A FORM OF MOVEMENT

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A FORM OF MOVEMENT:
The relationship between form and movement in a digital world

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Abstract

The aim of this thesis is to investigate if a deeper relation between form and movement can be achieved and strengthened with the help of digital tools. The work consists of three phases, starting with a foundation of interdisciplinary research regarding different theories about form and movement. These are then used as a broad toolset for experimenting with a physical proposal. In the second phase, a site and function is established as an arena for this experimentation to take place. This constitutes a cafe/study space in an old industrial building in Malmö, Sweden. During this phase a comprehensive folding topology is developed and executed with the help of parametric tools.

The third phase deals with different ways of breaking down the form derived from the previous phase into smaller subdivisions. These subdivisions embody movement in different ways and are designed to generate several constructable outputs where manufacturing, construction, cost and other real world parameters are a vital part of the process.

This project deals with continuity of geometry and material, altered perception and motion throughout different scales.

Keywords: Movement, Motion, Digital tools, Parametric design, Folding, Origami, topology, geometry

Table of contents

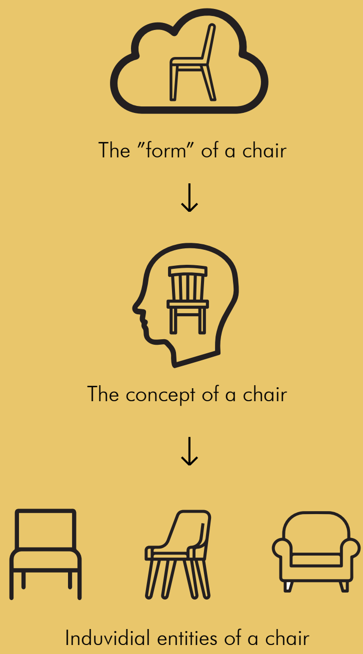
PHASE 1
Interdisciplinary research

The purpose of this phase is to look at a number of different theories regarding form, movement and digital design.

Platonic theory of forms

Asking oneself what the ideal version of something is could feel somewhat dissonant to the way we approach things in today's society. Plato did this some 2400 years ago (Nordin, 2017). In his dialogue "Republic" from around the year 375 BC he claimed that this is one of the most useful thought experiments we can execute. It's only when we have a perfect ideal of something that we can start to define problems and improve. Plato called this concept of ideals "forms". These forms are the higher essence of things, the non-physical or sensible ideas of them. Objects and matter in the physical world are merely imitations of these forms. He argued that pursuing a perfect form is essential to acquire knowledge (Nordin, 2017).

Early Greek concepts of form were mainly based around vision, sight and appearance. Plato introduced the forms as an ideal beyond that. Someone building a hut would in the platonic scheme need to acquire a form of this - an ideal hut. This person would have grasped the form of hut-building. The hut could then be assembled by breaking down the platonic form into some means of constructional elements. If in this example these elements were that of twigs, the combination of elements would generate a form. This form of a hut made out of entwined twigs would be a physical attempt to replicate the platonic form of a twig-hut (Nordin, 2017).



Plato’s Cave

In one famous attempt to visualise the lack of truth in how we perceive forms Plato uses a hypothetical cave as an example. A group of chained prisoners are sitting with their backs towards the opening of the cave and their faces turned towards the opposite rock face. Between them and the opening is a fire burning. Between the fire and the prisoners are a group of other people walking by with various shapes of animals and objects. As the objects cast shadows on the cave wall the chained prisoners discuss their appearance.

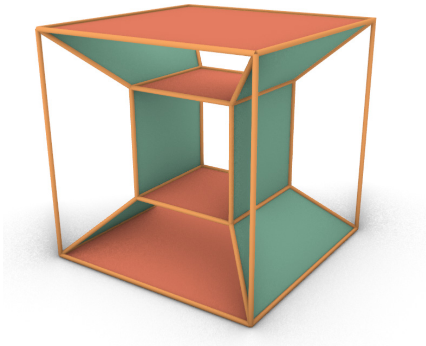
The prisoners’ only knowledge of the world or the objects are that of the shadows on the wall. If one of them were to break free and look in the opposite direction he would see the real objects and realise his world-view and knowledge of form were highly distorted. The revelations acquired looking in the opposite direction would also be very difficult to explain to the other prisoners (Nordin, 2017).

Plato uses this scene to claim that the objects in the sensory world are merely incomplete abstractions of the real existing truth, the ideas. The prisoners can be interpreted as ordinary people trapped in the world of false sensory perception. In the same way the shadows could symbolise the incomplete appearance of what Plato calls real forms (Theself, 1990).

Figure.1: Platos allegory of the cave

Four-dimensional-space

Another approach on the matter of understanding our human incompetence in perceiving form could be in the realm of physics. The inability we share to fully grasp our surroundings could be illuminated by the theory of multi-dimensional-space. This mathematical concept was established in the mid 1800-century and popularised by Charles Hinton some 50 years later. Hinton claimed that there's a mathematical possibility of higher dimensional space than the 3 dimensions we as humans can experience. He visualises this with a four-dimensional-cube that he named a "tesseract" (Hinton, 1998).



The tesseract can be unfolded into eight cubes into 3D space, just as the cube can be unfolded into six squares into 2D space.

Our human inability to experience the true form of these four dimensions could be compared to a video game. A character living in a two dimensional video game can only experience two dimensions. If we were to explain that the two-sided squares on which he stands are actually six-sided cubes he would not be able to see this. One could argue that he could grasp the idea of the form, but he could only experience it from his 2-dimensional world. The "true form" would be an idea beyond his perception.

The form of movement

To further grasp our perception of form one could approach it by observing how it constitutes in our most natural environment. When looking at where we come from, how we've lived and the nature of nature itself one can easily come to the conclusion that it's highly dynamic. The tree canopies sway like ever-changing ceiling elements over our walk through a forest. Thousands of leaves reflect, absorb and redirect the light on to the never ending spectrum of vibrating biological matter.

It's in spaces like this that we have evolved through evolution. It's in those scenes we have become who we are. Humans not only derive from nature but have been living in these environments for the better part of our history. As an extension one could argue that we have been living in non-static environments. Most of our cognition was developed over 10 000 years ago, which also means that our current cognitive abilities have been developed in dynamic environments (Harari, 2015).

Despite this our thoughts about form and architecture can easily be put in the realms of control and stability. The idea of static permanence. Something we construct to remain, an anchor on the ground. Architecture and movement combined are for many only relatable to vacation and transportation. Caravans, tents or sleeping pods in night-trains. Watching a wall come to life in your living-room may seem like something that belongs in a science-fiction movie or a horrific storm.

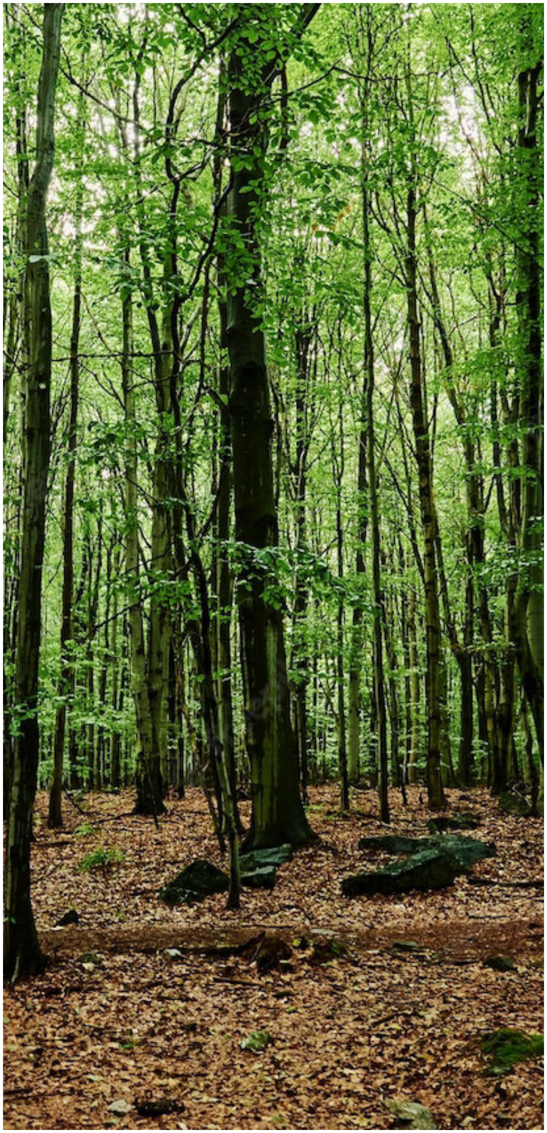


Figure.2: Dynamic environment

Movement in Architecture Vocabulary

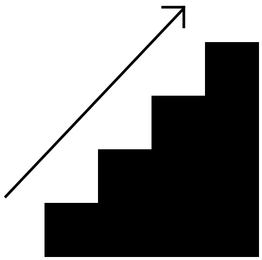
When we speak of movement in architecture it can house a plethora of different definitions. People physically moving themselves through designed space, wind blowing through a kitchen, elements pointing in a specific direction, repetitiveness, patterns, symmetries - the list goes on. The way we think about and address movement in architecture without referring to the physical relocating of ourselves, could be a result of our language (Forty, 2004).

Adrian Forty wrote in 2004 that this abstract approach to movement is a conventional part of modernist thinking. In his book “Words and Architecture - A vocabulary of modern architecture ” he examines the complex relationship between language and architecture. Adrian argues that words describe more than their factual meaning and actually direct the ways we live with and think of buildings. He points out that it’s widely taken for granted that forms can imply motion that are not themselves in motion. According to him this way of speaking about movement has directly affected how we experience movement (Forty, 2004)

Contained and represented movement

Observing this vocabulary surrounding expressed sensed movement Adam Hardy has in his paper titled "The expression of movement in architecture" identified two main language categories. These are those of "contained" and "represented" movements. Contained movement can be described as imaginative movement *in* the architecture. As an example when you read movement from a stair, imagining someone going up or down. It's not the architecture in itself that is thought of as moving. Instead it's the mind, with imagined bodies, forces etc.

Represented movement on the other hand illustrates the architecture as moving or a creator of the illusion of movement. Hardy describes a movement to be represented when the mind's eye can imagine a part of a building being transformed or passed through various stages of metamorphosis (Hardy, 2011).



Contained movement

Represented movement

Body vs Movement

A more bodily approach on how we deal with movement is that of August Schmarsow. He argued in his book ”The Essence of Architectural Creation” from 1893 that we are unable to express our relation to the built without imagining ourselves in motion. Thereby claiming that our perception of space is based upon the projection of bodily sensations. He argues that we always measure length, width and depth in relation to ourselves. Alternatively, we attribute static lines, surfaces and volumes the movements corresponding to our own kinesthetic ones. This happens regardless if we experience it from a static position or not (Schmarsow, 1893).

Literal translation of motion

Kari Jormakka writes in his bok “Flying Dutchmen” that the aim to mimic movement by implicating stream-lined forms has become somewhat conventional in today’s practice. He sees this as a failure since in his words you try to “spatialize time”, comparing it to music notation (Jormakka, 2002). One could assume that he’s referring to the very literal way music is translated into notes, leaving out a better part of the experience as a whole. He argues that parts of the digital based architecture field is approaching form in this way. In particular styles that are synonymous with double-bent surfaces and smoothness. These are, according to Jormakka, often a too literal way of translating movement to physical form (Jormakka, 2002).

Parametric movement

Jormakka claims that the road to successful results lies in the exploration of dynamic collaboration between fields and forces. A way to come about this is by using parametric design tools (Jormakka, 2002). This should not, according to him, be done by blindly translating movement to form but to let different parameters control the form.

This approach is somewhat similar to the one proclaimed by Greg Lynn in his book "Animate form" from 1999. He claims that the use of parametric tools shall derive from forces. These forces could be that of gravitational or thermal, if not even social. If one were to instead be working with visual, alleged muscular or spiritual elements the result will falter (Lynn, 1999). He points out the great potential in the alteration of form with various forces simultaneously. This he says, could create a "virtual" movement that alternately has been altered by different elements.

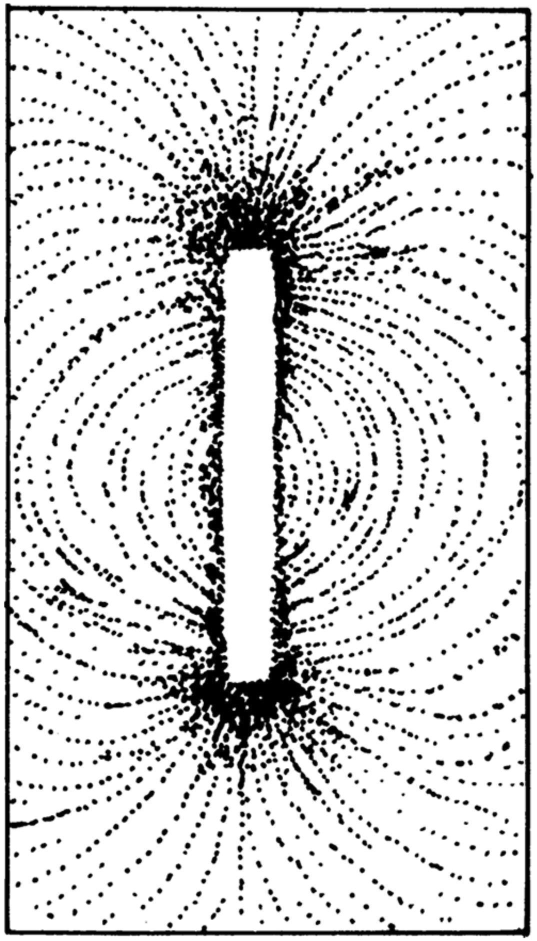


Illustration of a magnetic force in a magnetic field

Simplexity

Another risk in the exploration of algorithmic design and parametric tools is that it can result in unnecessary complexity. Tomoko Sakamoto investigates the relation between simplicity and complexity in his book "from control to design" (Sakomoto, 2008). The term "simplexity" is used to describe this relation. He claims that an ever-occurring tendency in parametric design is the production of extra unnecessary layers of complexity. This is not done in any beneficial way for the project but for the production of seemingly more complex forms.

To steer away from this unnecessary branching of intricate layering is not an easy thing to achieve. Parametric tools have unlimited capabilities to make complex systems more accessible to human intuition and thought. They unfortunately also have the capability to do the exact opposite. Sakomoto propose "a deeper understanding of the system on which the operations are carried out" to battle this dilemma. Parametric design deals with things as omitting elements, reduction, selection and abstraction. This, according to Sakomoto requires intelligent and responsible choices to be made through the process (Sakomoto, 2008).

Folding movement

A topological approach to combine form and motion is that of folding. The most important establishments of theories regarding this are often credited to the theoreticians and philosophers Gottfried Wilhelm von Leibniz, Paul-Michel Foucault and Gilles Deleuze. They commonly considered the act of folding as a concept that inhabited layering and multiplication, fluid interlacing, infinite continuity and motion (Abdolahzadeh, 2017).

Leibniz was focused on relativity and that nothing is independent by itself. He argued that everything that exists is “a moment’s graduation” of something else and that the world is a constant “becoming” where everything moves from one state to another (Deleuze, 1992). In this agreed unbounded congruency the world is constantly enfolding in itself. Each part is characterized by the individuality of the next in this structure. Everything is related and self-comparative. In this sense, a plane is a line in motion and a line is a point in motion (Deleuze, 1992).

Gilles Deleuze argued that by using folds “the outside” is transformed from a fixed limit to a moving matter. He uses the term “peristaltic movements” to describe the folding as an animator of a structure. The inside becomes nothing other than the outside, everything is the “inside of the outside” (Deleuze, 1992)

Although widely known as a deconstructivist, architect Peter Eisenman has expressed his beliefs in folding as a design tool. Deconstructive design uses inconsistency and conflict while folding architecture examines fluidity and network (Lynn, 1995). Eisenman put emphasis on its sheltering, functional, aesthetical and framing abilities. Moreover he claims that folding enables a shift from effective to affective (Schramke, 2016).

The Heydar Aliyev Centre

The folding of inside and outside, city and building can be examined in the Heydar Aliyev Centre in Baku, Azerbaijan. It was constructed in 2013 and designed by Zaha Hadid architects. It has been described by Zaha herself as a number of combined experimental “fluid space” structures (Abdolahzadeh, 2017). This aggregation of soft folds multiply and interlace all architectural members which generates movement from one form to another, seamlessly.

The extroverted ripple creases, highly visible from the exterior, folds fluidly but aggressively from the ground and becomes several walls and roofs until it softly unfolds again. This metamorphosis sets the whole structure in motion, creating a continuity that endlessly interconnects. The bifurcation - its changes in topology by a family of curvilinear trajectories, blurs the boundary between structure and urban environment, envelope and context, figure and ground.

Figure.3: The Heydar Aliyev Center

PHASE 2

Investigation and experiment

The purpose of the second phase is to investigate and experiment with the implications movement has on form. This was done by first establishing a site and a function in which the experimentation would take place.

Once these were decided I could begin to develop a form that would derive from the different movements affecting the site and function. Subsequently I subdivided this form even further and represented it with different kinds of movement in different scales.

The site

Panncentralen is an abandoned industrial building constructed in 1914. Its located in the middle of a grand industrial complex called "Lokstallarna'' in Kirseberg, Malmö. The area houses six main workshops which were used for locomotive maintenance on the complete Swedish train network. The largest carrier-workshop has a footprint of 16 000 m2. Panncentralen covers roughly 500 m2 and is constructed with the same red brick tiles as the rest of the buildings in the area.

The building consists of two main halls, with the largest covering roughly two thirds of the whole area. This almost cubical space has a number of distinct features such as nearly six metre high arched windows.

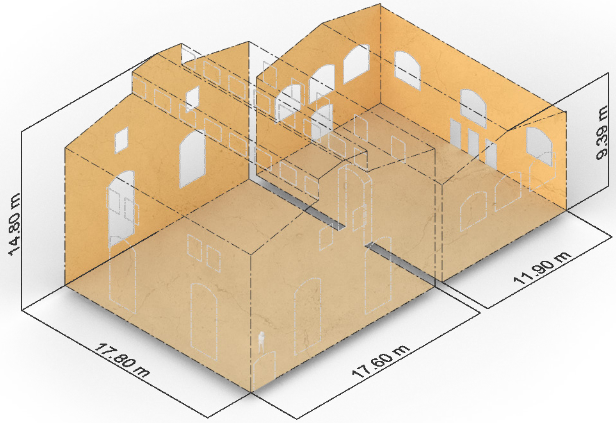
Figure.4: Aerial view of lokstallarna

The function

Lokstallarna has in recent years become a development for new cultural enterprises. Exhibitions, festivals, workshops, seminars, movie productions and restaurants which can be found scattered across the rusty train tracks. With this in mind I decided that panncentralen would be a perfect place for a cafe, study and work space. As we move further into the digital age with nomadic laptop-lifestyles a welcoming central workplace is needed. A substitution for the kitchen tables on which a lot of work is done by the common Malmö inhabitant, during pandemics or not.

The form

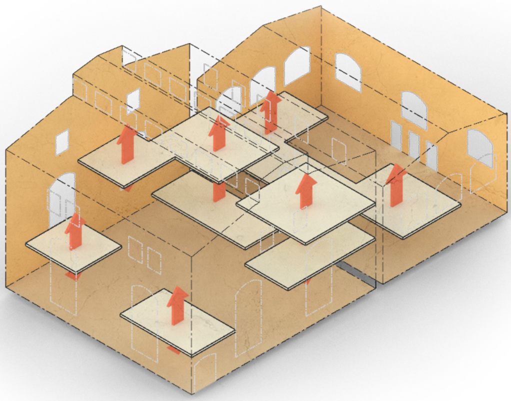
The main hall is in many ways a vertical space. The ceiling height reach almost 15 meters and 9.4 meters in the smaller hall. At the highest roof ridge a ribbon of window openings run along the east/west axis. A handfull of six meter tall windows illuminates the space from three directions and facing east stands an uninterrupted wall.



Measurements

Platforms

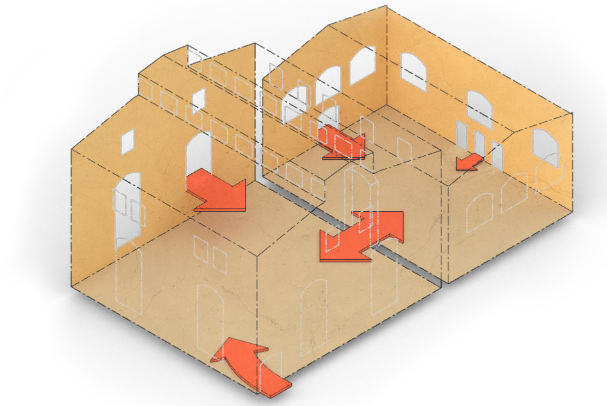
Early in the design process I wanted to take advantage of the hall's abundance in verticality which had unlimited access to daylight from all directions. Combining these features with the core elements of the function was therefore crucial. These features include different ways of sitting, eating, working and studying. I started to work with platforms, on which these central points of the function would take place. Moving between these platforms would be one of the most important aspects of experiencing the different spaces within the environment.



Platforms

Placing the platforms along each interior wall solved a lot of problems, not just those of pure constructional matter. It opened up a space in the middle of the hall, ocularly connecting the different floors to each other. This offers a readability of the form as a whole in and from many different directions.

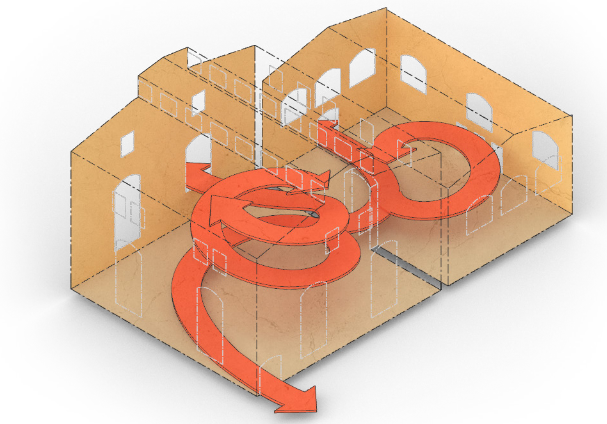
The next natural step in the process was to alter and adjust the platforms vertically, adding a layer of intricacy to the arrangement. I realised I could use one of the windows in the west facade to help me make decisions regarding overall proportions. The right window had previously been cut in half in favour of some extensional buildings. As a result of this the opening starts one natural floor height above the ground level. By placing a platform in front of the opening, an entry can be introduced. This would allow new movement to be added to the flow of the arrangement.



Entry points

A "force" as Greg Lynn could have described it is established that bends the form according to its strength. By moving hypothetically from the new opening and the pre-existing doorway in the south facade, a circular and vertical movement started to form inside the industrial hall. I use this momentum as a guide to proportionally add a third main floor above the previous.

A preexisting extension on the north facade which earlier functioned as a staircase is perfectly suited for an elevator shaft. By adjusting the platforms on the third main level they become accessible to the elevator and its users.

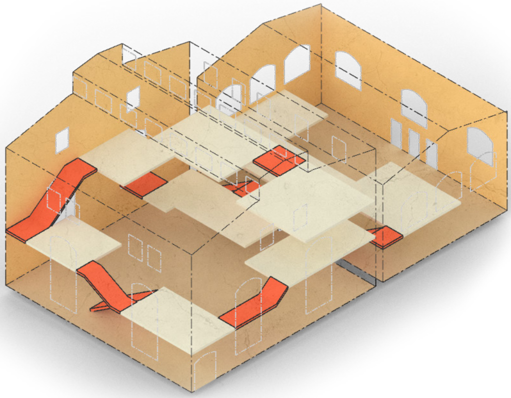


Vertical and circular flow with entries in mind

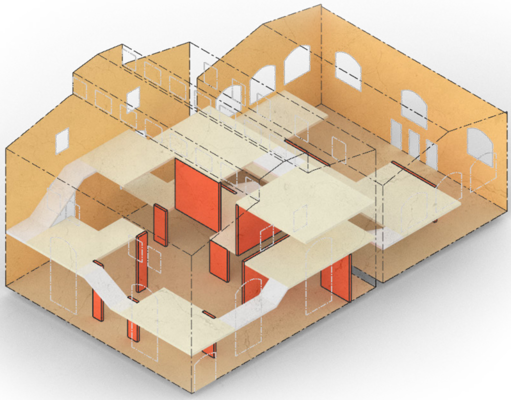
Connecting the platforms

The next step was to connect the platforms according to structural factors, flow and spatial experience in mind. Many of these connections would have to inherit a vertical component, thus resulting in them taking form as staircases. The placement would highly depend on strengthening the vertical and circular flow, minimising the obstruction of daylight and arrangement without the use of excessive constructional elements.

After this I introduced load-bearing members to the platforms. I wanted movement to be incorporated and guiding my design decisions even on the largest scale. This meant that I wanted a coherent dynamic "form" throughout the macro scale where movement could be read in different ways. Experimenting with load bearing elements such as walls and pillars I realised that a represented movement can be achieved by using my previous research on folding. By treating walls, platforms, pillars and handrails brutally as members of the same medium, they could be read as members of the same parent.



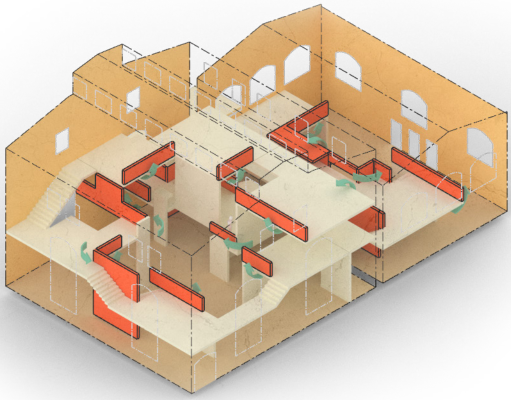
Connections



Load-bearing elements

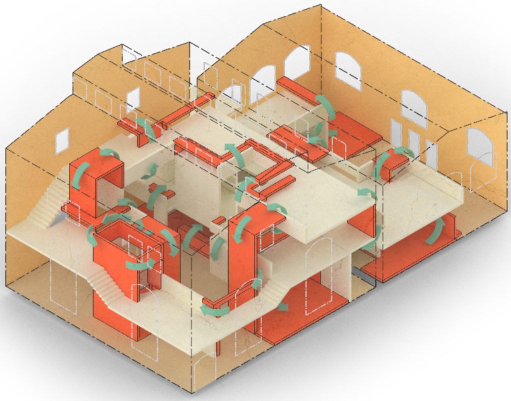
Folding

I proceeded by imagining the platforms as single sheets of paper, being folded into other architectural elements. Floor surfaces fold into walls, walls fold into railings. Not only is this topology interesting to follow with one's eye but also forces the user to imagine unfolding the form in his or her mind. This cognitive visualisation could effectively affect the overall perception of the space. It could also playfully make the user go back in time, figuring out how the folding was executed.



Initial folding

As the folding decreases in scale the elements become more detailed. Here's where one can start to use "contained" movement more thoroughly as a design principle. Folding walls into surfaces to be used as tables offers an opportunity for another type of dynamic readability. These smaller elements can easily metamorphose from railing to tables to even a structural rectangular pillar. This metamorphosis can quite rapidly travel in all axis of space. The reading of this movement could be considered contained since the user moves his or her eyes/mind along planes, lines or through spaces. A "snake"-like intricacy is folded out of the larger sheets of paper.



Continued folding

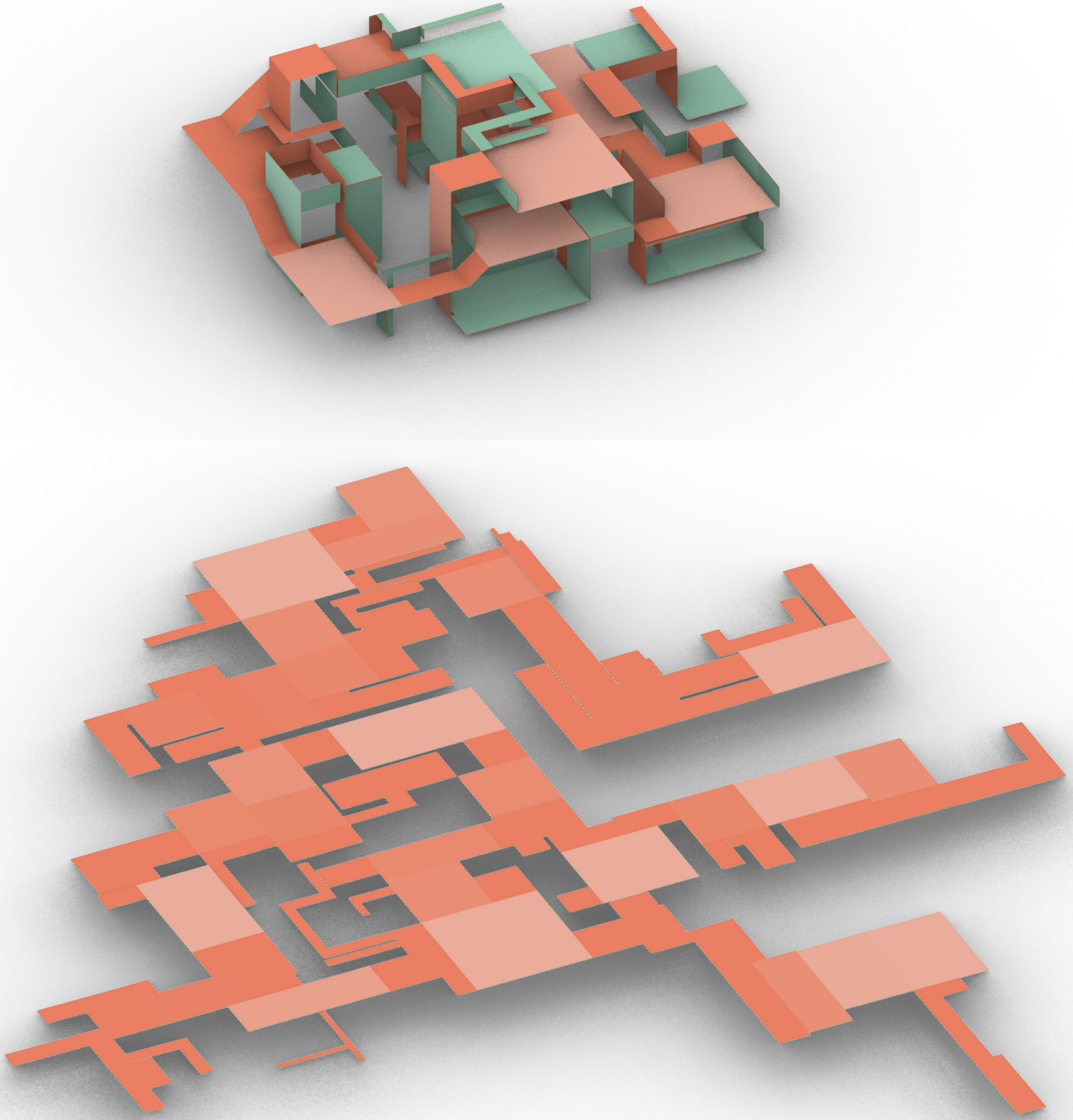
Moving back and forth using increasing strictness in folding topology I slowly developed a geometry that could hypothetically be unfolded. I connected each "plane" so that simple 90-degree angular rotations could ultimately be transformed into a single 2-dimensional surface without interference. This required a discipline where only two surfaces can intersect at any "crease", the same way a paper can only be folded in one direction at each crease.

The way I approached this intricate arrangement of planar surfaces is by starting with the largest ones, working my way down to more detailed elements. The latter would almost exclusively be that of smaller structural elements or furniture members which are easier to connect in different ways that the larger ones. As the folding progressed I encountered various problems with the topology not folding in different desired ways. I developed some tactics or work-arounds for this involving adding smaller pieces until a new crease could be achieved.

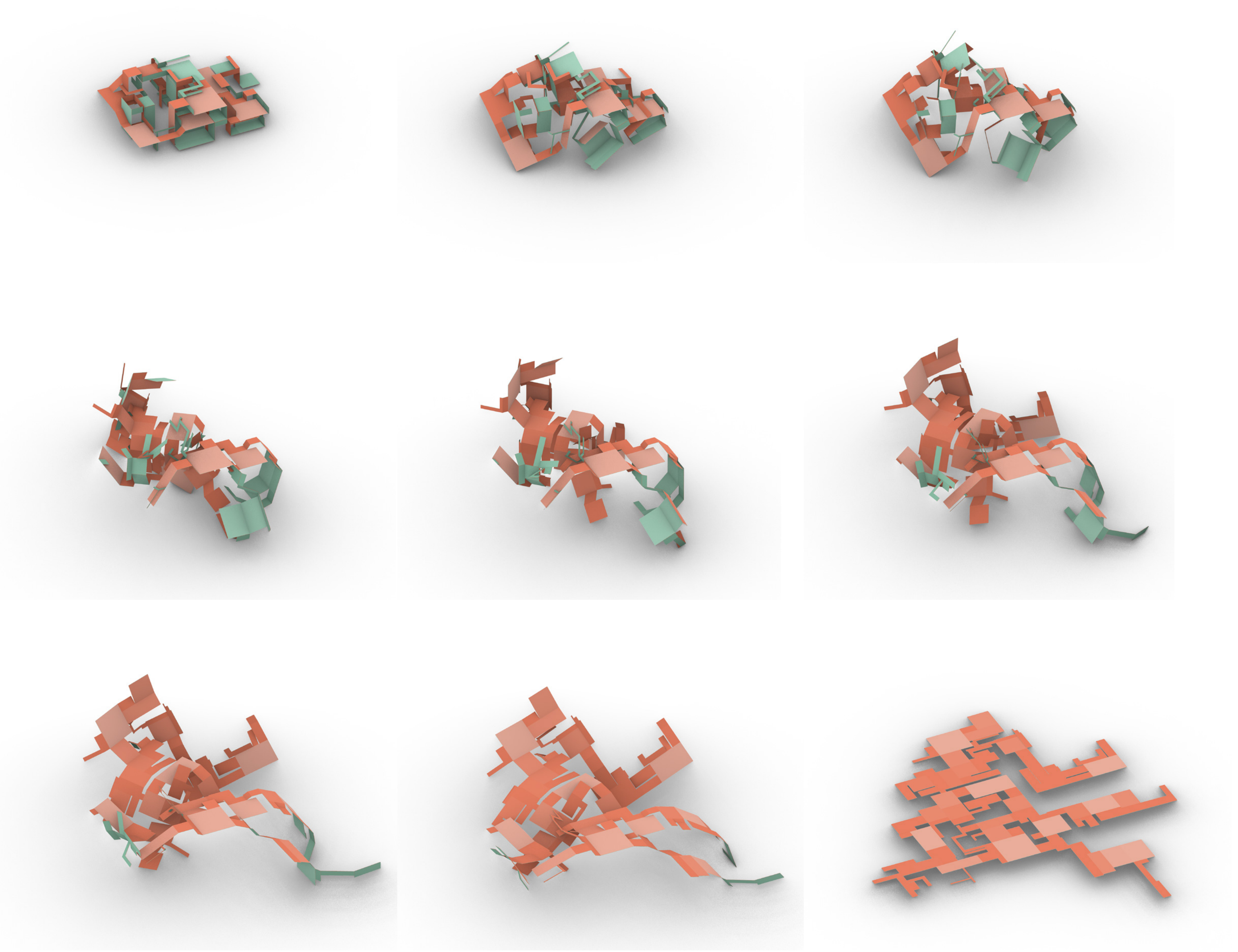
By unfolding the whole structure into a two-dimensional surface the geometry produced two sides, like those of a paper. By accentuating these sides an understanding of the folding can be increased. Giving the sides two distinct appearances can strengthen the readability of the structure and further clarify its represented movement. This ultimately means that the readability increases for the user, as the cognitive unfolding can be traced via the two accentuated appearances.

Materiality

Having two main geometrical sides was a good way to approach the introduction of materiality in the project. Since the third phase would contain the act of subdividing the folded geometry I concluded that tiling would be an effective way to do this dynamically. Using tiles the two sides of the geometry can be separated in appearance while still maintaining materialistic continuity in several other aspects. Ceramic tiles are also a highly dynamic material in its functional usage. It can serve as flooring, wall elements, ceiling and furniture.



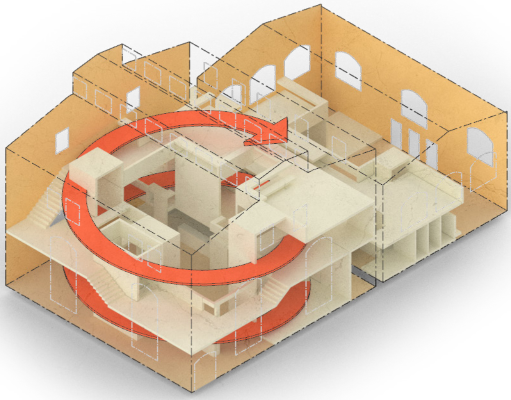
Unfolding the geometry with coloring according to side and area of each surface



Sequential unfolding of the geometry with coloring according to side and area of each surface

Streamlining/Literal translation of movement

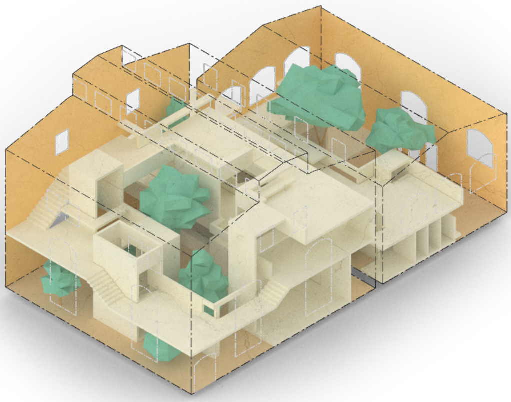
I continued with different approaches on how to further accentuate dynamics in the overall form. I experimented with beveling methods and rounding of planar surfaces with proportionate circumferences to each affected shape. Although this experimentation gave an effective flowing aesthetic, the principle of movement was not in itself strengthened. Just as earlier mentioned Kari Jormakkas idea of blindly translating movement in a too literal sense I found this to be true in this experiment. I concluded that a strict language can imply just as much motion as a curved one.



Vertical and circular flow

Biophilia

In order to create a non-static environment in panncentralen a biophilic approach was a viable option to consider. Biophilia is defined as the increasing connectivity to nature in direct and indirect ways (Kellert & Wilson, 1993). As soon as I started to explore the vertical qualities of the site I realised the potential nature could have in this project. By letting organic elements reach up through the vertical cyclical flow, a dynamic element is present throughout the experience. These organic elements would offer not only movement in their living status quo but also metamorphose as the user moves around them. Just as in a forest, a tree inside the hall would shimmer and behave according to the sun's rotation and the moisture in the air. The large windows could easily represent those of 19th century greenhouses and the environment would be perfect for growing a plethora of different plants.



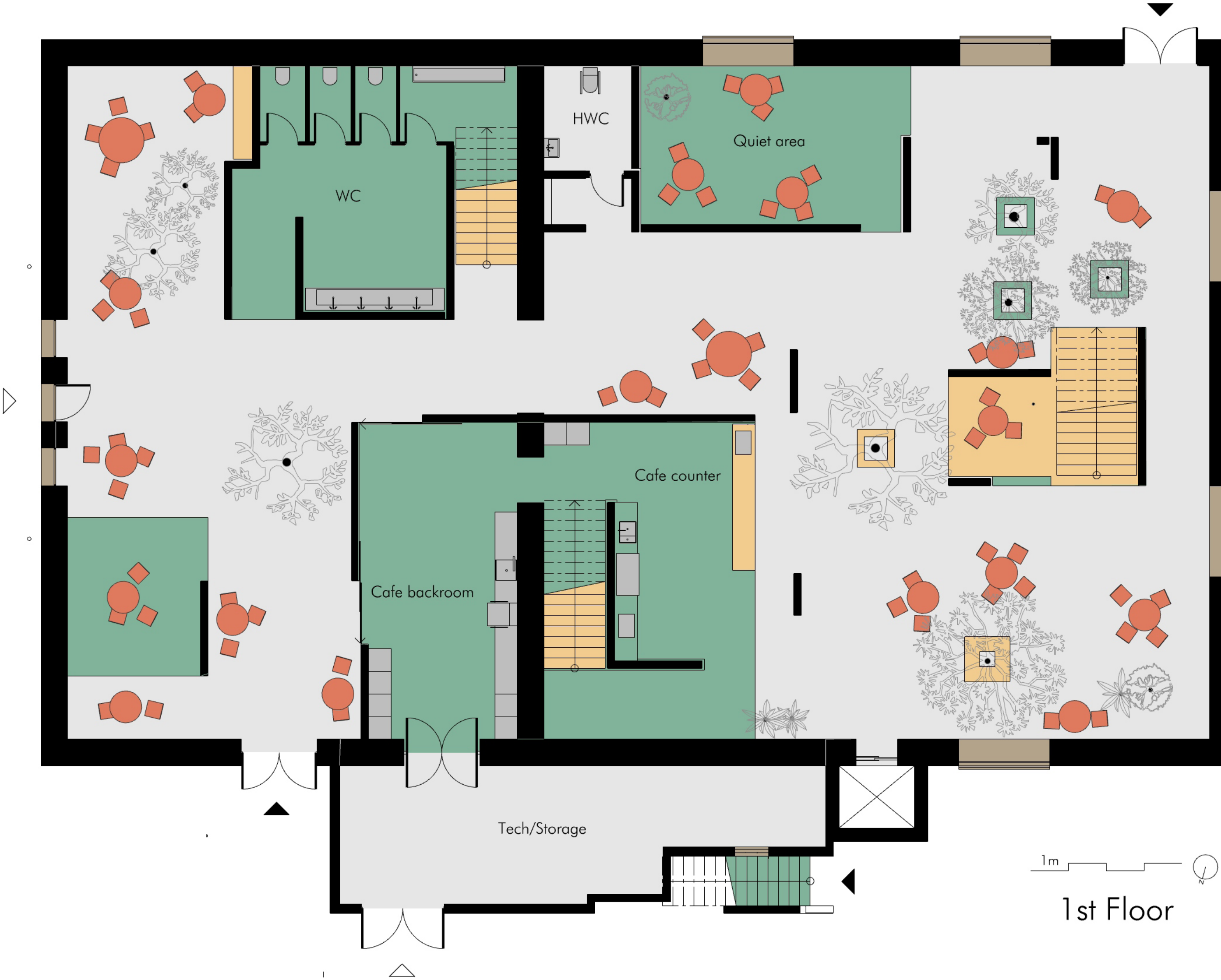
Organic elements

Ground

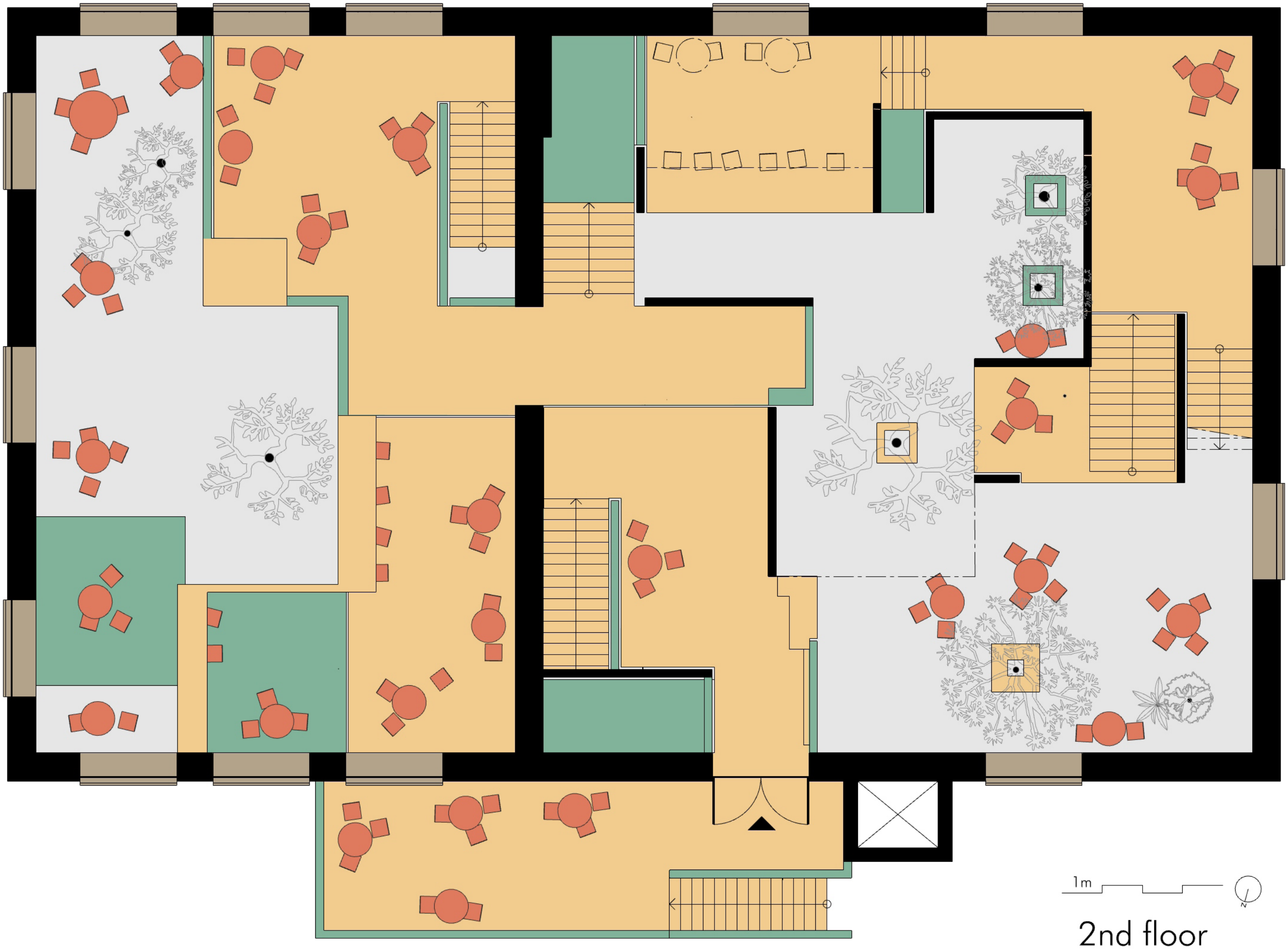
By letting much of the ground level mimic nature the plants and trees which are demanding more space for rooting could grow unobstructedly. As much as possible of the flooring would consist of earth and gravel where it would not get in the way of constructional purposes such as structural elements meeting the ground etc. This floor would offer a tactile sensation which would be heard throughout the building. The sound of this contained movement can be read by those who do not experience it visually. The tracks in the gravel will give insight in a movement already executed.

As the ground floor also acts as the ground outside the building, the borders between the two are blurred. Nature crawls into the space, moving from outside to inside. The hall becomes a place of observation of the dynamic elements in a dynamic environment.

Plan drawing

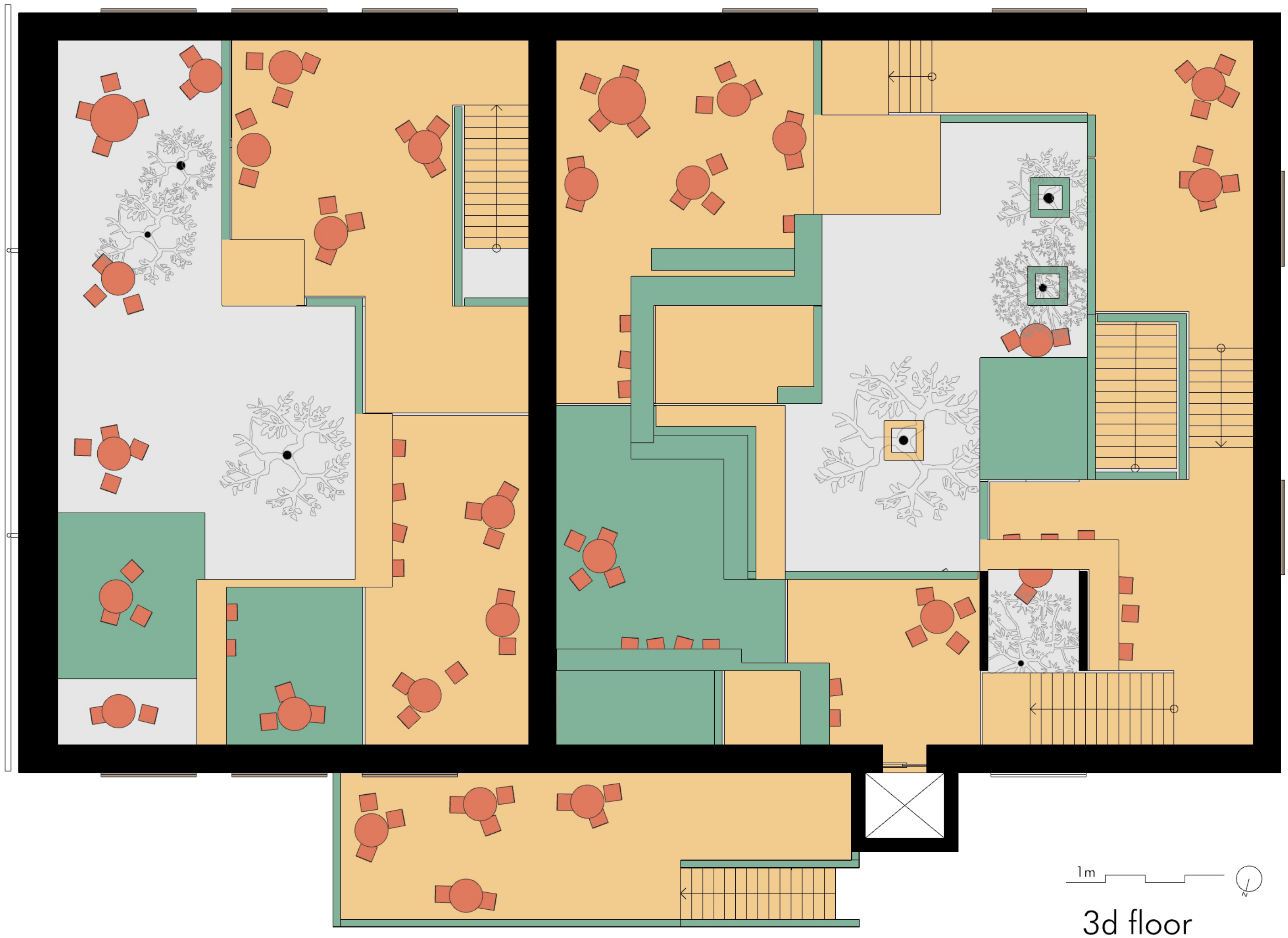


Plan drawing



2nd floor

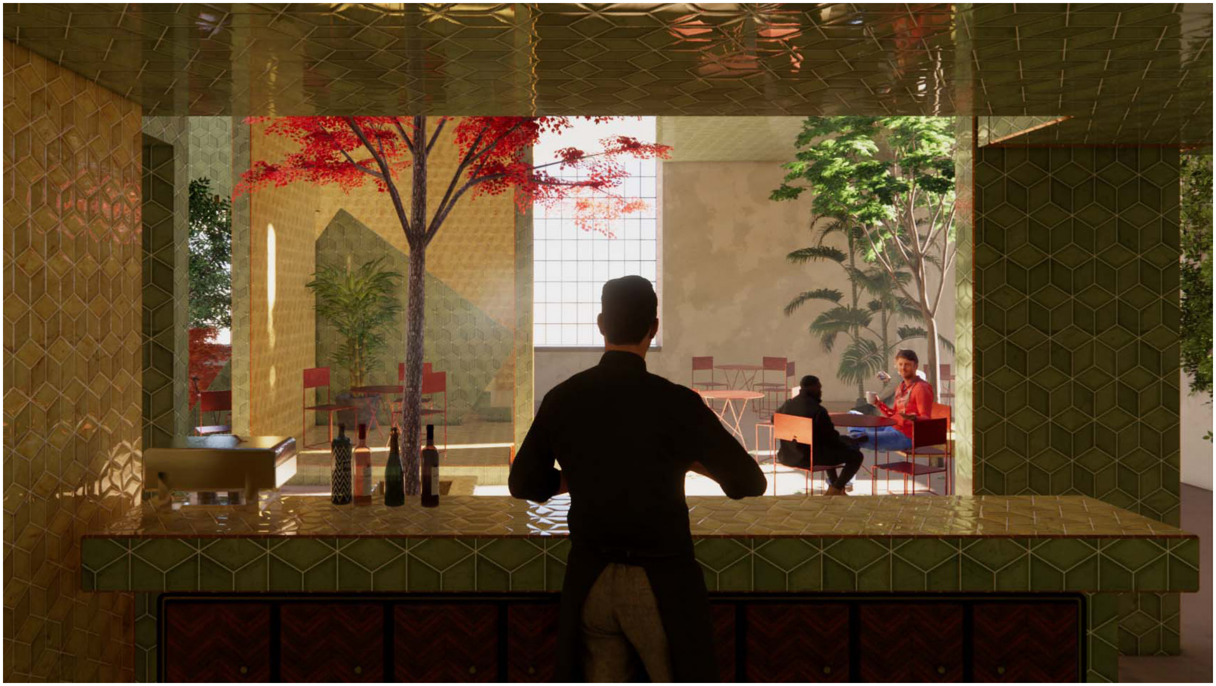
Plan drawing



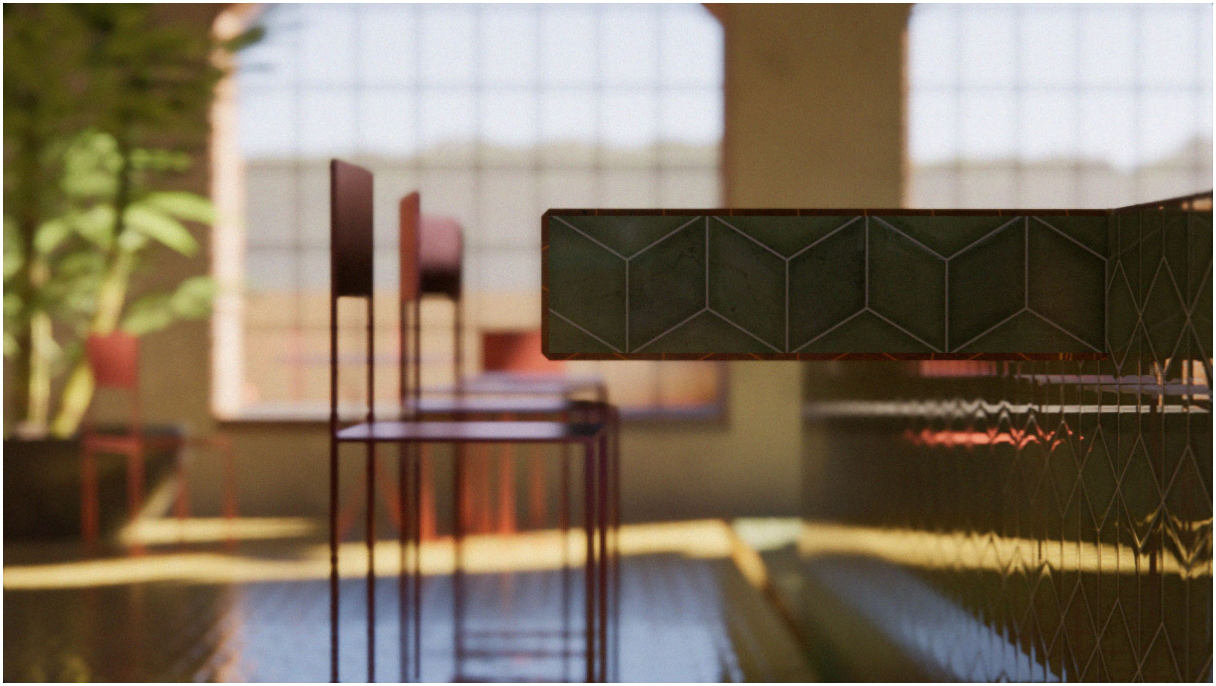
3d floor visualisation

Isometric visualisation

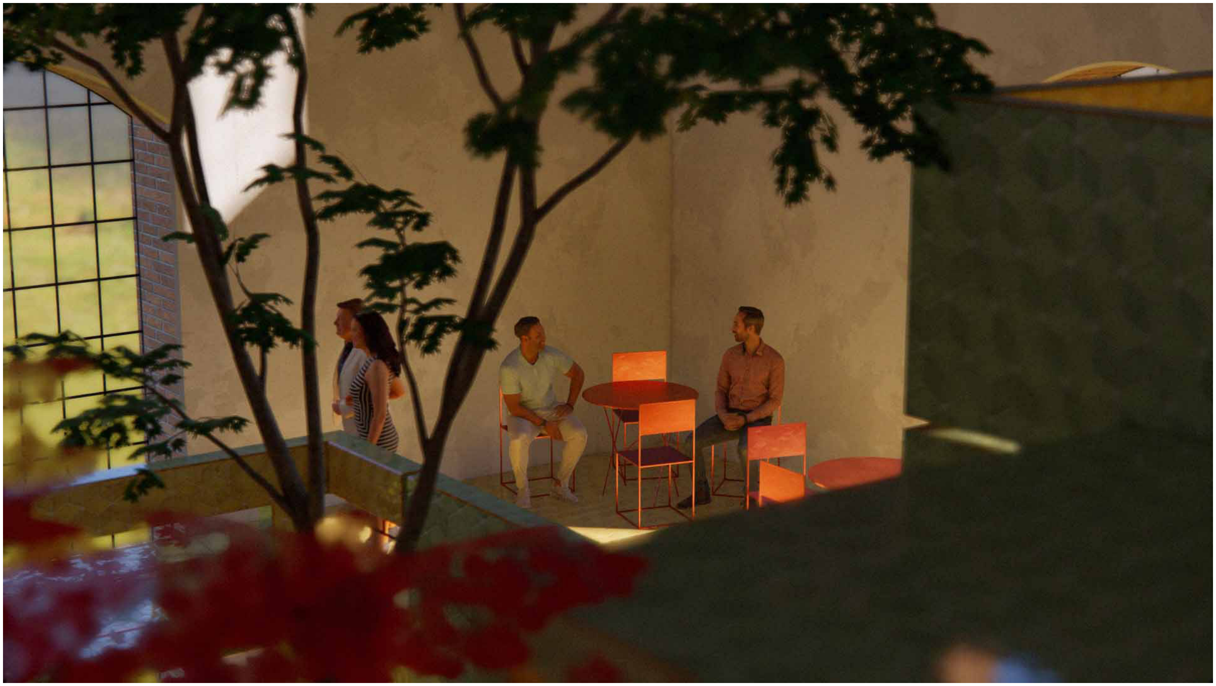
Sectional visualisation
- view from south



View from cafe

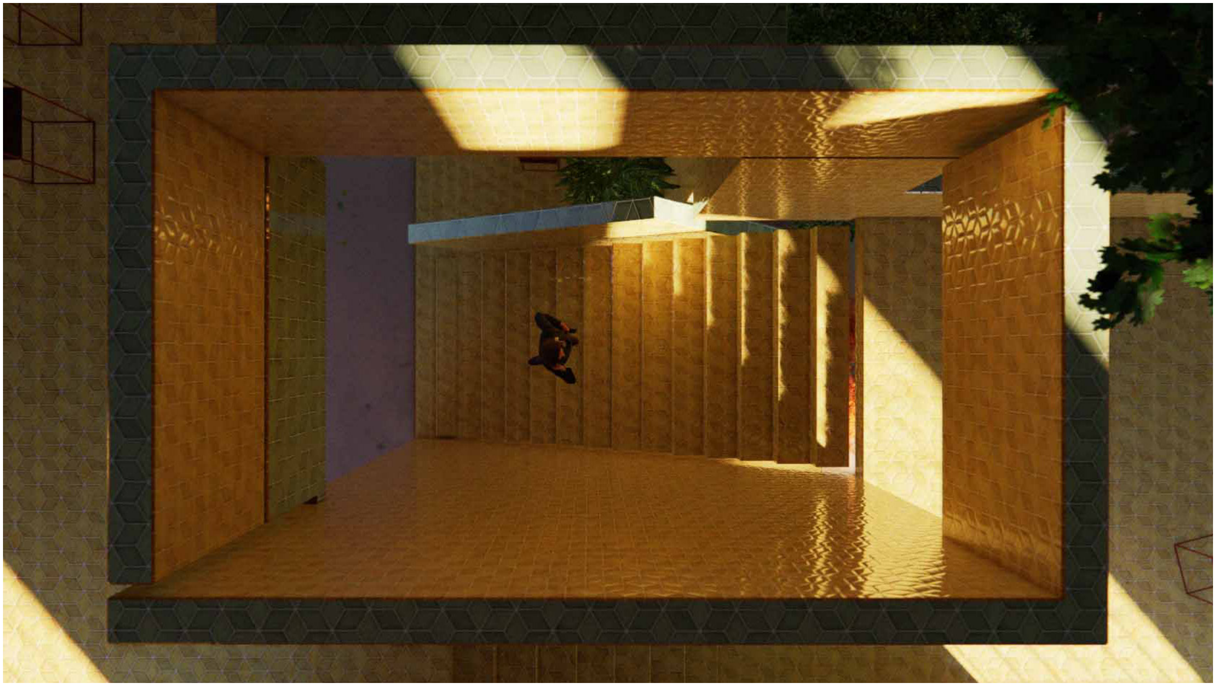


Detail of folded table



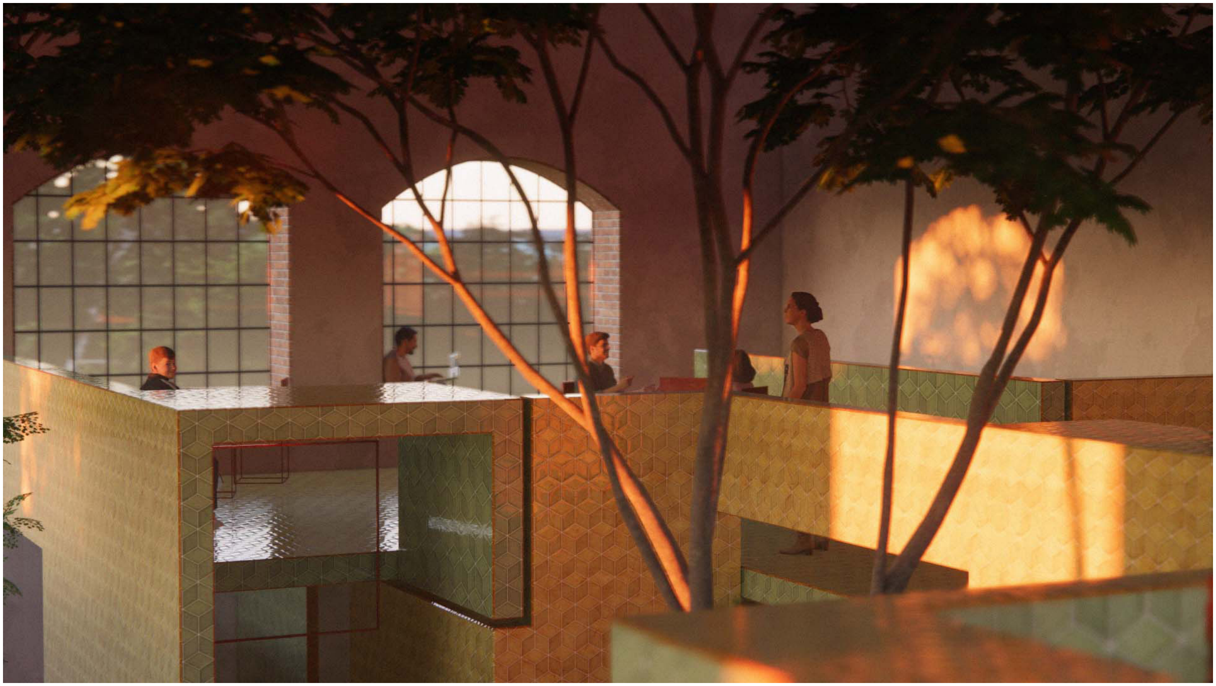
West hall

View of the thrid floor in the west hall



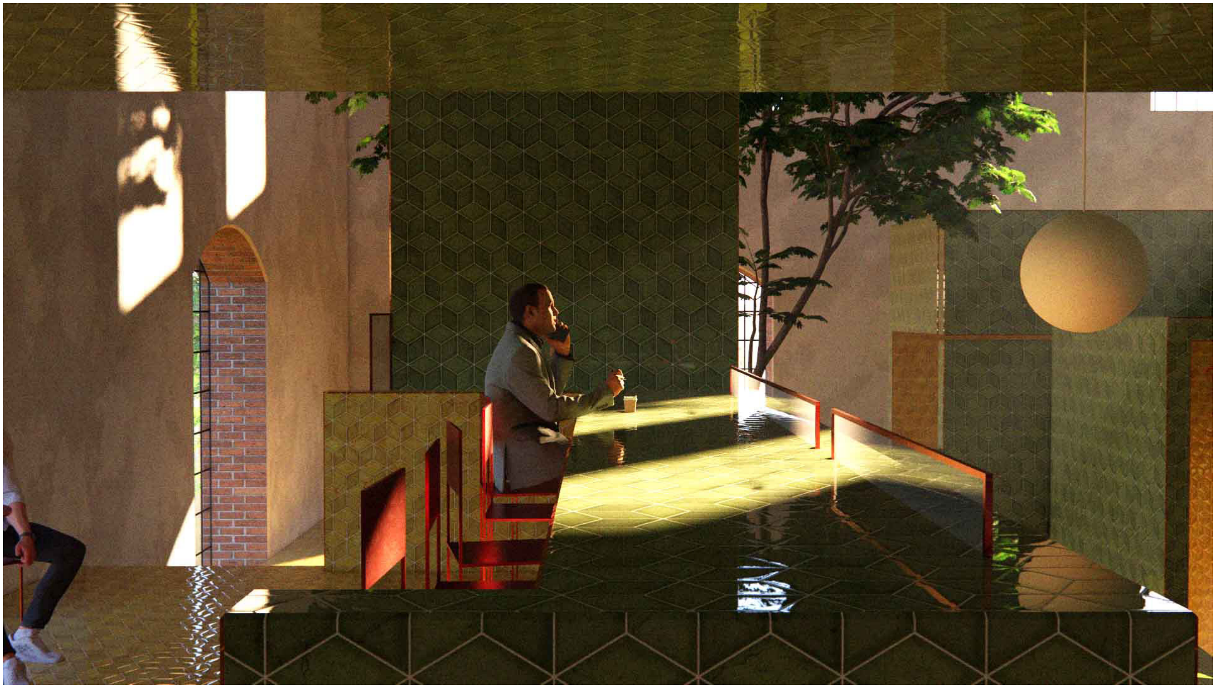
Stairs in the west hall

Cafe counter

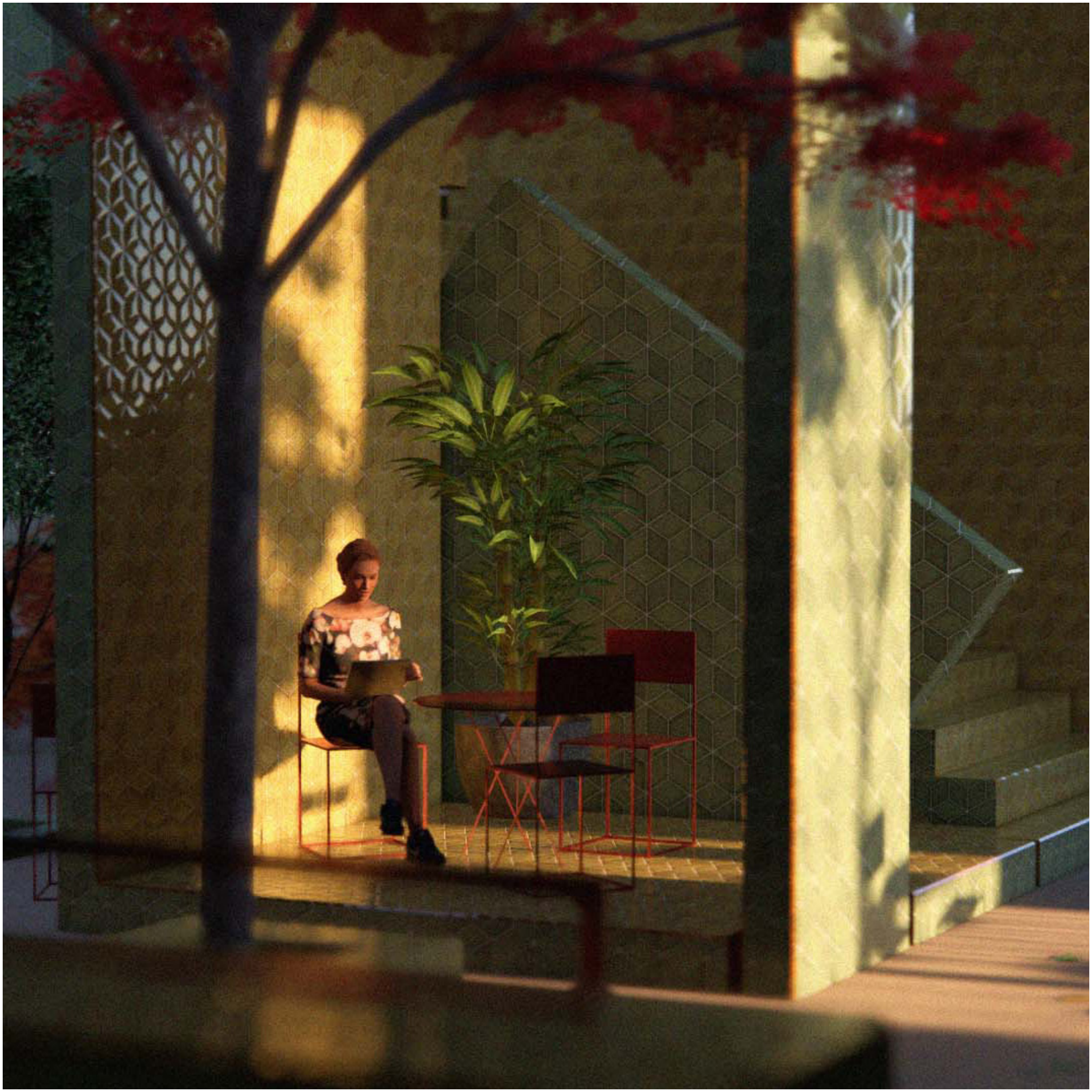


East hall

West hall detail



2nd floor balcony in the west hall



View from the west hall

PHASE 3

Movement in micro-scale

The purpose of the third phase is to break down my form into a multitude of constructable elements. My form would be that of the folded macro-scale geometry, broken down by micro-scale movement. This is an experiment in how divisions alter the experience of the whole, with movement in mind. By trying out different elements applied on the same form I can compare the results of different tessellations. By working with these different layers of movement I wanted to explore how this form in change is perceived and experienced. Could kinetic elements alter our understanding of how we perceive space? Could mechanical movement be used to understand the non-static part of architecture?

Moving into this phase I felt the need for a decision regarding what kind of movement I wanted to apply and work with in the subdividing of the form. The previous phase resulted in the decision to work with some sort of tiling. This seemed like a viable extension of the topological language generated by the work with movement in a macro-scale. I generated two strong "sides" in the folded geometry and these will be subdivided with tiles into two different, but communicating expressions. I also tried different variations of this subdivided geometry.

Movement was a great factor when deciding on tiles as a subdivision materia. Planar surfaces with applied literal motion could perhaps be a tool in experimenting with the movement in nature, as described in phase 1. Although the experience of nature is highly subjective and somewhat abstract, similarities with subdividing could be distinguished. Nature has clear hierarchical systems and outward branching into smaller and lighter elements throughout. The leaves follow the rules of the branch, and the branch follows the rules of its older relative, the tree.

Treating each tile as a leaf in a tree, one could experiment with the mimicking of this natural order of movement and its perceptual qualities. The tiles would just as leafs be members of a larger combined dynamic network. A dynamic multi-sensory stimulative environment.

Kinetic tiles can work in a plethora of different ways and I approach this establishment of a dynamic environment from different angles. I wanted to try different kinds of kinetics with slightly different methods. The first would deal with pattern alteration and the perceptual metamorphosing of a planar surface. The second will be more focused on a shimmering, chaotic effect but with slightly similar mechanical properties.

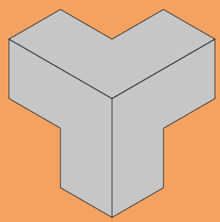
Designing the first element - The L-Cube

The first kinetic element I've decided to call the "L-cube". With this I wanted to achieve a perceptual illusion of surface deformation by controlling light and shadow. I realised that if you apply tilting to a given number of planar, parallel surfaces, they will respond ocularly.

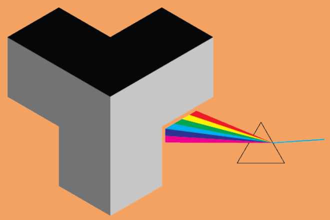
The darkness to brightness ratio would depend on how many different angles or directions you would tilt the surfaces in. In the L-cube-experiment I needed 3 different directions to achieve the illusion of multiple hexahedrons (six-sided cubes) being welded together in a symmetrical, highly 3-dimensional pattern.

The pattern can easily be achieved with 3 identical shaped static planar tiles, but with different colours. The colours have to be arranged symmetrically to achieve the 3 dimensional effect. Working with rotating planes there is no need for different colours. The effect would possibly be extra strong when the tiles are at their outermost rotation but this would create a problem when at the starting planar position. The pattern would then already be visible.

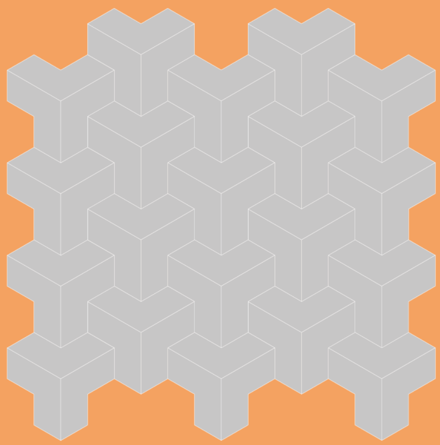
I had in mind to create the illusion of a single material or colored space, metamorphosing into a three dimensional pattern. This gradual change of space could, if performing well, give interesting spatial deformational results.



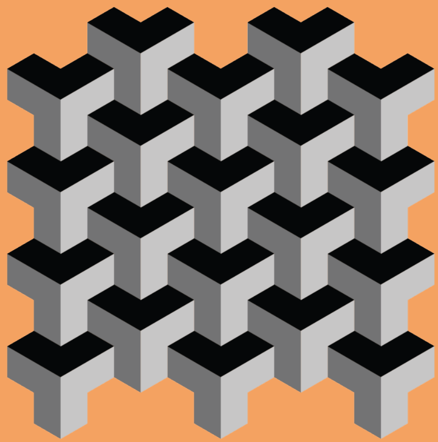
Planar elements



Shading effect on rotated elements



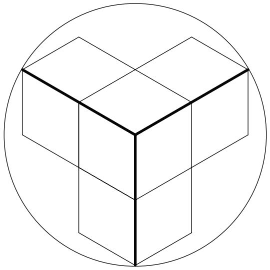
Planar elements

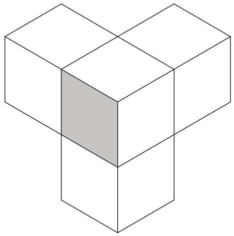


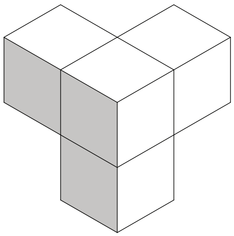
Shading effect on rotated elements

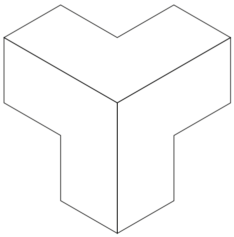
Geometry

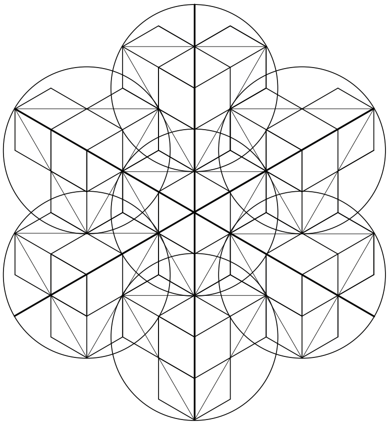
The base geometry was parametrically achieved by dividing the circumference of a circle in 3 equally long distances. These would then be connected to a centerpoint and rotated so that one line pointed straight in the y-axis orientation. To get the L-shape of each three divisions the lines were offsetted half a distance on both sides of each line. By the points created at the ends and middle of these lines, a number of rhombus shapes were possible to connect into the three desired L-shapes. One L-shape consists of three rhombuses.









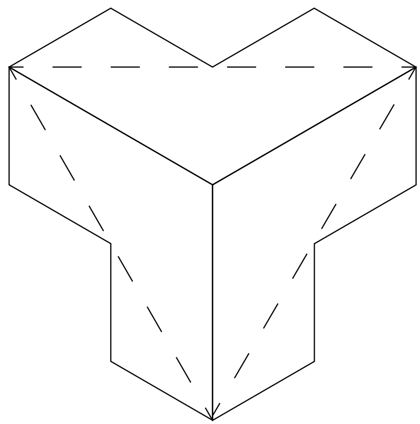


Geometrical conjunction

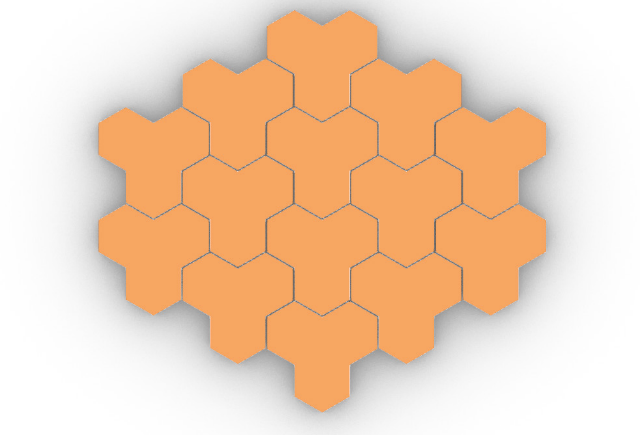
Rotation

The rotation-axis of each L-shape was crucial to determine. Each surface has to rotate at exactly the same angle or the shadow-effect would not work. So the next decision to be made was that of the rotational angle. It was important to find an equilibrium between the most amount of shadow contrast and the least amount of gap between the plates. The gaps created could decrease the effect by offering a depth in the structure that is not desired. This depth could possibly be handled with some kind of expanding material or mechanical part but this would also increase the complexity of the system.

The rotation of each plate is also affecting how each element is interfering with each other. A small gap has to be incorporated between the elements to prevent this interference. The gap is depending on the rotational angle of each plate but mostly on the thickness. These parameters have been incorporated in the script to counteract staticness in the process. In other words these characteristics are parametrized for the ability to be changed according to the material used.



Rotation axis



Planar elements

Complexity

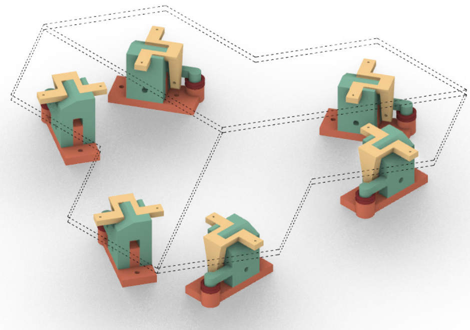
As written about in phase 1, an aim to decrease the complexity has been constantly pervading throughout the design process. Since every part of each element is multiplied by the number of elements the amount of parts can easily spiral out of control. There's also an increasing risk of failure with every new part added. In engineering design there's a common saying which goes "the best part is no part". This goes much in line with how I've approached the exploration in my process. I discovered the necessity to establish some kind of framework as a tool to facilitate my exploration process. This took gradual form as a list of key points/ rules to keep me on the right trajectory.

Key principles

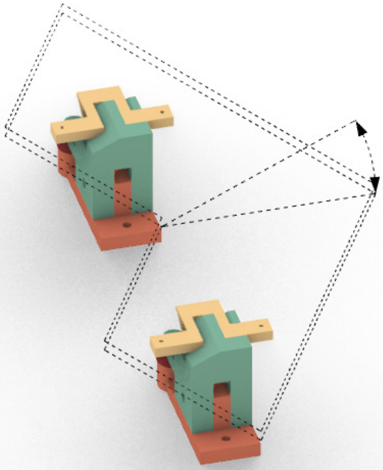
- Use as few parts as possible without compromising the result
- Have the manufacturing in mind when designing parts
- Have the assembly of parts in mind when designing the whole solution
- Use as few *moving* parts as possible without compromising the result
- Try to reduce the number of moving inputs as much as possible
- Do not design parametric geometry if not needed
- Design with cost in mind

Mechanics

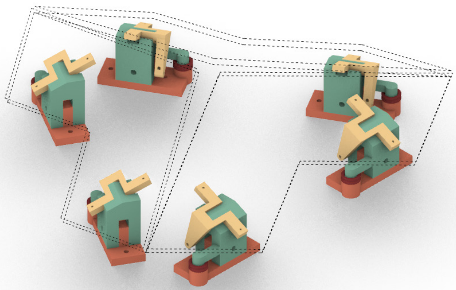
With the first keypoint in mind I started going deeper into the mechanics of the L-cube. Each plate would rotate and be mounted to a surface simultaneously. After testing out different spots on the rotating axis as well as different numbers of mounts I decided to place two on each plate. The “arrow base” shape forbids a single mount to be placed in the middle of the axis and two would as a bonus increase stability.



Planar elements



Rotation

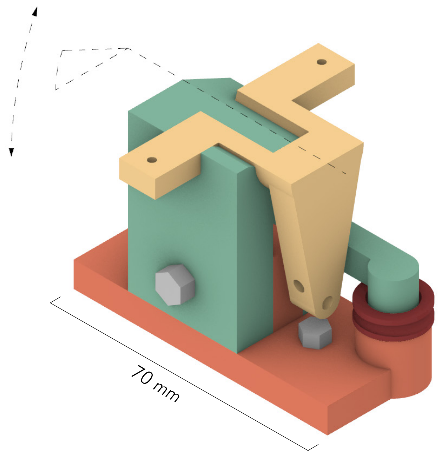


Rotated elements

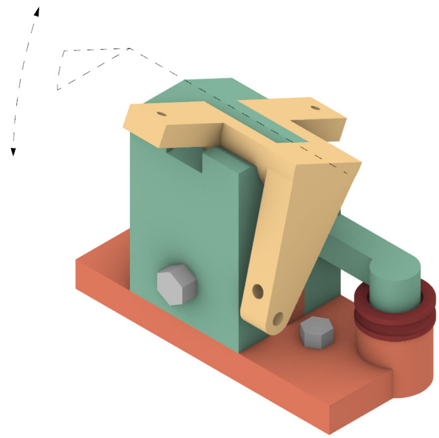
As many elements would be mounted next to each other the only way to put them in place would be directly from the front. This also means that there won't be room for anyone to drill from a diagonal angle or try to fix something in place through the gaps of the structure. This meant that the rotating mounts would have to be designed in a way that let them be assembled straight into each other, in the direction of the base surface.

A solution to this problem was to manufacture them in different steps and before that, designing them with this in mind. This resulted in the mounting "tower" to be split into multiple parts. The parts would be mounted with screws and assembled in a decided order to be fitted correctly. Some parts mounted would have to be screwed in place before the next is connected, covering the screw holes.

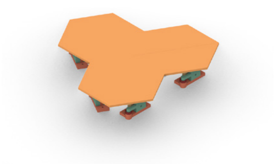
The rotating arm demands a number of aspects to be able to perform. It has to be able to rotate freely and be mounted on two towers without sliding to either side. It also has to have the ability to be easily mountable on the plates and rotate without breaking due to stress, force or friction.



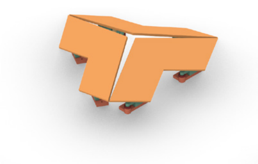
Planar tower



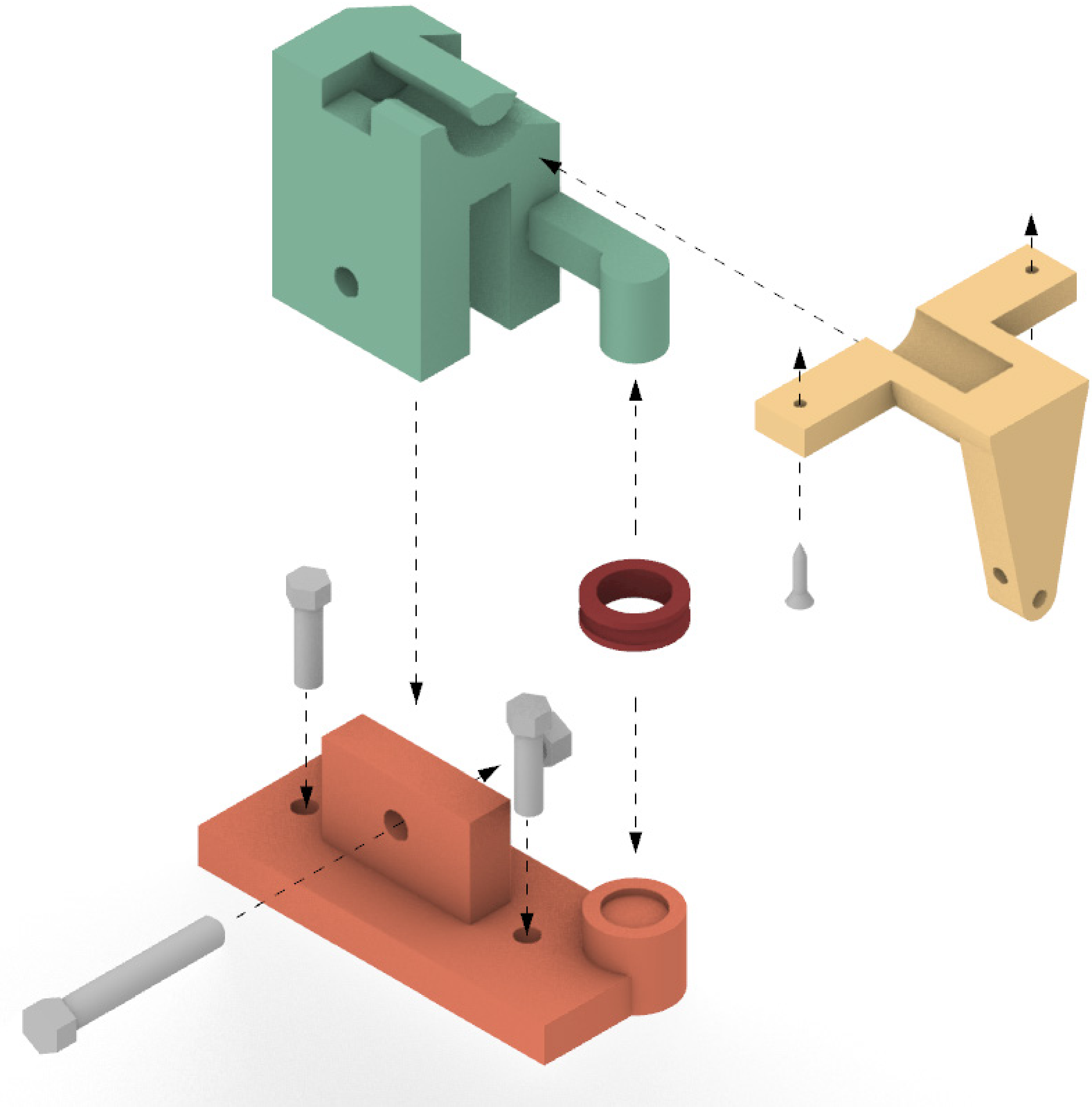
Rotated tower



Planar elements



Rotated elements

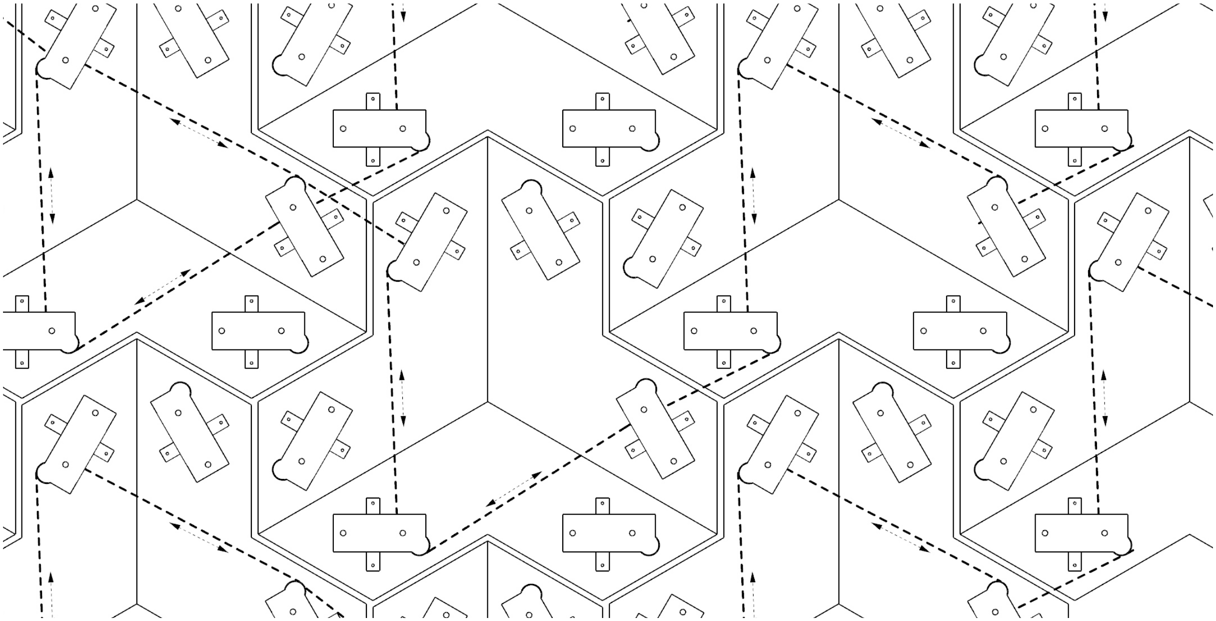


Exploded view of mounting-tower assembly

Wiring

The mechanical principles of the L-cube was a challenge. Each plate has one rotation which means that each element has three. Even though there will be a lot of multiplied elements this doesn’t mean that it will be equally multiplied rotations. The rotation of one element could be copied to the next since the distance of the rotation arm is the same on all of them.

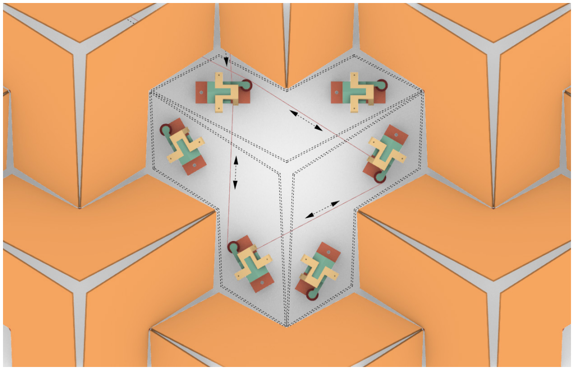
With this in mind I took the decision of using a wire-based mechanical system instead of a gear-based. With wires I saw a greater possibility of interconnectedness and a decrease in complexity, compared to rotational gears.



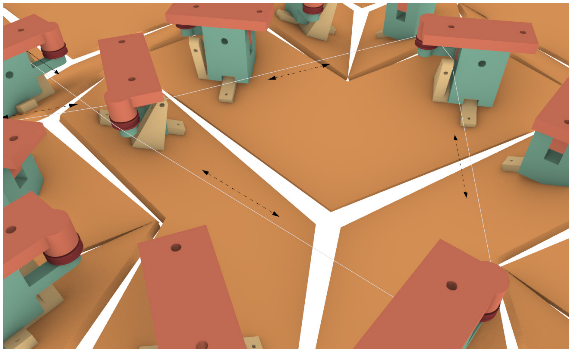
Wiring solution with some mounting-towers only used for stabilisation

Experimenting with wiring I discovered some benefits that opened up new possibilities. One plate could be connected to almost any other by wire as long as the trajectory was nudged. This changing of trajectory could be done with a rotating wheel, as long as it did not interfere with the rest of the mechanics. My solution to this was to embed a rotating wheel on a cylinder, mounted on the base mount. This meant increasing the base mount in size and designing it by the earlier mentioned aspects and assembling. A result of this was a looking mechanism that keeps the wheel from falling out. The rotating arm has holes in the far end in two directions, for the purpose of wire threading.

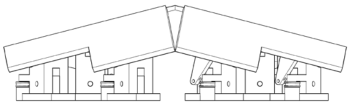
As each plate would have to open and close, I needed two forces of the same distance working in opposite directions. This means that I could manage to use only one closed loop of wire, connected to an alternating motion. This motion could be mounted to a rotating gearwork or a motor.



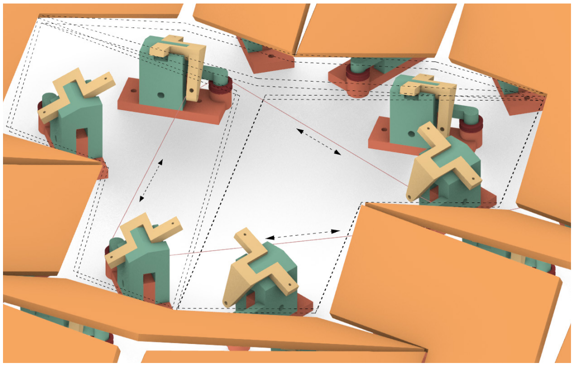
Front view



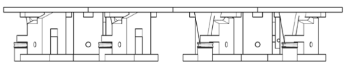
Mounting towers with wiring



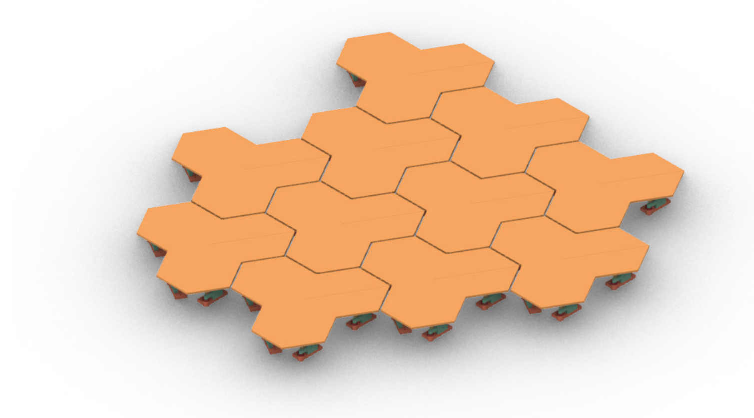
Rotated elements



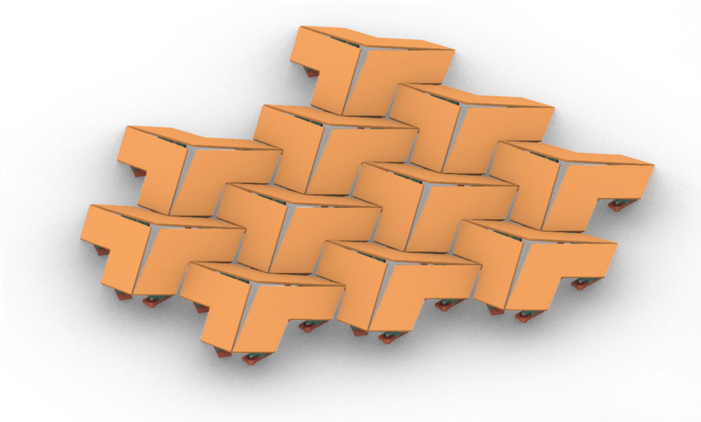
Transparent view of wiring



Planar elements

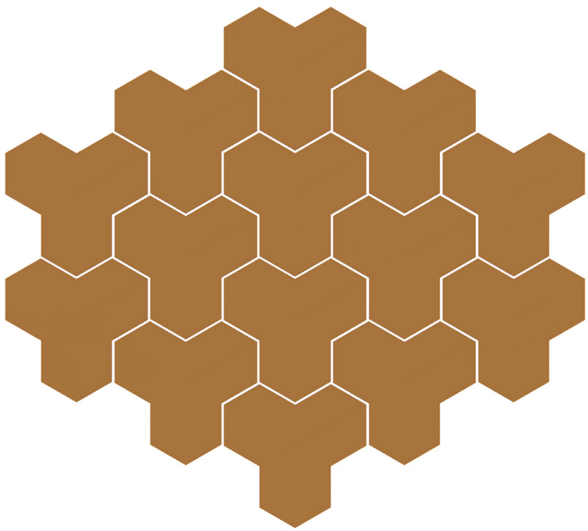


Planar elements - daylight rendering

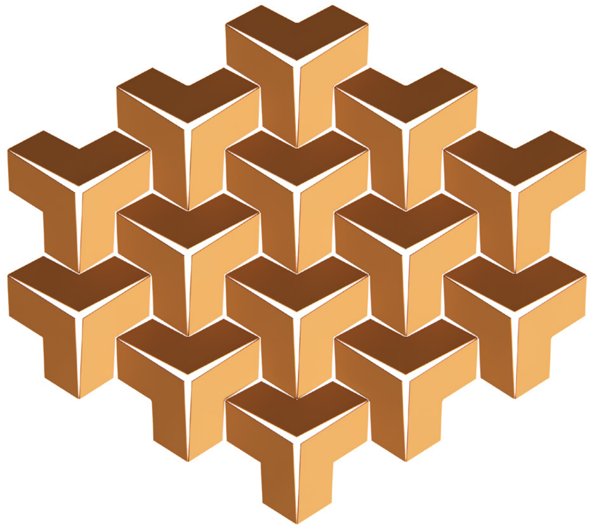


Rotated elements - daylight rendering

Renderings with natural set light to compare 25-degrees opened and closed elements.



Planar elements - daylight rendering



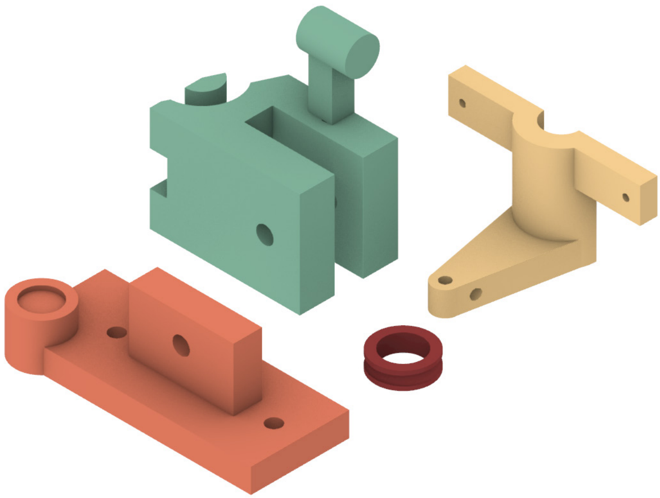
Rotated elements - daylight rendering

Manufacturing

The option to manufacture the mounting mechanics by 3D-printing was a strong alternative from the very start. Since the manufacturing method is always beneficial to have in mind as early as possible I realized a choice in the matter would help me step forward. This means that knowtion of the method of manufacturing has been present when designing the parts.

A couple of conciderations are good to keep in mind when designing geometry for 3D-printing. Deeper knowledge of the machine and how it operates is if not crucial, highly recommended. The nozzle diameter affects certain angles and corners of the print. As does the ability to print overhang from one layer to the next rule other aspects of the design.

When building the digital geometry for the mounting parts I always kept in mind how each part would be laid out on the printing table. Large spaces within geometries are best oriented so that they need the least amount of support printing. Support printing is "dead" structures that are needed to print something with space underneath it. This will later be manually removed. Since this can be a time consuming task (and multiplied with the number of elements) it's a good thing to keep in mind. The holes for the bolts and screws are mostly situated in a direction best suited for the print. This was something that took a lot of redesign to be made possible.



Mounting-tower parts

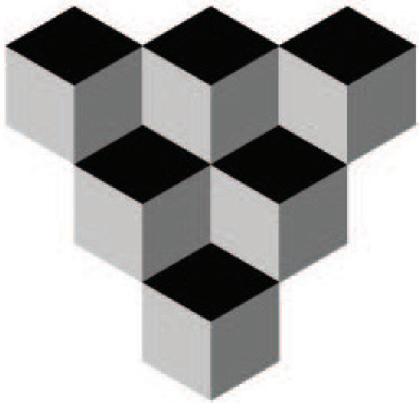
Designing the second element - The Diamond

During the development of the L-cube I realized the potential of another geometrical pattern. This arrangement could have a similar ability of achieving a metamorphosing cubic-effect as the L-cube, while also inhabiting a second function.

Planar elements

This effect would be the creation of a shimmering sensation. This could not necessarily be done at the exact same time, but with the same pattern and physical arrangement. The only difference would be the rotation of the planar surfaces. The first mentioned effect would have an almost identical mechanical arrangement as the previous element. The shimmering arrangement would depend on a more randomized distribution of rotations.

I choose to work with shimmering since it could be an interesting way of investigating form through movement with natural environments in mind. How we perceive and experience natural environments demands its own field of research. Without going too deep in the definition of this one can differentiate a number of aspects that could be translated into constructed form.



Intended shading effect on rotated elements

Nature is in many ways a hierarchical system with a branching of form from large to smaller subcomponents. These subcomponents often consists of a multitude of similar elements that are exposed to motion. The overall experience of this collection of moving elements affects the experience of the whole structure on a macro level.

Observing a forest, the leaves of a tree act as subcomponents, which are similar moving elements that alter the experience of a tree as a whole. The tree appears to shimmer when light refracts on the leaves in motion. A rapid, slight variation of brightness and color occurs throughout the medium.

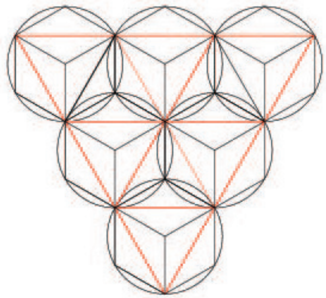
One way of translating this into built form would be to introduce the same type of hierarchy and motion to the subdivided geometry. This can be done in different ways. As shimmering occurs when a surface refracts light in various random ways this can be kinetically achieved with planar surfaces.

Working with tiles the shimmering would be generated by the reflective index on each surface. The greater the surface can refract light the greater the contrast between lit and unlit surfaces will be. The quantity of tiles will also be determining the overall effect. Larger number of kinetic elements will presumably result in a more flowing experience rather than having few elements. In the latter case the probability to read each element's rotation will be greater which can result in a "blinking" experience rather than a shimmering.

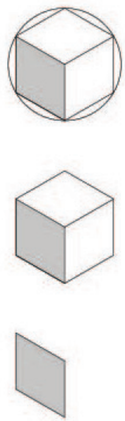
The shape/geometry

As the L-cube is made out of 3 elements that can be divided into three rhombus shapes, the diamond pattern is made out of only three rhombus shapes which are then repeated. The rotational axis is located from the longest diagonal line that can be achieved which also means that the axis aligns perfectly on three sides with the surrounding group of diamonds. This offers the ability to connect multiple numbers of elements to each other to the same rotational fixture, which can greatly reduce material and moving parts.

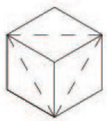
There would be three rotational fixtures crossing each other at 120 degree angles. The intersection of these would have to be structured to prevent interference from each other. When using random rotational angles for each element these three interconnected rotational rods can not be used. Instead the elements would have to be randomly adjusted to a starting position and then rotated individually. This would require a similar mounting tower design as for the L-cube connected with wiring. The only difference would be that each element only requires one tower.



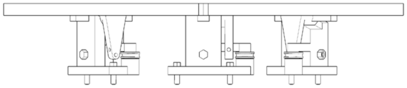
Base geometry with highlighted interconnected rotatioal rods (red)



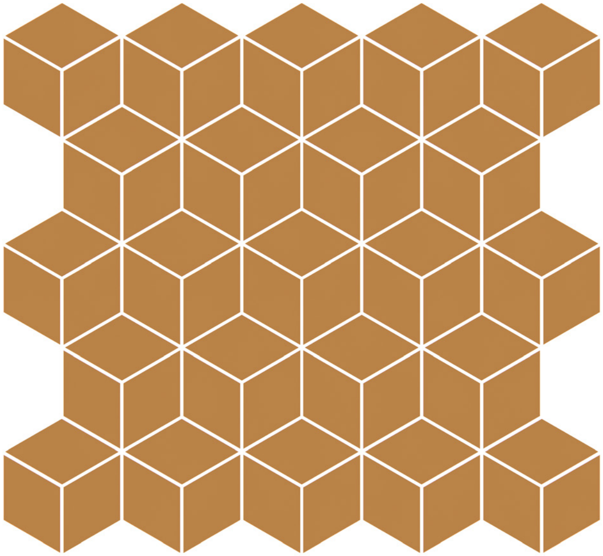
Diamond-tile



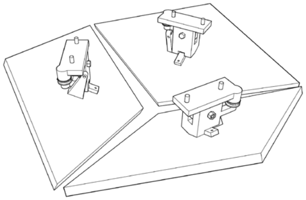
Rotation axis



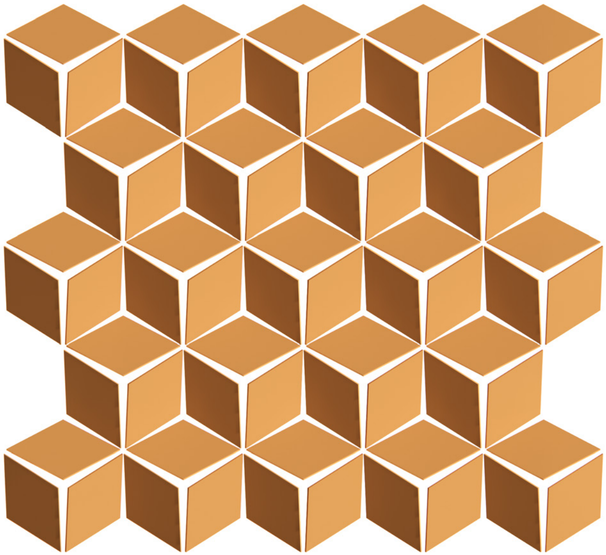
Planar surfaces - side view



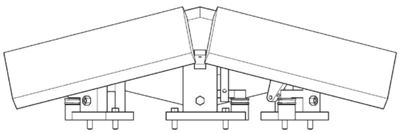
Daylight render with Planar surfaces - front view



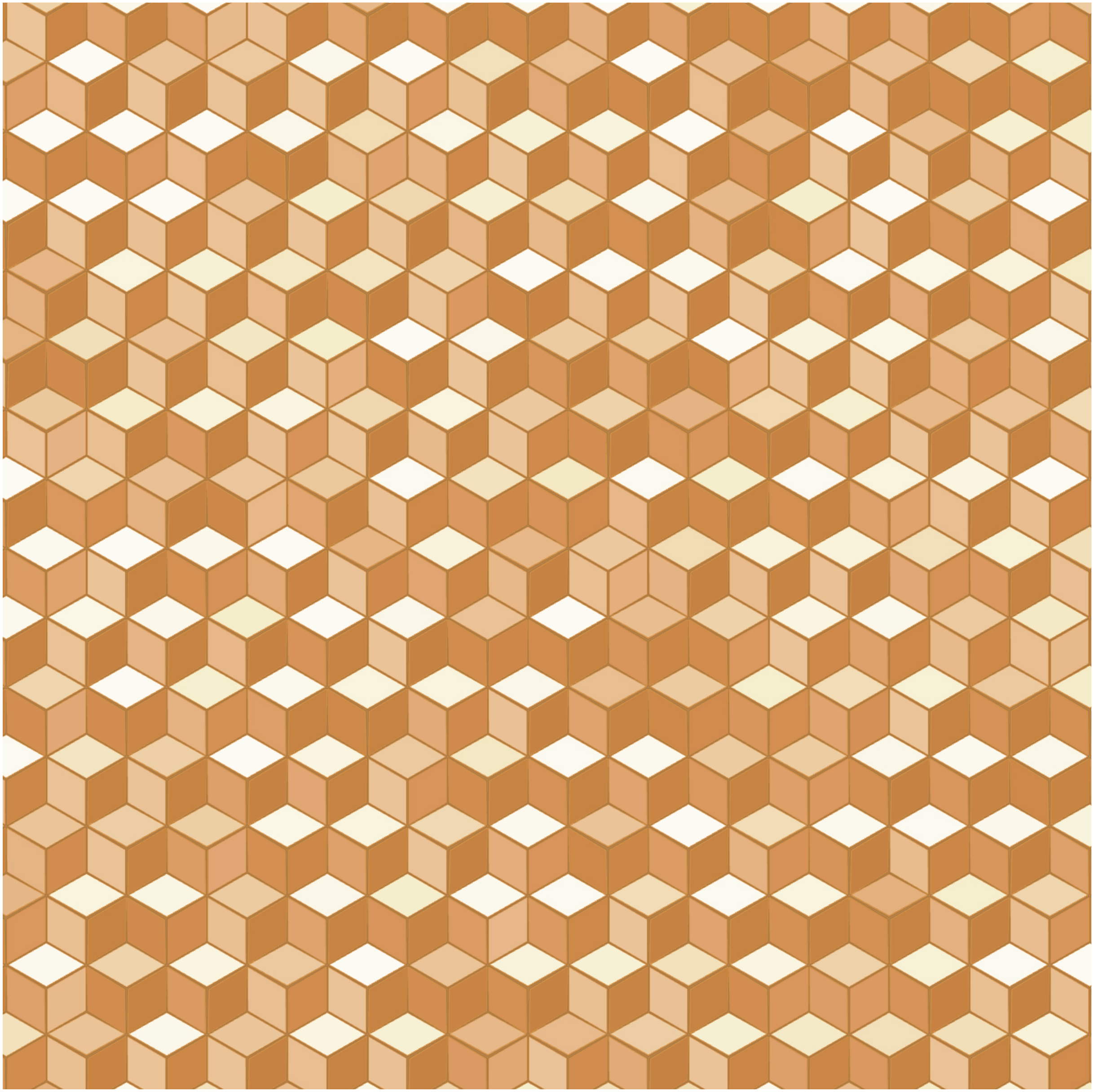
25 degree rotation of each surface with non-intrerconnected mounting towers - perspective view from underneath



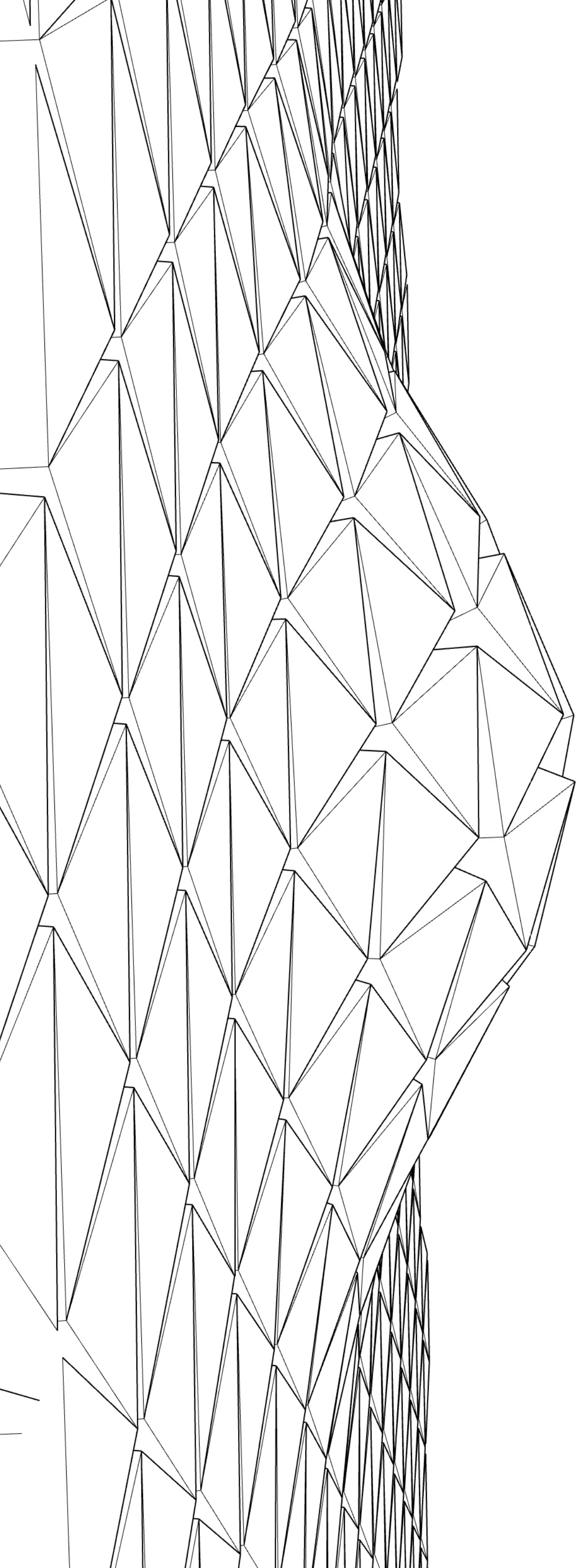
Daylight render with 25 degree rotation of each surface - front view



25 degree rotation of each surface



Randomly assigned rotations



Designing the third element - The Triangle

The third element is based on origami, an ancient technique of paper folding. This type of geometrical subdivision of a single surface has gained increasing respect amongst mathematicians and engineers during the years. Approaching form this way is highly effective in designing curved shapes from planar ones and folding surfaces to occupy minimal storage area.

Since folding has been present throughout this project I wanted to see if it could be of benefit in the smallest scale as well as the macro one. By using origami principles I could experiment with a kinetic movement that alters space by changing angular directions within its structure, while maintaining its surface area.

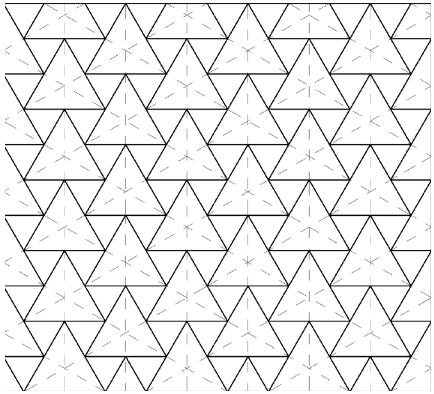
I established some goals that I wanted to use as a reference guide while developing the origami. I could use many separated multiplied elements. If I on the other hand managed to use a single folded planar surface for each architectural element I wanted to break down, this would generate a much stronger identity. Just as the folding in the macro scale enhances the user's ability to read the form as a whole, a continuous folded surface would maintain integrity. This would be an honest form in the way it can be kinetically understood and ocularly followed.

Another goal would be to create an organically moving pattern that would be integrated within the structure. Since I've already experimented with pattern alteration and shimmering effects, I needed some other way of making the form imply and translate motion.

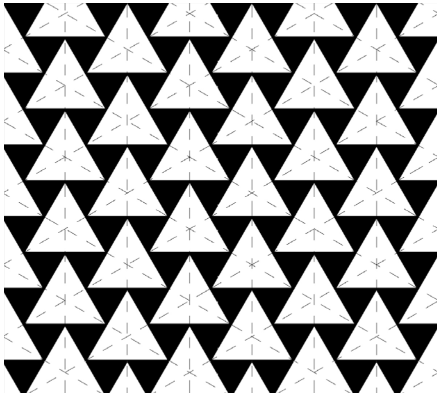
Fold

By looking at different origami patterns that are primarily designed for three way curvatures of a planar surfaces I realized that these types of arrangements could be used in a kinetic setting. Given that these types of kinetics are applied to a vertical building element, the surface could be pushed out from the wall. This would generate a strong alteration of the vertical surface while maintaining its surface area. A pattern difference would be a very positive outcome of this which can be further worked with in many ways.

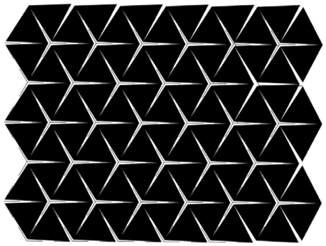
Origami is based around two different folds which are commonly known as "mountain" and "Valley" folds according to which way you bend the paper. The geometry I used is achieved by folding a constellation of triangles. The dashed lines symbolize valley folds and the continuous lines the opposite, mountain folds. This means that the surface will shrink in great proportion when it's fully folded, leaving only the smaller triangles visible.



Folding pattern



Unfolded structure

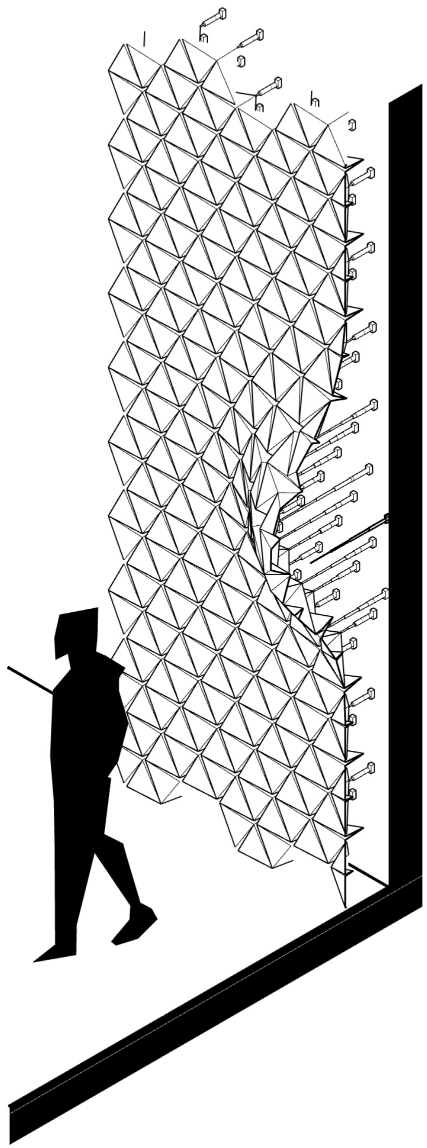


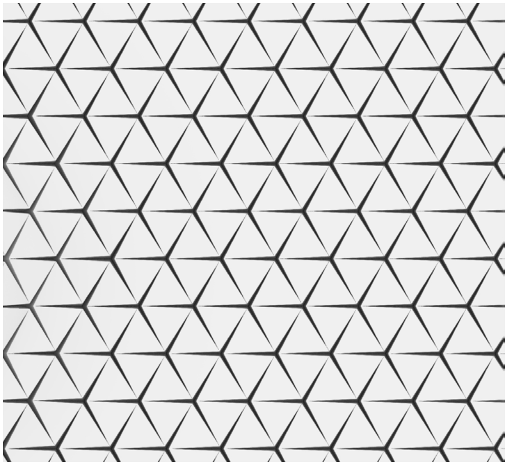
Folded structure

Kinetics

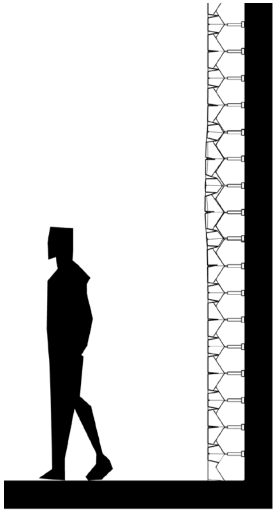
By using the intersection where the three valley-folds meet in the pattern I could establish the multiple centerpoints of motion. These would be the points that will be moved in an horizontal axis. As these points move, the rest of the structure will follow. Since the surface is continuous the surface will unfold once the centerpoints are set in motion. Moving one centerpoint results in a round expansion in all vertical directions. If each point is controlled individually a whole new range of patterns can be achieved. Different speed, expansions, flow and force can be experimented with to generate a desired output.

An interesting result of the experimentation with this pattern arose when designing the parametric definition for it. As only a portion of the surface is visible when folded, the rest of the surface could have a different appearance. When the structure unfolds this second part would appear and be increasingly contracted with different materials. If one were to work with transparent materials for the folded valley folds, these would be opened up, exposed and could channel light when expanded. This could create a very alive effect, almost like lava bursting up through a dark rock.

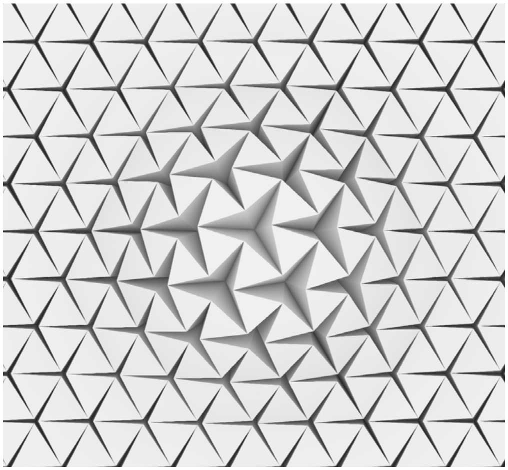




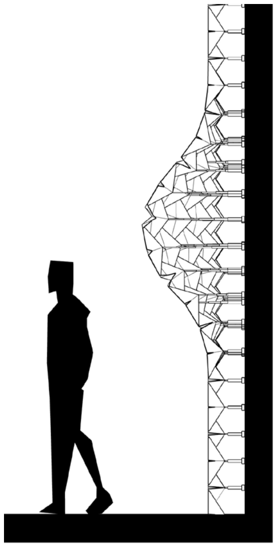
Front view



Contracted origami structure with internal expandable rods



Expanded front view

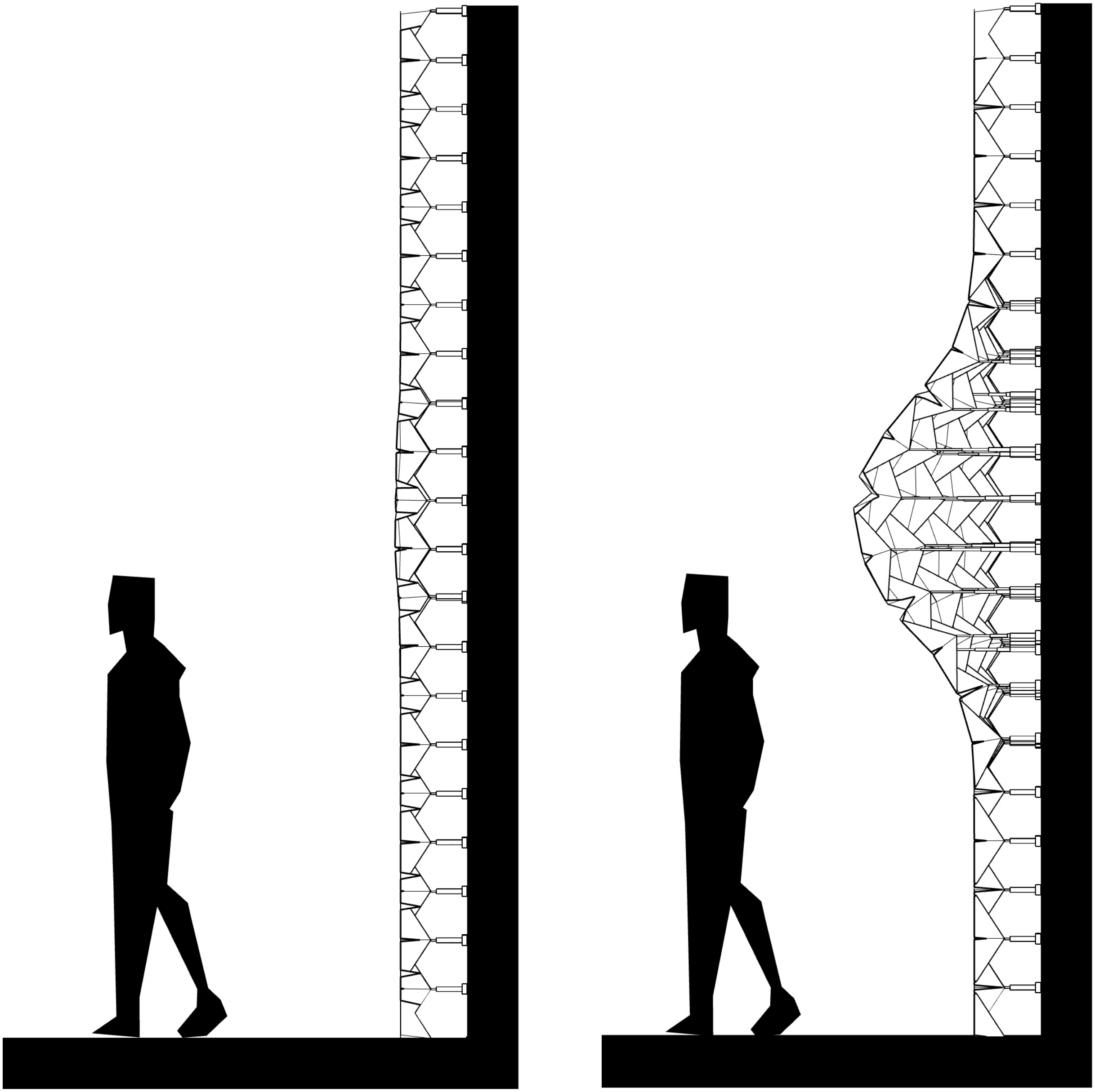


Unfolded origami structure with internal expandable rods

Mechanics

The mechanics of the expansion's main objective is to generate a horizontal movement from the centerpoints. According to my conclusion this is best done in three different ways. With expanding hydraulic rods, connected mechanics or inflation which affect a greater area simultaneously. I first decided to go further with the expanding-rod solution.

The previous elements could all be connected to a single mechanical rotation or force. This will be harder to achieve in the current situation. Although individual programming of expanding rods can be materially demanding and digitally challenging, it is perfectly constructable. Each rod is identical and executes the same motion, just in different time and strength. The placement of the rods could also vary. If one were to only use a few on a whole kinetic wall this would not make that much of a difference. The desired effect could be a guide in this choice of quantity. The surface would not need much expansion in order to generate a strong effect.



Unfolding of the origami structure with internal expandable rods

In generating a more mechanical solution, the centerpoints could be used in the same horizontal motion as with the rods. The difference here would be that each point would be connected to another point. One solution would be that this connection would generate a reversed effect on this other centerpoint. All these interconnections would be rooted to a single source of motion. The difference in horizontal motion would be predeterminately adjusted and then only affected by speed. This would offer a big overall kinetic effect but won't be as dynamic as the previously mentioned. In regards to materiality, technical and overall cost, this solution would be superior.

Visualisation of wall elements where reflective mirrors are attached to the origami surface

Visualisation of wall elements where reflective mirrors are attached to the origami surface

Conclusion

The purpose of this thesis was to investigate if a deeper relation between movement and form can be achieved and constructed with the use of digital tools. I approached this by implementing different theories and interpretations of movement in different scales, as a physical proposal.

Starting with Greek philosophy offered a very broad way of approaching form, yet gave valuable insight in how one can perceive, think about and break it down into smaller components. This way of thinking about the subject was constantly present for me in all scales of the project. Using the platonic theories of form enabled me to differentiate these scales and investigate them through motion on multiple levels.

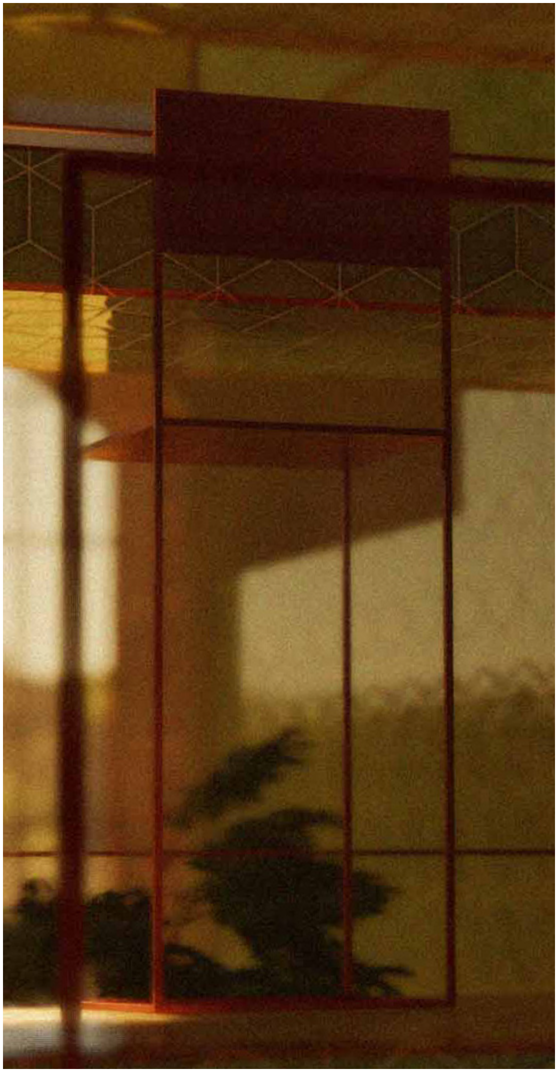
To create an understanding of the relation between form and movement a number different theoretical points of view were considered. This interdisciplinary research also inhabited a number of theories regarding the digital implementations and translations of movement and form, which guided me in the establishment of a digital workflow.

In a macro perspective, with the contextual situation and the primitive functional needs at hand, I could imply and work with the theories very early on in my proposal. Using it to analyse space and establish directional and rotational trajectories. Combining these with forces to generate flow.

Treating the platforms and entry points as forces with varying amounts of gravitational pull, I used Greg Lynn's method of generating a "virtual movement" affected by these forces. The generated form directly relates to this movement. Using the penetrating greenery as a negative subtracting force of this form further deepens the relation between different movements and the geometry.

By using these deeply rooted forces I could confidently disregard different variations of a more flowing topology executed during the process. Kari Jormakkas call for caution in blindly using streamlined forms helped me realise that the cubic language of form can imply just as much motion as a streamlined one.

A vital part of the process was the implementation of August Schmarsows theories about bodily projections. Using these I could generate a better understanding regarding proportions and the relationship between people and matter in my proposal. This was helpful in deciding dimensions of especially smaller scale components. It also gave insight into how space can be altered according to changes in perception during physical relocation.



Studying how we express sensed motion in our architectural vocabulary gave me insights in the relation between form and motion in my proposal. By categorising different architectural members in what we could refer to as contained or represented movement, a deeper understanding of their part of the whole was achived. This was especially interesting for me when treating the whole geometry as the same medium, knowing that we still differentiate and categorise parts of an interconnected, metamorphosing geometry.

The use of folding as a topological tool enabled the relation between movement and form to be increased and studied in several ways. By using this approach the functions and macro-scale motions became integrated and rooted in itself, in an interconnected, continuous geometry. This resulted in an increase of readability and a cognitive understanding. A user can go from reading each architectural member as a solitary to connecting them all in a comprehensive motion, acting in all axis of space.

This metamorphose combines motion and form to an animated structure where everything is related and characterised by its own neighbour. This ultimately generates a strong identity which can be further enhanced by the introduction of material, accentuating the transcending movement throughout the form.

Folding has been a practical tradition for thousands of years. To work with this craft in a digital environment is therefore very exciting. The work of restructuring a physical geometry to make it readable through folding would have been very time consuming and intricate work. Developing tools for architects to aid these kinds of topological work could therefore be necessary. Merging this practical method with a digital environment could open new ways for architects and designers to explore and understand form. Although generating the scripts for this methodology was a challenge in itself the end result was very rewarding. To be able to have this kind of tool at disposal during the process was very viable for the understanding of the form and its identity in the project.

Parametric tools offer a great potential in architecture and an insight I've concluded from this recess is that we can benefit greatly from this type of informational design. As long as architects focus on the right type of information and lower the use of unnecessary complexity. I concluded this especially when working with the elementary subdividing of form. Keeping a trajectory based upon non-complexity with digital tools can be a very effective way to study the relation between form and movement.

View of 2nd floor in the east hall

My experiments with kinetic elements resulted in a substantial spatial effect with a small input of mechanical forces. Using this kinetic effect one can study the perceptual differences in a metamorphosing environment. Rotational planar surfaces reacting to light can create geometrical patterns with great depth and spatial reconstruction. A randomised shimmering that mimics nature's dynamical multistimulative appearance could give us insight on how motion can relate to the perception of form, transcending through different scales.

View of 2nd floor in the east hall

Thank you

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List of figures

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