the district is very effective at absorbing heat and warming up the microclimate. The lack of large amounts of green infrastructure is an indication that the temperature regulating ecosystem services that could help mitigate the urban heat island effect need to be strengthened.

A district in Stockholm that matches all of the above criteria is Norrmalm which is located right in the centre of the city. On the following spread, the centre of the district is presented in an analysis to help find a public space that is suitable for a temperature regulating intervention and to also help understand the local context of the site.

The figures on the opposite page are based on data from Befolkning 7 åldersklasser and Sociotopkarta Norrmalm, Stockholms stad, 2004

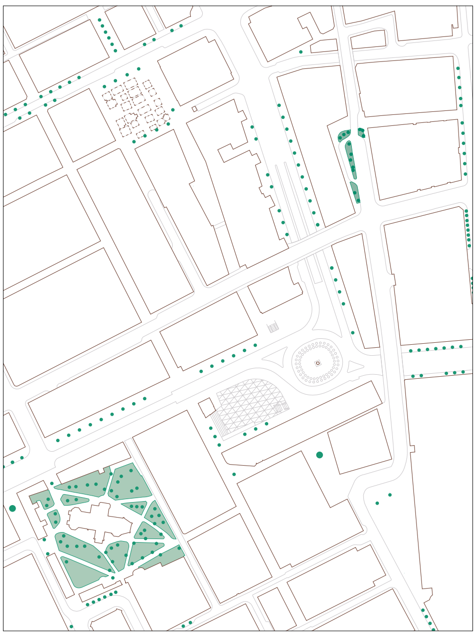


pedestrian traffic · vehicle traffic · metro · tram

COMMUNICATIONS

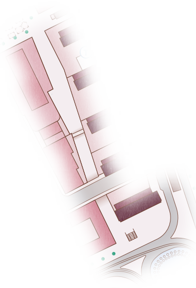
building height · market stall

BUILDINGS



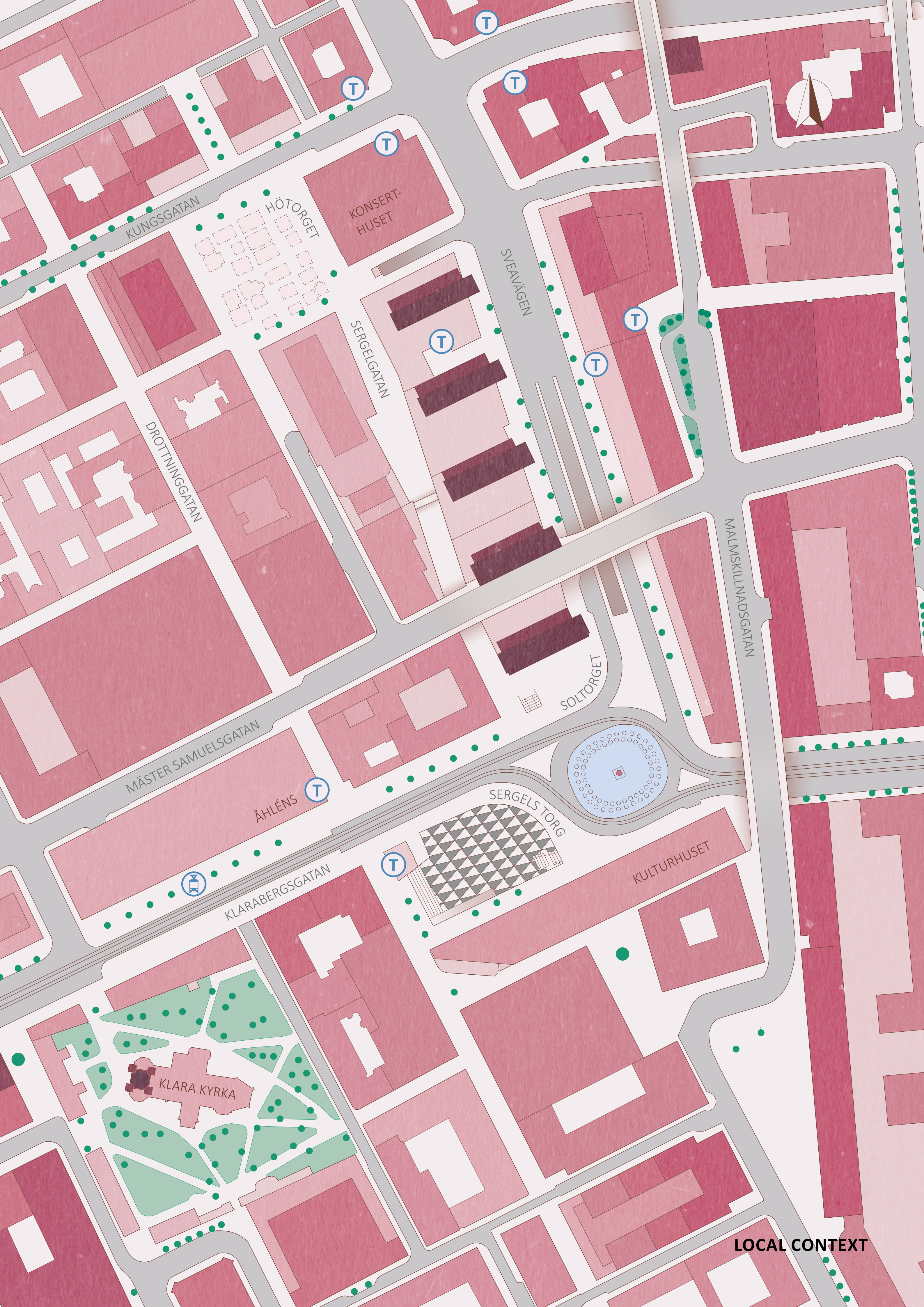
park · tree · grassed traffic island

GREEN INFRASTRUCTURE



SITE

The site is located in the commercial centre of Stockholm. Both Sergelgatan and Soltorget are free of car traffic. The varied conditions of the site give an opportunity to test the flexibility of my structural system.



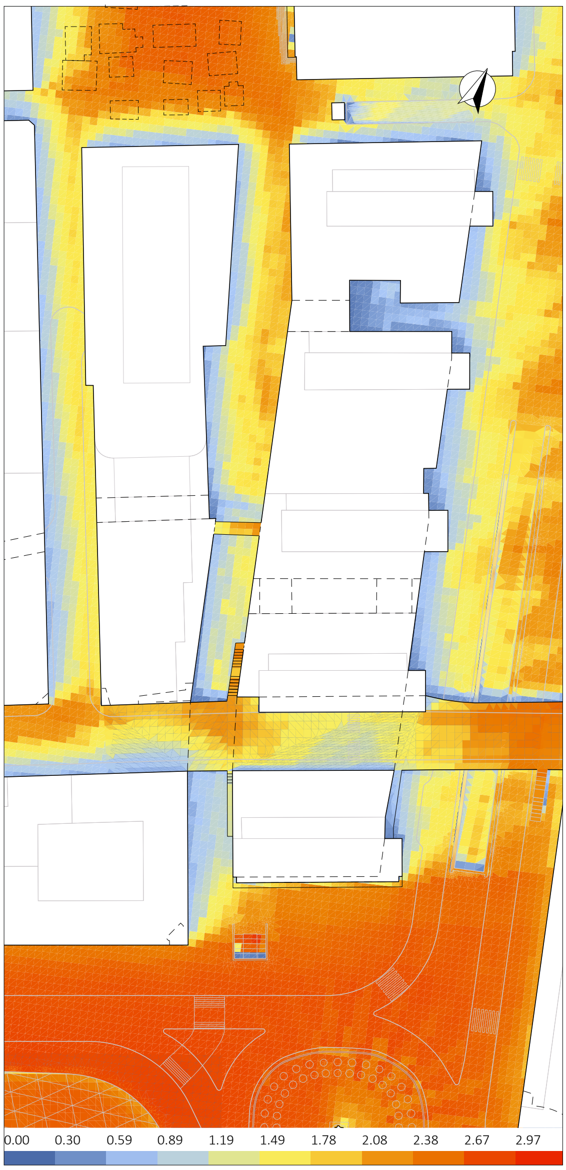
LOCAL CONTEXT

APPLYING THE SYSTEM ON URBAN GEOMETRY

SOLAR ANALYSIS *before*

SHADOWS

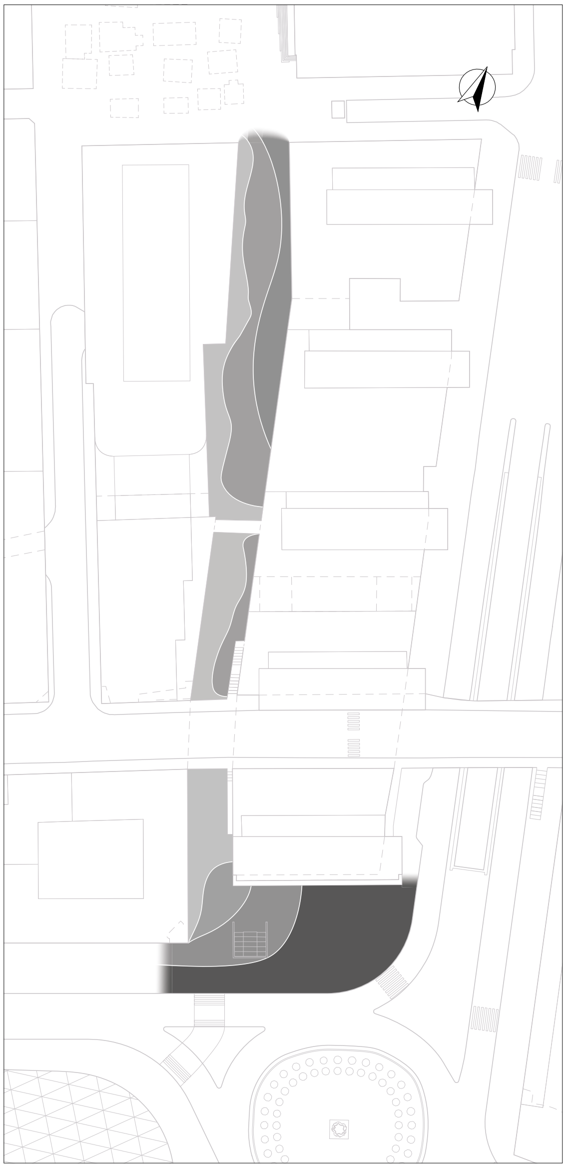
summer solstice 11 a.m. to 15 p.m.



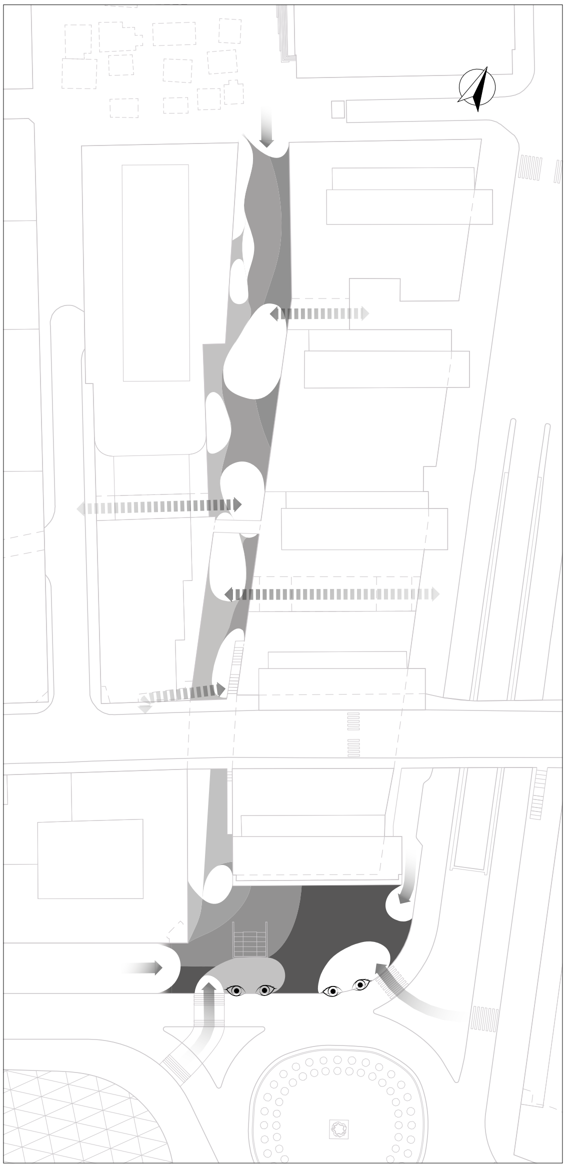
SOLAR RADIATION kWh/m²

summer solstice 11 a.m. to 15 p.m.

BOUNDARY
ANCHOR POINTS



PATTERN CONCENTRATION
based on solar analysis

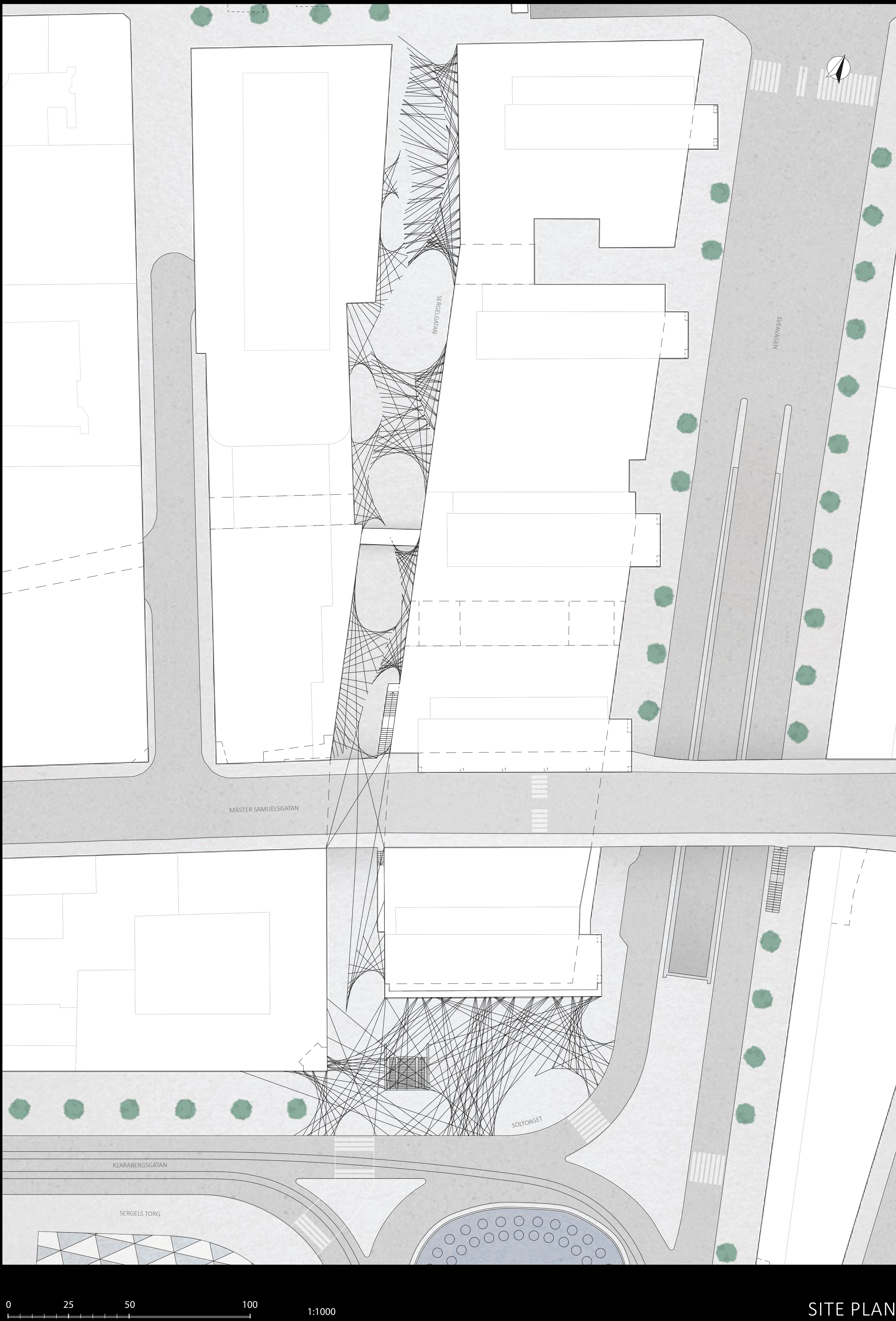


OPENINGS

views and connections

DEFINING
THE STRUCTURE

The boundary for the structure is based on the geometry of the surrounding built environment which includes the roofs of surrounding buildings, edges of sidewalks and also the edges of the staircase on the square that leads down to Sergels torg and the metro. Most of the anchor points are distributed along the roofs of the surrounding buildings. The anchor points for parts of the structure that don't connect to the roof of a neighbouring building are located on the ground. Arcs are either added for shading or for shape-making which means that not all of the available anchor points are used.
The structure gives different levels of shading according to the solar analysis of the site. Openings in the structure at all the entrances to the site to give contact with the sky in places where a lot of people would gather. On the square, the view towards the fountain is framed.



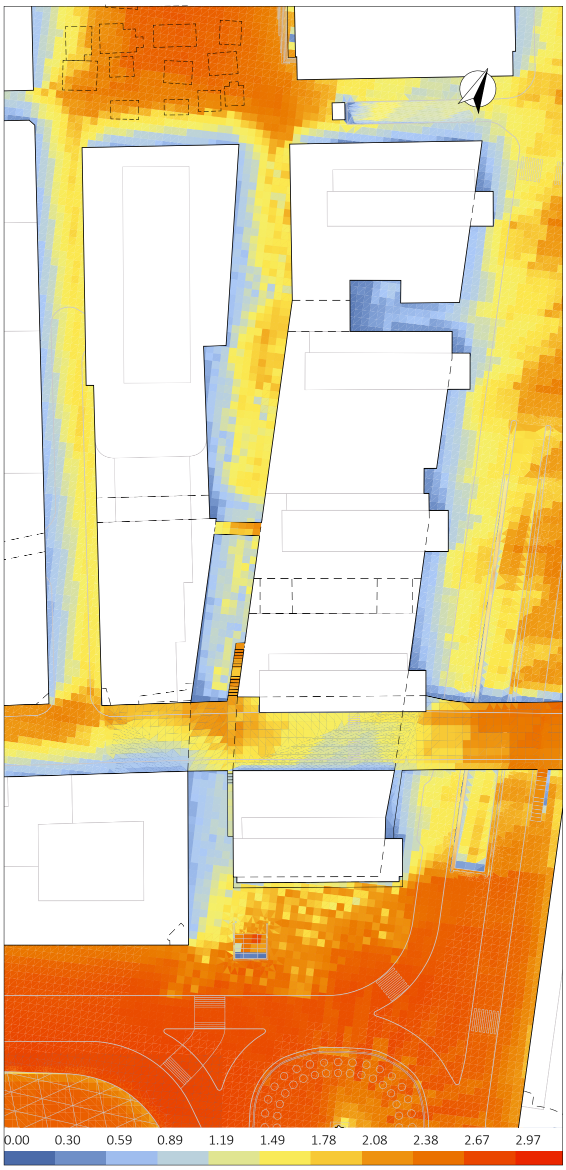
SERGELGATAN
SVEAVÄGEN
MÄSTER SAMUELSGATAN
SOLTORGET
KLARABERGSGATAN
SERGELS TORG
0
25
50
100
1:1000

SITE PLAN

SOLAR ANALYSIS *after*

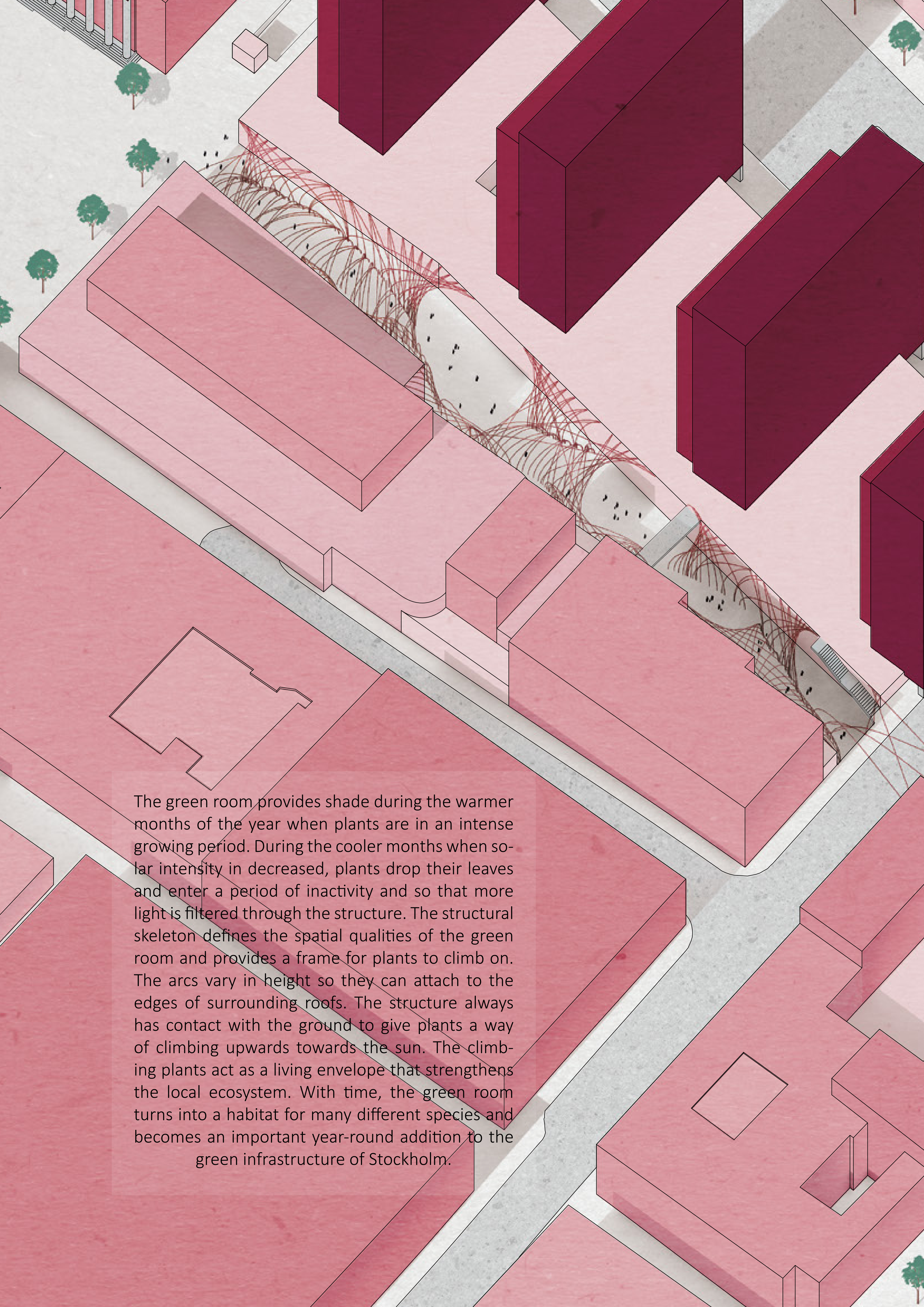
SHADOWS

summer solstice 11 a.m. to 15 p.m.

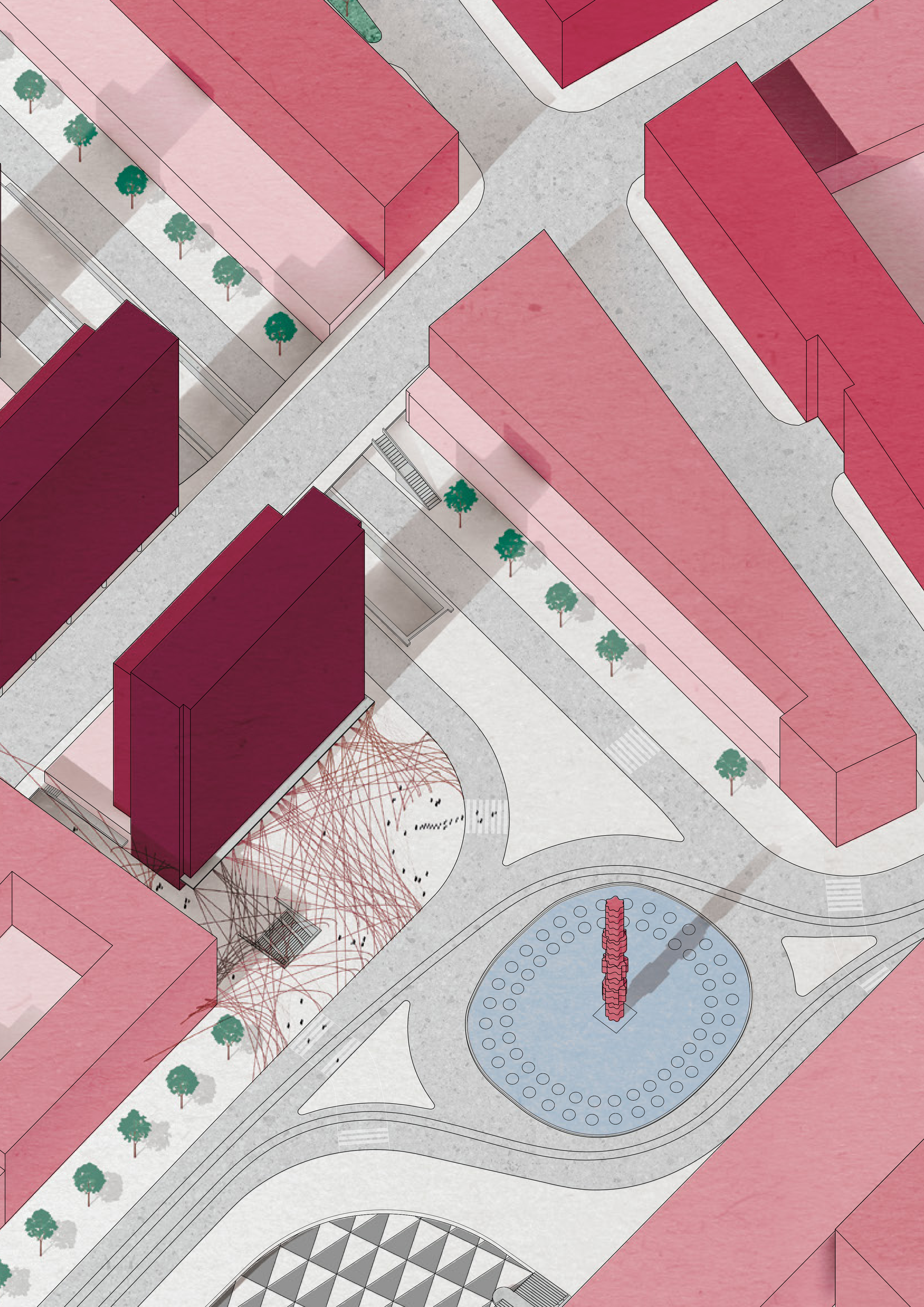


SOLAR RADIATION kWh/m²

summer solstice 11 a.m. to 15 p.m.



The green room provides shade during the warmer months of the year when plants are in an intense growing period. During the cooler months when solar intensity in decreased, plants drop their leaves and enter a period of inactivity and so that more light is filtered through the structure. The structural skeleton defines the spatial qualities of the green room and provides a frame for plants to climb on. The arcs vary in height so they can attach to the edges of surrounding roofs. The structure always has contact with the ground to give plants a way of climbing upwards towards the sun. The climbing plants act as a living envelope that strengthens the local ecosystem. With time, the green room turns into a habitat for many different species and becomes an important year-round addition to the green infrastructure of Stockholm.



DISCUSSION

Through my literature studies, I have found that extensive periods of high heat can pose a serious threat to the lives of vulnerable groups living in cities. The ongoing warming of our climate means we have to prepare for new extreme summer temperatures. The built environment in Sweden is designed for a cool climate and the people living here are not used to extreme heat which is why it is so important to adapt our cities to a warmer future.

I have learned that nature has the potential of solving several issues related to climate change. However, the scarcity of vacant plots in our ever-expanding cities has made green spaces into a commodity too profitable not to build on. These two factors have led me to my research problem of introducing more greenery into urban environments without taking up extra space.

Starting the process of defining the structural system of the green room with the basic goal of enclosed space gave me the chance to shape the logic of the structural system from the bottom up. During the experimentation process, I learned how to control the different parameters of my structural system to achieve different results. Allowing myself to trust the research by design strategy led me to new discoveries that I couldn’t have come to using any other method.

The resulting structure doesn’t just solve the issue of shading but is also an addition to the green infrastructure of Stockholm. When looking for solutions to the consequences of climate change, instead of just focusing on fixing the symptom, I believe it is important to understand and address the bigger picture.

In this thesis, I have solely focused on finding solutions for increasing summer temperatures as one negative consequence of climate change. The issue of extreme heat is only relevant during a limited time of the year, however, nature provides us with many different ecosystem services all year round. Living outdoor green rooms can be seen as a new type of green infrastructure that has the potential to mitigate a number of urban problems such as flooding, problematic wind microclimates as well as noise and air pollution. Living outdoor green rooms also have the potential for providing cities with locally produced fruit and vegetables while at the same time bringing us closer to nature.

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REFERENCE PROJECTS

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TETSUNORI KAWANA
Reincarnation

(Flickr.com user "Nicolás Boullosa", 2016) CC BY 2.0

BAUBOTANIK
Plane-Tree-Cube

(Flickr.com user "the real janelle", 2006) CC BY 2.0

nARCHITECTS
Canopy

(Movez, 2010) CC BY-SA 3.0

MARCO CASAGRANDE
Bugdome

(Härmägeddon, 2012) CC0 1.0

MARCO CASAGRANDE
Sandworm

IMAGE REFERENCES

Flickr.com user "Bosc d'Anjou" (2017). *Reincarnation* [Electronic image]. Retrieved from: https://www.flickr.com/photos/boscdanjou/37598769625

Härmägeddon (2012). *Sandworm by Marco Casagrande @ Wenduine, Belgium* [Electronic image]. Retrieved from: https://upload.wikimedia.org/wikipedia/commons/7/73/Sandworm_by_Marco_Casagrande_%40_Wenduine%2C_Belgium.jpg

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