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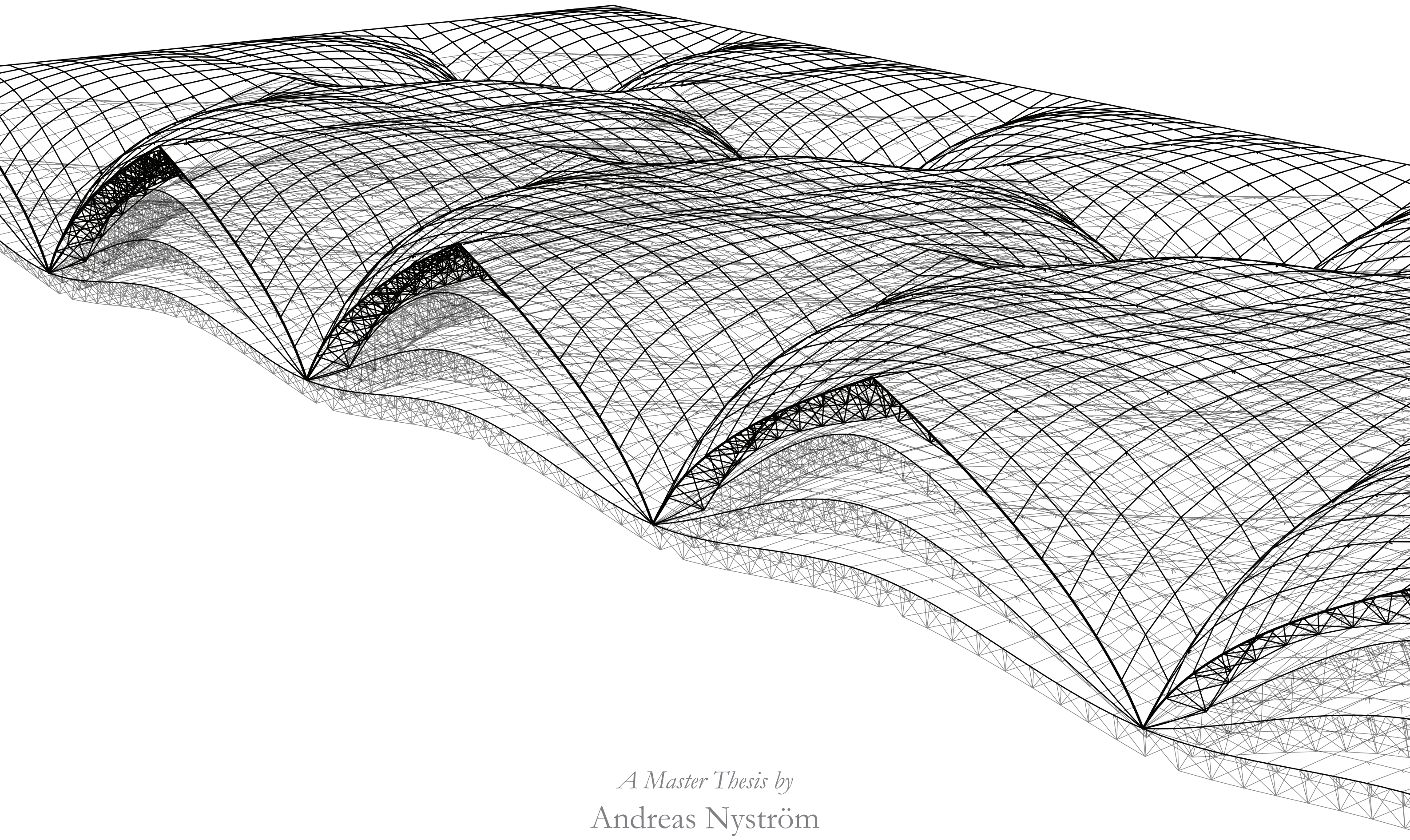
KINETIC ARCHITECTURE AS MEANS FOR RESPONSIVE ENVIRONMENTS FOR PUBLIC SPACES.



A Master Thesis by
Andreas Nyström

Chalmers School of Architecture
Department of Architecture and Civil Engineering
Examiner: Jonas Lundberg
Supervisor: Kengo Skorick

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CHALMERS
UNIVERSITY OF TECHNOLOGY

ANDREAS NYSTRÖM

Master Thesis Spring 2020

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Content

Abstract

Kinetic architecture can be found to some degree in almost every building today. From automatic doors opening when you approach them, to automatic ventilation and sun shading systems. Even regular doors and windows that can be opened could be considered kinetic architecture, using mechanics to change and adapt the building. In most cases it is used as an addition to the building, a dynamic layer of kinetics added to a static structure. Quite rarely it is used in the structure and architecture itself, making it possible to transform the entire structure.

This thesis explores the use of a kinetic structure in a public urban setting and how the use of a dynamic structure transforms the space. With the purpose to test the advantages or disadvantages of a kinetic structure and how it can transform public urban spaces. By exploring different scenarios of the interaction between people and a responsive structure that can adapt and transform.

This thesis also explores a structural system that is very flexible and dynamic with the ability to completely transform the public urban space.

Conceptual design is used to develop ideas of different ways to interact with public spaces and an architecture that can adapt to transform the space. This results in ideas of a responsive structure that can transform with people's direct interaction or adapt over time. The conceptual design is investigated by creating scenarios of how the structure can directly respond to the users as well as adapting over time.

Student Background

Andreas Nyström

Education

2014-2017

B.Sc Architecture and Engineering - Chalmers University of Technology

2018-2020

M.Sc in Architecture and Urban Design - Chalmers University of Technology

Matter, Space, Structure 1

Design & Communication Tools

Future Visions for Healthcare, Housing and Work 2: Housing Inventions

Matter, Space, Structure 3

Practice

2017-2018

Arkcon Byggkonsulter, Borås

Questions & Delimitations

How can a typically urban static space, be designed to be completely dynamic and transforming based on people's behaviour and interaction using systems of kinetic architecture?

This thesis aims at investigating how a typical static urban space can be transformed into a dynamic space using concepts of kinetic architecture. By proposing a concept of a structure that can transform itself and by that also change how the space is used. Exploring how the space can be transformed based on different scenarios to fit several functions.

To what extents can the user experience be understood through schematic scenario-planning of responsive public spaces?

The thesis explores how a structurally dynamic space can be used to match the dynamic use of the space itself. It regards this from a perspective with the interaction between the structure and user in focus. To investigate if the use of the space can be made more efficient and usable using kinetic architecture by exploring different scenarios were the structure is responding to the people using the space and transforming thereafter.

Delimitations

The focus of this thesis is on how a kinetic structure can be used and applied to a typical public urban square. The application of the system is by that meaning the main area of investigation in the design process of this project. To be able to show how the structure can transform and to decide its limitations, the mechanical system is designed to a certain degree. Ideas of each element and mechanisms in the system is shown, but they are not fully tested or designed to every detail.

By working with structures that transforms based on how the space is used, the work is focusing on the systems reactions and how people can benefit from a dynamic space. Without involving real people or physical system in full scale, this is done through scenario development. With the aim to investigate how the system will react and enhance the use of the space, the system is exposed to several alternate scenarios.

Background

"Since the time of early man, architecture has been, in essence, static. Structures were built to last, the criteria being the longer a building last, the better it was. By analogy to biological evolution, architecture has been at a low evolutionary level, with little or no adaption potential as is found in higher biological or technological developments. However, certain exceptions occur historically in this pattern of staticism which indicate a definite evolution to kinetics."

Clark & Zuk, 1970

Kinetic Architecture

The traditional way of constructing buildings is to make them last and the longer they last, the better. This has been achieved by developing structural systems and using materials that will improve the buildings lifetime. We can almost assume today that most buildings will always stand until they are rebuilt or demolished. By this architecture can sometimes be referred to as the permanent expression of its time. Everything surrounding the building and the society will change, but the building will still be there.

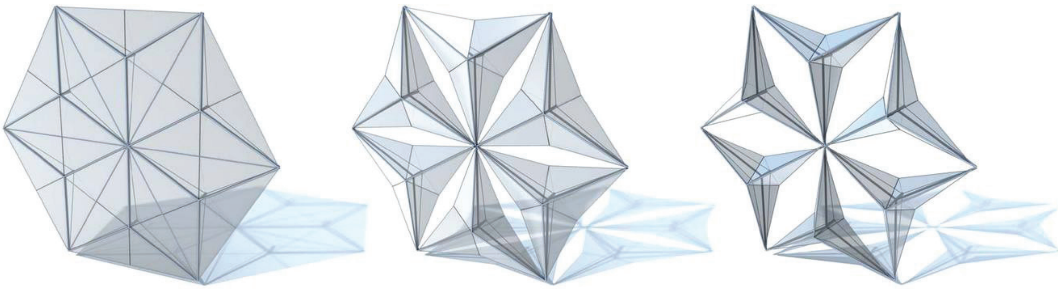
The result of this has been a very static architecture with buildings built for one purpose and dimensioned accordingly. However, the way a building is used can be very dynamic and the demands we have on them can change. For example, most office buildings are only used during certain hours and public areas can be flooded with people during a couple of hours and then be completely empty hours later.

In the seventies William Zuk and Roger H. Clark presented the concept of kinetic architecture in their book Kinetic Architecture. They state that primitive forms were quite simple and emerged as a direct response to extremely limited needs and how this does not work today, with a society that constantly changes. We design buildings to be monuments and architects become monument builders. However, they are not directly against this approach, but they predict a change occurring with more dynamic and adaptable structures using kinetic systems in some degree. In this way Zuk and Clark proposed a new idea and concept of architecture that would reject the perception that architecture is static.

Kinetic Architecture in History

The earliest example of kinetic architecture can be found in the early days of our history when mankind used logs and movable stones to cover openings. Looking at how kinetic architecture is mostly used today, almost nothing has changed. We use kinetic components to open and close openings, doors and windows. There have been some exceptions were the kinetics has been taken to another level and many of them started to appear during the 18th and 19th century. The dining room table of the Palace of Versailles is one famous example, with its table that lowered down to the servants who set the table and then rise it back up again (Clark & Zuk, 1970).

In some areas kinetic systems is used quite frequently, for example in theatre design with curtains and stages that can transform. Elevators that were introduced in 1853 by Elisha Otis (Clark & Zuk, 1970) is also one common example of kinetics used in architecture. The use of kinetics has not changed too much until today, one more recent example is dynamic façade systems. Automated sun-shading systems protecting buildings from sunlight and heat.



1 The facade system of Al Bahar Towers in Abu Dhabi by Aedas Architects. One recent use of kinetic architecture with a triangular pattern opening and closing to protect the buildings indoor climate from the sunlight. A modern example of using kinetic components in architecture.

Concepts of Kinetic Architecture

The concept of kinetic architecture was first introduced in 1970 by William Zuk and Roger H. Clark. Following are interpretations of the eight concepts of kinetic architecture formed by them.

1. Kinetically Controlled Static Structures

To some degree all buildings and structures move, they are affected by different forces such as weather loads, vibration or heat. Wind can have a serious impact on tall buildings and large span suspension bridges. Making a tall building deform and move with the wind back and forth, or making a suspension bridge moving with both wind as well as heat. Newer construction methods and materials makes structures move more than older massive masonry buildings.

Controlling moving structures can be made using principles of kinetics to make buildings more static. A principle of this was introduced in 1960s by Eugene Freyssinet, the idea is to cancel out the movement of the structure by a counteracting force.

This is how our human bodies function all the time when moving our legs and arms. For example an arm or a leg can be seen as a cantilever beam that is always counteracting the forces put on them.

2. Dynamically Self-erecting Structures

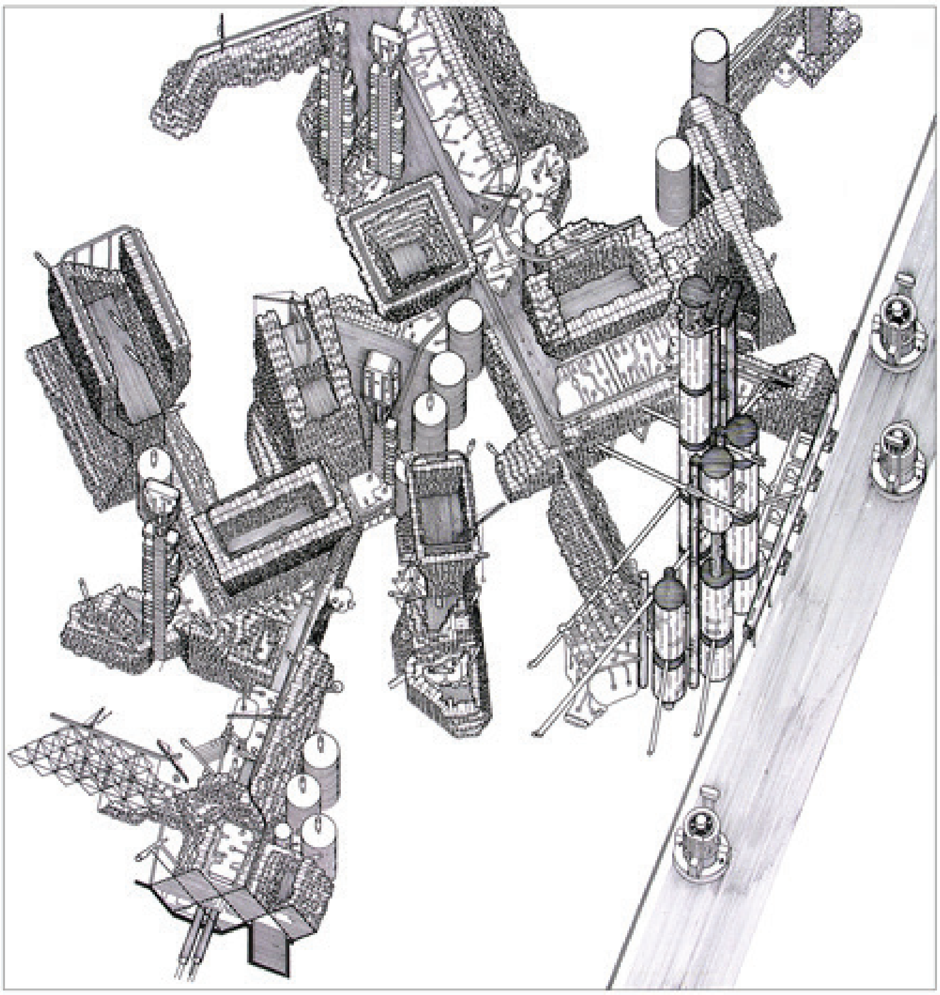
The most common and traditional way of forming a building is by stacking blocks of material until the desired structure is reached. This has mostly been made using stone blocks and in some rare cases the structure has been carved out from rocks. In more recent times structures is built more by assembling pieces and elements together until the structure is finished. A different and more rare approach is a structure that builds itself or raises itself.

There are some examples of that today, like construction cranes that are self-erecting structures and can assemble themselves. It is not quite common with self-erecting buildings, but there are other examples of objects that are self-erecting, such as umbrellas or a roof on a convertible.

3. Kinetic Components

Almost all buildings today feature some type of kinetic architecture and is a necessity in many cases. Most buildings today are built to be very static, but there are almost always some kinetic elements even in a static building. Doors and windows that can be opened can be considered as kinetic architecture and there are also some examples were kinetics has been used in larger elements. An example can be stadium roofs that can open and close or automatic sun shading systems.

The use of kinetics in architecture can be quite simple as a door or quite complex with larger structures moving. It is a more common concept than people might think, one area that has been using kinetics for a long time is theatres. By changing the stage as well as the auditorium itself to adjust the acoustics.



2 Plug-In City by Archigram, Peter Cook 1963. A concept of kinetic architecture by Peter Cook, with modules that “plug-in” to a large structure and cranes moving the units. Making it an example of incremental architecture.

4. Reversible Architecture

Reversible architecture is a quite rare concept and is exactly what it sounds like. An architecture with the ability to reverse the entire building process. A building that can be built and then be dismantled and rebuilt again in the same or another location.

There are some similarities with self-erecting structures, for example both camping tents and construction cranes can be both self-erecting and reversible. The idea of making it reversible takes it one step further with the ability to redo the process several times without damaging the structure. A more different example of this use is modular architecture, with modules being stacked and can then be taken down again. Habitat 67 in Montreal by Moshe Safdie is a housing project made by stacking concrete boxes.

5. Incremental Architecture

The concept of incremental architecture can also be quite similar to reversible architecture. The biggest difference is that in reversible architecture the transformation that takes place is pre-determined and that does not have to be the case with incremental architecture. The transformations that takes place in incremental architecture can be divided into three categories, addition, subtraction and substitution.

Each category is almost self-explanatory, with addition you add to the structure, subtraction you subtract and with substitution parts of the structure can be changed to other parts. There have been some concepts of this idea, two famous examples are The Fun Palace by Cedric Price and Warren Chalk's Capsule Homes.

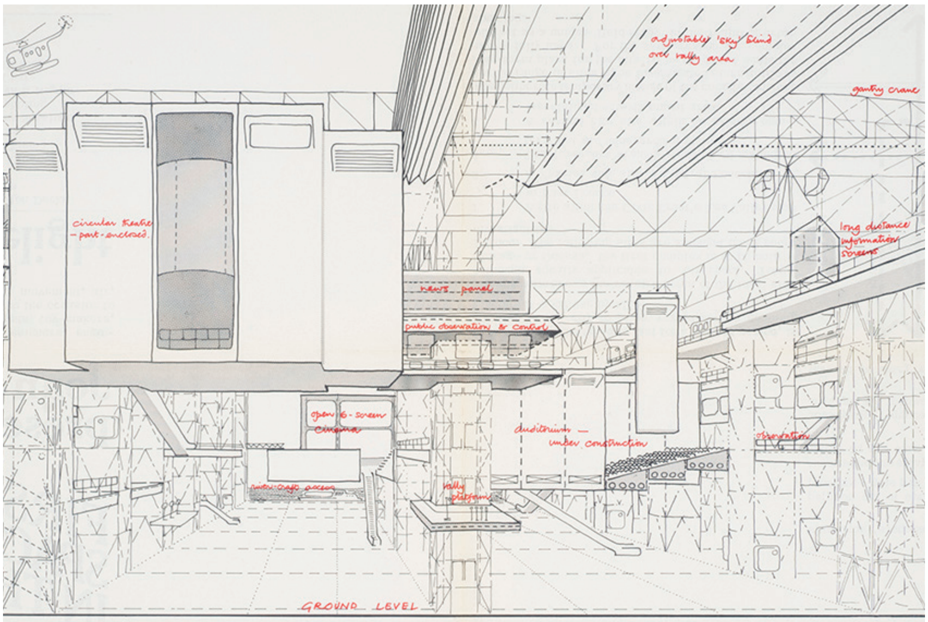
6. Deformable Architecture

The biggest difference from deformable architecture and the previous mentioned concepts is the ability to deform and change without adding, removing or changing parts. An architecture with the ability to deform its actual form and structure within a pre-defined range that limits the structure.

This can be done in two ways, either before the structure is built or after. When the deformation takes place before it cannot be used until the deformation process is completed. This is quite similar to self-erecting structures and is useful during transportation. The other way is to deform the structure after it is built by transforming its shape and structure in some way. In this case the structure can be used both before the transformation and after, perhaps even during the transformation.

7. Mobile Architecture

Mobile architecture is also a very self-explanatory concept, with the ability to move the entire structure. This has been done throughout our history with people moving their homes to find food and water. Today the most used concept of mobile architecture are caravans or other mobile homes. Most common is to transport homes on roads, but there are also other examples of house boats in some cities connected to water.



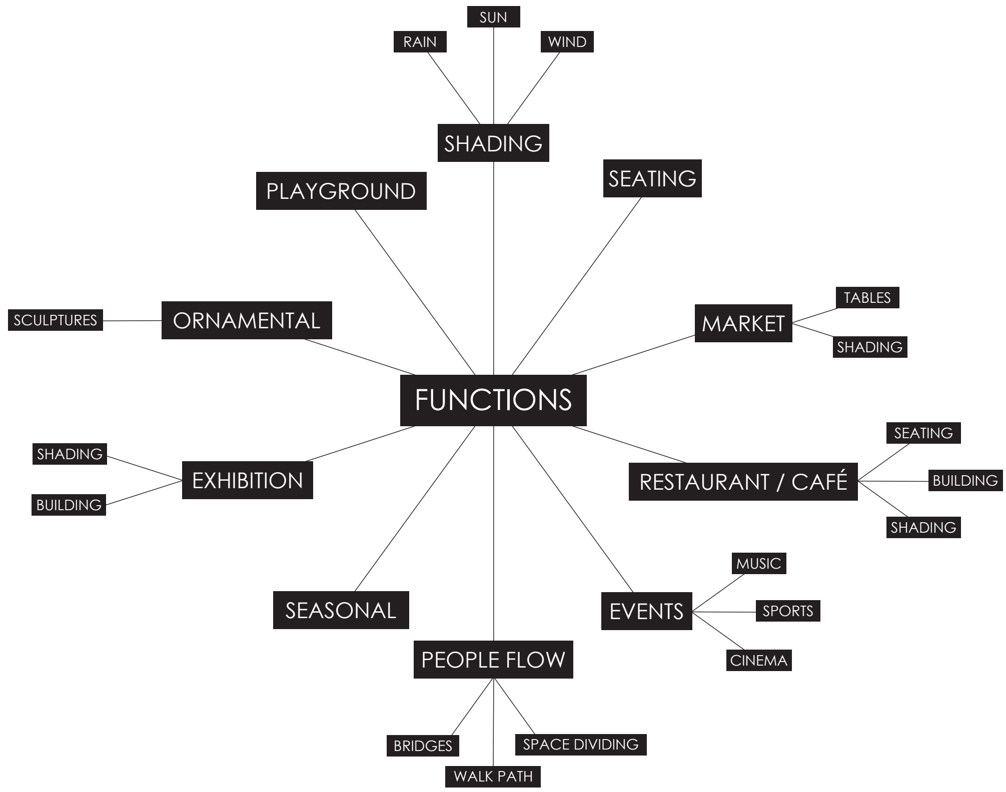
3 The Fun Palace by Cedric Price. A never realized idea of a "laboratory of fun", made by Cedric Price and Joan Littlewood. Using new technology which could make the building interactive to the visitors to adjust after all the activities taking place. The idea is a building with many functions and can therefore adapt after what the visitor wants.

8. Disposable Architecture

One of the most basic principles of kinetic architecture is a structure that is exposed to a set of forces and then responds accordingly. A big challenge when designing kinetic architecture is to predict changes that will occur in the future. In some cases, the architecture cannot fulfil that change and become disposable. Some quite common examples of this can be huts, igloos or shelters.

Everything will eventually become old and disposable and the pace of aging varies between every single object. In architecture there are three things to consider when a building becomes disposable. First, there is the functional aspect with the way a building is used and the demand we put on that building can change. The forces we put on a building and how we use it are dynamic and the structure itself is static. Second, there is the aesthetic aspect that takes place fully in our heads, by changes in fashion and trends. Third, there is physical deterioration when the building will age and deteriorate in its materials and structure. There can also be a fourth category which is economical, but this is also a reason in all previous three categories.

Design Concept

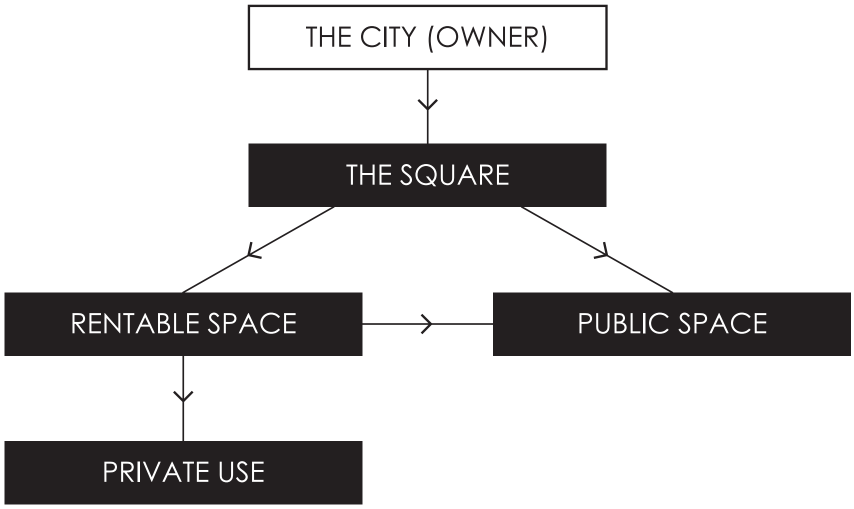


In this concept, kinetic architecture is used to transform regular open public spaces. To adapt after how the space is used with instant reactions and transformations. As well as changing the space into other pre-determined states to create a very flexible and more usable space. Transforming a completely open and flat public square into a building or an arena for sports or other events.

When needed the surface of the space can change its topology to create zones with different use and functions. It could be due to a large temporary people flow and the system could then react and create zones for people in motion. Achieving this by changing its topography in real-time, reacting to people and adapting over time. Making the system both a responsive system, as well as an adaptive system.

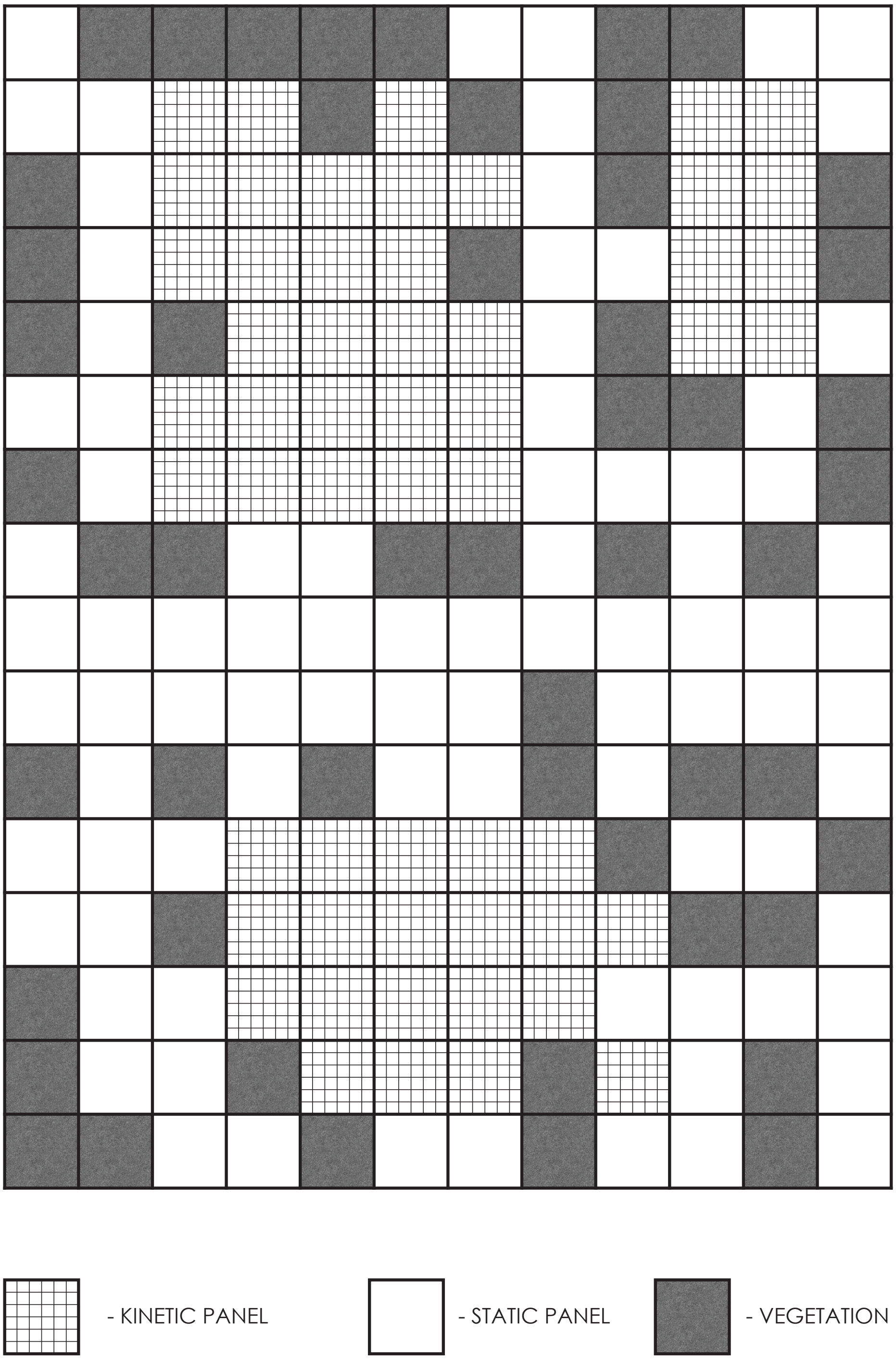
The use for the system will also be to transform the space into pre-determined structures, like entire buildings or stands for events. Making it a self-erecting structure that can take different shapes for different uses. For example temporary events or a temporary building as a space to gather people in the city.

The Public Square

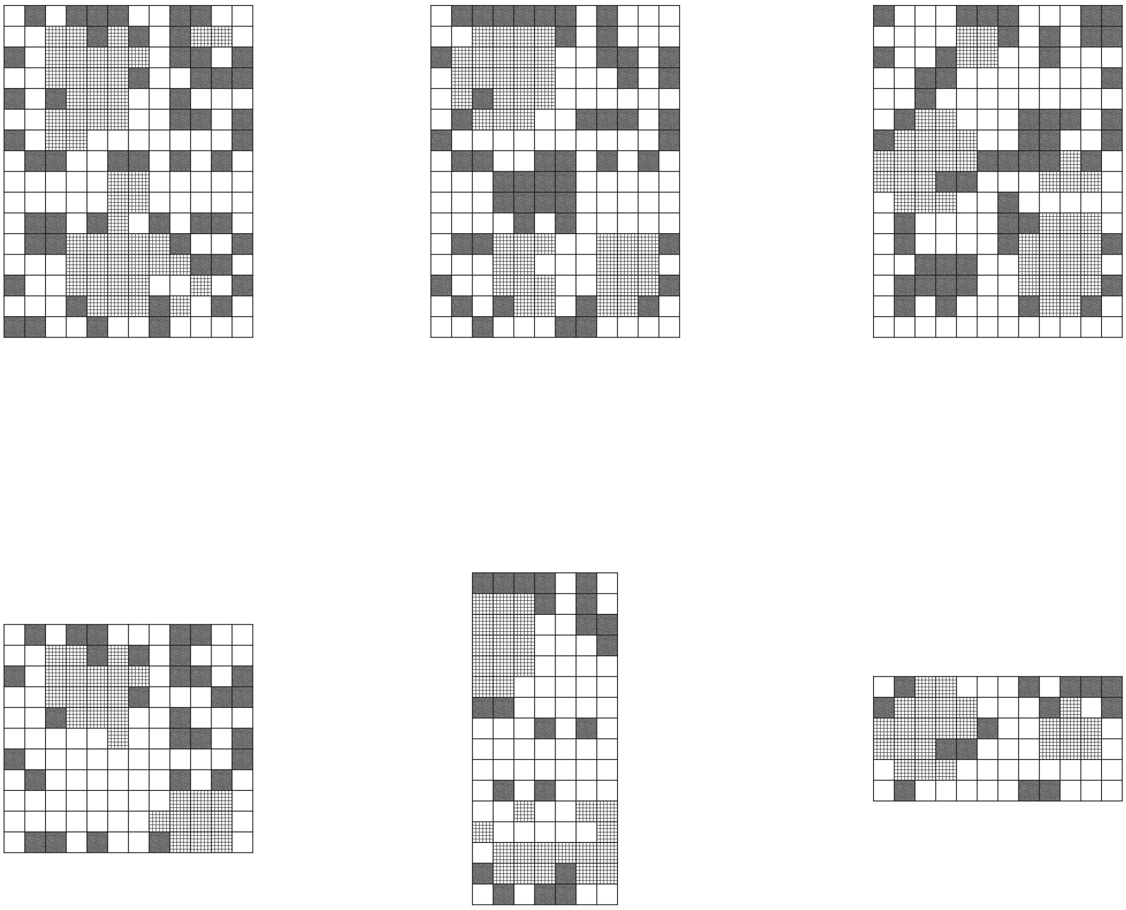


The space will be mainly used as a public square with the ability to transform and house other public functions. Such as markets, musical or sports events or by simply adapting the square after how it is used or what is needed. With the ability to transform the space into completely different structures more suited for private use some panels in the square can be made rentable.

Dividing the space into 5m x 5m panels, some static and some kinetic panels. With the kinetic panels as the rentable space that can be transformed into other structures and be used for both public and private use.

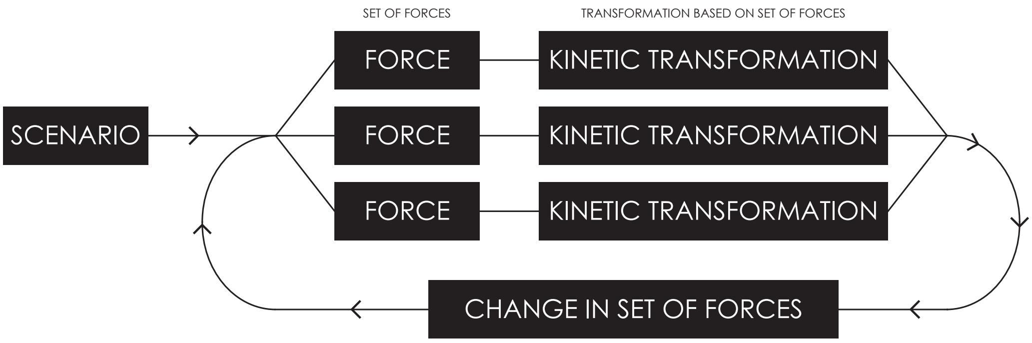


The Public Square. Grid Layout 12x16. Example of how the panels can be arranged to create a public square.



The Public Square. Versions of how the space can be arranged.

Scenarios



The space is constantly being exposed to a set of forces acting upon the space and these forces can change all the time. These forces are generated by the people using it, the weather or other changes that might occur. In response to these forces the system and the space can transform to meet the requirements of the forces. However, these forces are rarely static, they change all the time by a change in number of people using the space or how they use the space.

To show how the system is used in different functions and situations, several scenarios are created with a variety in functions and timespan. Each created scenario has a set of forces that the system responds to and transform the space to fulfil the required needs.

Market & Music

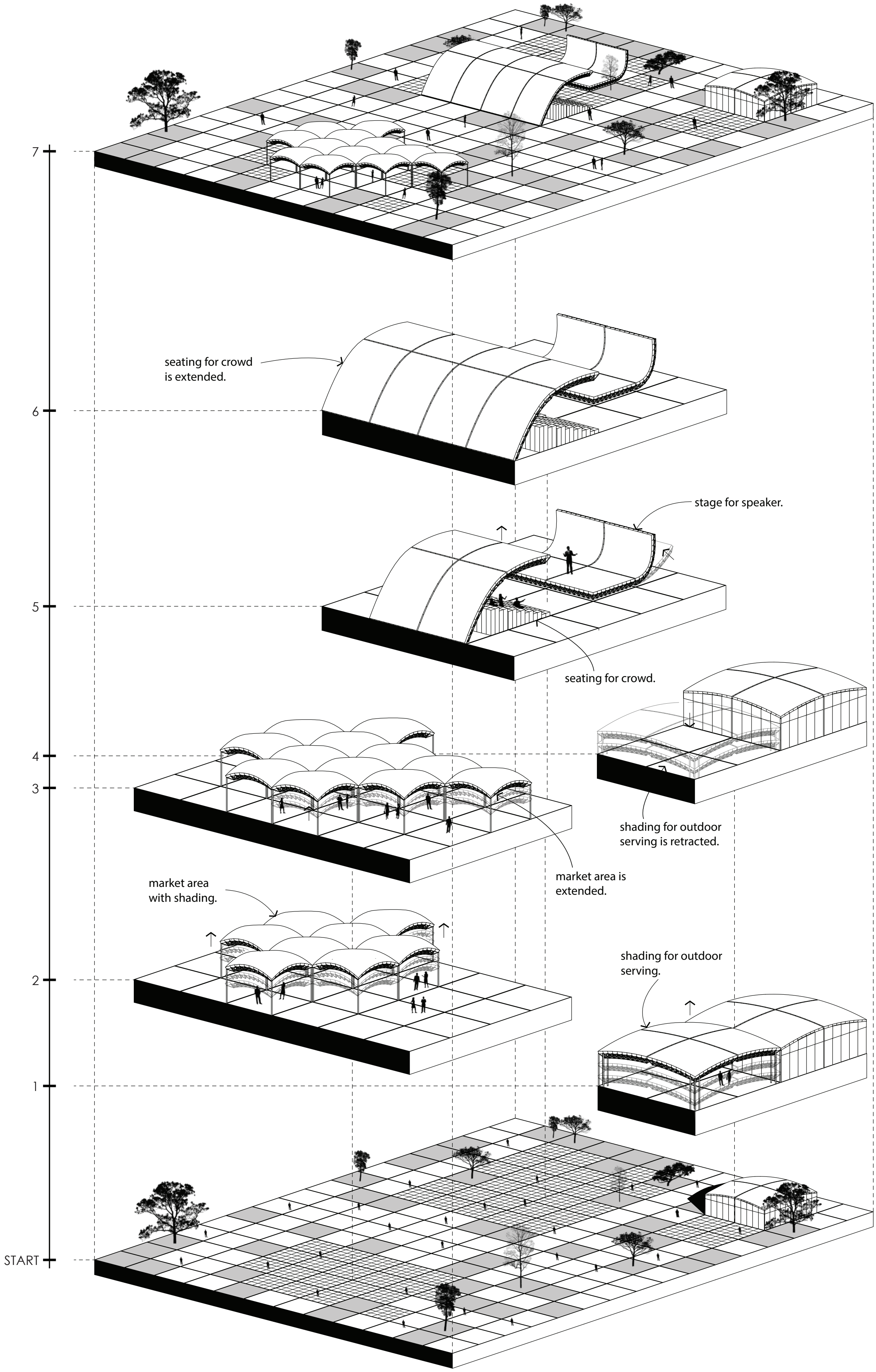
The building for the seasonal café has already been raised for the summer, it is mainly used during all the events taking place. In the morning, a few visitors arrive to the café for breakfast and a morning coffee, with seating both indoors and outdoors. Later the sun arrives and shading for the outdoor serving is raised (1). This is well populated during the entire day and later when the sun disappears the shading is then retracted again (4).

During the day and evening an area of the square is meant to be used for a public market. Before it opens, an area with shading and tables is raised (2). During the day, more people than anticipated arrives and the market area is expanded (3).

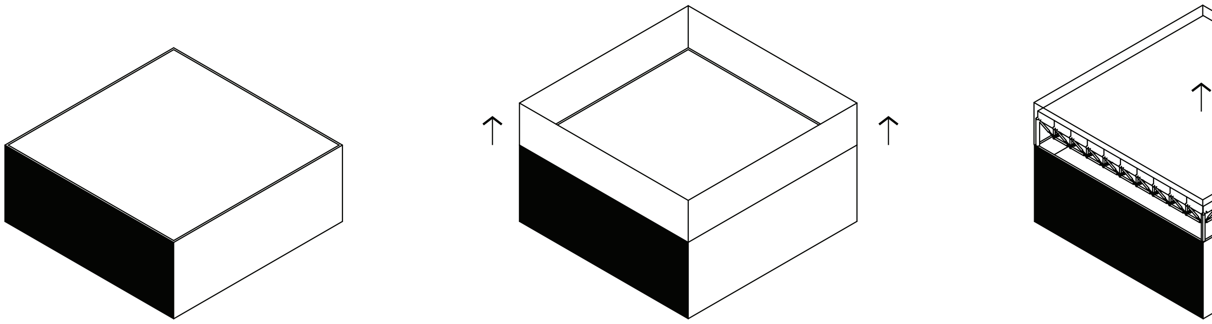
When the evening approaches the stands and stage for a public speech is raised (5). During the speech begins there are about 50 people in the crowd. After the speech, the space is to be used for a smaller concert and additional stands is raised for more visitors (6).

Timeframe

One day.
(Café: a couple of months.)



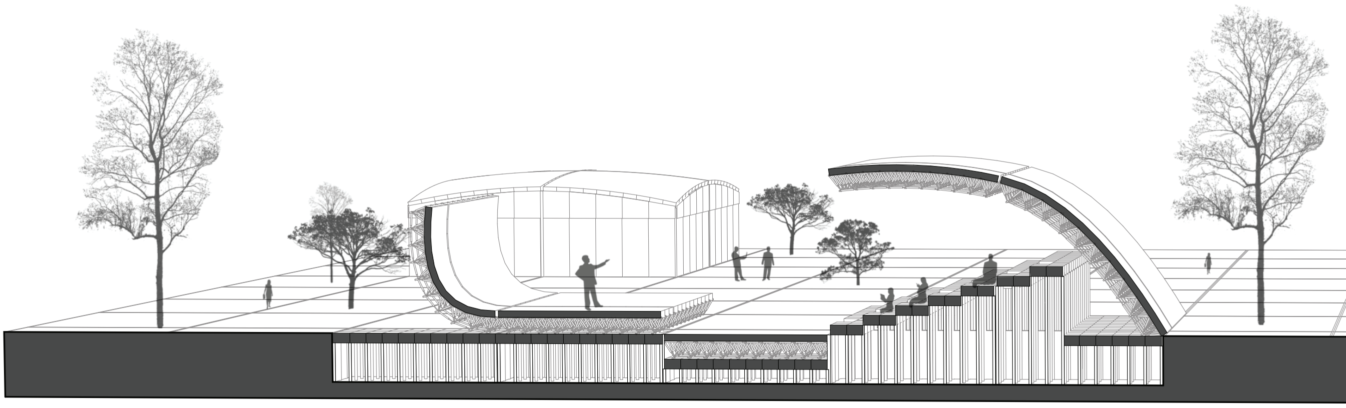
Scenario 1. Timeline of the transformations.

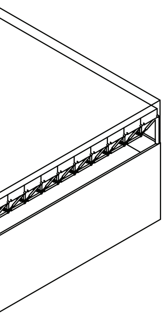


1. Start.

2. Safety rail is erected.

3. The transforma
starts by elevatin
space frame.





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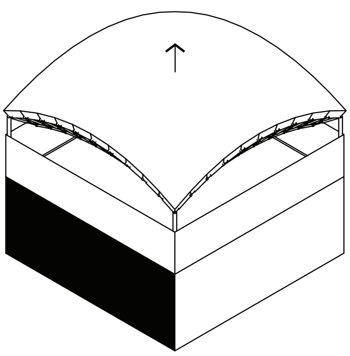
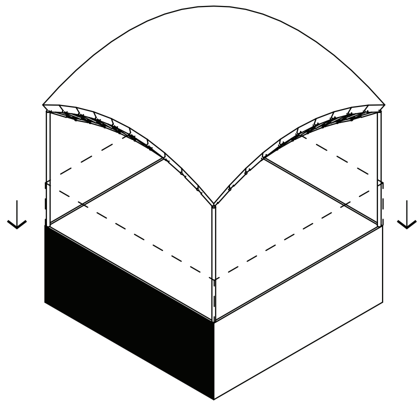
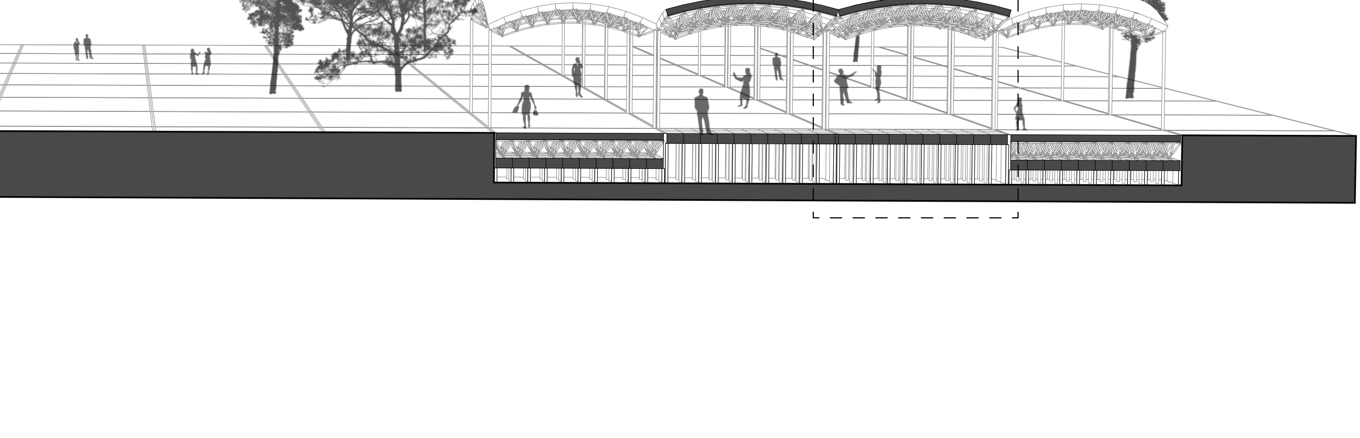


4. The kinetic space frame transforms and changes shape.



5. When the transformation is completed the safety rail is retracted.



Everyday Use

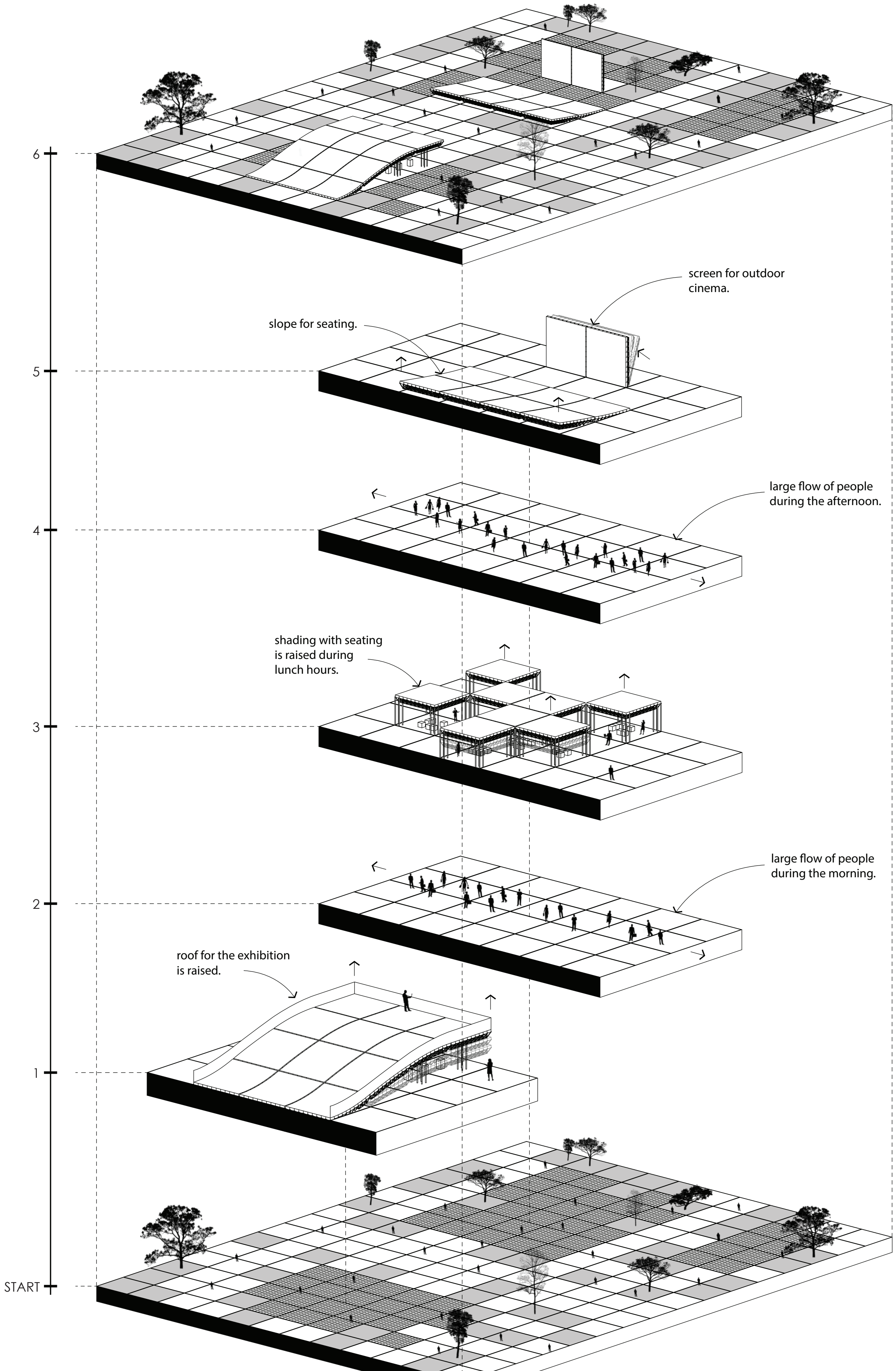
An area of the public square is set to be used for an exhibition during a couple of weeks. The surface of the square raises and creates a protected space for the sculptures that are to be exhibited (1). After the transformation railings are attached to the roof as the space on top of the exhibition can still be in use.

As the space is close to the public transport of the city, during the morning and evening there are a lot of people flowing over the space (2). This is also an extremely popular place during lunch-hours in the summer, with lots of people seeking for a place to eat their lunch. For this, some shading and benches is raised in the same space that was full of people on their way to work just hours earlier (3).

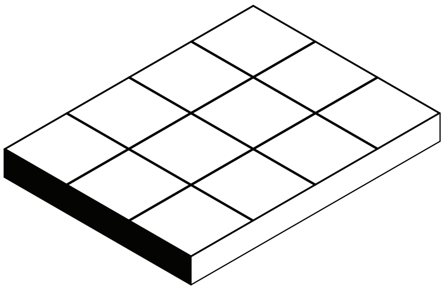
In the afternoon, the space is expected to be flooded again by people on their way home from work or school and all the shadings and seating's is retracted again (4). In the evening, a smaller slope is created for people to sit on for the outdoor cinema that takes place occasionally during the summer (5).

Timeframe

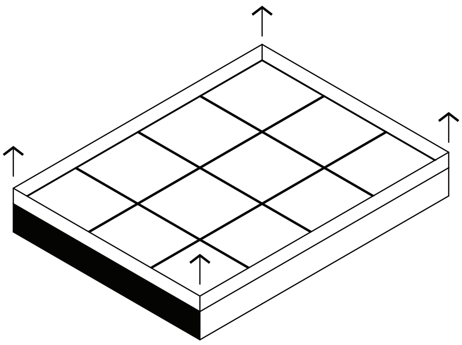
One day.
(Exhibition: a couple of weeks.)



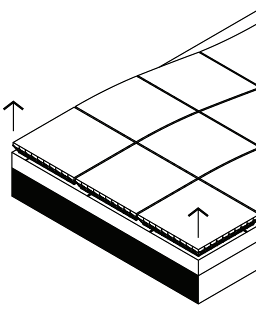
Scenario 2. Timeline of the transformations.



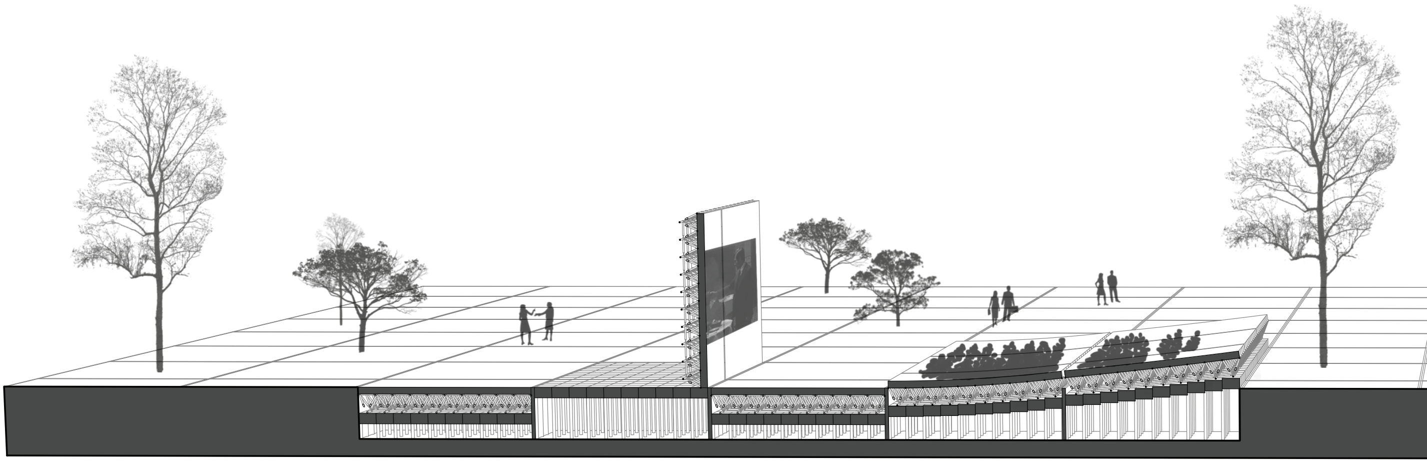
1. Start.

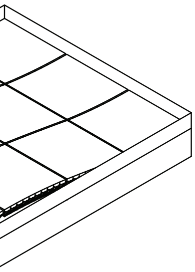


2. Safety rail is erected.

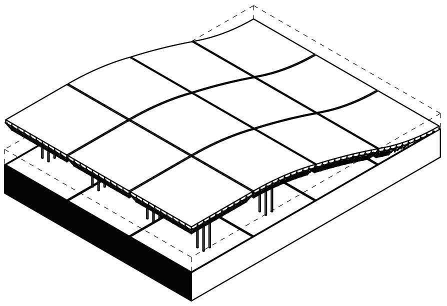


3. The transformation
starts.

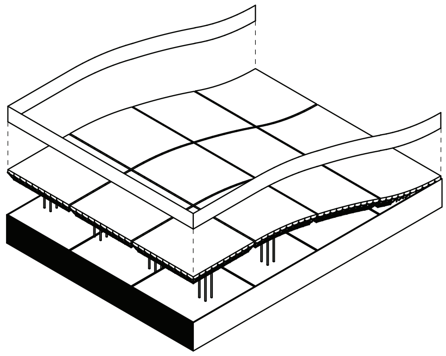




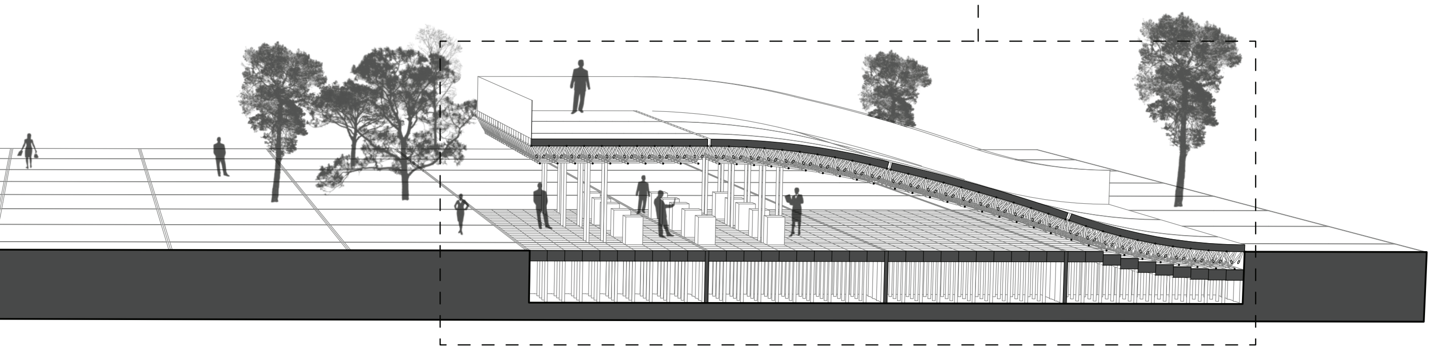
process



4. When the transformation is completed the safety rail is retracted.



5. A railing is attached on top of the space frame so the roof can be used by people.



Event Park

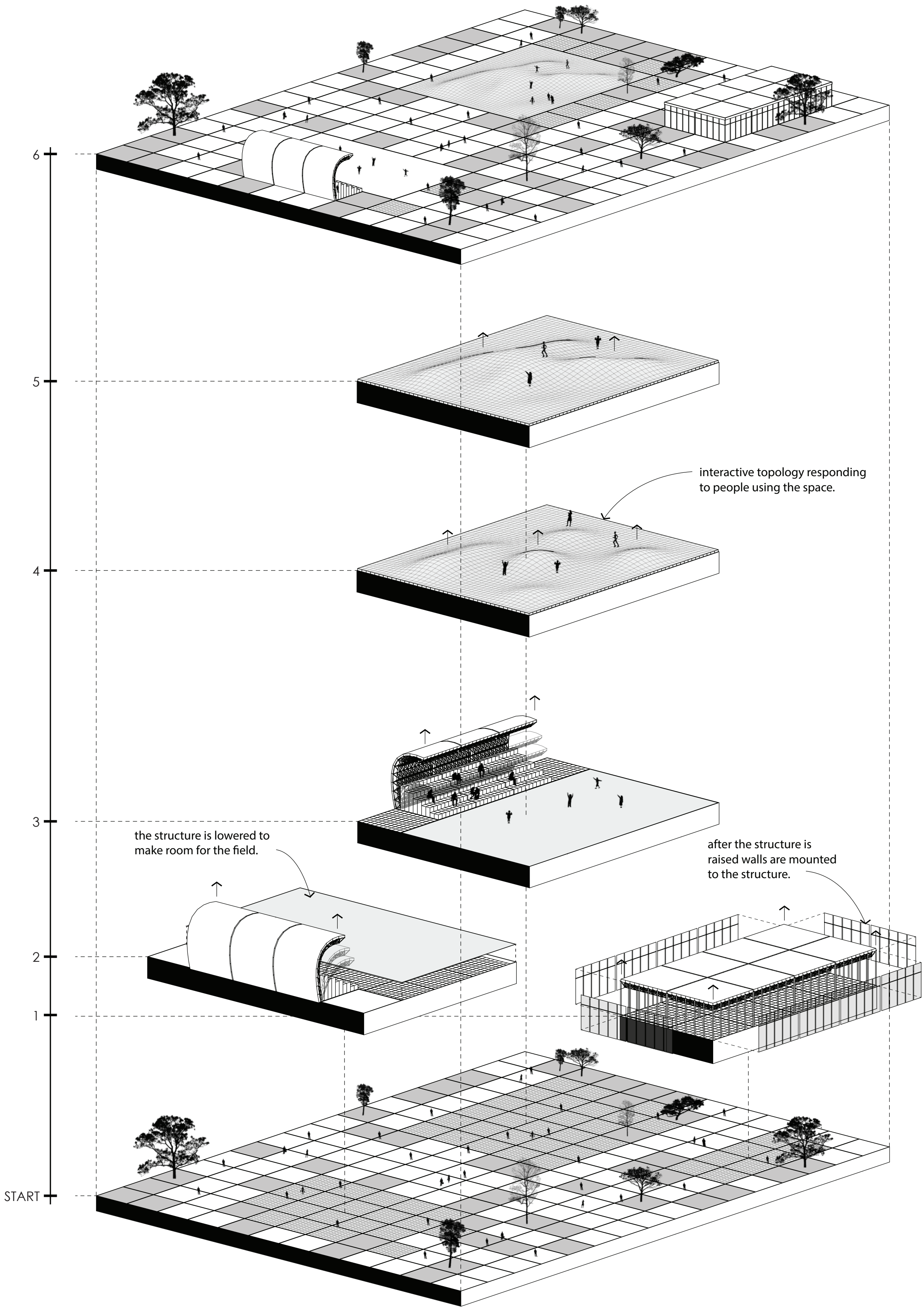
A sports event is set to take place for two weeks, with the need for two fields and a smaller crowd for both. There is also need for a smaller building were food can be prepared for people visiting the event. A smaller area is then transformed into a smaller building by raising the structure and then manually attach the wall units (1).

At the same time the event area is prepared by raising the stands and preparing the fields (2)(3). Since the surface of the square is not ideal to use as a surface, the area for the field is lowered to make room for a new surface that can be installed manually.

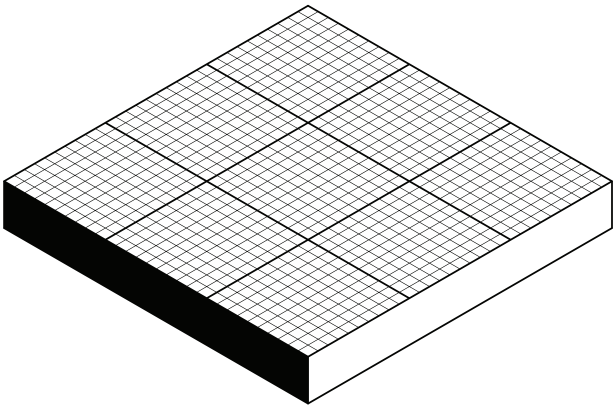
The second week of the event only one field is needed so the other is transformed back and turned into an interactive park (4). With the topology of the surface changing and responding to people walking on it (5).

Timeframe

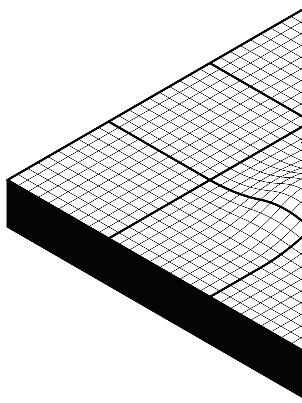
Two weeks.



Scenario 3. Timeline of the transformations.



1. Start.



2. The system re
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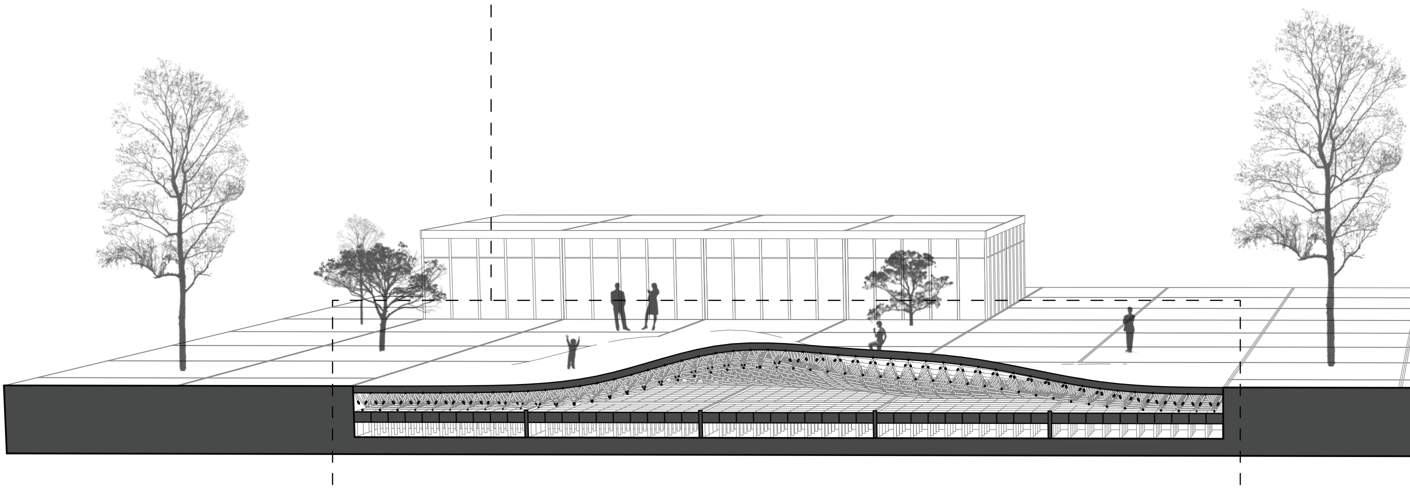

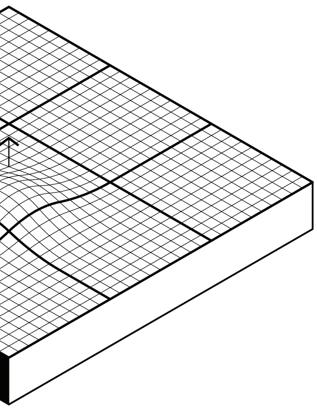

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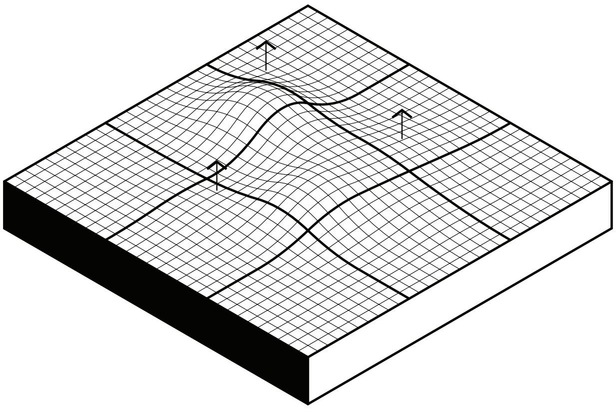


3. The response can be completely induvidual and responsive to every single user.

Adapting

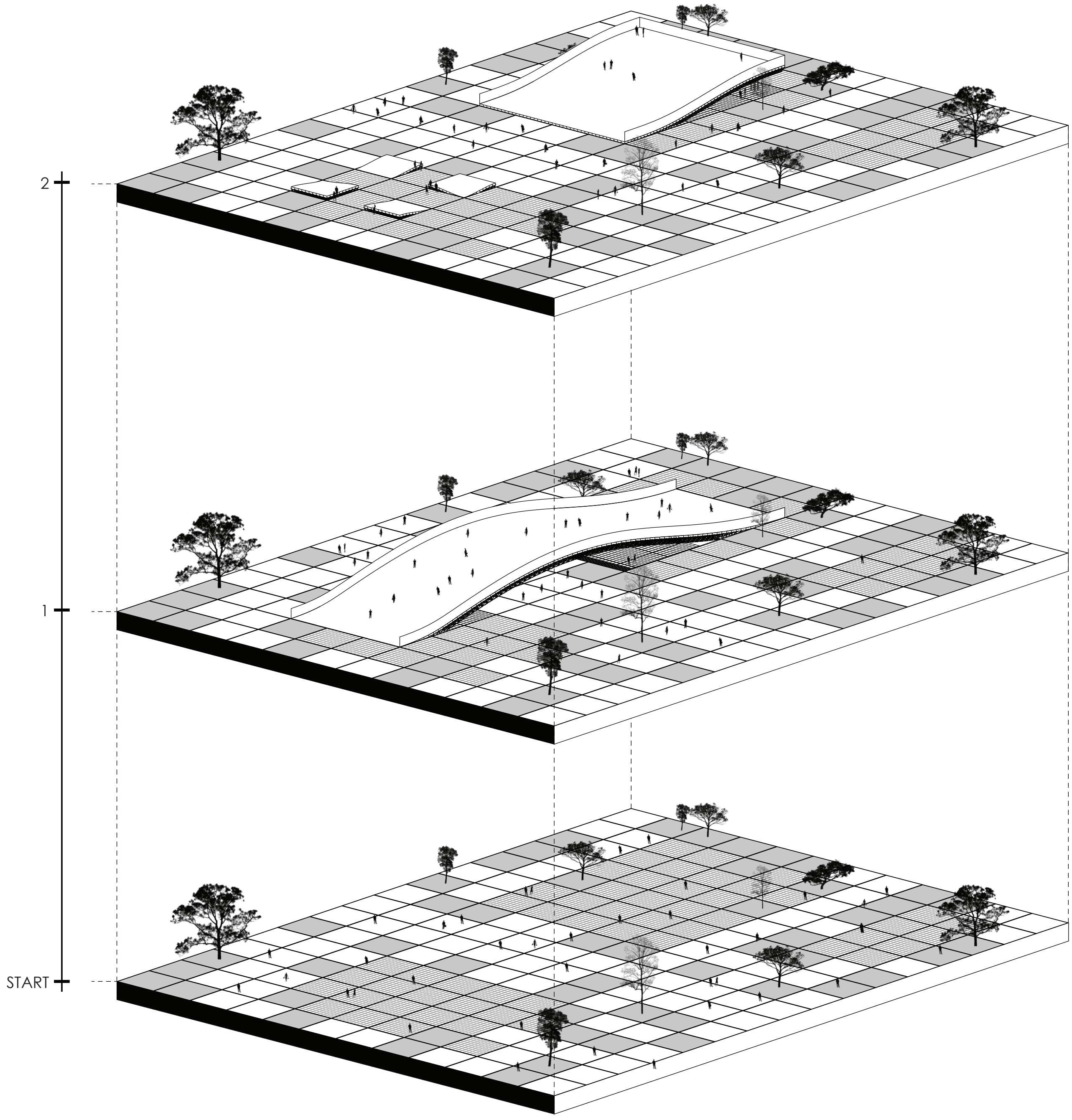
With time, the surroundings of the square will change which can have a large impact on how the square is used. From the start this square is mainly used as a place were people gather and use the kinetics of the square to make smaller local transformations based on their needs.

Years later, the public transportation system has changed and moved closer to the square. This results in larger people flow over the space in two directions, creating a crossing in the middle of the square. To avoid this the system adapts and creates a walk bridge in one of the directions so people can cross the square without interference (1).

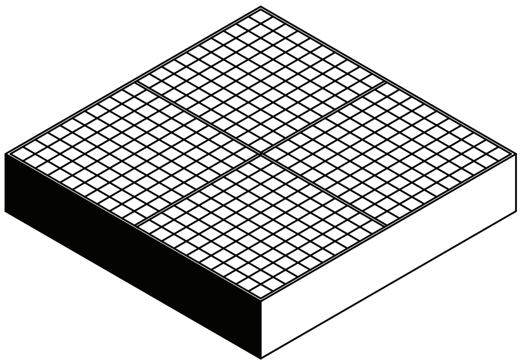
As time pass, the public transportation system has once again been changed. This time the result has eliminated the flow of people in one of the directions. Leaving a square with a large flow of people across the middle of the square and the walk bridge has now disappeared (2). The square is now divided into two parts with the ability to make smaller local transformations on each side. Creating seating, shadings and changing the topology to create spaces where people can gather and use the space as they require.

Timeframe

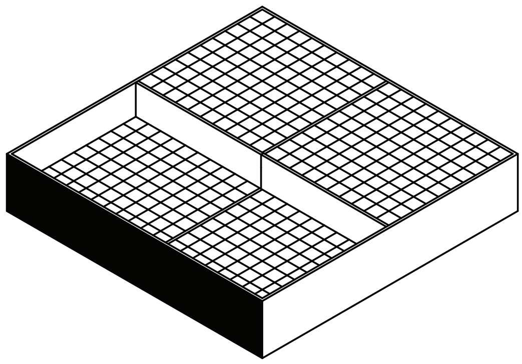
Ten years..



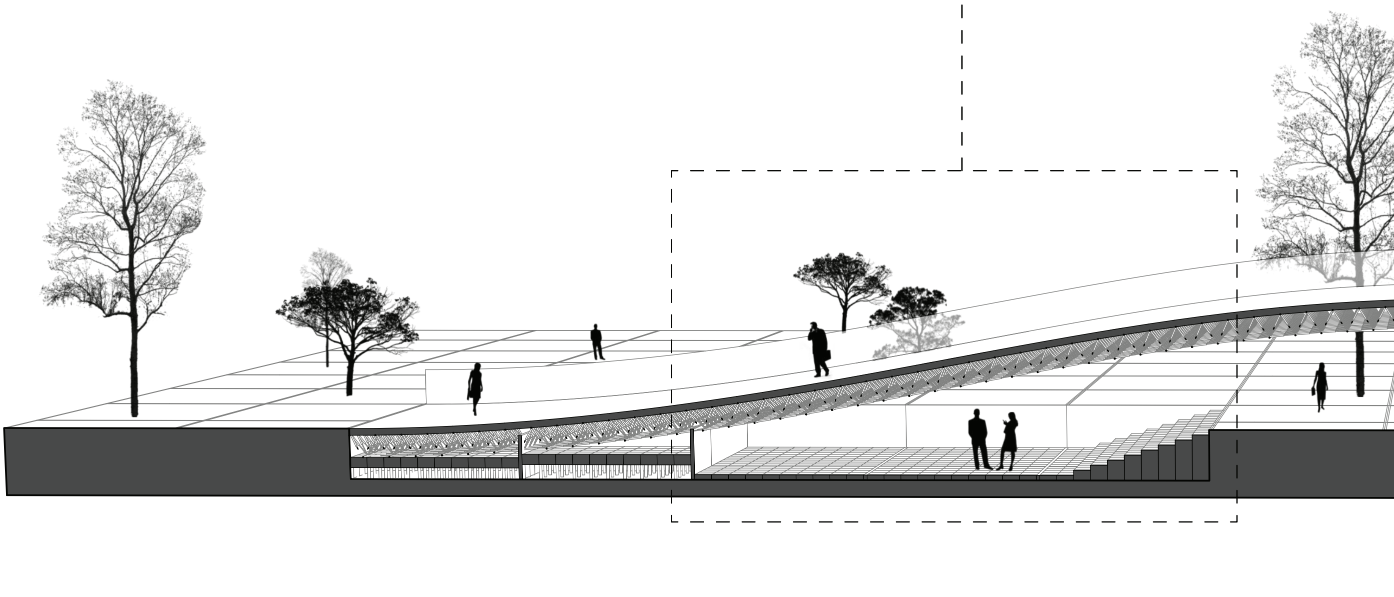
Scenario 4. Timeline of the transformations.

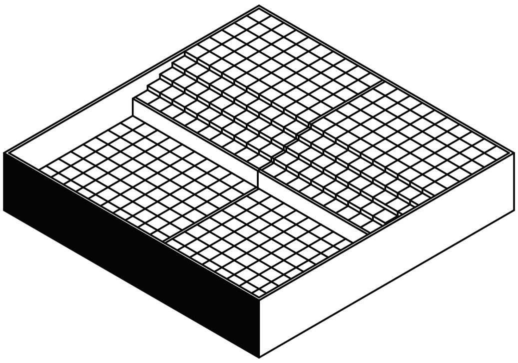


1. Start.

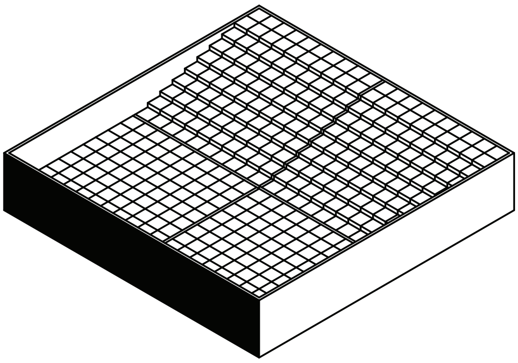


2. The platform is lowered.

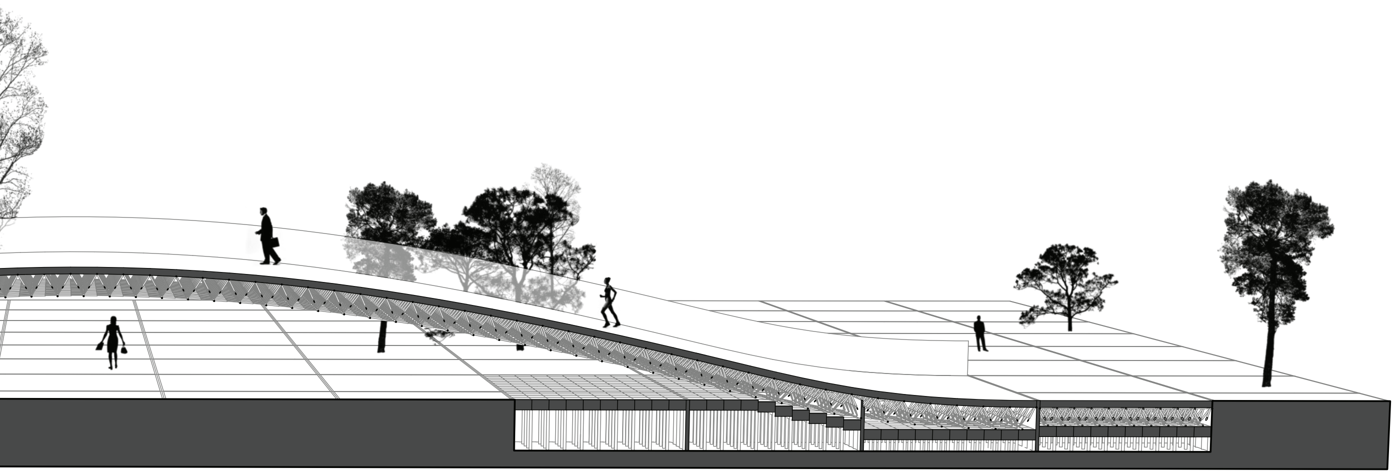




3. Floor panels are lowered to create a stair to the lower platform.



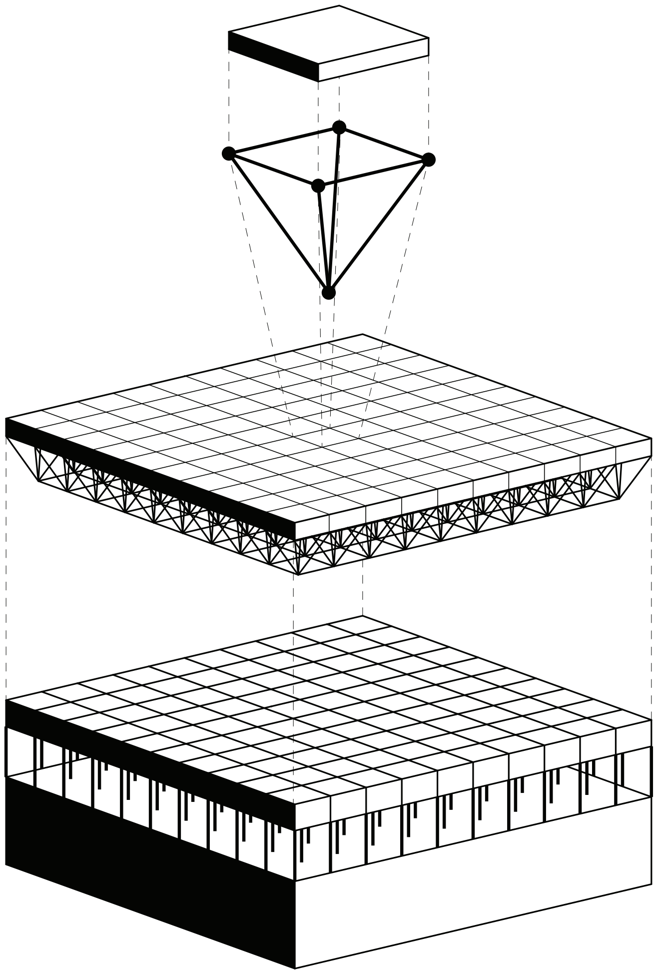
4. The transformation is completed.



Kinetic System

The structural kinetic system involves two layers of separate mechanisms working together to make the system as flexible as needed. Making it possible to transform a square into many different shapes and functions. Each system has its own limits to what it can achieve which in return determines the limits of the entire design and the whole system. The top layer and the main system for the transformations is the kinetic space frame, with actuators changing length and rotating freely in every connection point.

The layout of the public square is divided into a grid of 5x5m panels that forms the surface of the square. These panels are then divided into a 10x10 grid which forms the outer grid of the space frame. With each actuator in that grid having the length of 0.5m in a flat condition and the ability to extend to even longer. Each of these squares in the 10x10 grid creates the basis for an upside-down pyramid, with all the centre points connected creating the inner 9x9 grid.



Kinetic System. Illustration of the layers in the kinetic system.

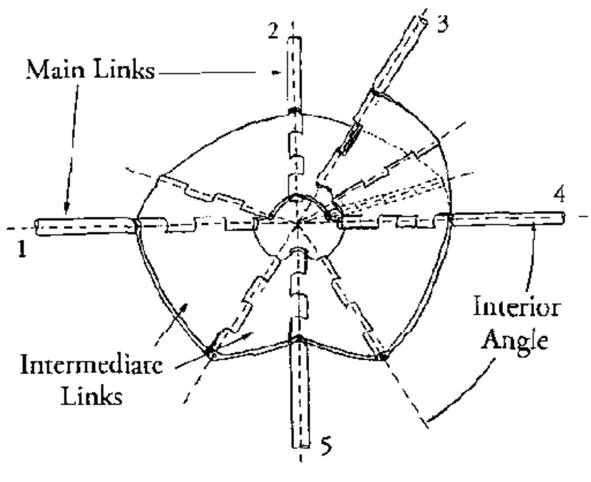
Actuators & Joints

To make the entire system kinetic, there are two elements needed, the joints and the actuators. In this system the actuators are hydraulic cylinders that can individually extend and retract themselves, changing the length of every single line element in the space frame. However, if one changes so will another, so the change must be controlled over the entire system. Creating a space frame system that can act and behave almost as a flexible surface with abilities to bend and fold.

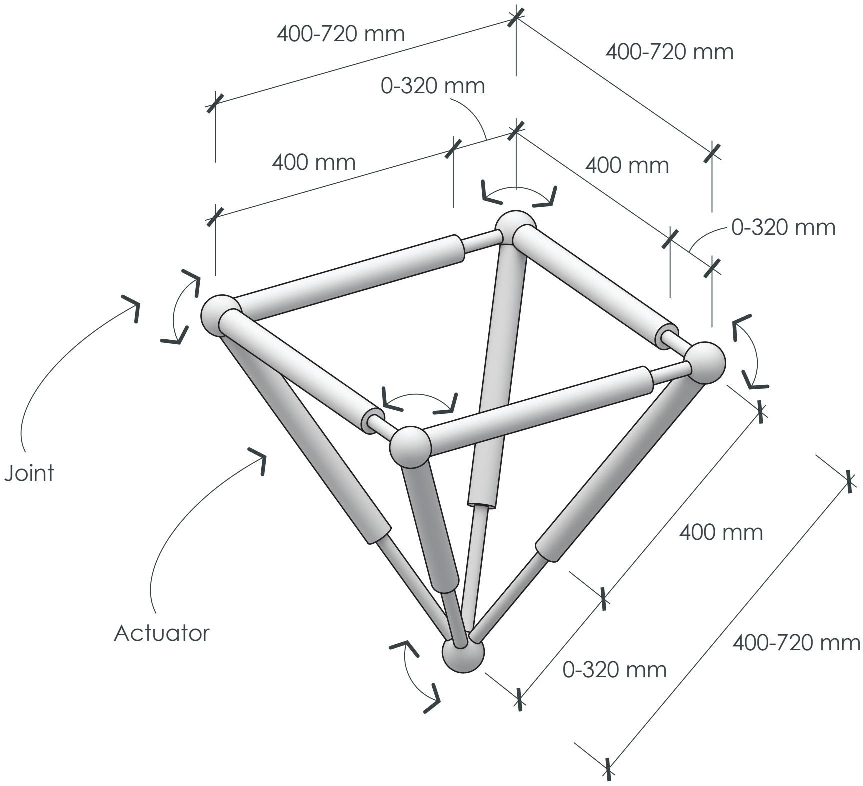
Since each actuator in the system has a limit to what it can extend or retract to, this also creates the limitations for the entire system. The actuators in this example are dimensioned with the fixed element as 0.4m and the extension ranging between 0 - 0.32m. This means each actuator in the system can fluctuate between 0.4 – 0.72m.

To make a fully kinetic space frame like this, the joints need to be as flexible as possible. Each joint has several links connected to them that needs to rotate freely in all directions. This makes the joints the most complex piece of the structure and are therefore simplified with a simple sphere in the models. However, a spherical joint can only handle two links in the way needed for this system.

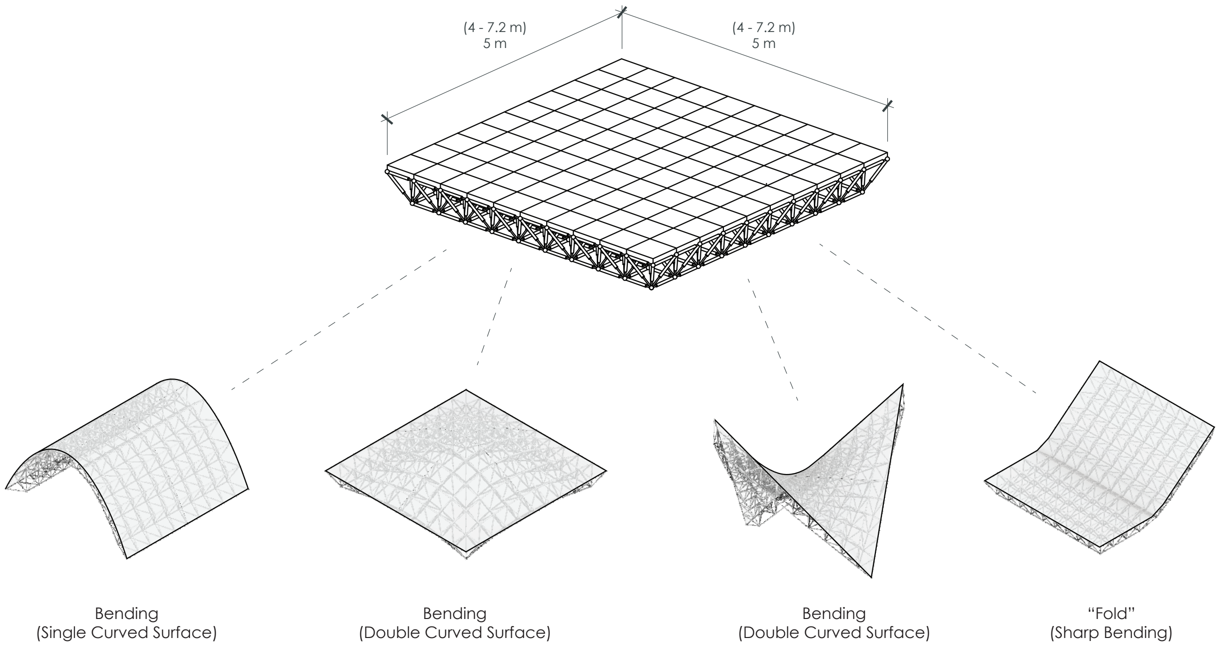
There have been several attempts to create better spherical joints that can handle multiple links. In 2003 Bosscher, P & Ebert-Uphoff, I proposed a spherical joint mechanism with the ability to rotate several links around one centre point.



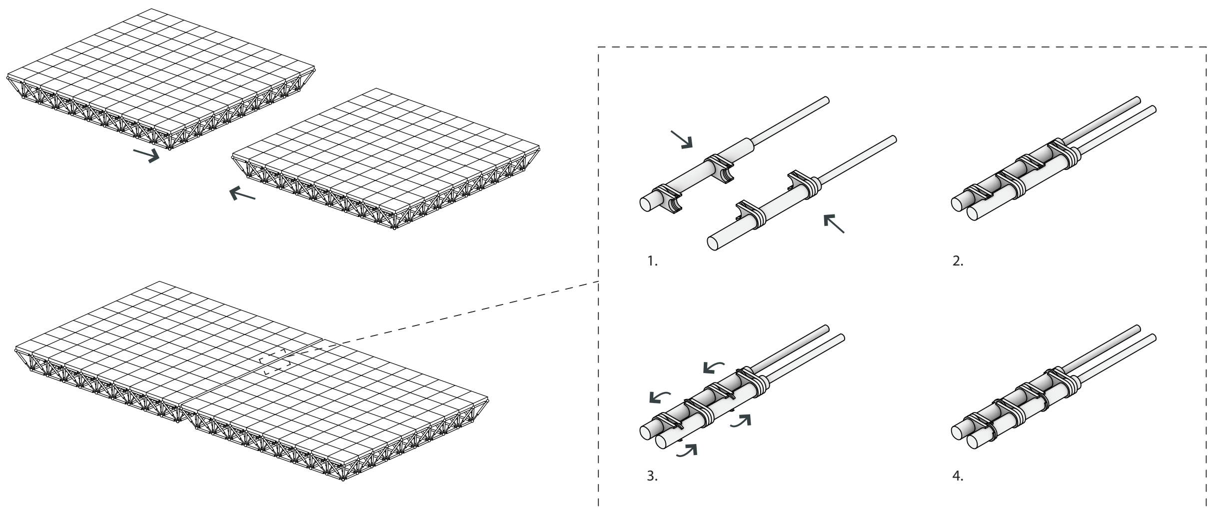
4 Spherical Joint Mechanism. Bosscher, Paul & Ebert-Uphoff, Imme. (2003).



Kinetic System. Illustration of one pyramid in the structural system. Showing the dimensioned actuators and their limitations.

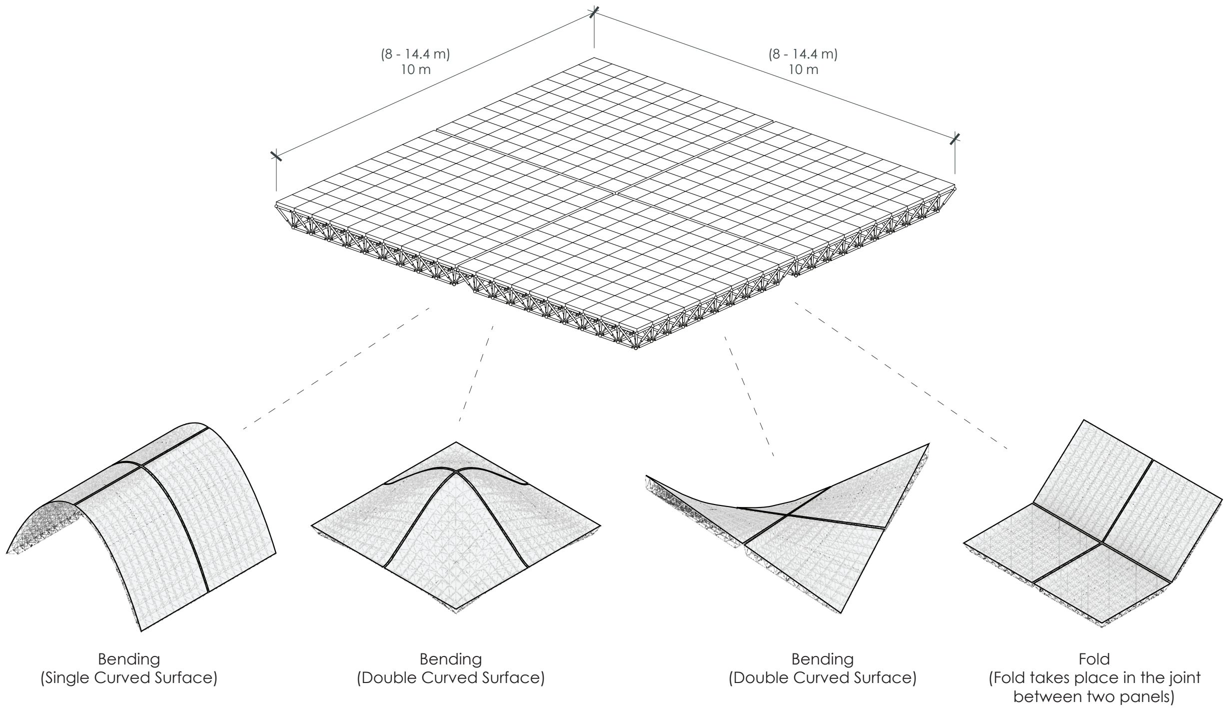


Kinetic System. Illustration of one kinetic space frame panel and how it can be transformed.



Kinetic System. Illustration of the joining process of two panels. With detail of the locking mechanism between the actuators on each panel.

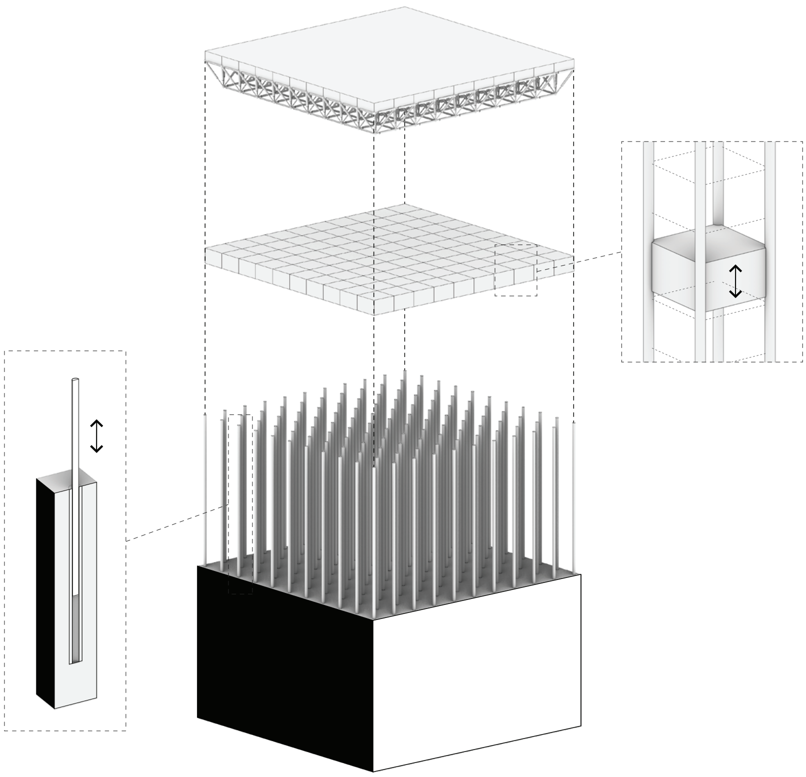
-Design Concept



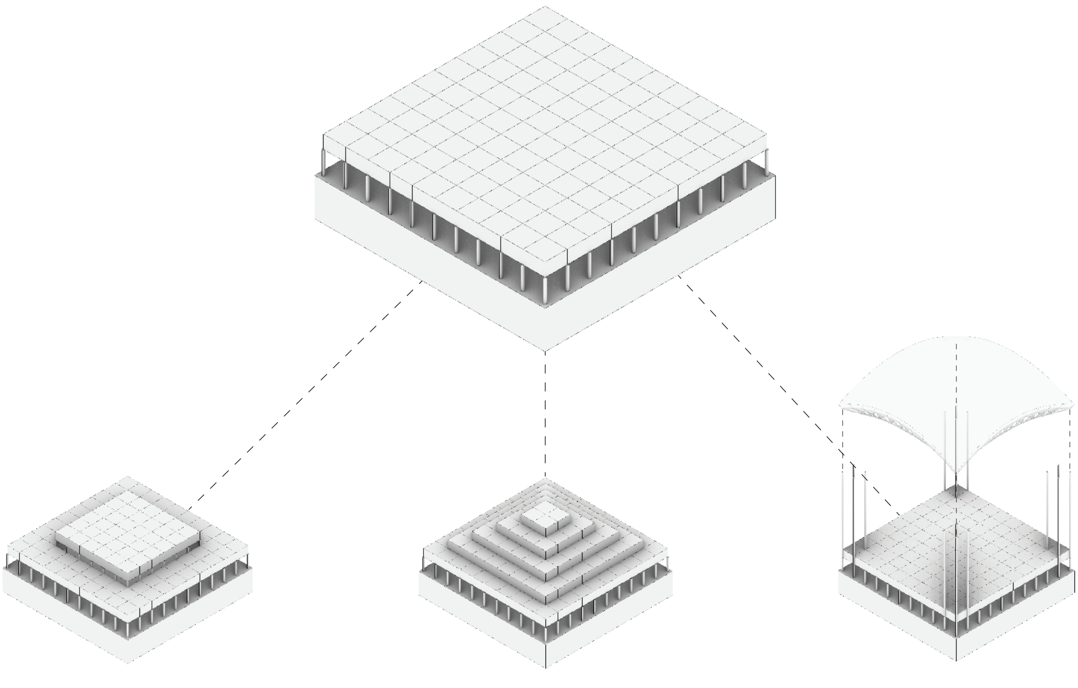
Kinetic System. Illustration of four joined kinetic space frame panels and how they can be transformed.

Columns & Floor Panels

The second layer in the system is a simple kinetic mechanism of floor panels and columns. This layer is also divided into the same 10x10 grid as the space frame above, with a column in each intersection. These columns can rise and be used as support for the kinetic space frame, turning the space frame into a roof system. Since the space frame can be moved out of the panel, there needs to be another system functioning as a floor for people to walk on. This is the main function for the floor panels in this layer, they will individually move up and down on the columns as rails and fill in empty spots when the space frame has transformed.



Kinetic System. Illustration of the columns and floor panels beneath the kinetic space frame.



Kinetic System. Showing how the columns and floor panels can be transformed and used in the system.

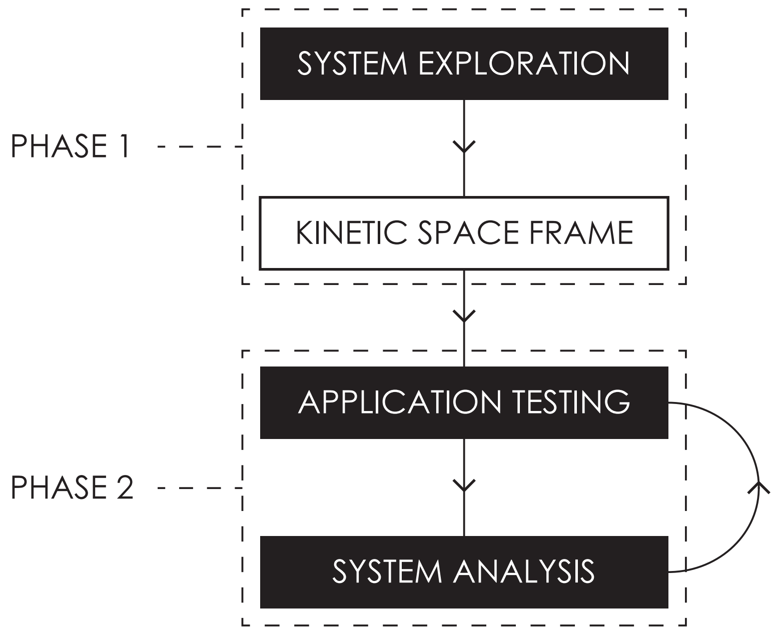
Design Development

Starting the exploration of kinetic architecture and mechanical structures, involved a phase of testing different mechanical and kinetic structures. To find a system to continue working with and finding qualities from different elements to learn, what and how they can be used. As well as develop a method of how to work with structures that are moving and explore ways to illustrate the motion and transformation of the systems.

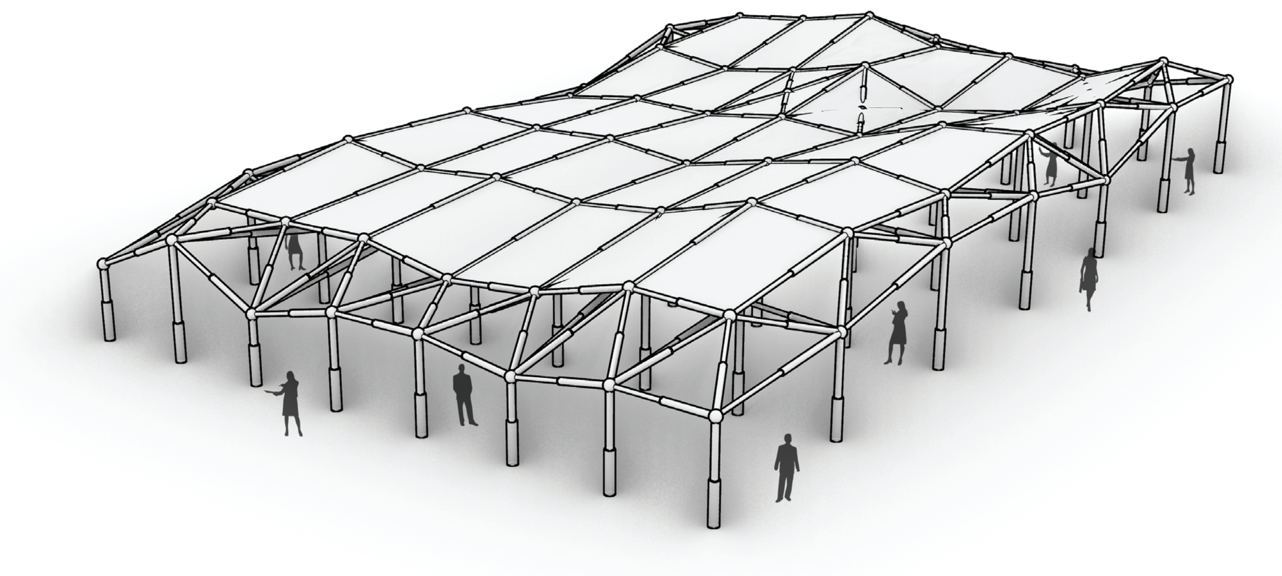
The development of the system can be divided into two phases, the first to find a system and the second to develop that system. The first phase started with making quick concepts of kinetic structures and applications for those structures.

Once the system was found, the second phase started with analysing the system and testing its boundaries. Since one key aspect of working with kinetics is the systems limits, which is what defines the entire design and decides what can be done. Exploring this by developing a systematic and analysing approach of how to make kinetic structures and analyse it to find the limits of that design.

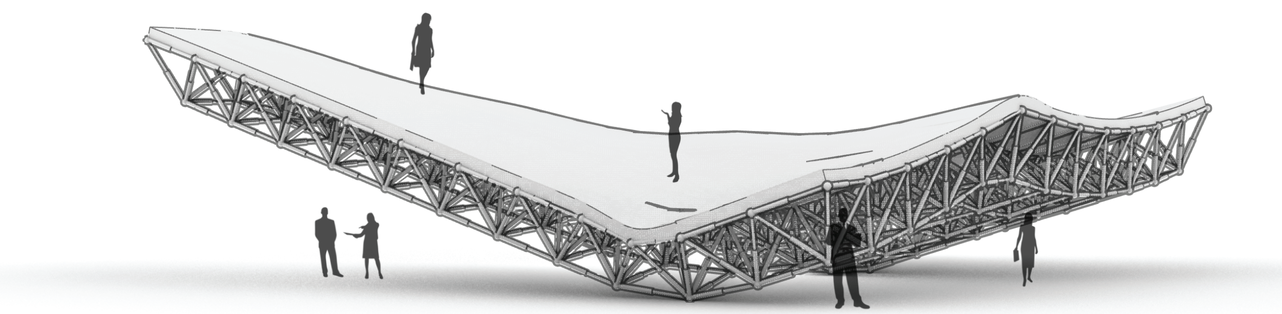
By going back and forth between analysing the system and testing how the system can be used and applied in different scales and settings.


SYSTEM EXPLORATION
PHASE 1
KINETIC SPACE FRAME
APPLICATION TESTING
PHASE 2
SYSTEM ANALYSIS

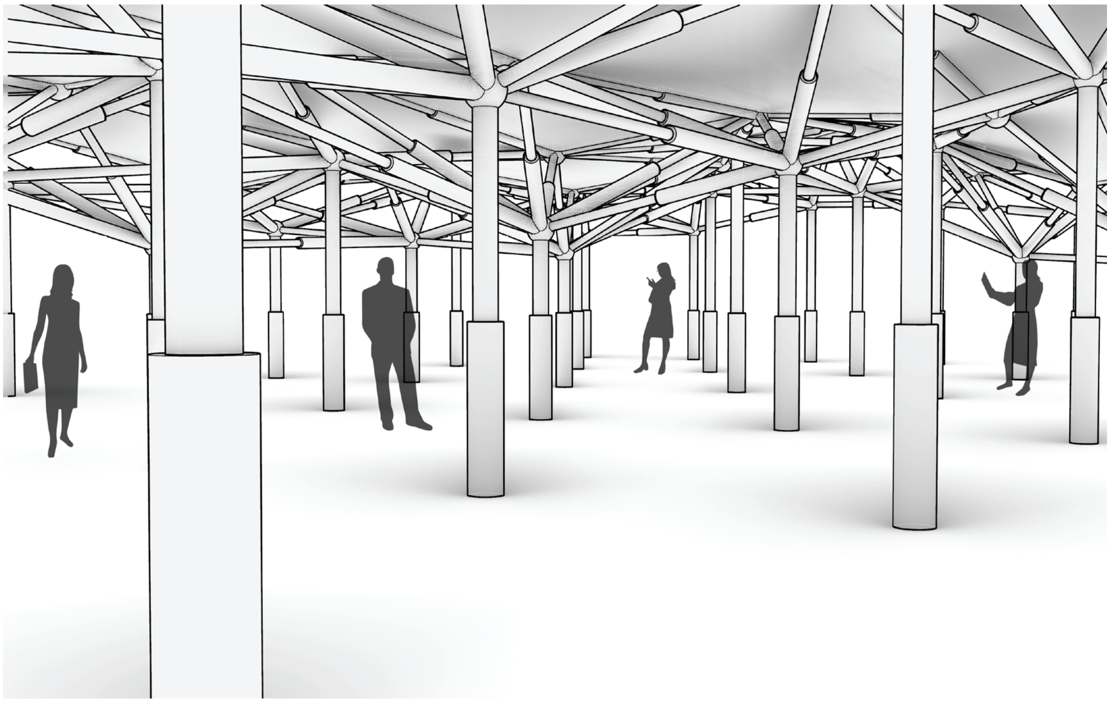
System Exploration



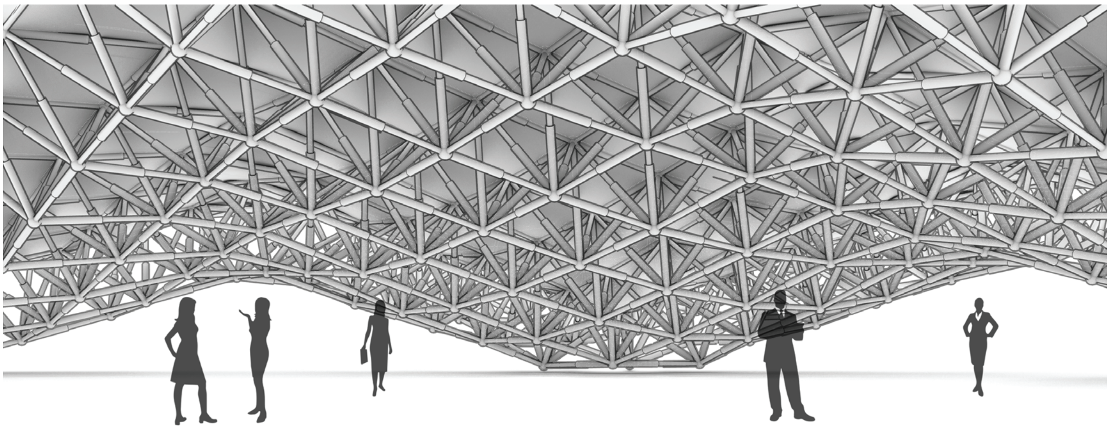
Phase 1. Kinetic Space Frame. Perspective from above.
A kinetic space frame resting on top of a set of columns in a grid layout, with the ability to transform itself. The columns themselves can change in height to adjust for the transformation of the space frame.



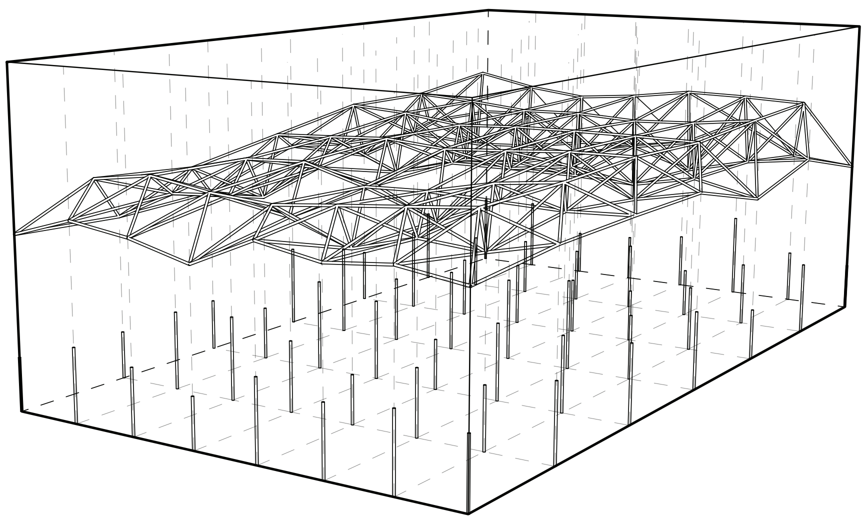
Phase 1. Kinetic Space Frame Version 2, Perspective.
The space frame is self-supporting and will create its own supports where it is needed and can create a large variety of shapes. Reaching down to the ground, making it possible to use both the space underneath the frame and the space on the top.



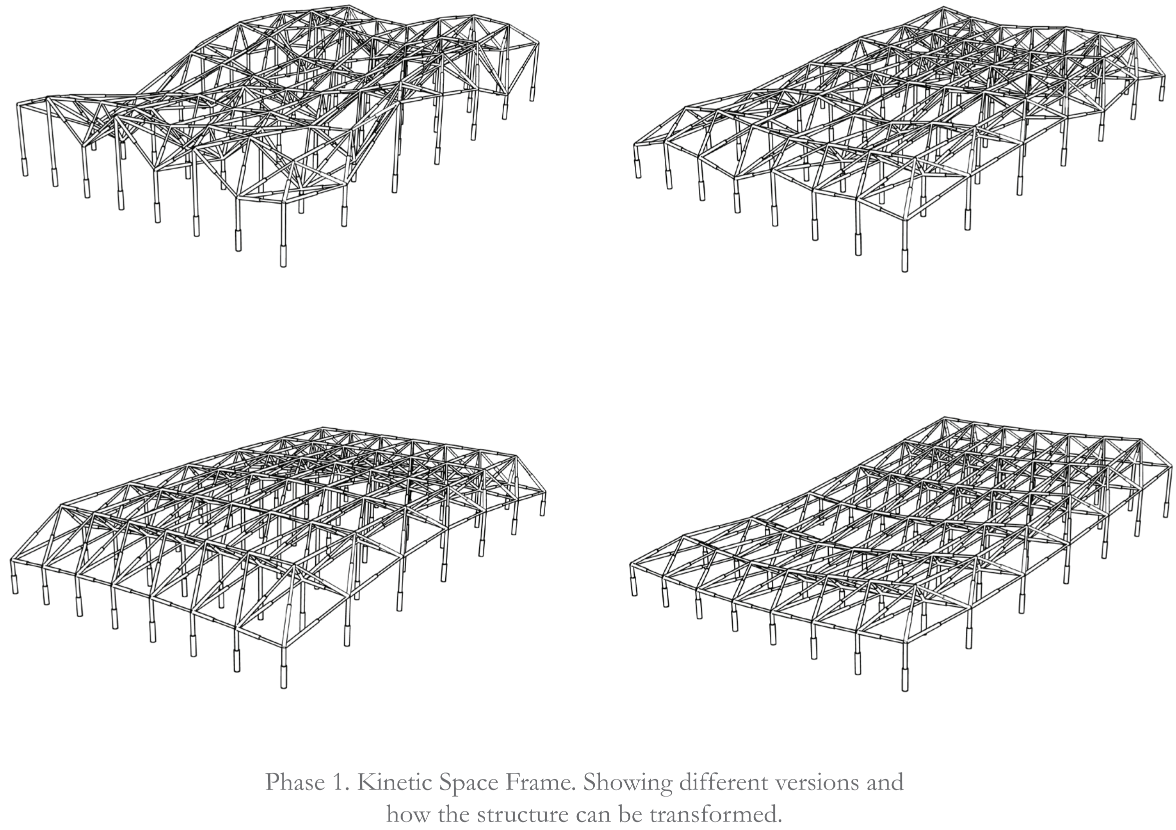
Phase 1. Kinetic Space Frame. Perspective from underneath the system, showing the kinetic columns carrying the system.



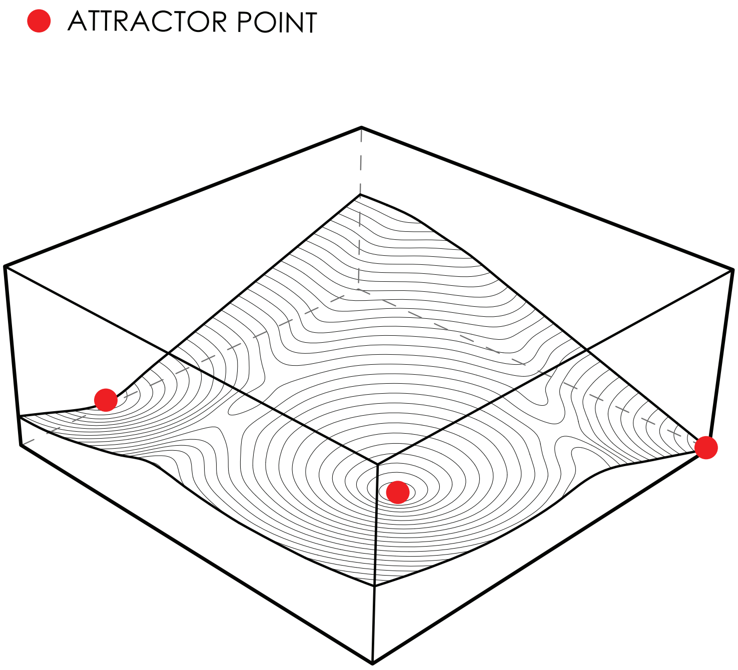
Phase 1. Kinetic Space Frame Version 2. Perspective showing the space underneath the structure.



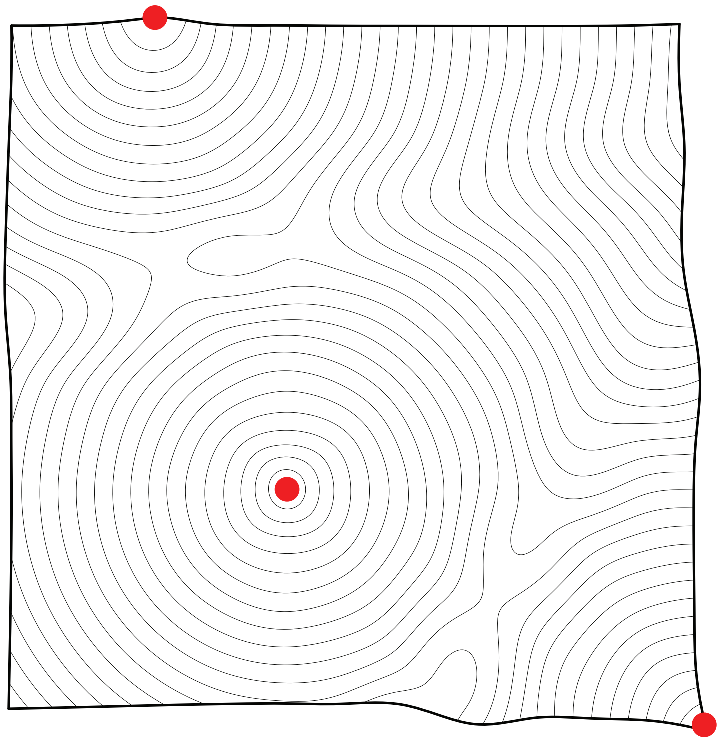
Phase 1. Kinetic Space Frame, Exploded - Perspective. Displaying the different elements and structure of the system.



Phase 1. Kinetic Space Frame. Showing different versions and how the structure can be transformed.

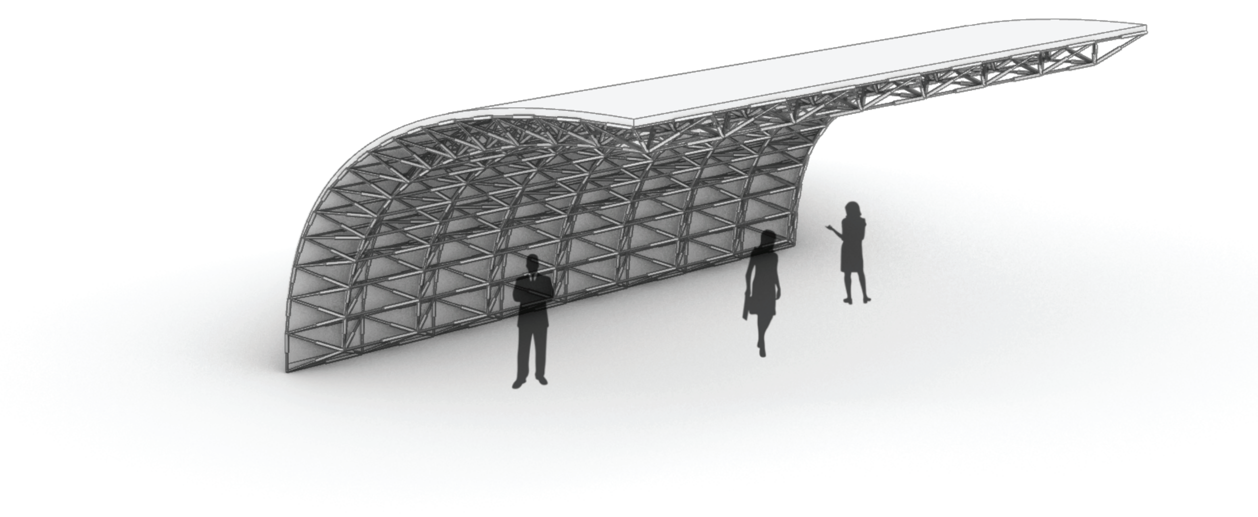


Phase 1. Kinetic Space Frame Version 2. Attractor Points - Perspective. The shape of the surface is controlled by three attractor points creating a three-support basis for the structure to stand on. The height of the surface is controlled by the distance from a point in the surface to an attractor point. If the distance to an attractor point equals zero, the height of the surface in that point is also zero and creates a support for the structure.



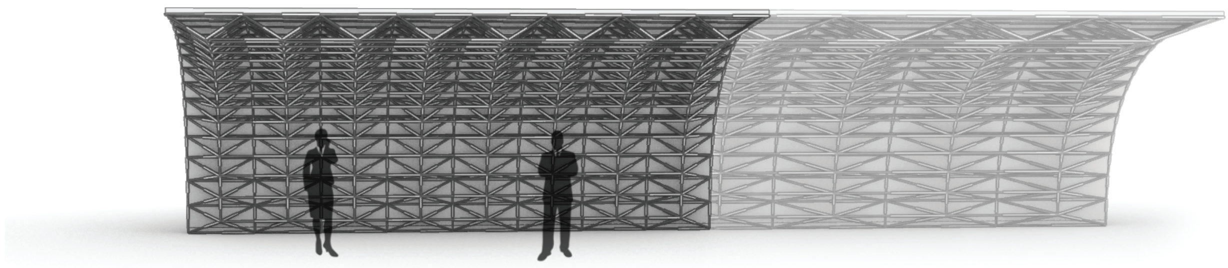
Phase 1. Kinetic Space Frame Version 2. Attractor Points - Top View. Showing the topography of the surface and the three attractor points creating the support for the structure.

Application Testing

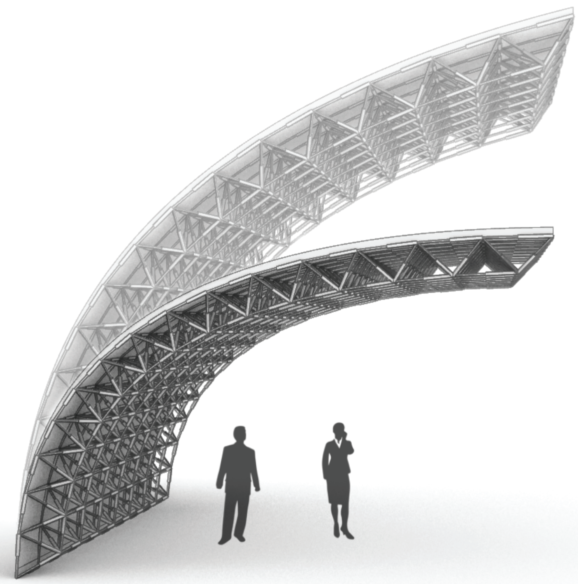


Phase 2. Application. Small scale pavilion.

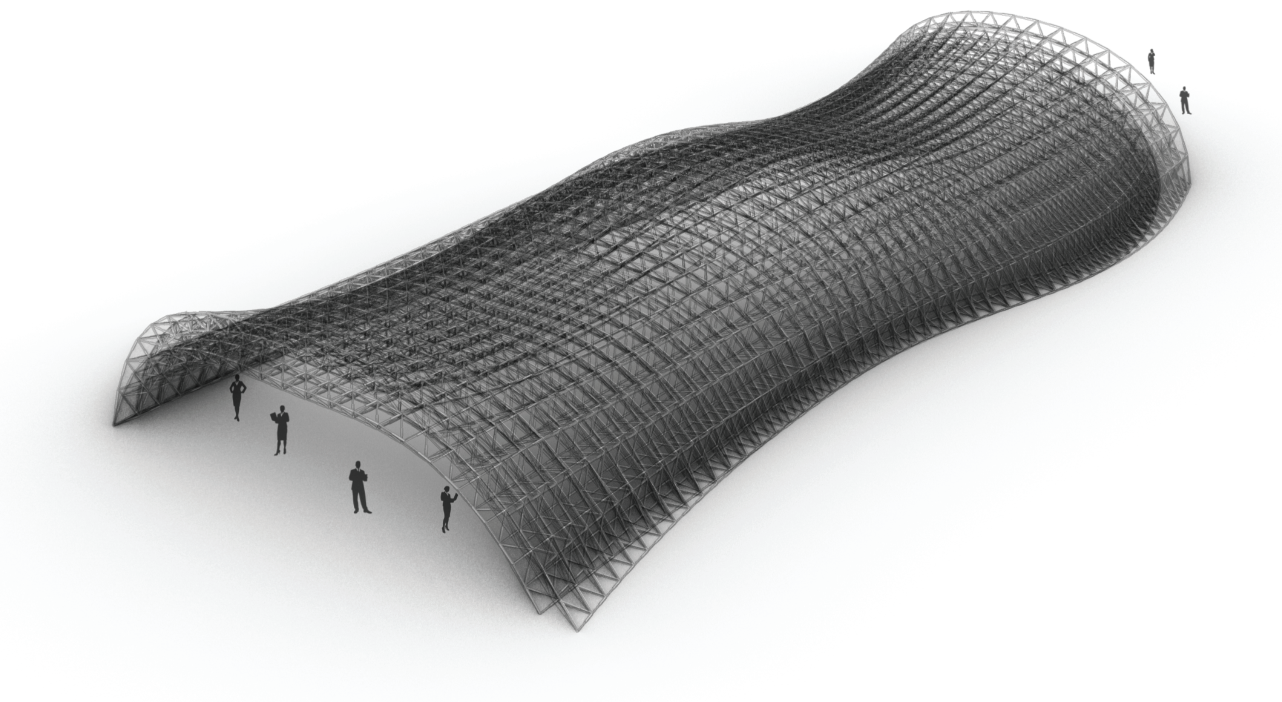
The space frame can be used for many scenarios and in different scales. This smaller scale pavilion is one very simple form that it can adapt to. Providing a small shelter protecting from weather, such as wind or rain and can make adjustments to its shape to optimize protection. By folding itself and creating a different profile or fold in the edges to create a more enclosed space. It can also expand to some degree to make room for more visitors.



Phase 2. Application. Small scale pavilion, showing the potential growth of the system.

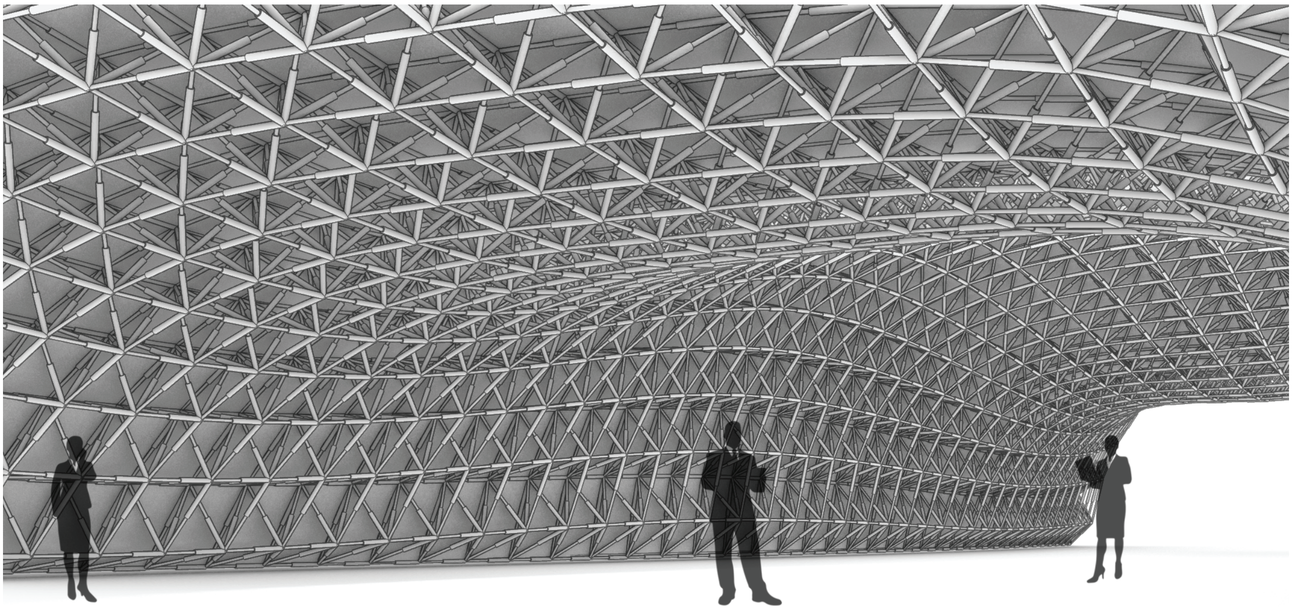


Phase 2. Application. Small scale pavilion, changing the curvature of the pavilion.

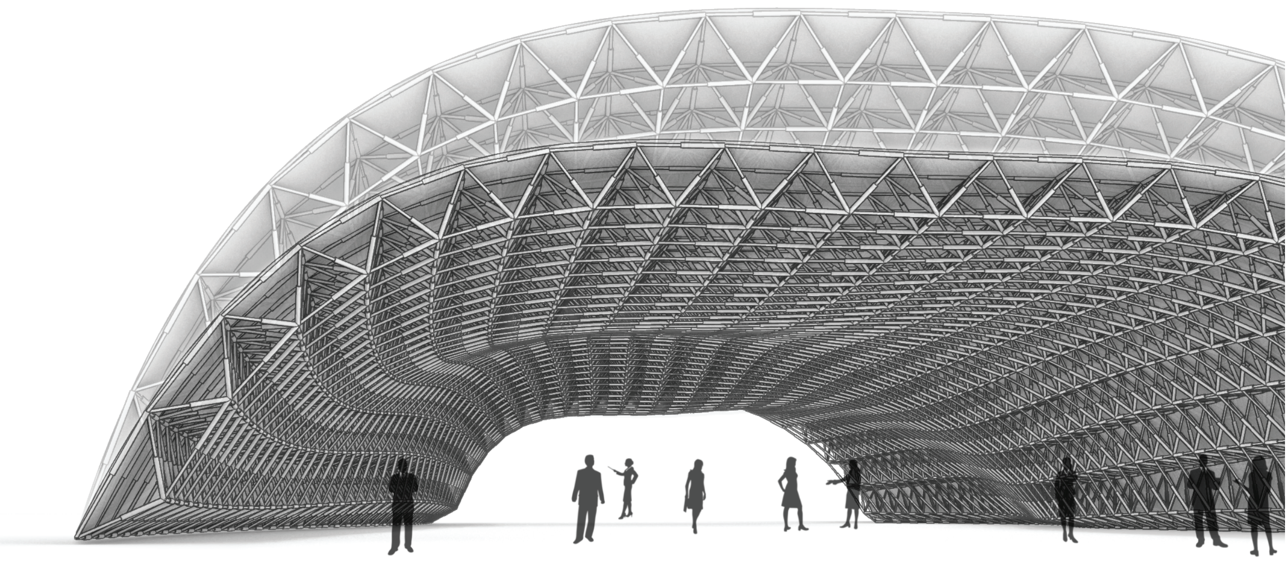


Phase 2. Application. Medium scale structure.

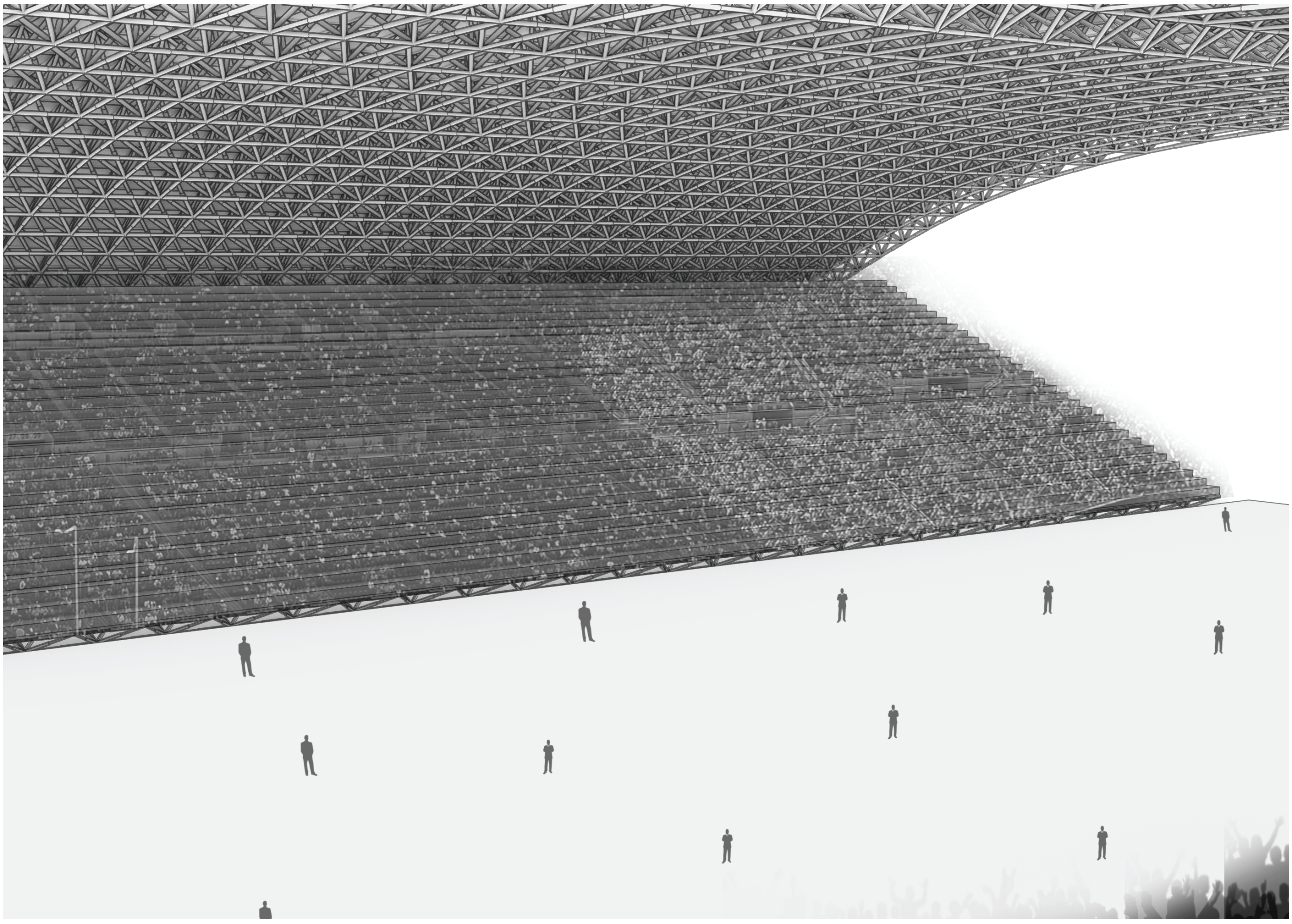
The frame can also be used to create larger enclosed spaces. In this example the frame structure is used as a roof structure creating a quite large open space that can adapt and change its form and overall volume. Changing its volume can have a large impact on heating and cooling the space, as well as creating more space for certain areas where it is needed.



Phase 2. Application. Medium scale structure.

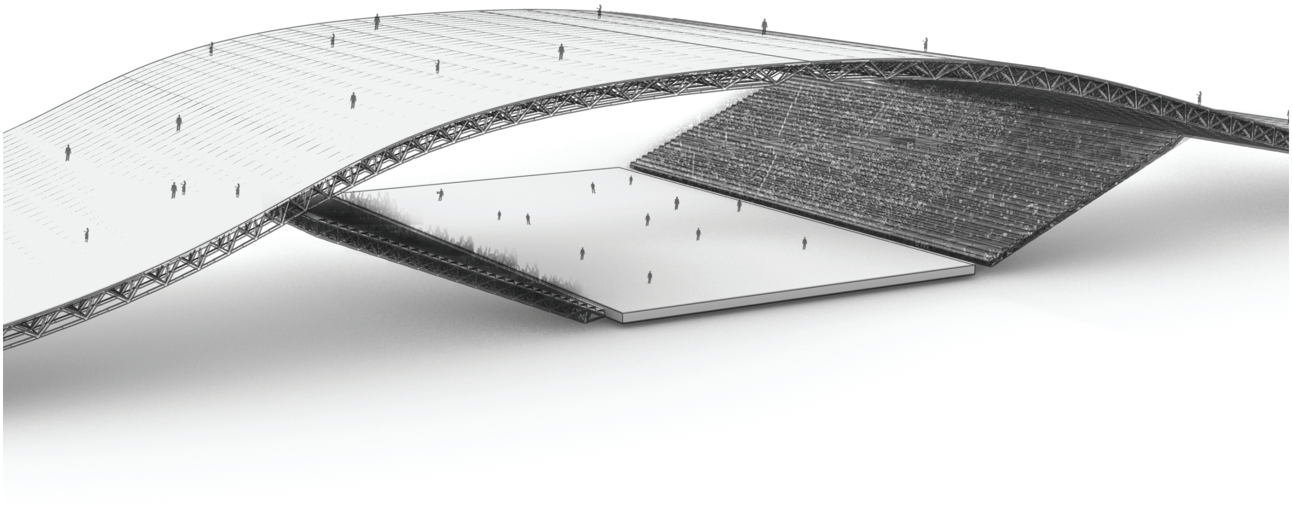


Phase 2. Application. Medium scale structure, showing how the volume of the space can be changed.

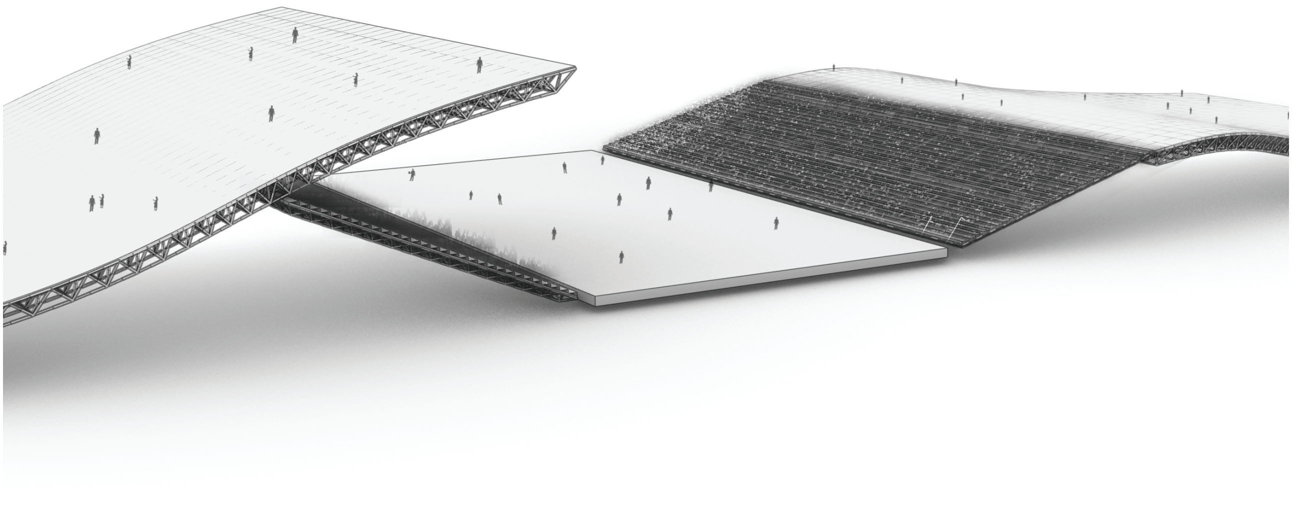


Phase 2. Application. Large scale stadium.

The frame system can not only be used for creating enclosed spaces as a roof or a wall, it can also create a kinetic landscape and transform cities. In this example the system is used in a stadium, were the roof is fully kinetic and also functions as an urban landscape for people to experience. The system can in this example open or close the roof of the stadium which is also being used as a walk bridge for people.



Phase 2. Application. Large scale stadium, closed roof.



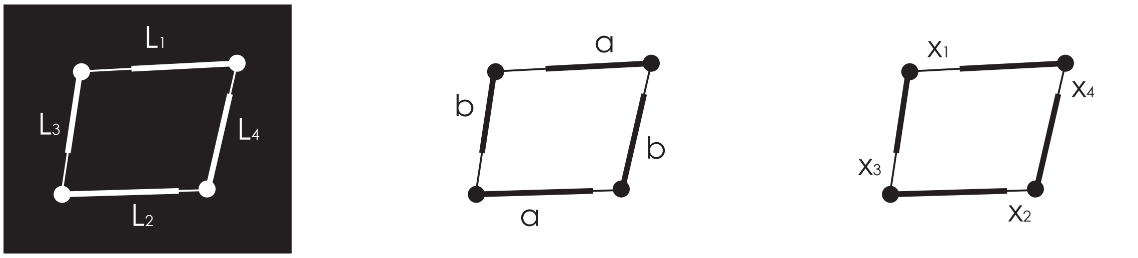
Phase 2. Application. Large scale stadium, open roof.

System Analysis

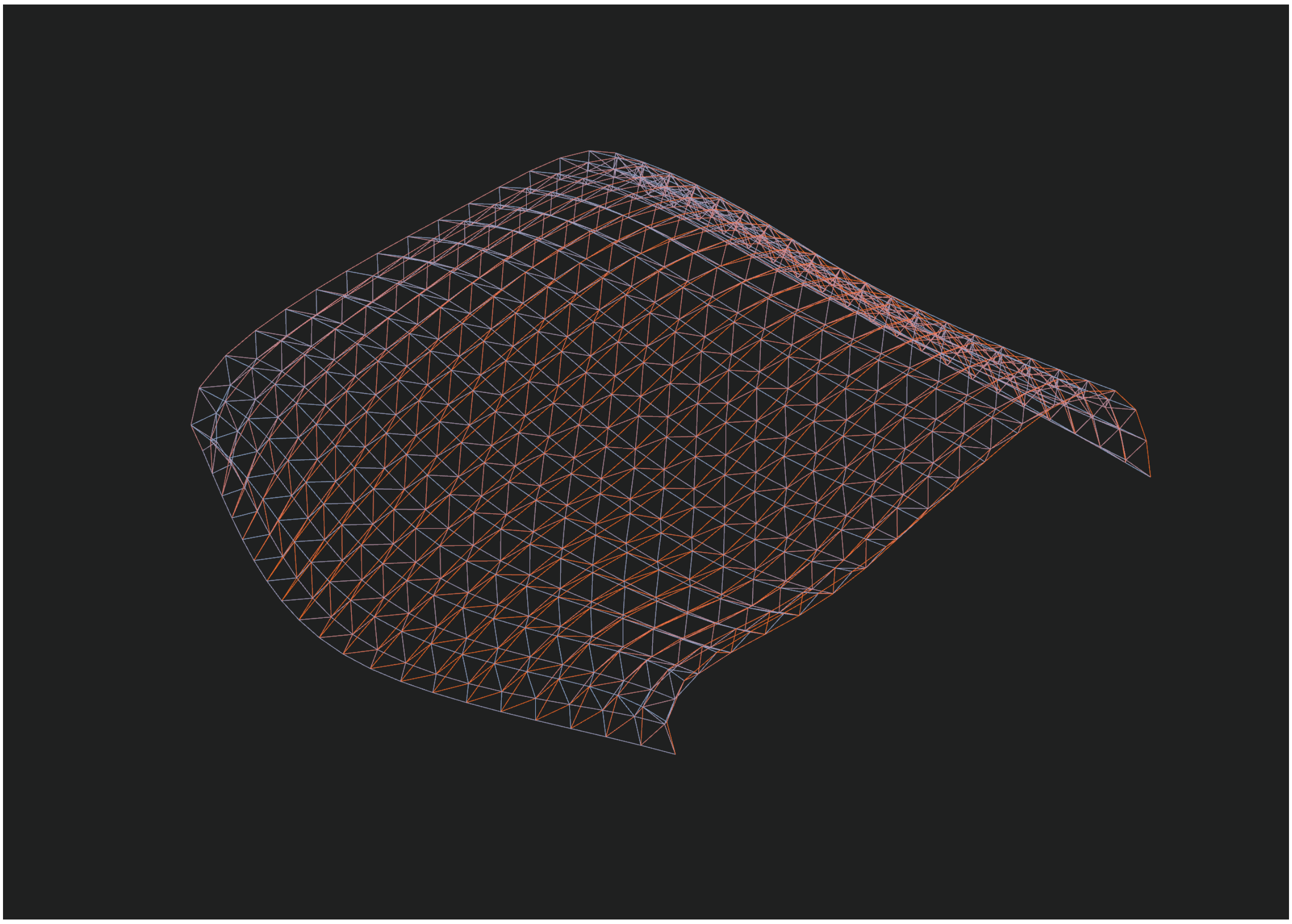
Finding the systems limits and to set dimensions to the structure is done by a three-step analysis of the system.

The first part is to analyse each line element in the space frame and the length of each line. By finding the shortest and the longest element to create a domain for which each other element is within. Every element in the structure will have a set starting length which will be the minimum length of that line element. Based on the length of that starting element, the maximum extension for that line element can then be calculated.

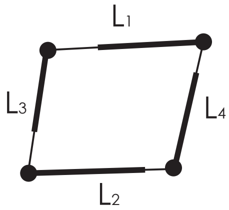
This is done in step two, by grouping all the line elements based on their total lengths and then decide a length for the fixed segment of that element. The final step of the process is to analyse each elements extension and making sure that it is within its limits.



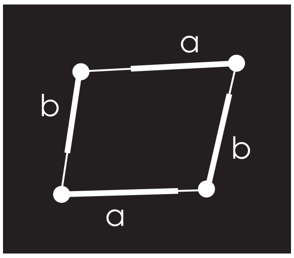
1. Evaluate Length 2. Set Start Length 3. Evaluate Extension



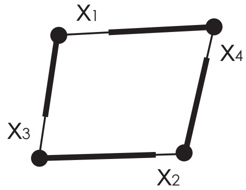
Phase 2. System Analysis. Step 1 - Evaluating line elements.
Showing the length of each line element with a gradient ranging
from blue (shortest) to red (longest).



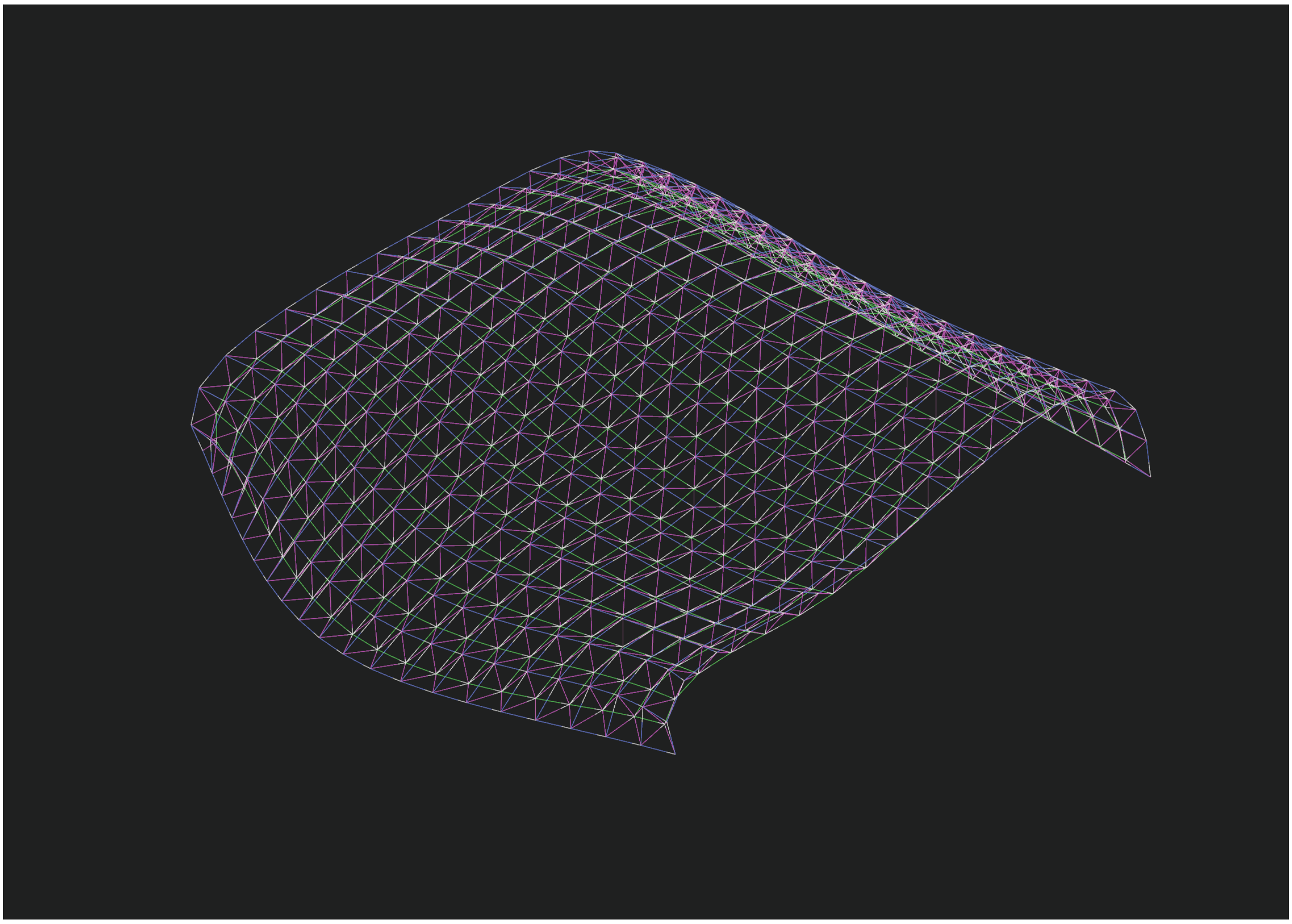
1. Evaluate Length



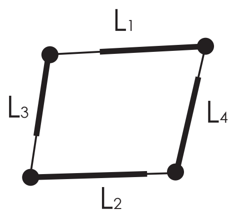
2. Set Start Length



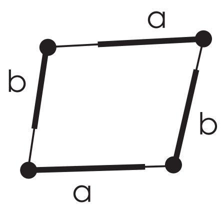
3. Evaluate Extension



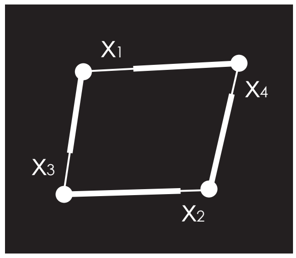
Phase 2. System Analysis. Step 2 - Set Start Length.
Grouping the line elements and set a dimension for each start segment. Showing the lines with the same dimensions for the start segment in the same colours.



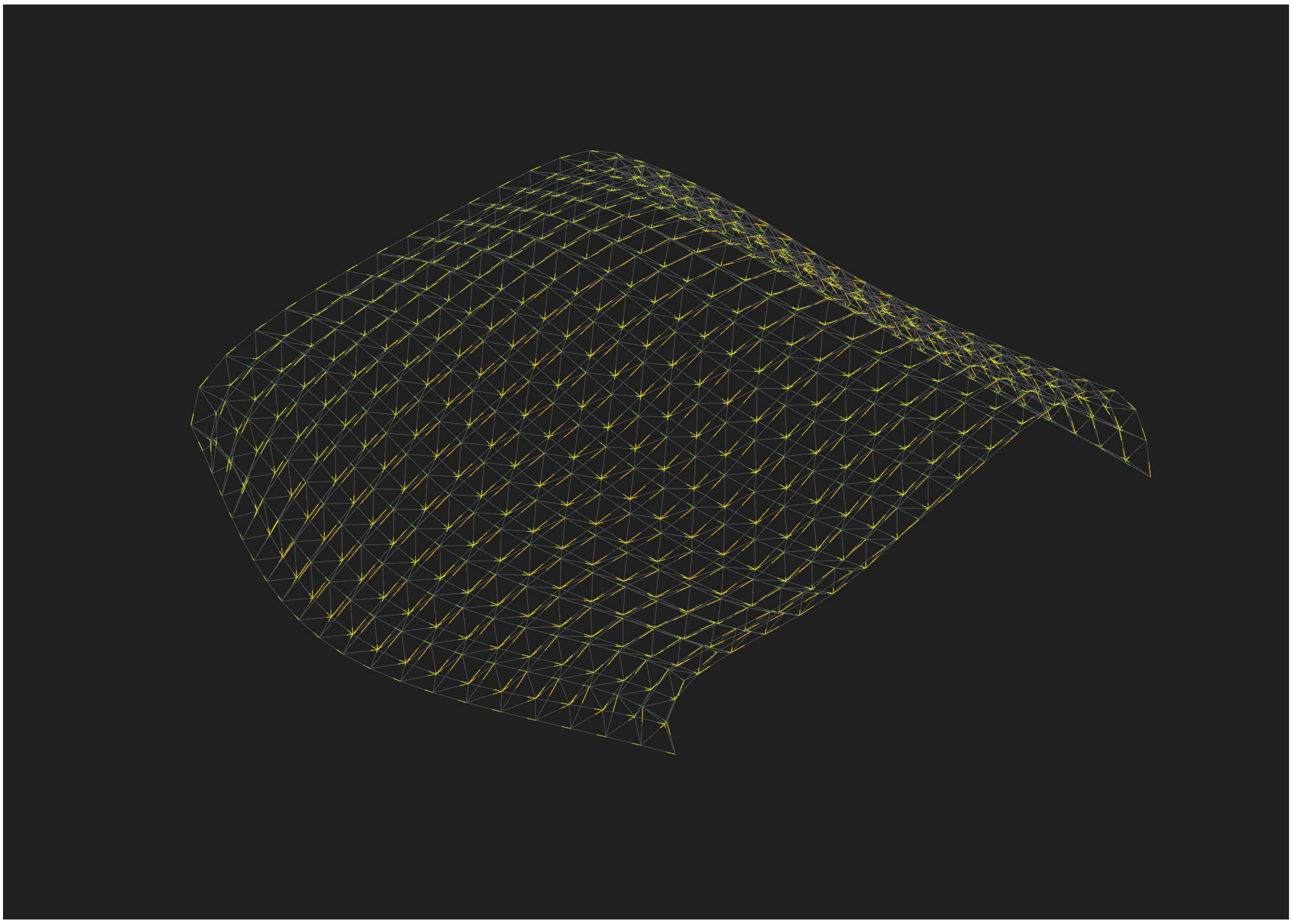
1. Evaluate Length



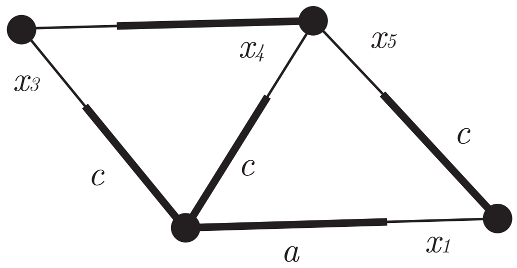
2. Set Start Length



3. Evaluate Extension



Phase 2. System Analysis. Step 3 - Evaluate Extensions. Analysing each line element and checking if the extension of each element is within its limits. This is shown in a gradient ranging from green to orange and displaying elements outside of its limits in red.



$$e = 0.8 \text{ - Extension Factor}$$

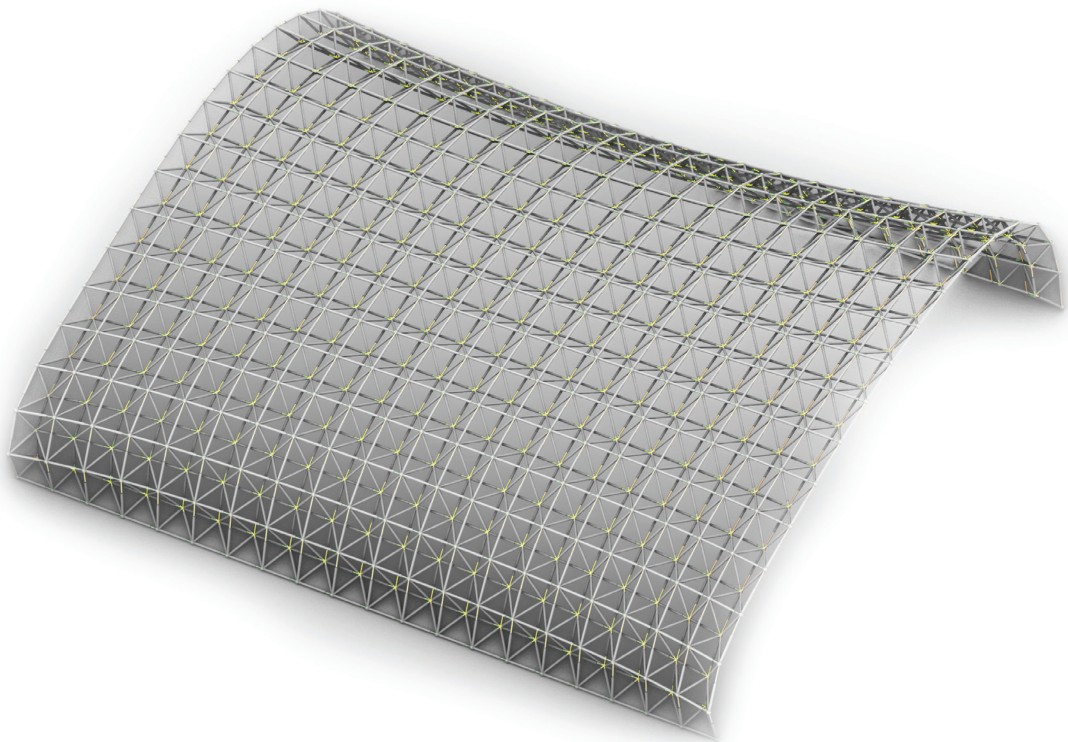
Conditions

$$x_1 < e*a$$
$$x_2 < e*b$$
$$x_3, x_4, x_5 < e*c$$

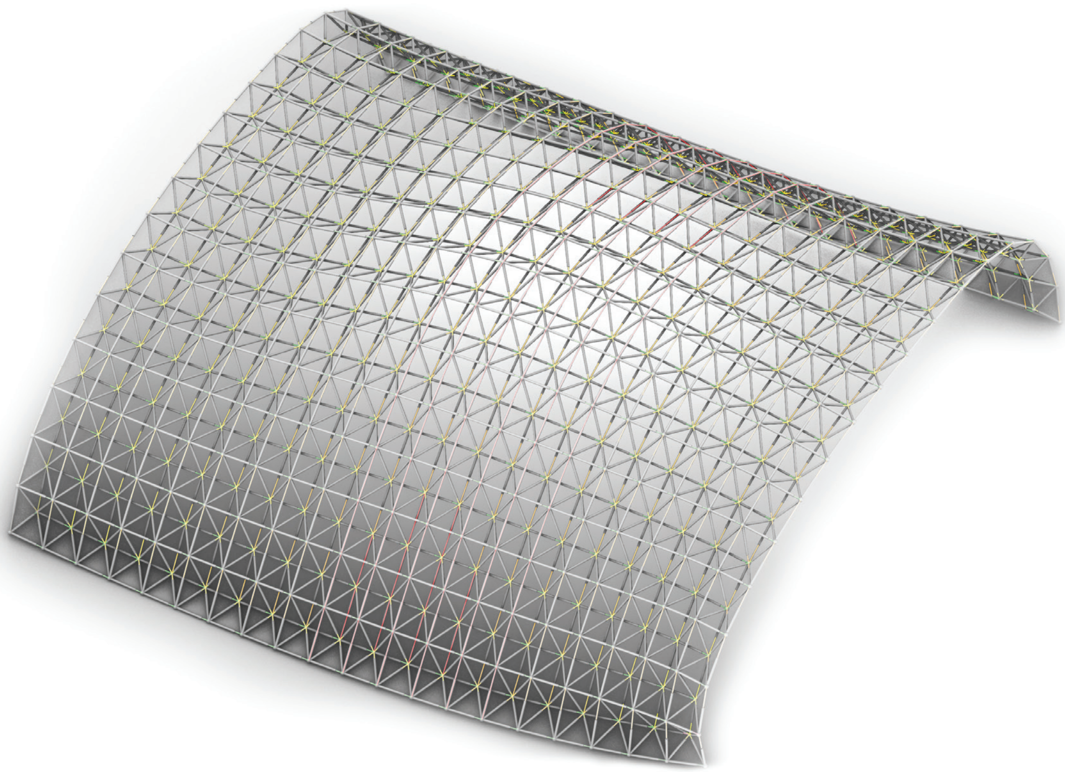
Phase 2. System Analysis.
Diagram of the conditions for each line element or hydraulic cylinder in the system. With the fixed segment described as a,b,c and each extension with x.

To be able to test the boundaries and limits of the system there are some conditions the system must follow. Since each element in the system is a hydraulic cylinder, they all have limits to what they can be extended to. Previously each line element was given a starting length a, b or c, which is the segment of the hydraulic cylinder that is fixed. Each line element or hydraulic cylinder in the system can be extended to some degree, this can be explained with xn.

For example, the length of element a is therefore, la = a + e*x1. With e being the factor of how much each element can extend, in this case e = 0.8. This is so that an element cannot double its length or grow even longer, there is always some overlapping in each hydraulic cylinder.



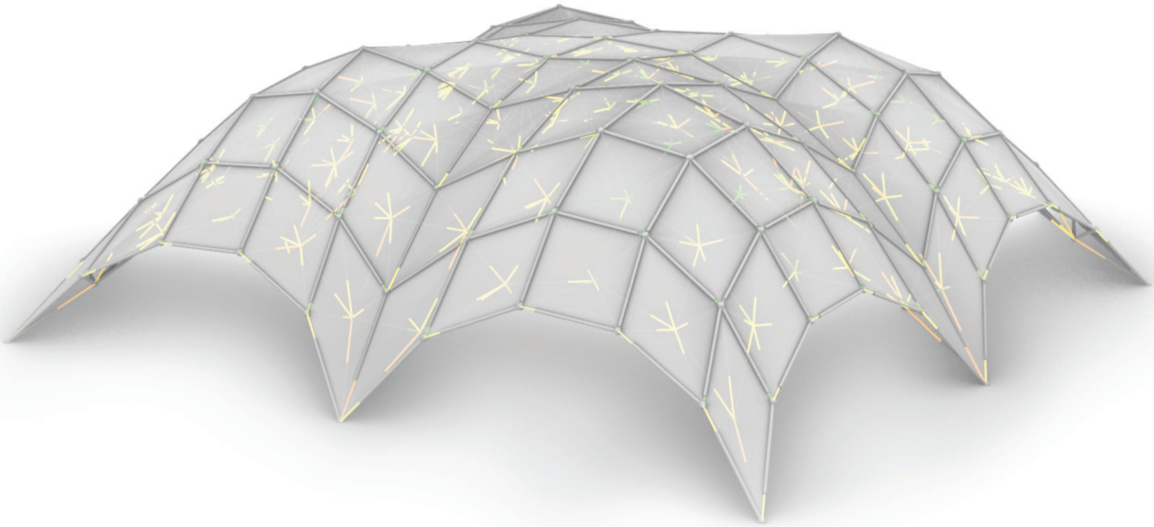
Phase 2. System Analysis. Testing the system - No Errors.



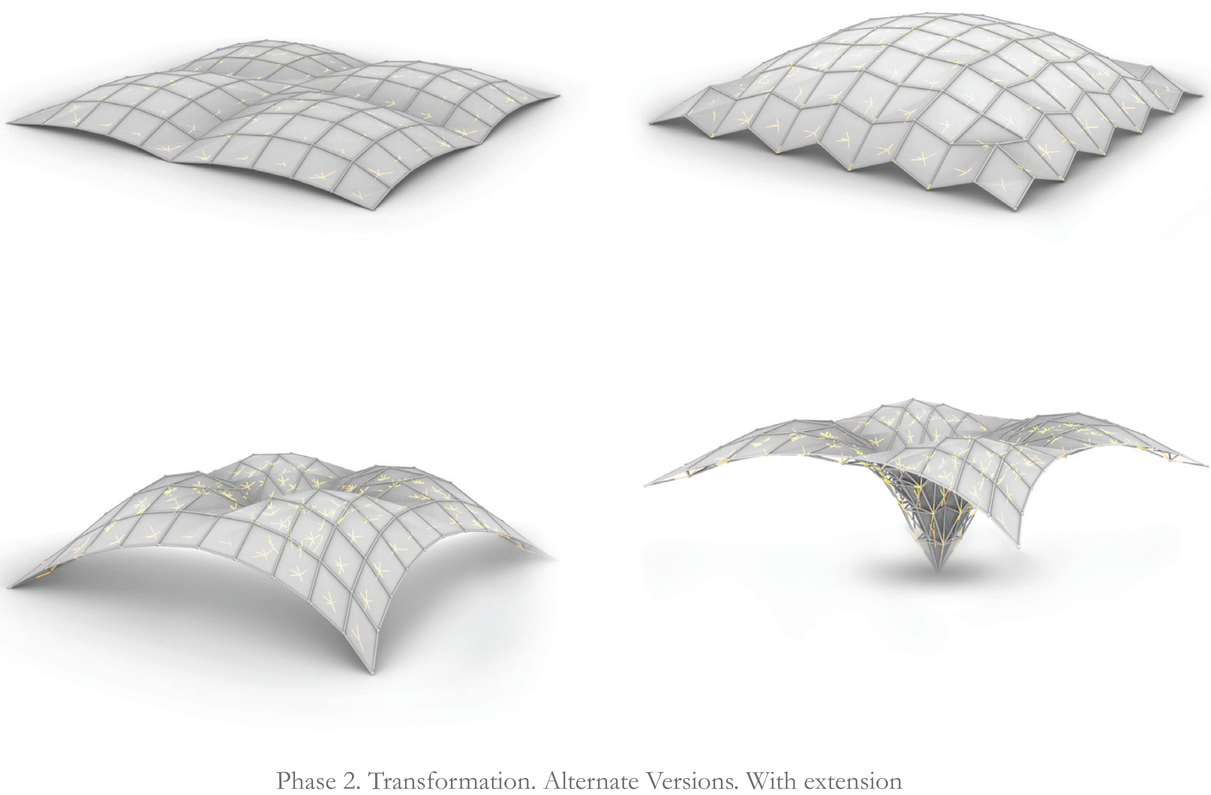
Phase 2. System Analysis. Testing the system - With Errors shown in red.

Transformations

By using the analysis view on the system, to control that the system can take the shape designed without any errors. As well as checking during the transformation if the system can transform between the different shapes. When designing a system that can transform between forms, the analysis described in System Analysis is a key factor for dimensioning the system. Each form that it intends to form must be checked using the same dimensions as well as the transitioning between every form.

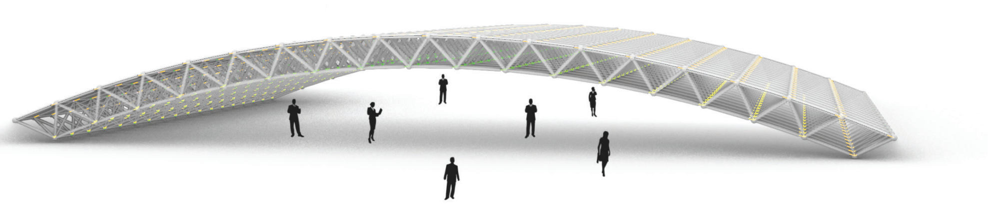


Phase 2. Transformation. Perspective. Showing each elements extension with colour coding from step 2 in System Analysis.

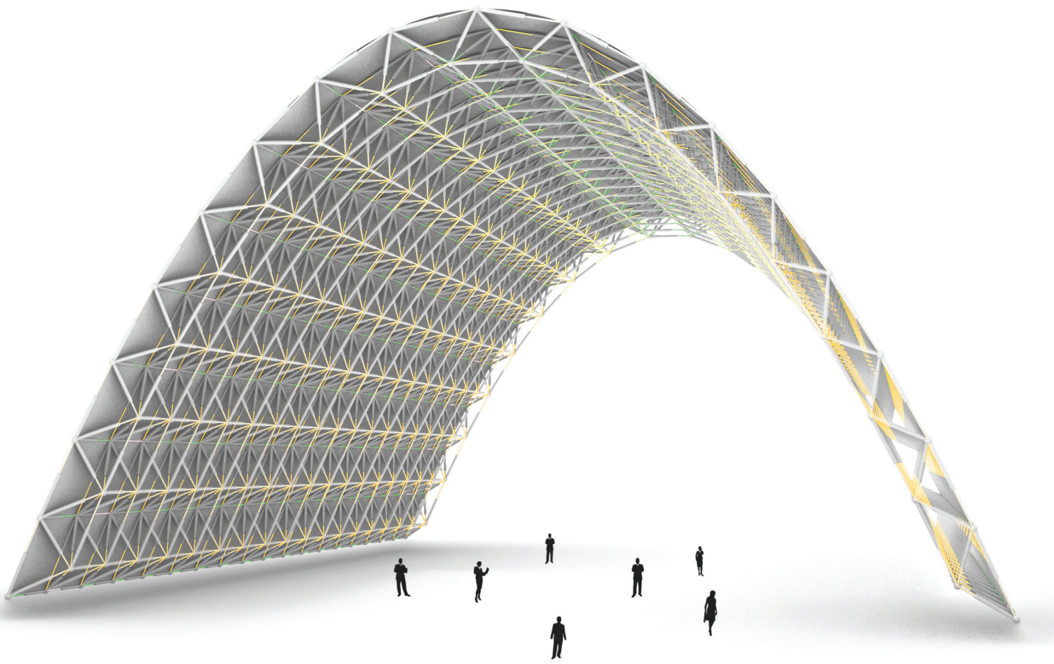


Phase 2. Transformation. Alternate Versions. With extension analysis shown in yellow and green. All shapes are using the same dimensions and can therefore transform into each other.

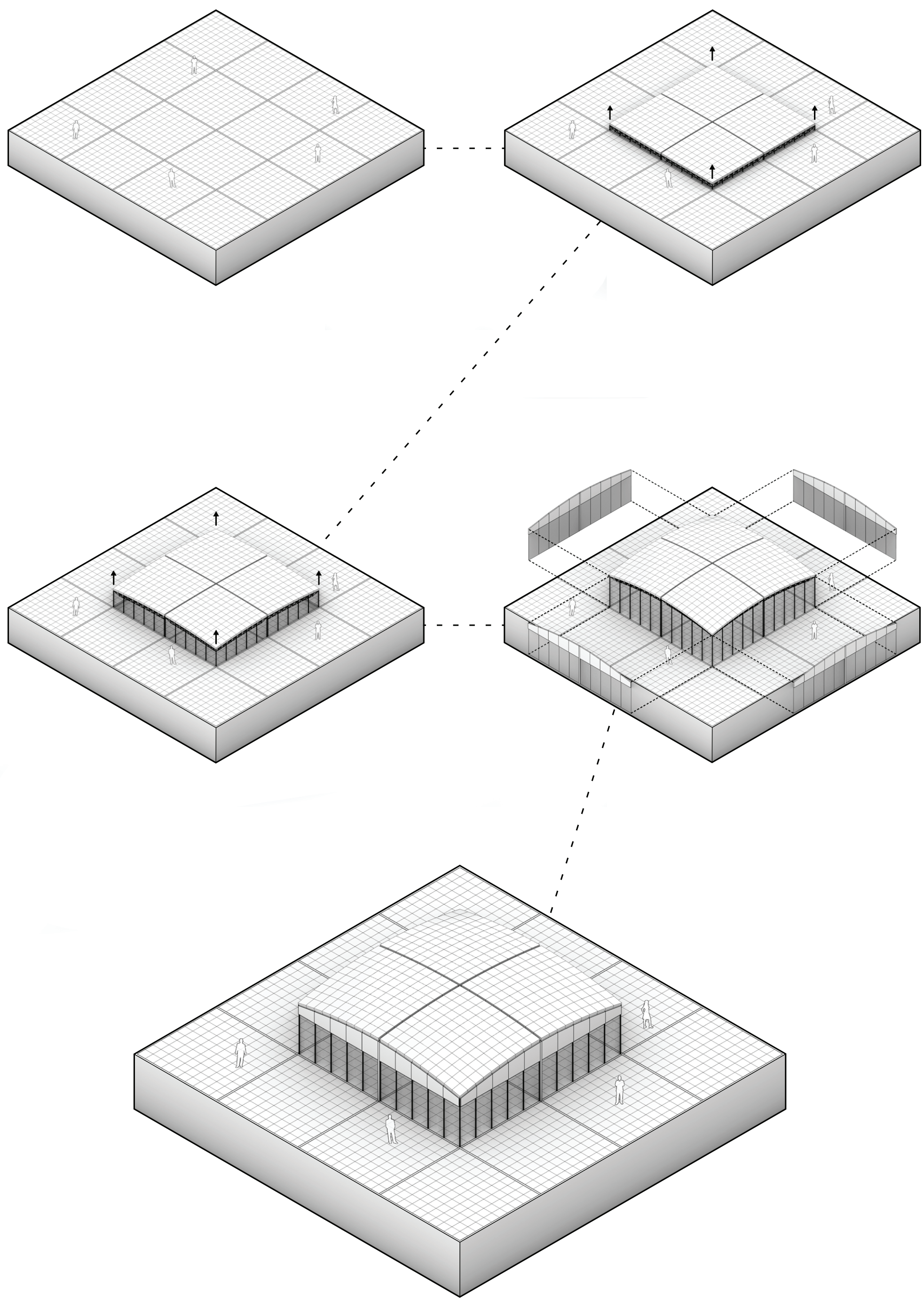
Each element in the system is quite limited to its maximum extension and the transformation is not that drastic in each actuator. However, in a larger system with many actuators that can extend, the system can create very drastic changes to a structure and the spatial experience of that space. In this example the system is used on a simple single curved surface, one shows the system almost fully retracted and as small as possible. The other, pushing the system to its limits by almost fully extending every single actuator.



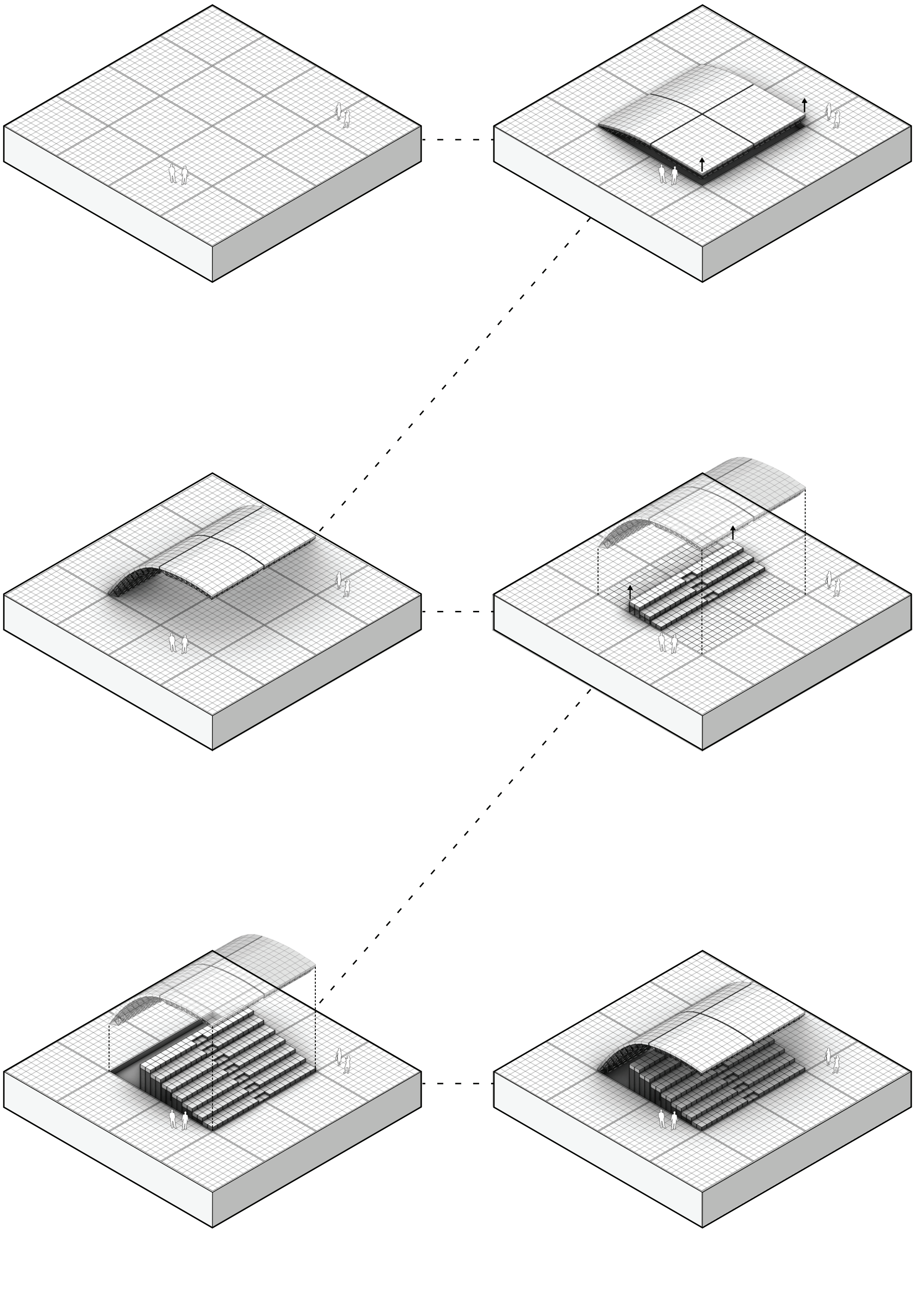
Phase 2. Transformation. Perspective of the system in a fully retracted setting.



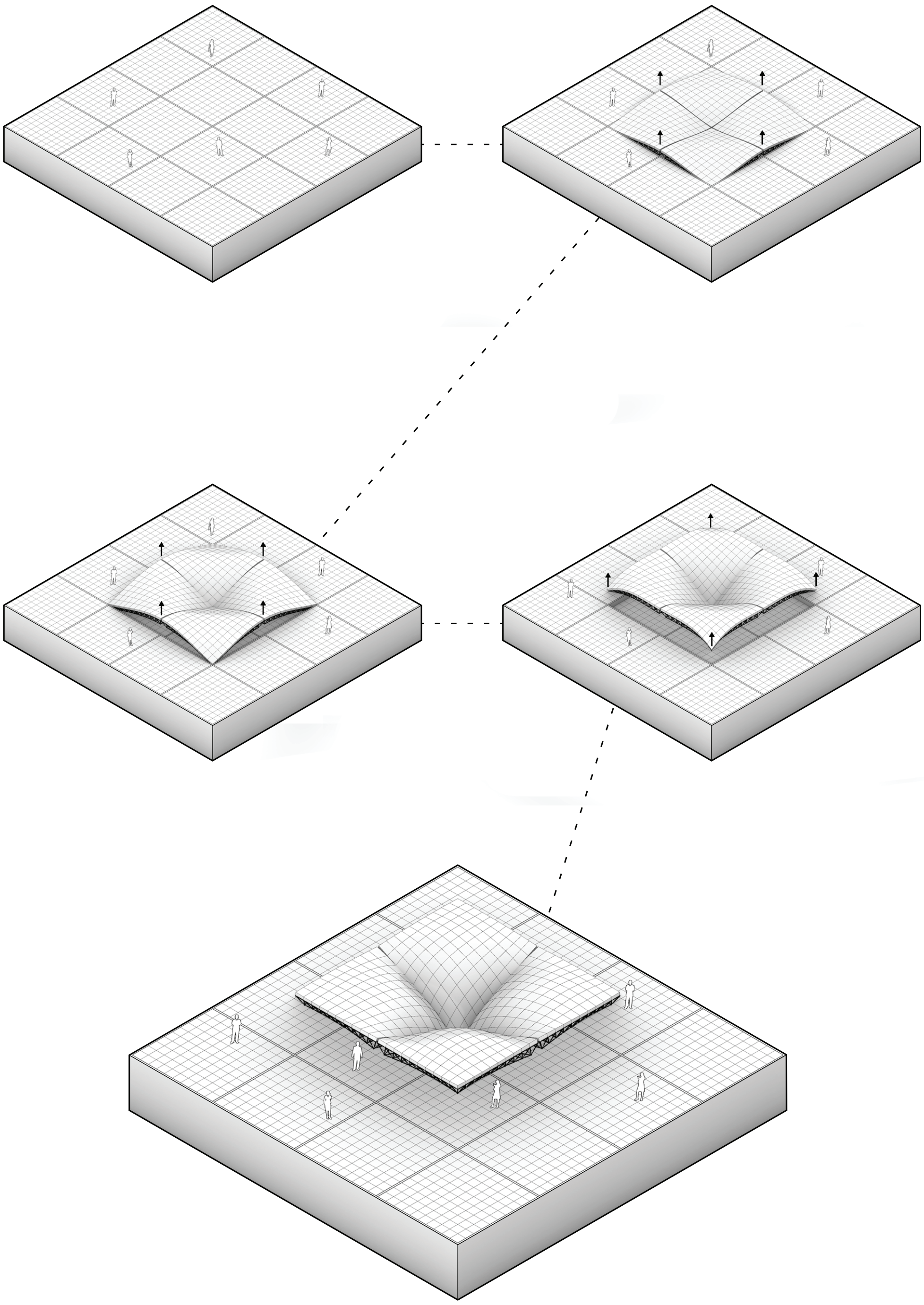
Phase 2. Transformation. Perspective of the system in a fully extended setting. In this example the volume underneath the structure is 8.9 times larger than in the example above using the exact same structure.



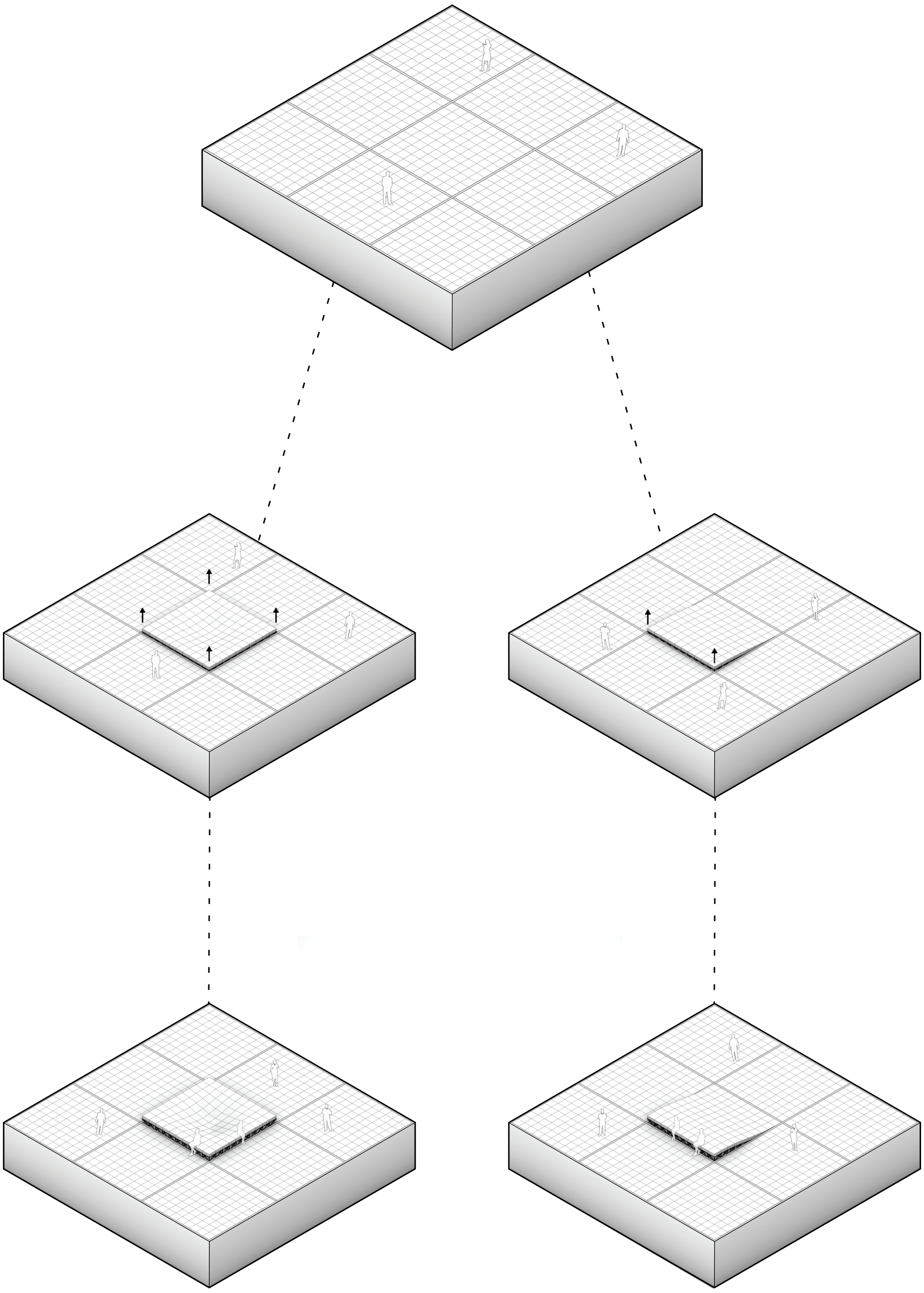
Phase 2. Transformation. Sequence of the transformation of a building.



Phase 2. Transformation. Sequence of the transformation of a stand.



Phase 2. Transformation. Sequence of the transformation of a roof structure.

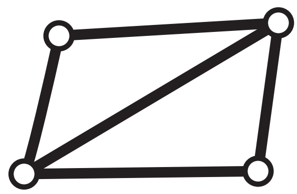


Phase 2. Transformation. Sequence of the transformation of seating's.

Conclusion

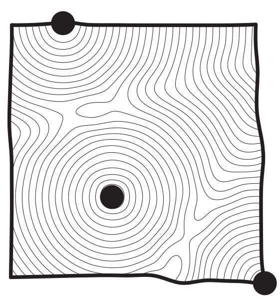
Structure

The very flexible structural system can change both its shape and size quite drastically. This makes it fit into many settings as a modular system with the ability to be used at different scales. Its development was based on a method of how to find the limitations of the structural system and how to work and make designs with it. The creation of analytical tools for the structural system exposed the errors and limits of the structure in terms of its transformation.

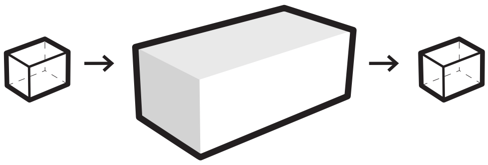


Control

The transformations of the developed system can be controlled in different ways and respond to various interactions by people. This was developed through a method of how to control the structure and what that control means in the real world. The method included development of scripts to control the systems and translations of the different elements in the scripts to real world scenarios and interactions.

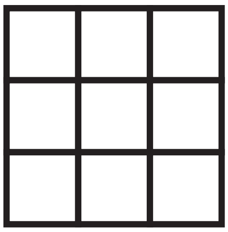


Elements



The limitations of the system can be extended and made more flexible by using different parts and elements that can be substituted either manually or automatically by the system itself. This was developed through a method of how to integrate elements that can be added to the kinetic structure to make it more adaptable for more specific needs.

Grid



The kinetic system can be made more flexible and adjustable by fitting the system into a grid that can be altered in size and dimensions. This was developed by making a modular system with each module working on its own and in combination with the other modules. By making the system modular it will be possible to fit into a variety of settings and adjust the system based on its specific use.

Self-erecting

By making the system self-erecting the structures needed can be created by the system itself without interference from people. This was developed by using the analytical tools to make sure the transformations were possible, as well as determine what triggers the transformations.

Discussion

This thesis explores the idea of a more dynamic architecture, contradictory to the static architecture we are used to. Hence the name of the thesis, Static to Dynamic, with the purpose of exploring how a statically designed space can be made in a dynamic way. Since no space or building is used in a static way, this thesis revolves around the concept of matching the dynamic use of a space in the space itself.

A starting point for this work is the book Kinetic Architecture by William Zuk and Roger H. Clark. They discuss and introduce a lot of concepts of kinetics in architecture that makes the concept a lot more common than you might think. With the fact that in some sense you can say that every single building uses kinetic architecture to some degree. The main reason for using kinetics in architecture that they mention is the ability to catch up with the drastic changes in society. Making the architecture change in unison with the society itself and adapt after its changes. The projects and concepts they mention are mostly not kinetic to that degree, where they can completely transform or adapt. At least not any realized projects and there still are not any examples of that kind of projects today.

Since the book was released 50 years ago, not that much has happened in the field of kinetic architecture. The concepts and ideas they predicted to happen in the future has not yet happened and we have not really taken many steps further. Some more recent innovations in the use of kinetics in dynamic façade systems has been made like the Al Bahar Towers in Abu Dhabi. Systems like this has started to appear more recent, dynamic façade systems that uses kinetics to protect the buildings from mostly weather conditions. These systems are still only kinetic components that are added to a typical static building.

The investigation in this thesis is meant to explore and conceptualise what William Zuk and Roger H. Clark predicted. An architecture that can transform and adapt with the changes of society and not just only by adding elements of kinetic systems to a static building. A great portion of making this design concept involved analysing the structural system and finding its limitations. In kinetic architecture, the limits of the structure are what defines the entire design since it can be anything in between those two boundaries. This has been the biggest challenge of working with kinetics, that you do not exactly know what it will be. The architecture is not designed for one purpose, but for many.

This has had a great impact on the process and the overall time spent on the different parts of the design concept. By dividing the work into three parts, developing the structural system, analysing the system and explore how the system can be applied and used. The development of the actual system and analysing it required more effort and time then I wanted it to. Since the overall purpose of this thesis is to explore how kinetics can be used in architecture and what benefits that might bring. Making the most difficult part of the process to find a good balance between the system and application of the system. To what degree do you have to develop the system before you can apply it? As mentioned before, in kinetic architecture the limits of the system are what decides what it can do. Which means the system needs to be developed to a certain degree to find those limitations before the investigation of what it can do.

I think this thinking has had a big impact on my overall result and process. The work became divided into two parts, the system and the application of the system. With the system perhaps taking a bit too much time and effort in the process. Due to this the final proposal of the concept came quite late in the process and some areas of the design was not completely developed as I wished it would have been. One aspect would have been to take the design to a more individual level and explore how one person would interact with the space. The scenarios created are a way of showing how the system can be used in a daily use and to show how the people would use the system. Showing the possibilities and benefits of a dynamic space instead of a static space.

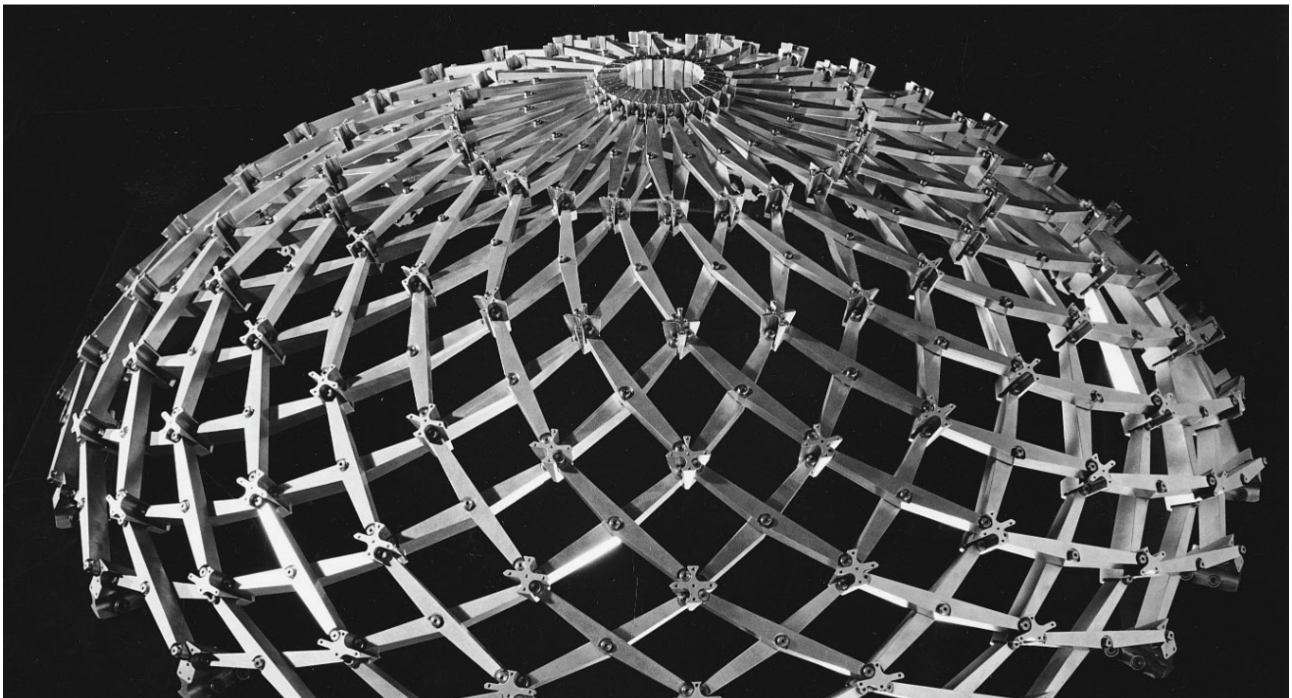
References

Chuck Hoberman

An artist, architect, engineer and inventor of the famous Hoberman Sphere. His work combines art, architecture and structure in foldable and adaptable structures. In 1990 he founded Hoberman Associates, who are now focusing on transformable designs and have many patents for folding systems.

Chuck Hoberman and his work is a great inspiration for how to design transformable structures. Some of his work can have quite a vast transformation, like the Hoberman Sphere transforming from a sphere with a diameter of 23 cm to 76 cm.

5 Expanding Geodesic Dome, Chuck Hoberman



6 Iris Dome (1994), Chuck Hoberman

The Shed, Diller Scofidio + Renfro, New York

The Shed in New York is an example of a project using kinetics to transform a space after its needs. Featuring a big glass shed on rails sliding out over a square, transforming the space and the building doubling its footprint. The building is used as a home for different types of arts, with music performances and exhibitions. Using the transformed space to accommodate a larger audience when it is needed.

This project uses kinetic architecture to transform spaces and change the building itself after what is needed. Mechanically it is quite simple with a large shell structure sliding on rails. However, the transformation offers a substantial change within the building and the public space being transformed to a usable private space.

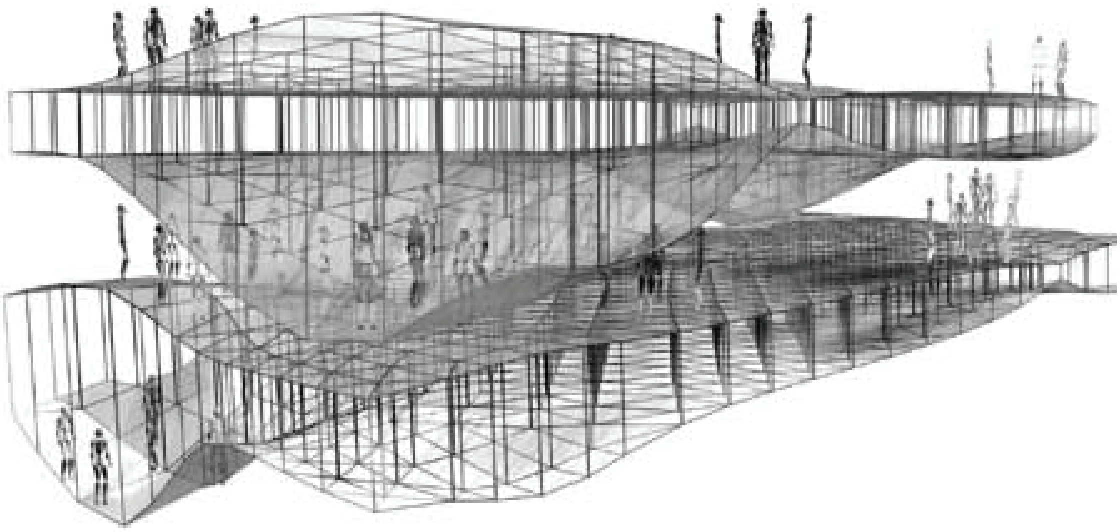
7 The Shed, New York

8 The Shed, New York, Photo of the wheels.

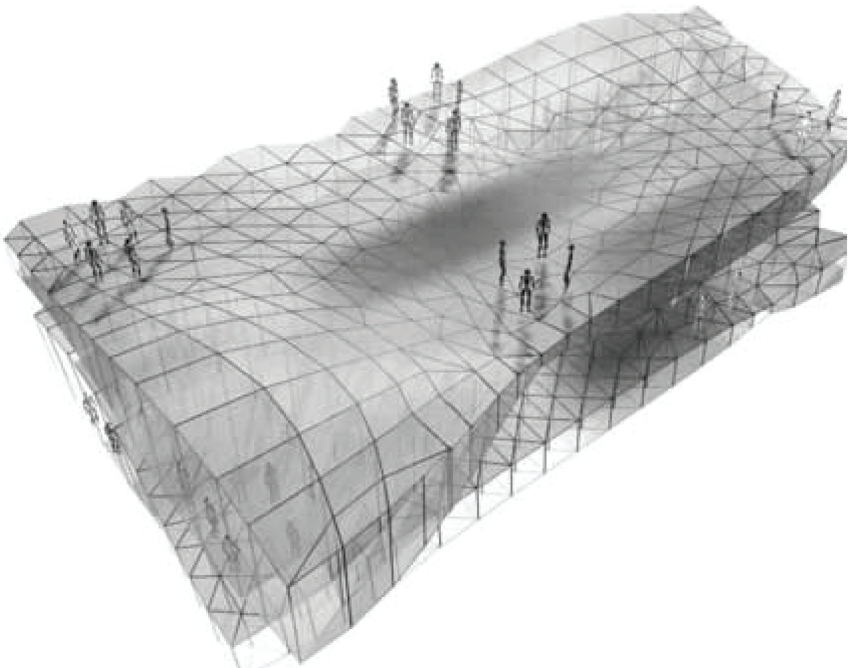
Topotransegrity, Robert Neumayr

Topotransegrity is a project investigating how responsive and kinetic architecture can be used in the public space. Challenging the assumptions of architecture as something passive and exploring the impact this would have on the urban public life. Constructed of a kinetic structure, Topotransegrity can reconfigure itself and adapt to fit certain spatial requirements. The transformation can be smaller surface deformations or a large deformation, creating temporary enclosures and spaces.

Topotransegrity has different ways of interaction with the users, it can respond in real time to behavioural patterns and movement. It can also be a predetermined transformation, the structure can be programmed to change for a specific need.



9 Topotransegrity, Robert Neumayr



10 Topotransegrity, Robert Neumayr

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