SET

Programming Funicular Wood Mosaic

by ***Jacob Flårback***
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Master's Thesis in Architecture and Urban Design
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ABSTRACT

Great design is in the details, it is on this touchable scale that the characteristics of a material can be fully experienced. Be it the striped edge pattern in a sheet of plywood, the structural flex in a thin rod of steel or perhaps the subtle grain pattern of a birch veneer.

By applying architecture and engineering to the furniture scale, investigation of details and materials will be at the core of the process. Through the design of a furniture set of three objects, this thesis aims to investigate the aesthetics and behavior of wood, and apply it to object design. Furthermore the thesis will, for these three objects, investigate the nature of an aesthetic relationship and how a balance between connection and individuality can be achieved in a set.

This thesis will work on understanding the behavior of a wood panel membrane. Unlike the vast majority of shell structures, the key here will not be finding a stable design but rather to explore ways in which to promote deformations in the structure. Through investigations and tests a skin of wood can then be designed to control and program the response when interacted with, as well as play with ways in which this relates to the aesthetics.

This process is then concretized in the form of three seating furniture pieces for which the target placement can be a hotel lobby. In this designed set aesthetics, comfort and ergonomics all will heavily depend on the programmed features of the skins.

THESIS QUESTIONS

What architectural principals of the building scale can transfer to the touchable scale and how can this be concretized in the shape of three furniture pieces for a hotel lobby?

In what ways can the structural interaction of forces for a furniture piece become both governing for the design process and perceived in the final product?

How can an aesthetically relationship between a set of objects be concretized and how can this be used to predictably create a harmonic yet dynamic set of furniture individuals?

In what ways can simple components come together in an understandable pattern and complete as well as govern the characteristics of a homogeneous whole furniture piece?

CONTENT

Barcelona chair (1929)
by *Mies van der Rohe*

Dream chair (2013)
by *Tadao Ando*

Model No. 41 (1931)
by *Alvar Aalto*

Plastic side chair (1950)
by *Charles and Rey Eames*

Villa Savoye (1930)
LC 1 - "Basculant" (1928) & LC 2 - "Petit confort" (1928)
by *Le Corbusier*

Heydar Aliyev Center (2012)
Kuki Chair (2013) & Crest Chaise (2006)
by *Zaha Hadid*

change of scale - from **BUILDINGS** to **FURNITURE**

ARCHITECTS and CHAIRS

The field of furniture design is frequently visited by architects. Perhaps it is the clear isolated task, the small object to sit on, which has captured the attention of numerous famous architects over the years. Regardless of the reason many big names in the field have attempted this change of scale.

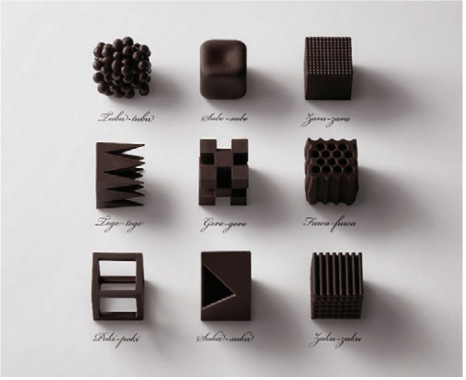
COMPARISON

There is an interesting connection when looking at the works on both scales of certain architects. Take Zaha Hadid for instance, her buildings and chairs bare such resemblance that it seems reasonable to assume that the same original sketch could be applied to both scales in her case.

Another approach is found in Le Corbusier's designs, his notion of elevating the function of the building on a slender set of columns is very similar to the metal frames supporting the function of the chair in his furniture.

RIO chair set (2015)
by ***Mehran Gharleghi***

Ume-play Collection (2013)
by ***Nendo***

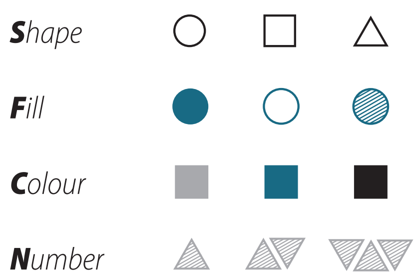


Chocolattexture (2015)
by ***Nendo***

Seven doors (2015)
by ***Nendo***

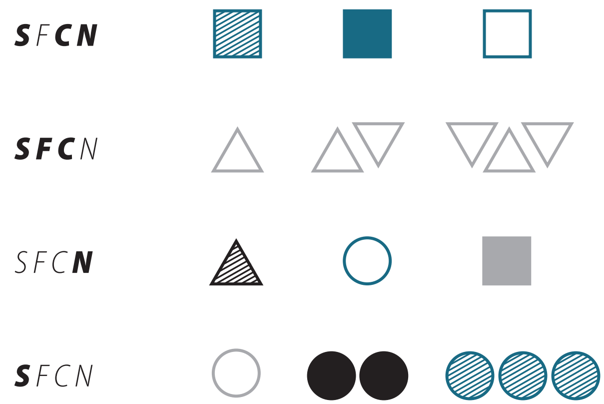
THEORY of an object **SET**

A very concrete way to look at object relationship is the theory behind the card game *SET*. In this game a valid set of three is achieved when the attributes of all three individuals either match or are all unique in the set.

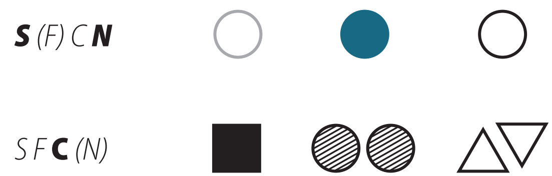


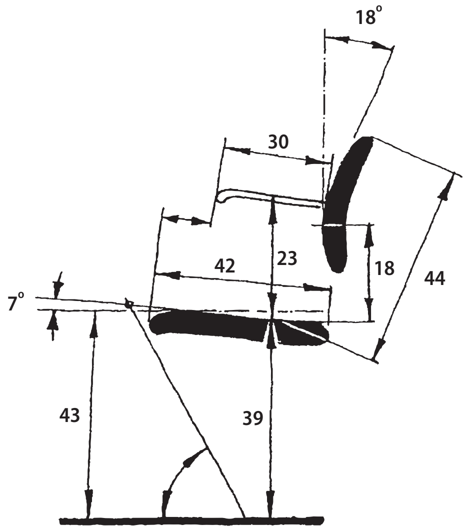
Target set level

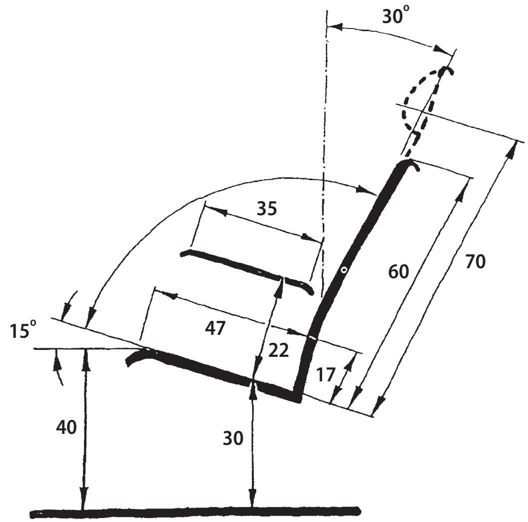
Valid sets



Invalid sets







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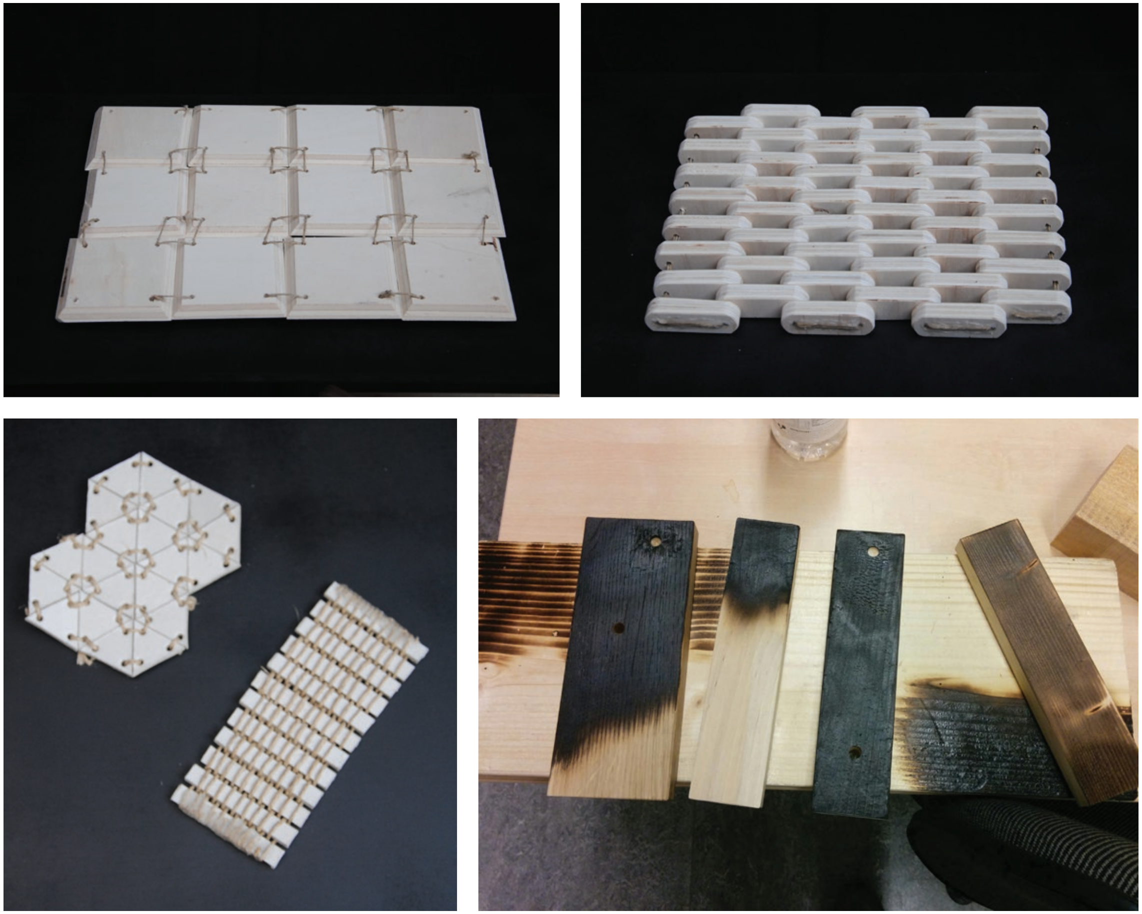
ERGONOMICS and **COMFORT**

THE FIRST RULE OF ERGONOMICS

In ergonomics there is one truth that governs the field, everybody is different. In order to handle this there are two main solutions, adjustability and adaptability. The common association to ergonomic furniture is to the adjustable chair, such as the office chair with numerous levers and switches to allow optimization for the body shape of its user.

The alternative method of adaptability is most commonly known in the fluffy stuffing of the average sofa. This pillow behavior will reshape the seat upon interaction thus adapting to its user.



Various models from the initial sketch phase

a set of **ITERATIONS**

INITIAL PROCESS

The process of this thesis commenced with a set of sketch models, the idea was to create double curvature in wood. The method of lamination is one of the most common solutions to this issue and was therefore not investigated further. Among the initial tests the three main methods that came up were: kerfing (reducing bending stiffness through strategic cuts), milling (carving out curvature in solid blocks) and plate networks (connecting wood board pieces into a network).

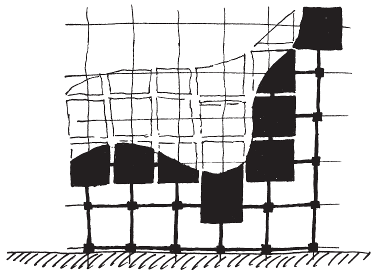
After some iterations the two latter principles were chosen for further investigation, both utilizing the principle of building up a whole from simple components.

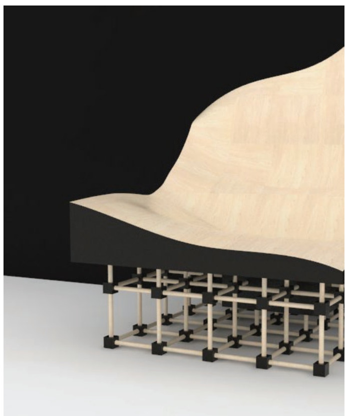
COLOR FROM HEAT

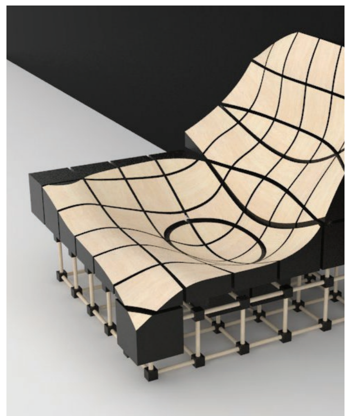
In parallel with the investigations of the structural setup of the furniture different ways of treating the wood were tested. The one that got the most focus was the Japanese art of "Shou Sugi Ban", preservation by means of fire. By combining burning of the wood with oil treatment it is possible to get durable wood with the side effect of completely changing its color.

1 the boolean modules

At the start of the design process various ways of creating double curvature in wood were investigated. The first concrete chair designs utilizing this were based on milled out solids in a space grid, however this concept yielded sculptural art pieces rather than exiting realistic chairs.

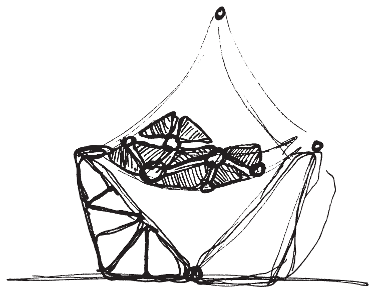


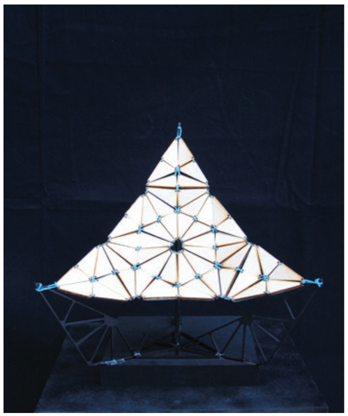


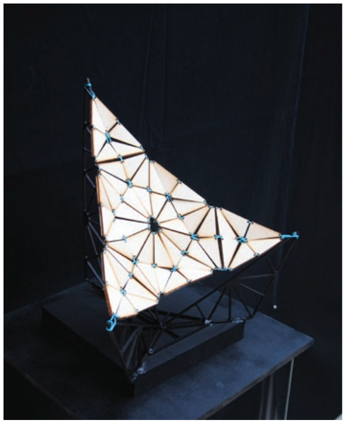


2 the funicular network

Eventually the concept of the funicular plate network emerged, initially the goal was to incorporate a yin yang relationship between the network and the frame, where the plates were cut out from a board where the then leftover became the supporting truss.

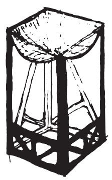


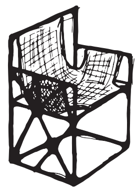


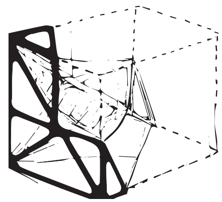


3 the chair space

By keeping a strong rectilinear shape of the support and hanging the curved surface inside the goal was a clear understandable logic, however the complexity of the frame overpowered the target main focus of the funicular network.

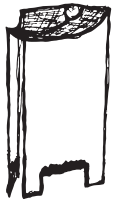


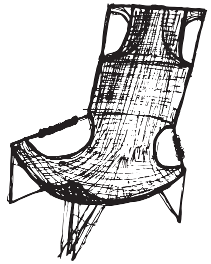




4 the suspended programmed surface

Accumulating all the conclusions of the process the final concept became the one that added an new material, steel, allowing a slim frame that did not scream for attention and gave the stability required to let the funicular network do the main work of controlled structural pliability.





Trada Pavillion (2012)
by ***Ramböll***

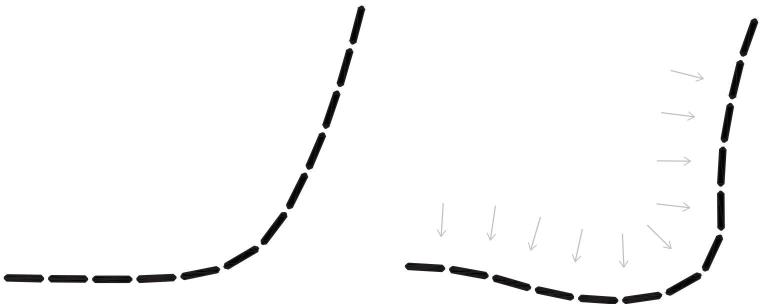
Flex Wooden Hammock (2007)
by ***Adam Cornish***

a pliant **SHELL** structure of **WOOD**

Creating a thin curved surface on which to sit follows the logic of shell structures, objects in 3D with a curvature in their unloaded state and where one dimension, the thickness, is significantly smaller that the other two. On the building scale shells usually consist of a thin concrete layer or a grid of steel of timber bars, a gridshell. Common for all these is the goal of a stable structure, in this thesis however that is not the case.

The optimum sitting experience consists in a combination of rigid support and flexible yield. This project therefore strives to combine these two behaviors, the stability of a plate shell like the *Trada pavillion*, and the pliancy of a hammock such as the *Flex wooden hammock*.

The choice of wood as the material comes from the ease of which it can be modified and its somewhat unpredictable nature, which through great design hopefully can be tamed.



The target behavior is an uloaded state that is deformed when sat on into a comfortable and ergonomic shape

ADJUST OR ADAPT

The back side shape of a body sitting down forms a double curved complex shape that varies greatly from person to person. If perfectly molded to fit someone the resultant shape would prove very uncomfortable to someone else.

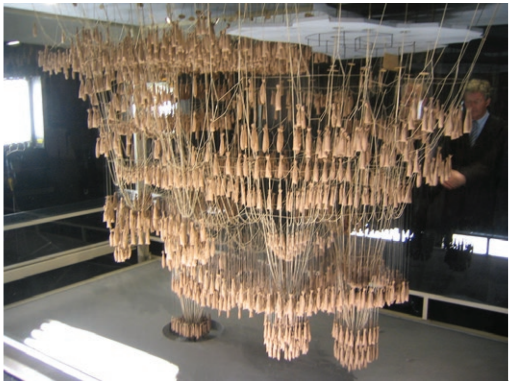
This issue is commonly solved in two ways, an adjustable machine with levers such as the stereotypical office chair or an object that adapts its shape to the user such as the hammock or padded sofa.

The latter principle has a more integrated design but the common solution of cotton stuffing does not require any further investigation, therefore this project strives to achieve the same adaptability but with the use of stiff wooden plates.

A BALANCE BETWEEN RIGID AND FLEXIBLE

When going from a hard wooden chair to a hammock of fabric it is tempting to assume that the closer to the latter the more comfortable it is to sit, this however is not necessarily the case. When a hammock sweeps around a body pressure is moved from ones back to the sides, applying pressure on areas more sensitive and less used to it.

The ultimate solution is therefore the programmed intermediate where some areas are very yielding, such as the behind, and others give a rigid response that supports a sitting body, for example under the thighs.



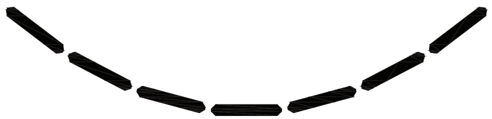
Creating shapes with natural hanging funicular curve shapes gives aesthetics with inherent structural optimization
La Sagrada Familia model** (1890) by **Antonio Gaudi

Apart from enabling low material usages there is natural beauty in the catenary logic
L'oceanografic** (1996) by **Felix Candela

SUSPENDING a **FUNICULAR** plate network

FUNICULAR BEHAVIOR

The logic of a hanging chain, catenary behavior, is based on the shape obtained when a set of identical links with mass are acted upon by gravity. The related term of funicular is the wider term including non homogeneous units or chain-like behavior.



A catenary chain of links creates a faceting of the ideal curve

EXPANDING INTO 3D

The logic behind funicular behavior can easily be expanded into 3D by hanging for instance a network of chains or a fabric, this simple principle of design allows complex shell structures to be designed using simple physical modeling techniques, a method used by for instance Antonio Gaudi and Felix Candela.

The last step of the process above is the solidifying and turning upside down to create a stable shell, this is where this thesis takes another route in the design evolving the model in its suspended state instead.

The principle of a chain can be extruded to create a surface but is limited to single curvature
100 piece chair (2013) by Perrine Vigneron

Approaching double curvature of plate networks risks the creation of uncomfortable origami folds
Wood-skin (2012) by G Masotti & G Lo Presti

The stiffness and weight of a hanging leather chair attains a shape near that of a funicular plate network
Bat chair (1938) by Hardoy, Bonet & Kurchan

A NETWORK OF PLATES

When the process of securing stability in the shell structure is undesirable a convenient design approach is to expand on the suspended chain of links into one more dimension, thus creating a network of hanging plates.

The resultant network however, if consisting of plates that do not have large gaps between units, will be of a rigid nature. This inherent feature of shell structures finding stability is usually part of its success, but becomes a problem when this is not desirable.

FROM PLANAR TO CURVED

One way to ensure a certain degree of flexibility is to start planar and find a plate network than can deform into its desired shape from there. This way the network in its curved shape is sure not to have a geometrically stable mesh and will most likely be able to deform a bit further still.

This however raises the issue of curving planes identified when folding a paper, if a sufficiently double curved shape is to be created there needs to be folds in the paper. This can be amended by introducing waists in the planar shape. When the network is then curved there is less material in the way and folds can be significantly reduced or even avoided.

In membrane structures support axes yield strong effects on the aesthetics, this strong relationship between form and function creates a readable design ***Entrance Federal Garden Exhibition*** *(1957) by* ***Frei Otto***

Structural optimization of gridshells can absorb main axes in a shape for efficiency adding aesthetic logic in the process ***Chiddingstone Gridshell*** *(2007) by* ***Buro Happold***

main **AXIALITIES** and **SYMMETRY**

PROGRAMMING with AXES

When creating a double curved shell of flexible nature an efficient way of controlling this lack of stiffness is axes that only bend in single curvature. These backbones in the plate network can then prevent undesirable torsional deformations and give a degree of stiffness, without reducing the flexibility in its main directions.

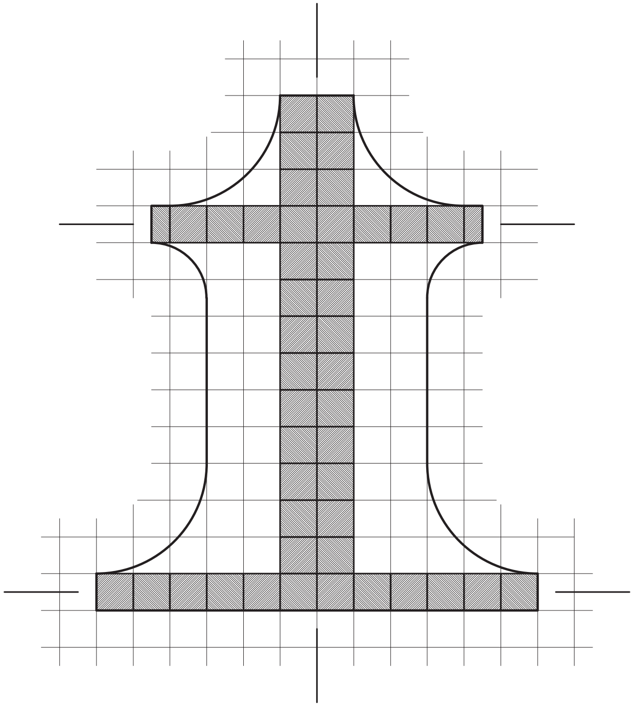
In order to ensure this behavior in the plate networks the use of quadratical plates is the apparent solution, the folds between these plates only exist in the parallel and perpendicular directions of the axes and will thus only allow bending in these directions.

DESIGNING WITH AXES

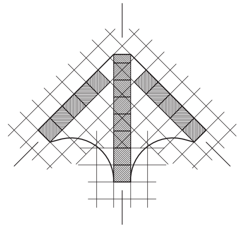
Apart from the functional benefits mentioned above axes can give a logic and understandability to a mesh. This is proven repeatedly in nature when inspecting the skin of an animal with patterns or the scales of a reptile, where the axes of the spine or limbs are clearly visible in the appearance of the animal.

The notion of indicating main axialities through the aesthetics is common in nature and can be seen in most patterned animals
Leopard hide

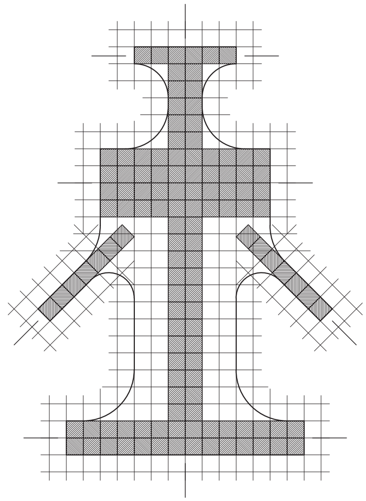
In some reptiles the existence of main axes in a skin can be seen in changes in the scale patterns
Gecko lizard



The programmed axes of the KOMODO mesh, covering the areas of single curvature in the otherwise double curvature shell



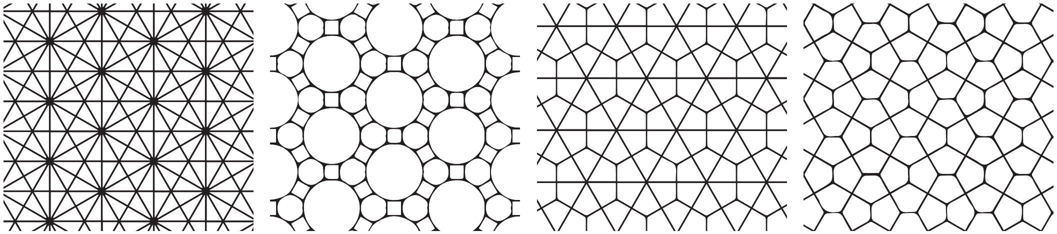
main axes in the GECKO mesh..

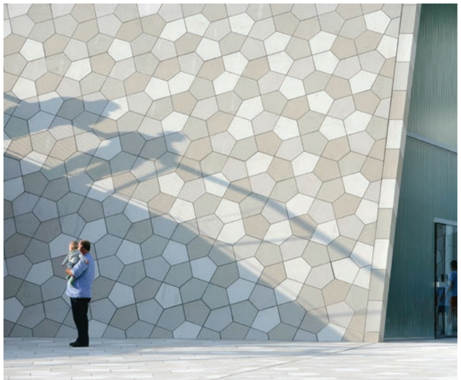


main axes in the CAIMAN mesh

main **AXIALITIES** and **SYMMETRY**

Numerous methods of tessalation were tested to determine their effect upon suspension in a network





Tessellating tiles of certain shapes can fill planes with identical pieces giving a homogeneous aesthetic
Zemet Centre** (2009) by **3LHD architects

The mathematical logic of certain Islamic patterns enables a readable design despite high complexity
Facade in Fez, Morocco

TESSELLATING patterns of the **MOSAIC**

TESSELLATING A SURFACE

Tessellation refers to the filling of an infinite plane with geometrical shapes, this is also how architectural precedents usually use tessellating patterns, an infinitely stacking pattern that is cut when needed.

In difference to that approach the world of animals as well as this thesis aims to tessellate a closed area of a certain shape, a goal that changes the possibilities of patterns

FOLDS IN A MESH

When designing a curve-able mesh the setup of mesh edges becomes crucial to the design. Many tessellating patterns such as the one on the *Zemet Centre* do not have continuous edges through the surface, this severely limits the flexibility of that surface to the point of some being completely rigid.

Straight folds through the whole mesh add no resistance to bending and gradually as folds curve or kink they become stiffer. This behavior can be theorized on a principle level, many continuous folds with low spacing in high curvature areas and kinks in the folds in areas that benefit from planarity. In practice however the actual behavior of a certain mesh needs to be simulated.

The voronoi pattern is among the most common in nature, it forms the structure of an insect wing as well as color pattern on some mammal skins
Giraffe skin pattern

In nature flexible skins of hard scales are achieved not in one flat layer but with overlaps
Bush viper snake

QUADS AND TRIANGLES

The main axes previously discussed are represented in the mesh with quadrilateral faces of varying sizes. They limit the bending of the fabric to single curvature in their axis and form the structural core of the mesh. Around them, in the areas of double curvature the mesh requires triangular faces. Since a triangular grid has folds in more directions they also promote curvature to a greater extent.

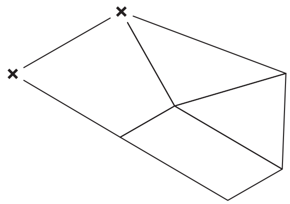
Inspired by the animal skin patterns in nature the border around the axes is dissolved and the face types of the mesh are allowed to intrude onto their respective zones.

HOMOGENEOUS AND DYNAMIC

A crucial feature of the funicular plate networks is the variation in plate sizes, small pieces allow for much bending and large ones the opposite. This aspect of the mesh however is in conflict with the beauty and simplicity of a homogeneous pattern.

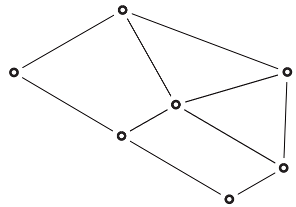
The final mesh setups therefore strive to find a balance between the dynamic of the pattern and a uniform whole.

Kangaroo driving goals



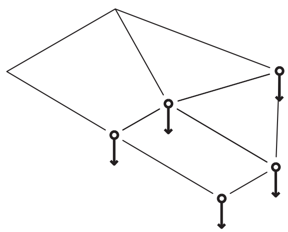
SUPPORTS

The points that hold up the mesh are locked from translation i the directions of all of the axes.



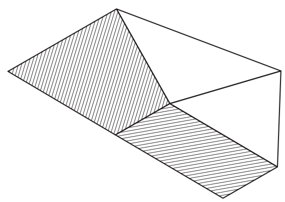
EDGE LENGTHS

All of the mesh edges are turned into stiff spring bars to maintain their starting length



GRAVITY

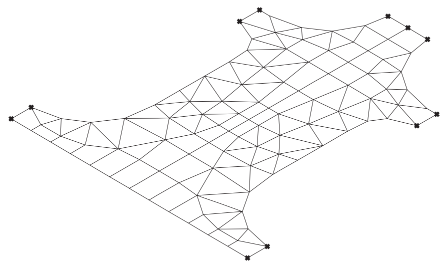
In all of the free nodes a vertical force is added in order to simulate the effects of mass



PLANARITY

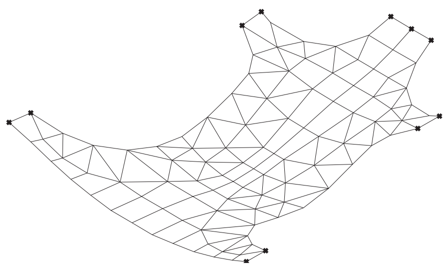
Since quadrilateral mesh cells can contain curvature all of them are held planar by force

virtual **SIMULATION** of forces



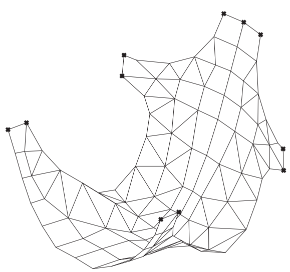
PREPARATION

The mesh to be evaluated is imported into Rhinoceros and Grasshopper. The parametric script for the analysis is prepared using the Kangaroo physics engine and some of its driving goals, mentioned above. The points for the supports are marked out as a final preparation for the analysis.



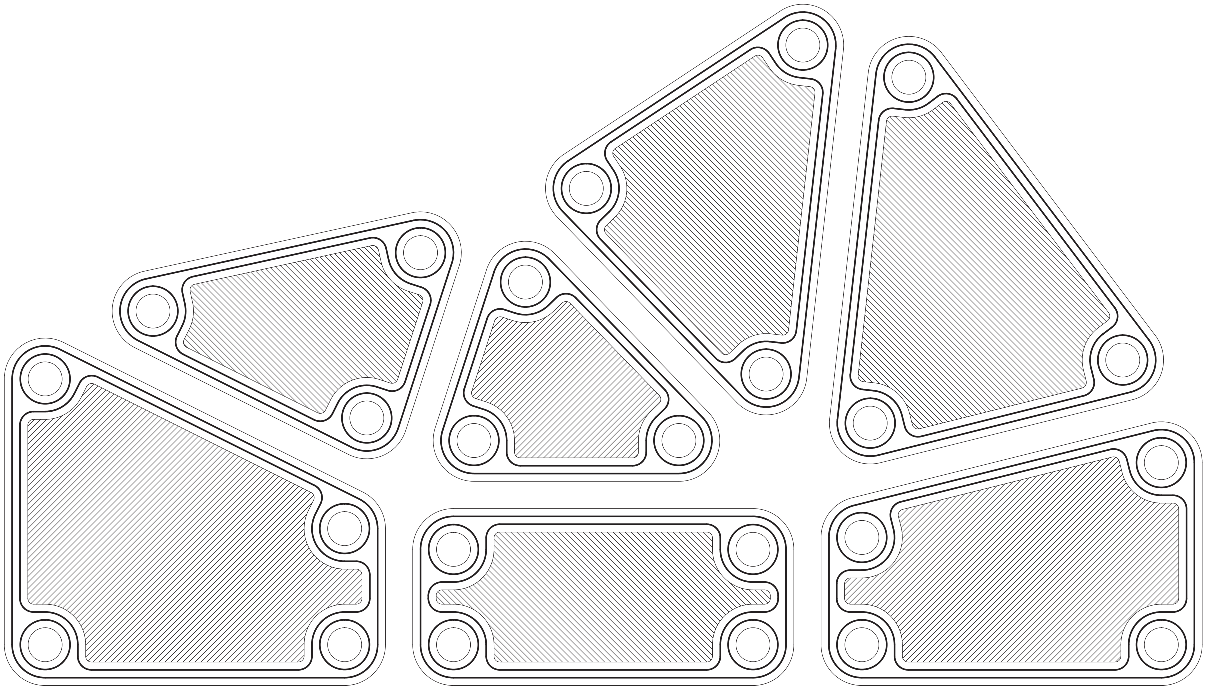
ACTIVATION

As the physics engine is activated the mesh begins to deform at a set time step, eventually the first stable position is found. At this point the mesh can be checked to make sure all the faces connect and that the applied forces and stiffnesses are appropriate.



MODIFICATION

With the engine running the supports of the mesh can be live translated to their target position. This has to be done in gradual steps for the engine to handle the calculations but eventually the final shape is given and can be inspected for sitting section, unwanted folds etc.



CNC DETAILING 1:1

CNC milling the **DETAILS**

TURNING CHARACTERISTICS INTO QUALITY

The choice of plywood upon deciding on the plate network meant the addition of the characteristic glue pattern of the board material, in order to have a motivated argument for keeping this material this feature required a prominent spot in the design.

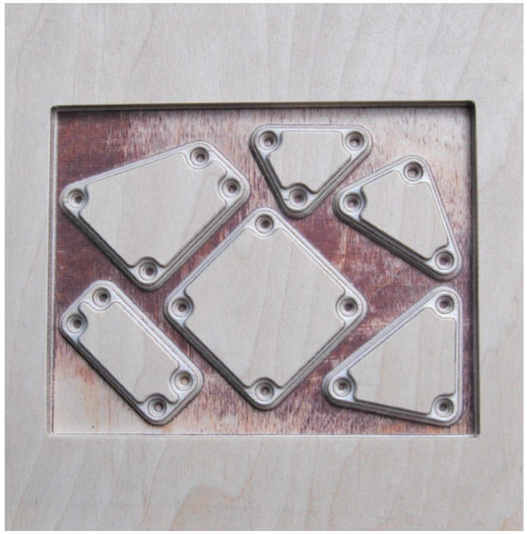
By chamfering down the sides of the plywood the glue pattern becomes not just a side attraction, in both senses, but also a main feature visible from all directions.

In addition to its aesthetic qualities this feature also tells the narrative of the construction process, instead of molded units of the right shape the plates become the end products of a delicate milling process.

ZOOMING IN EVEN FURTHER

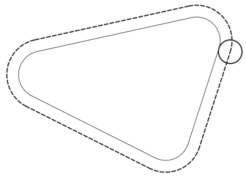
The process of designing at a more and more detailed scale finishes with the grains of the wood, as a final characteristic the wood fiber angles of the units are alternated in the network creating a very subtle complexity that in certain lights give the furniture pieces an extra level of deliberate character.

Gradual evolution of the plate units



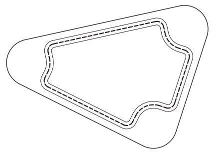
Output from the CNC mill showing the top side of the units

Cutting sequence for the CNC



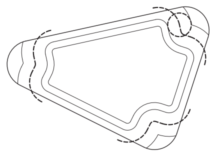
CIRCUMFERENCE

The outline of the units are milled out down
4.5 mm *to the centre of the plywood*



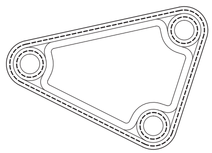
TOP CHAMFER

The first chamfer level is milled along an offset of the top
creating a ***1.75 mm*** *deep cut*



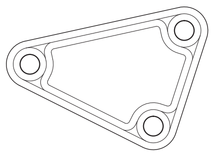
CORNER FLATS

The corners are milled down flat ***1.75 mm*** *to align with*
the base of the top chamfer



LOWER CHAMFER

The second chamfers are milled out ***1.75 mm*** *deep*
around the circumference and planned holes



HOLES

The openings are drilled through ***9 mm*** *to the other side*
finishing the CNC milling of the top side

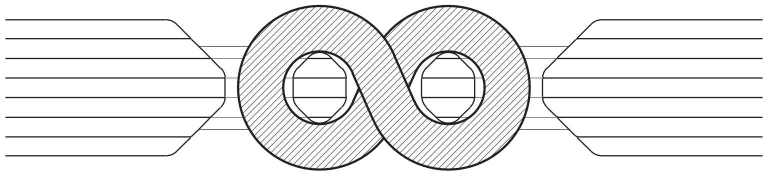
a **FRAME** supporting the network

DISCRETE YET CHARACTERISTIC

To avoid an attention conflict between the funicular network and its supporting structure the concept of the frame is simple, black round steel bars joined into closed loops.

In the interest of bringing more character to the set this concept is then used to create prominent spines in the back of the supports. Marking out key locations in the individuals the frame is also wrapped in colored string aiming to further enhance the goal of a homogeneous yet dynamic set.

LINKING the units together



JOINT SECTION 2 : 1

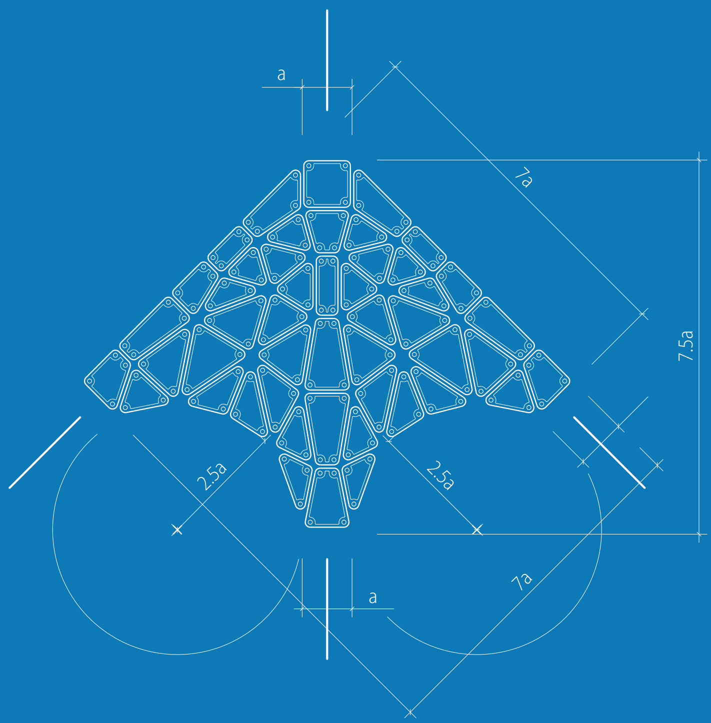
INFINITY KNOTS

The list of features that the joints in the plate network need to hold is long, simplicity for the manufacturability and aesthetics, rigidity to allow for efficient transfer of forces, controlled spacing for the appearance and to avoid pinching... And so on.

A solution that fulfills all these demands is the chosen nylon loop above. Being a melt able material the nylon allows for the creation of a closed loop, when done in the shape of an infinity sign this joint also works as a spacer between units and creates a moment free joint even when tightened, since the string does not bend but rather roll over to the other unit.

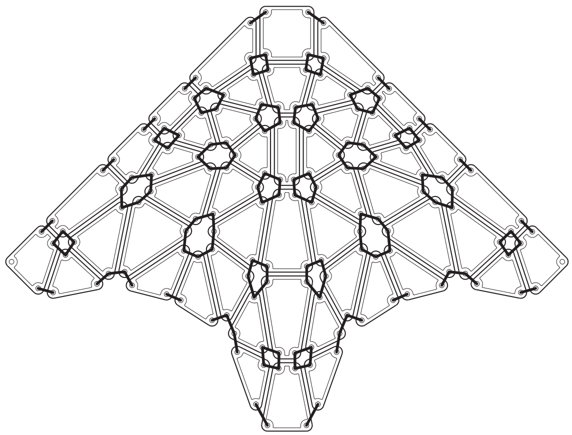
GECKO

the Bar Stool



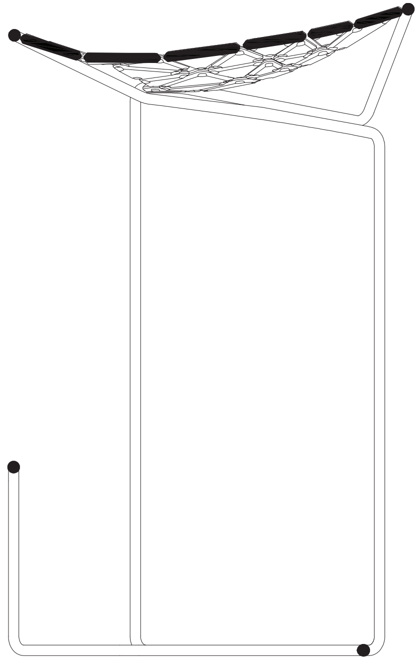
1 : 10

a = 60 mm



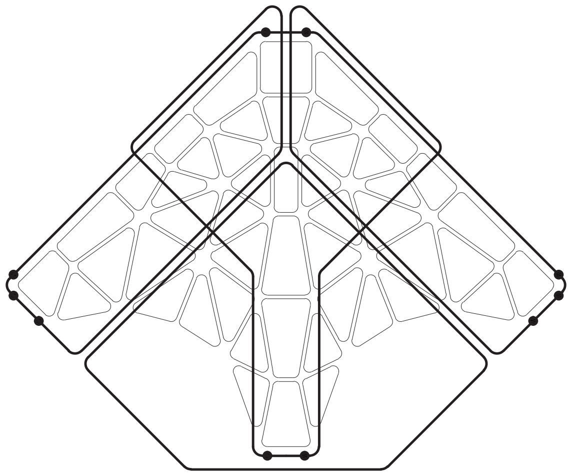
KNOT PATTERN

GECKO
the Bar Stool



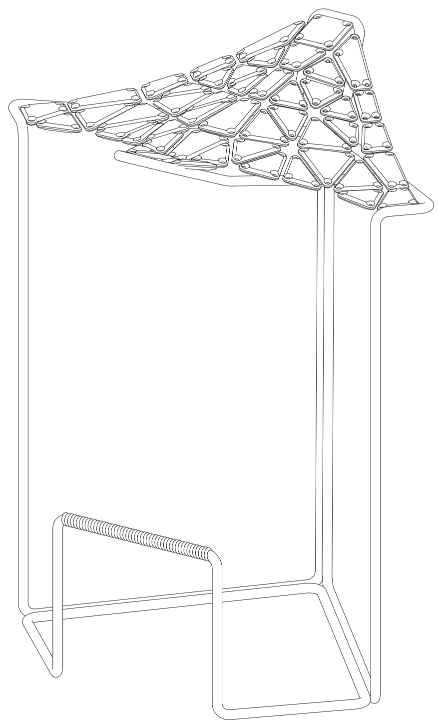
SEAT SECTION 1:10

GECKO
the Bar Stool



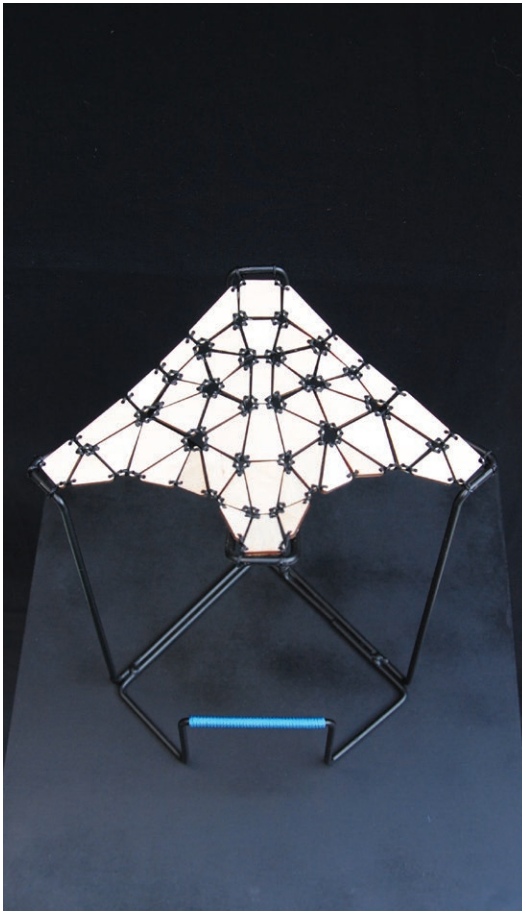
FRAME CONNECTIVITY

GECKO
the Bar Stool



AXONOMETRIC VIEW

GECKO
the Bar Stool

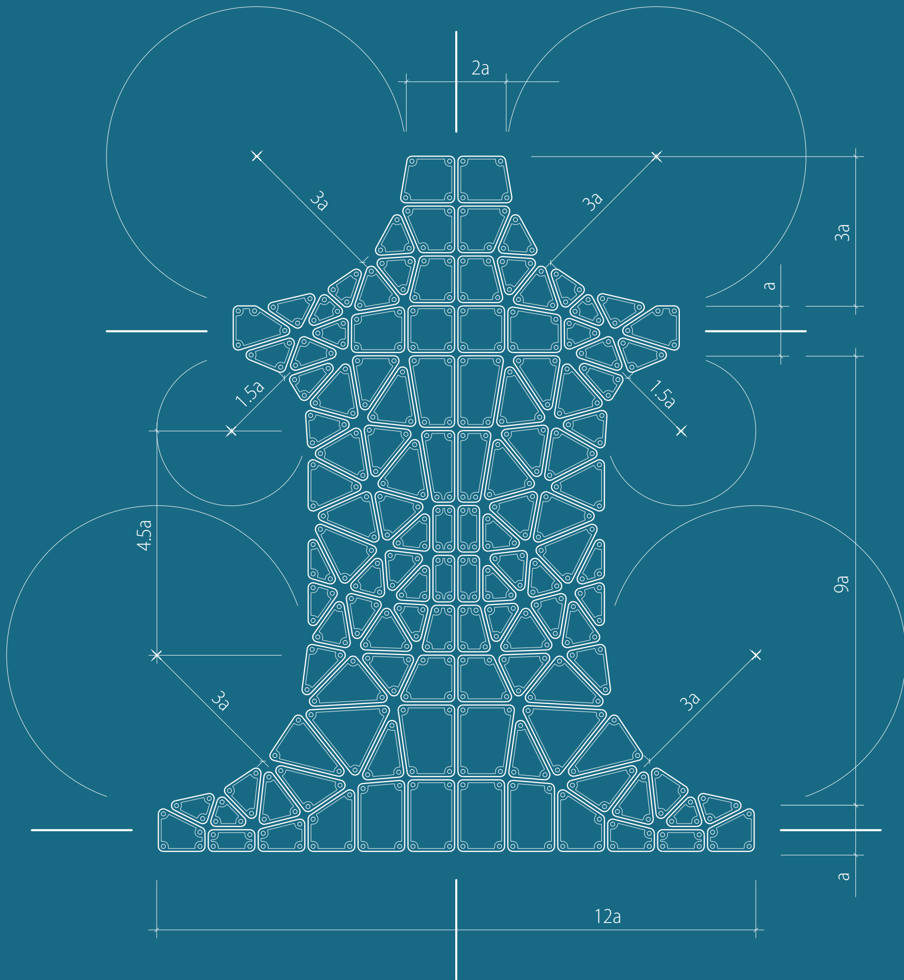


GECKO
the Bar Stool

GECKO

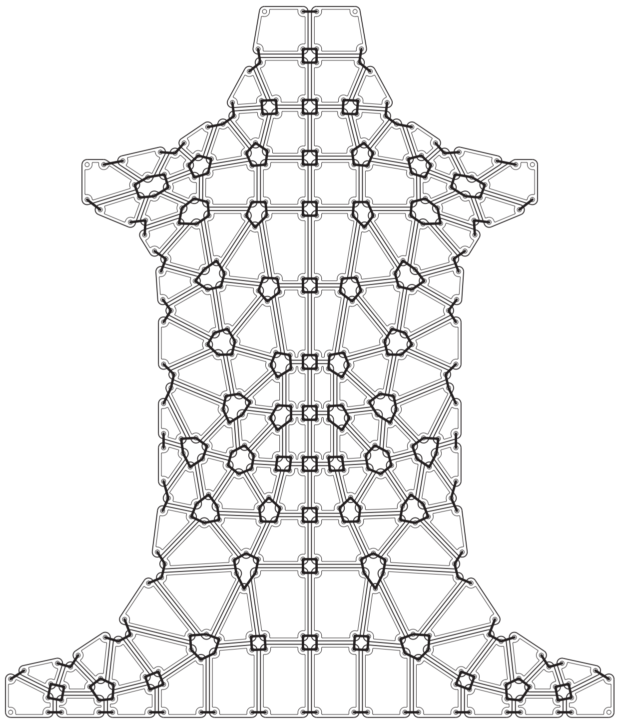
the Bar Stool

KOMODO
the Table Chair



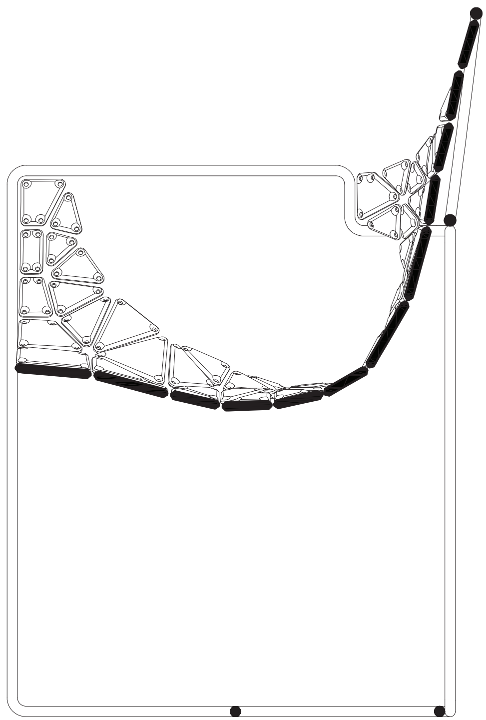
1 : 10

a = 60 mm



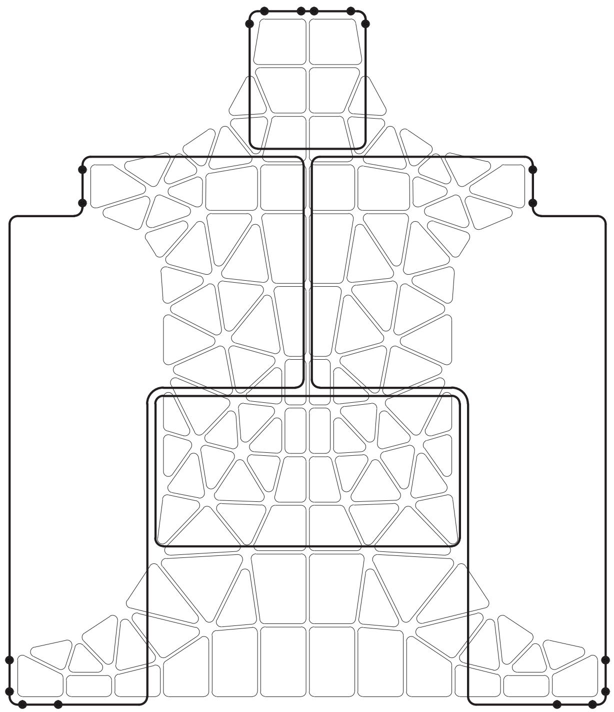
KNOT PATTERN

KOMODO
the Table Chair



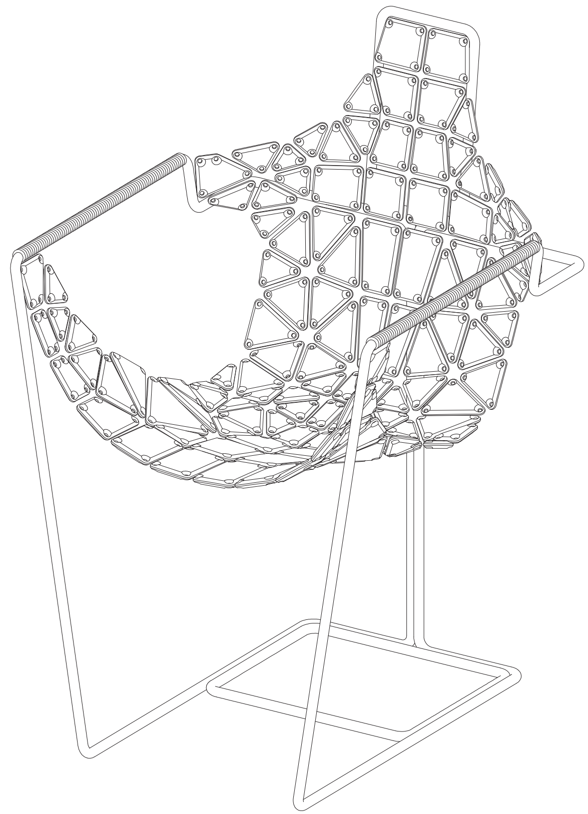
SEAT SECTION 1:10

KOMODO
the Table Chair



FRAME CONNECTIVITY

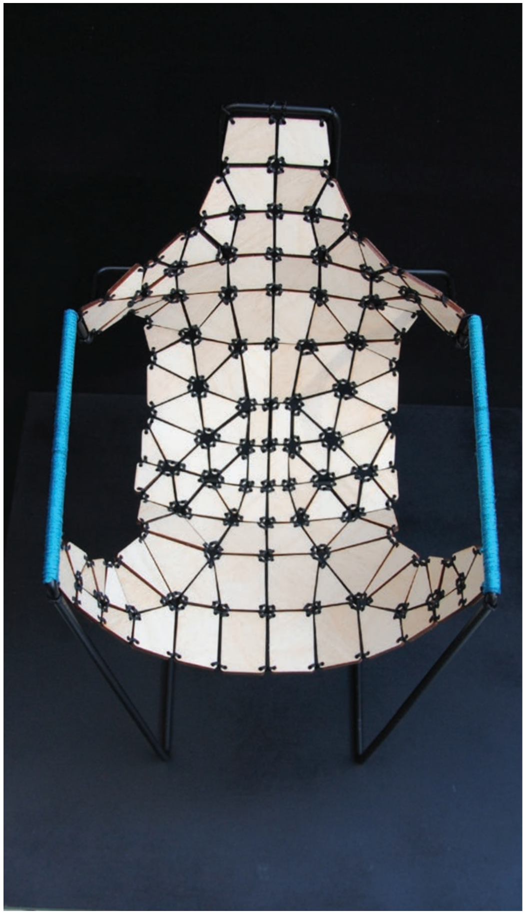
KOMODO
the Table Chair

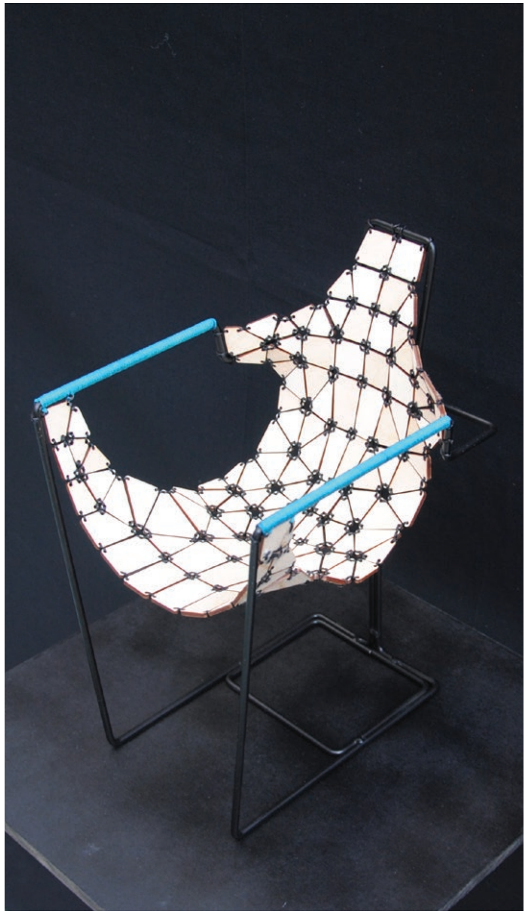


AXONOMETRIC VIEW

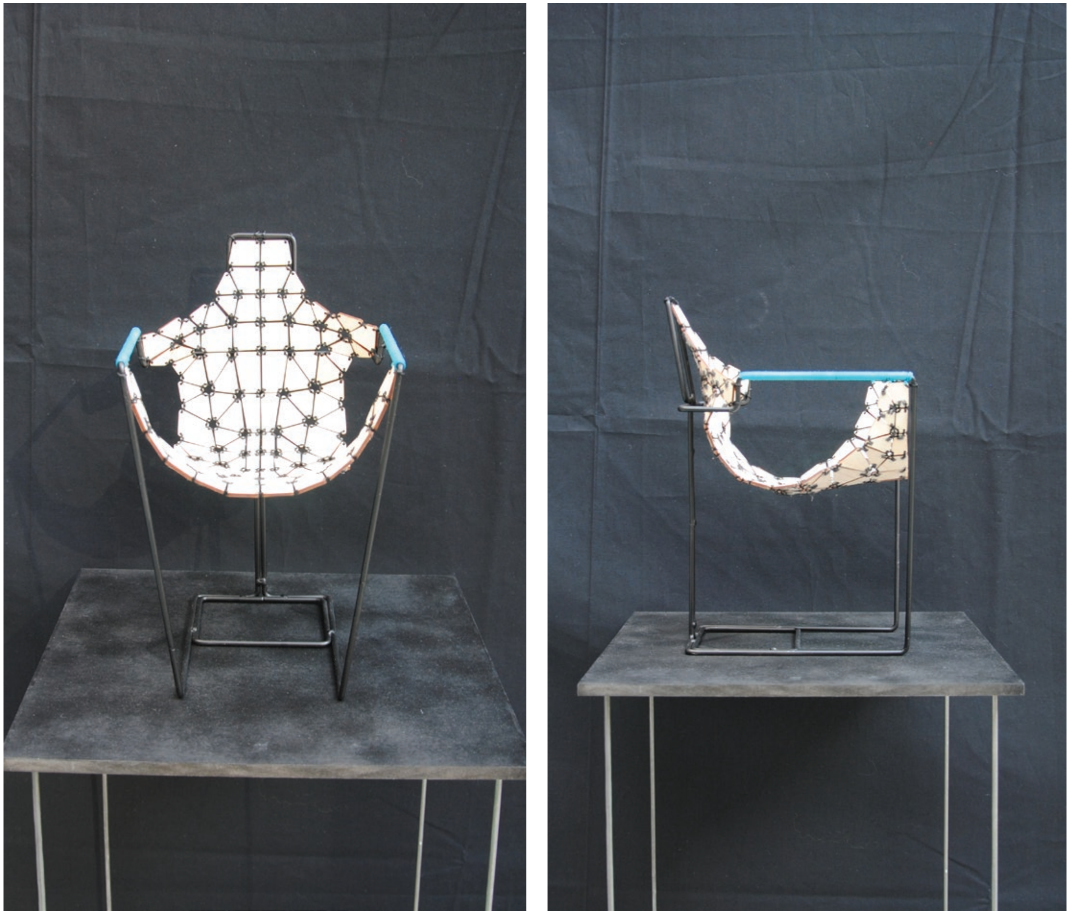
KOMODO

the Table Chair





KOMODO
the Table Chair

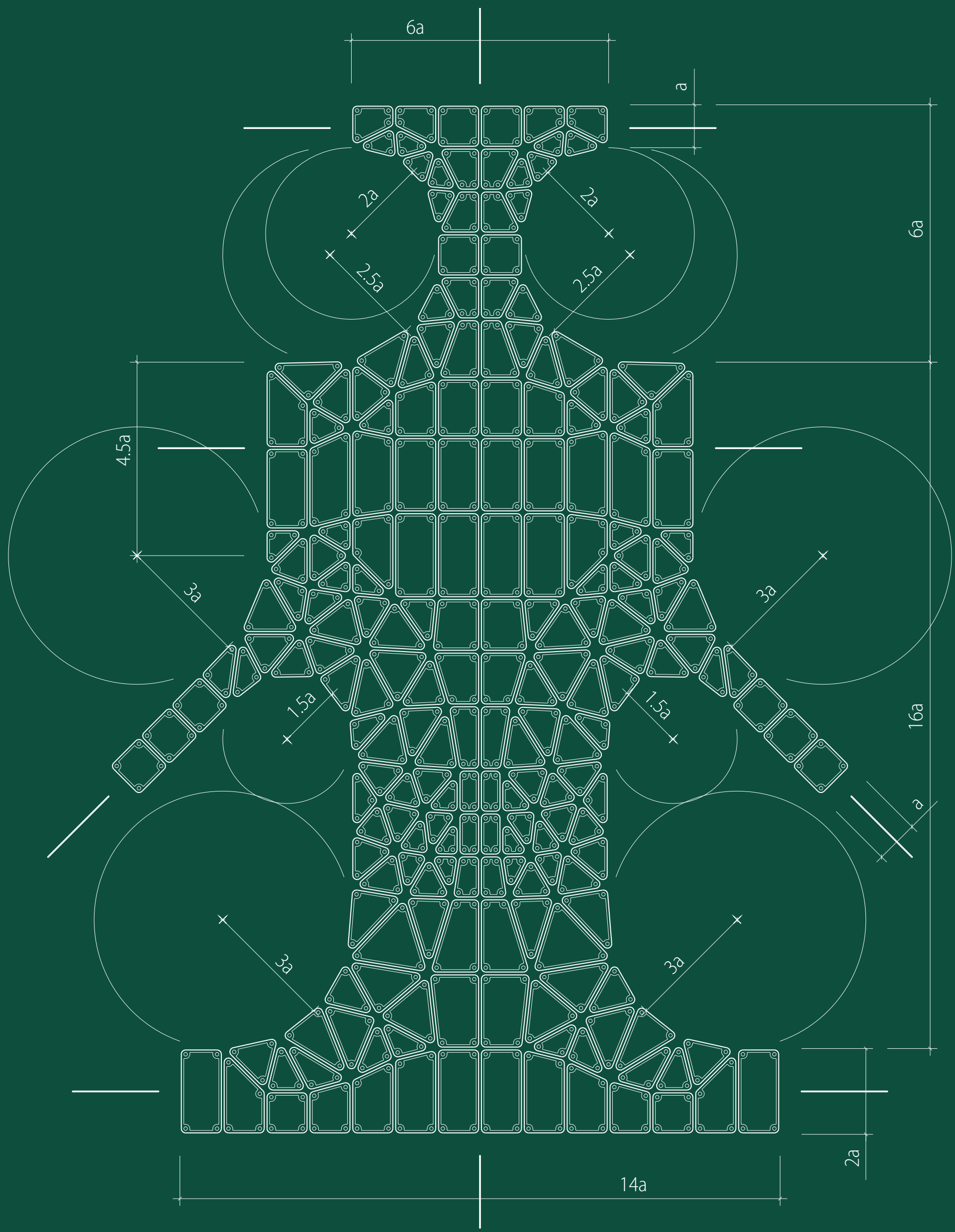


KOMODO

the Table Chair

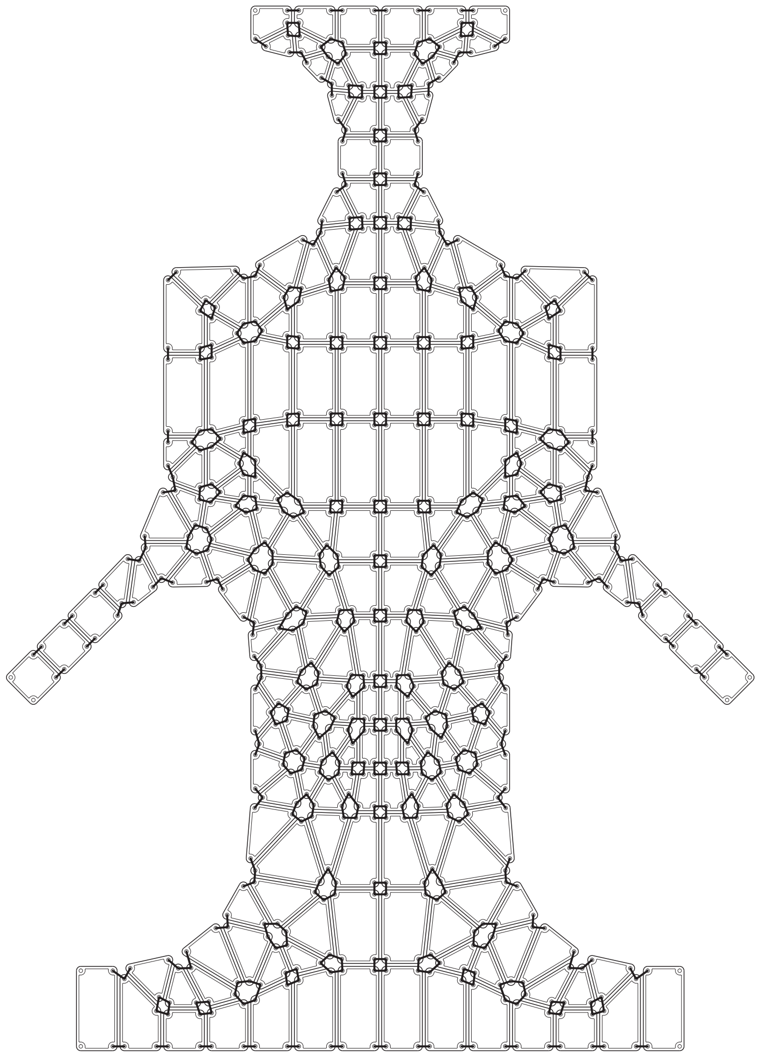
CAIMAN

the Lounge Chair



1 : 10

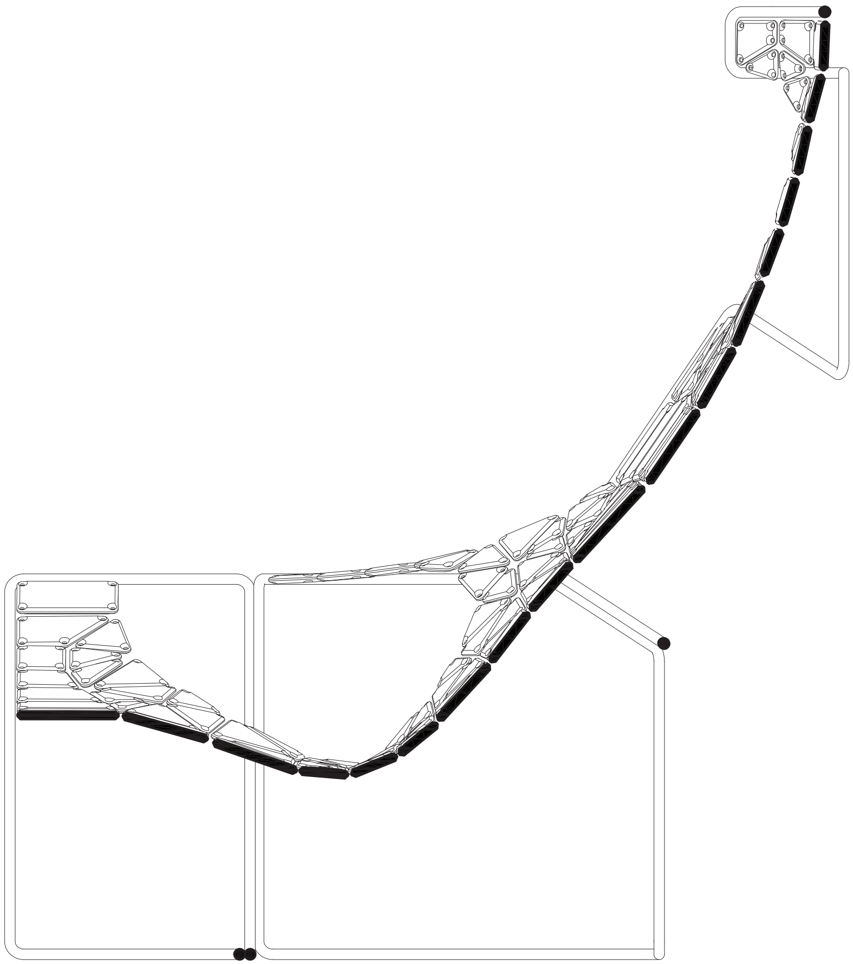
a = 60 mm



KNOT PATTERN

CAIMAN

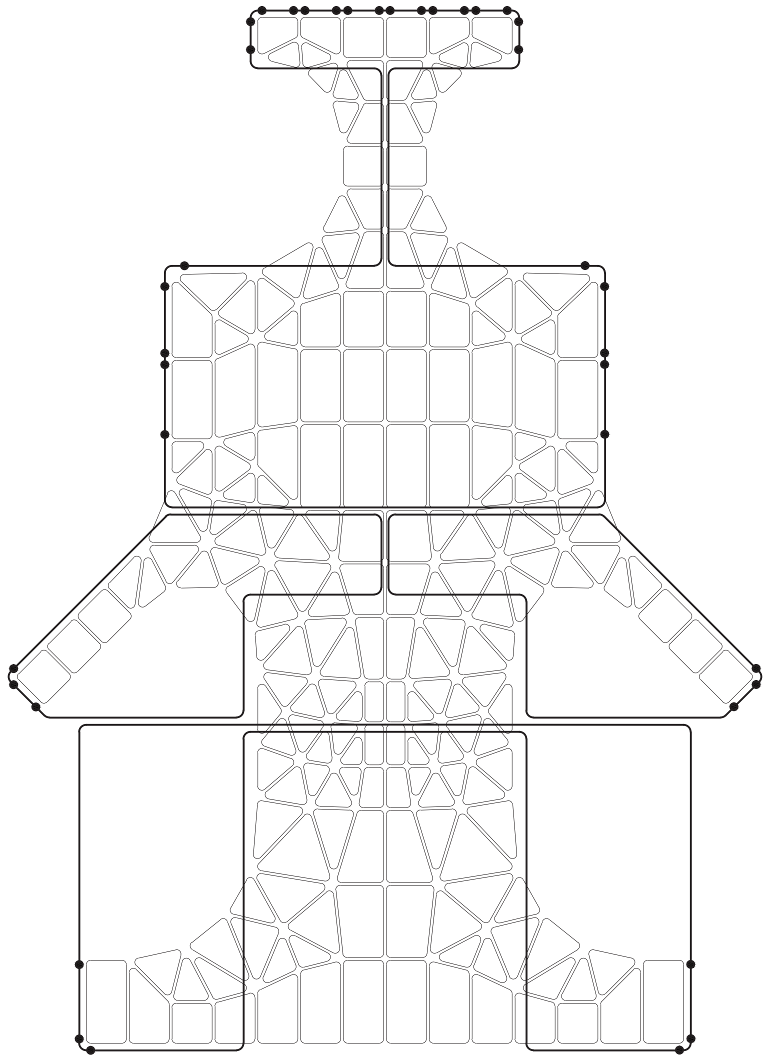
the Lounge Chair



SEAT SECTION 1:10

CAIMAN

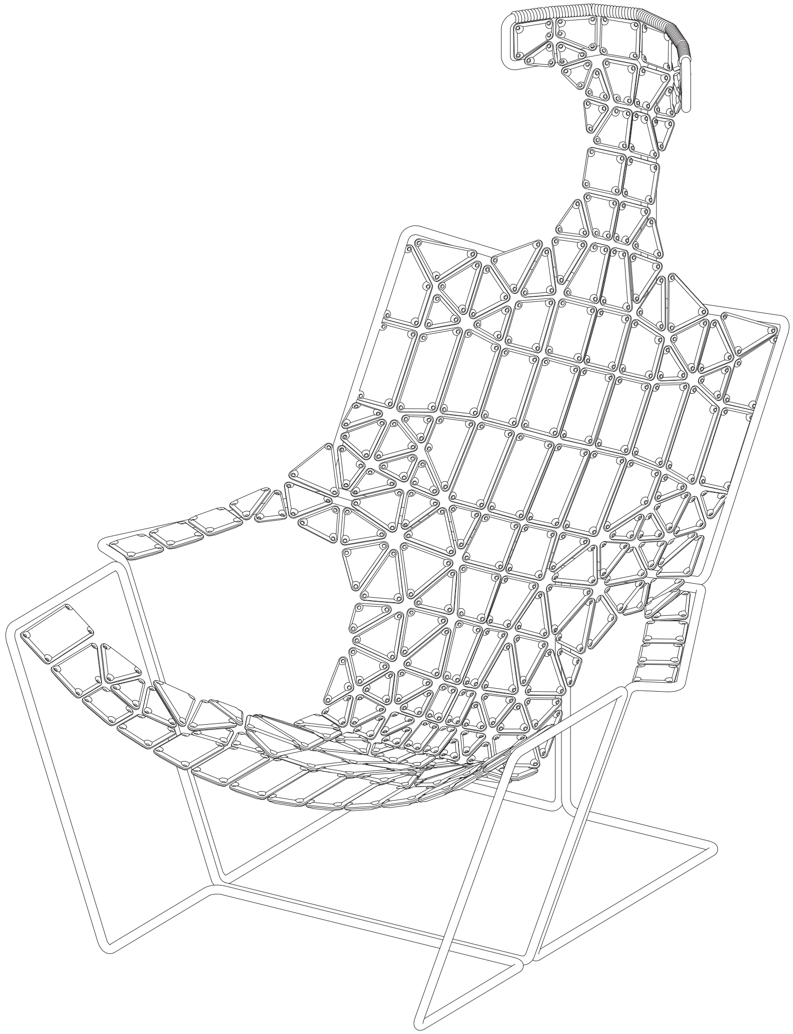
the Lounge Chair



FRAME CONNECTIVITY

CAIMAN

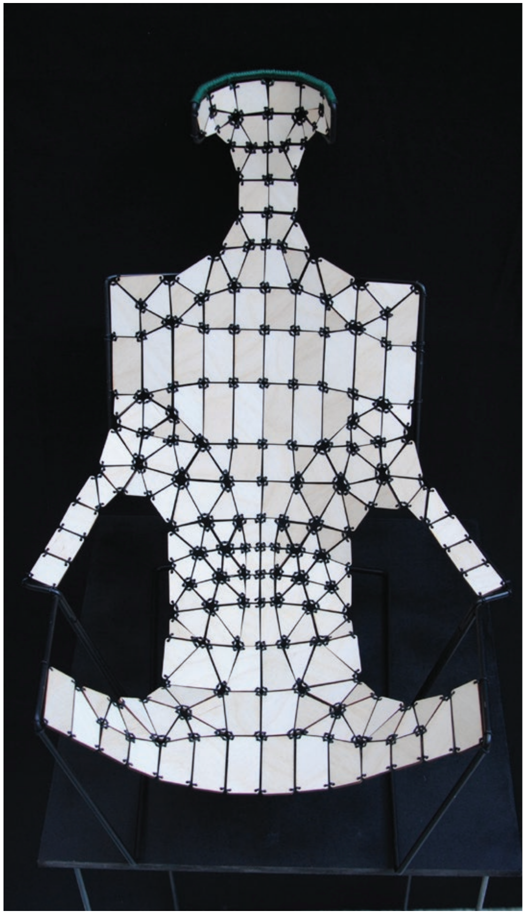
the Lounge Chair



AXONOMETRIC VIEW

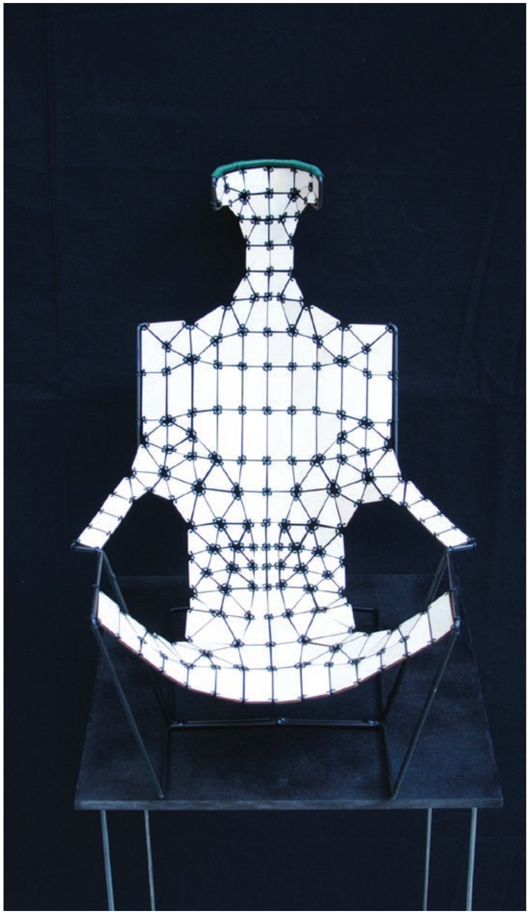
CAIMAN

the Lounge Chair

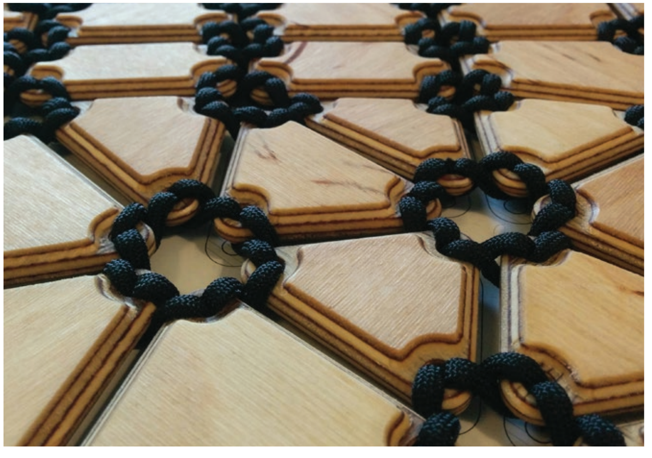
CAIMAN

the Lounge Chair

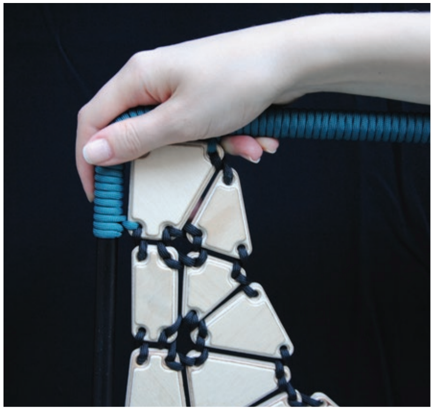
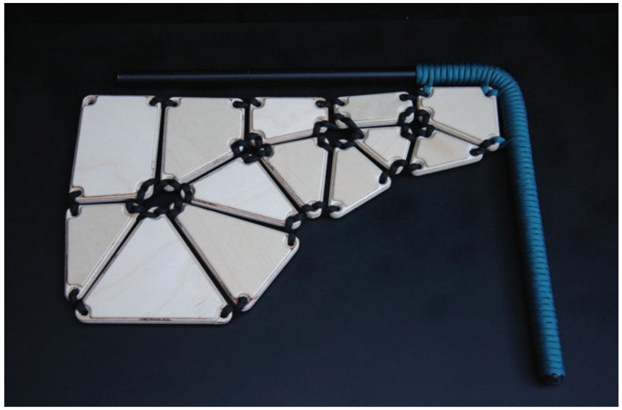


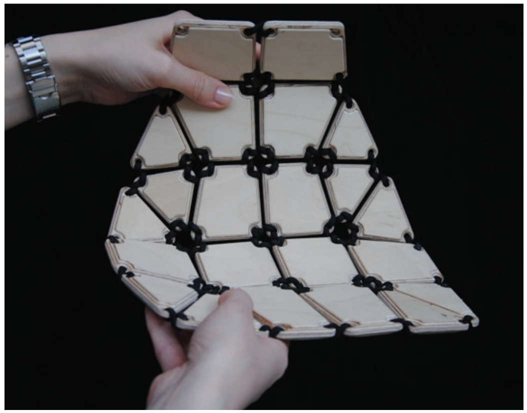
CAIMAN

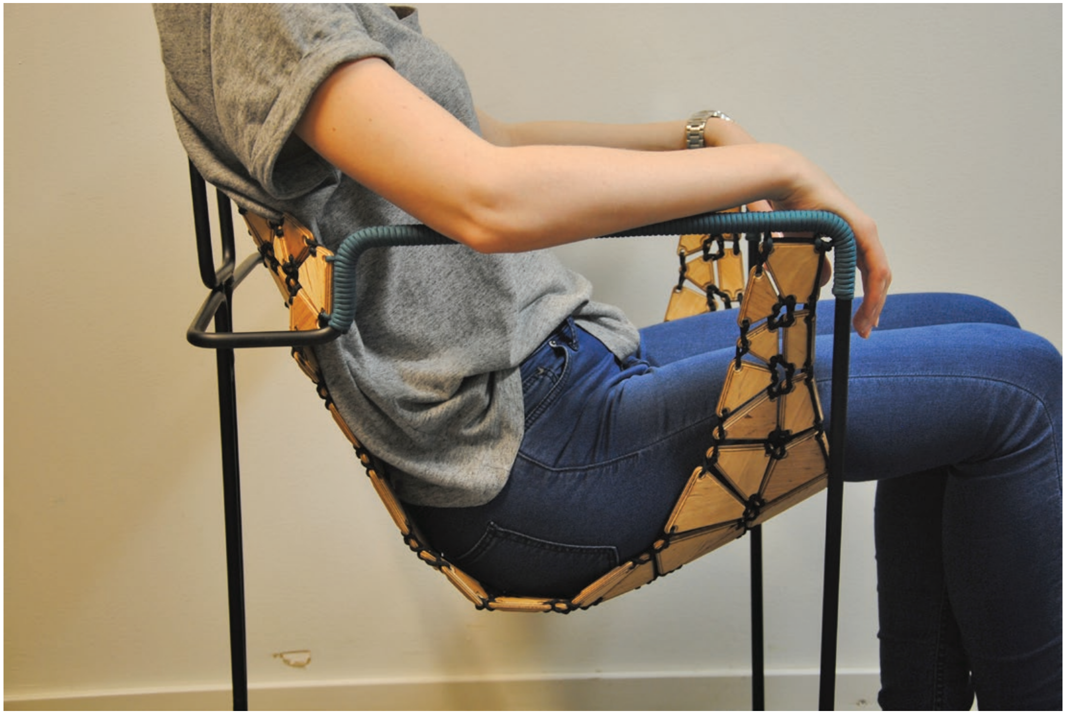
the Lounge Chair



CONSTRUCTING **1:1**





LIST OF LITERATURE

Clifford W Ashley
The Ashley book of knots *(1993)*

Erik Berglund
Sittmöblers mått: handbok för möbelformgivare *(2004)*
English title: The dimensions of seating furniture

Gustav Person
Provinssnickarens poesi *(2013)*
English title: The poetics of the carpenter of the province

Källemo
INSPIRATION *(2015)*

SET

Programming Funicular Wood Mosaic

by ***Jacob Flårback***

Master's Thesis Spring 2016
Architecture and Urban Design, MPARC
Chalmers University of Technology