stitch by stitch

knitting as ornamentation, form and formwork

Master's thesis
Karin Sahlin
2023

Chalmers School of Architecture
MPARC, Material Turn
Supervisor: Kengo Skorick
Examiner: Jonas Lundberg

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Abstract

A big shift in the building industry must be made due to climate change. Doubly curved geometry in architecture are often a result of structural optimization, and can be made with material efficient constructions of reinforced concrete. These geometries could therefore be used to decrease the building industry's impact on the environment. Unfortunately, they are both expensive and often built with material intensive structural solutions.

KnitCrete is a formwork system which has the potential of drastically reduce the amount of concrete and single-used formwork material. By tensioning knitted textile against a supporting falsework, it can be used as a stay-in-place mold for casting.

This thesis investigate fiber in architecture through the principles of KnitCrete. It explores the design possibilities of the method with an aim to understand how knitting, form and ornamentation can interact in an architectural design. The focus lies in how the knitting's inherent properties and attributes can be used as a design tool when using the KnitCrete method. The possibilities and limitations with knitting is the core and framework for this thesis.

The explorations are divided in two parts. The first part is investigating the potential of ornamentation in a knitted structure and the second part explores the possibilities of creating form with the knitted fabric. This form searching resulted in various models.

Through hands on explorations, I have showed that the color of yarn and coating, how the knitting is tensioned, size of the cavities, choice of knitting pattern and where you choose to place increases and decreases determine how the final visual expression will be. Lace knitting patterns have been of special interest since they are created by alternating smaller and bigger cavities. These patterns not only create an ornamentation, but also gives the surface a varying texture when coated.

In order to approach KnitCrete in practice, the explorations were combined in to a pavilion. In this work, the complexity of creating a knitting pattern from a large bespoke, doubly-curved geometry become evident. This process must be simpler if KnitCrete is to be used as an effective construction technique in the future.

Keywords: KnitCrete, doubly-curved geometry, lace knitting pattern

Contents

Part I

Introduction

Purpose

A shift in the building industry must be made due to climate change and the industry's impact on the environment must be reduced. Today the building industry stands for more than 40 % of energy-related CO_2 emissions and 35 % of the global energy consumption. The industry is also heavily dependent on concrete, which stands for 6 - 8 % of the global carbon-dioxide emissions every year.

Doubly-curved geometry in architecture could be used to decrease the building industry's impact on the climate. These geometries are often a result of structural optimization which can be built with material efficiency using reinforced concrete.

Unfortunately, they are mainly used to create iconic buildings today since they are both expensive and often built with material intensive structural solutions. For example, the single-used formework/mould turns to waste after the casting (approximately 50-70 % of the structure´s cost (Popescu, 2019)).

At the same time, computer has made it possible to create complex geometry with ease. 3d printing and CNC machinery have made it possible to build this geometry. Popescu (2019) even claims that we from the 1990 onwards can talk about a "mass customization", instead of the 1960- and 1970s mass standardization. While I don't agree that this shift has fully occurred and may never be able to out-compete the standardized architecture due to economics, it is an enticing thought.

KnitCrete have the potential to create "mass customized" buildings while reducing the amount of concrete needed at the same time. As Popescu (2019), one of the authors to the method, puts it:

> "... there is a need to develop better, more efficient building methods for non-standard and non-repetitive concrete structures. These methods need to reduce embodied energy, waste, labour and cost while increasing customizability, productivity and construction times." (s. 15)

My interest

In addition to the fact that KnitCrete has great potential as an environmentally friendly and economical technology, my interest lies in the exploration of what design possibilities this technique offers: how knitting, form and ornamentation can interact in an architectural design. I am especially interested in how the knitting's inherent properties and attributes can be used as a design tool

Explorations and outcome

The explorations is divided in two parts. The first part is investigating the potential of ornamentation in a knitted structure and the second part explores the possibilities of creating form with the knitted fabric.

The outcome of these explorations are used in the design of a pavillion. The research done is in this chapter combined and rearanged in order to be able to build it in a larger scale.

The pavilion has both architectural and artistic values. Its function is to provide protection from rain and sun, to be beautiful, and to show how knitting can be used in a new way.

Thesis questions

How can knitting's inherent properties and attributes be used as a design tool when using the KnitCrete method?

What expressions are sutable to use with knitting as ornamentation when using the KnitCrete method?

How can knitting, form and ornamentation interact in an architectural design when using the KnitCrete method?

Background

In this chapter, the discourse of the thesis in relation to ornamentation, form and formwork is presented. It combines visual references with technical information about knitting, the KnitCrete method and tension active structures.

Form is introduced in relation to the basic geometries of tension active structures. In "Textile and textile form in architecture" a selection of references with doubly-curved geometries is presented. These references have inspired this thesis in different ways.

In addition to the KnitCrete formwork system, two other methods using knitting as scaffolding is presented which gives an overview of the formwork systems available.

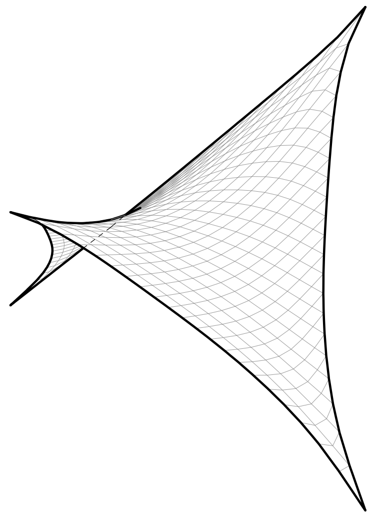
Knitting as a structural system and a comparison between the knitted and the weaved fabric is done to give the basics of the material's properties.

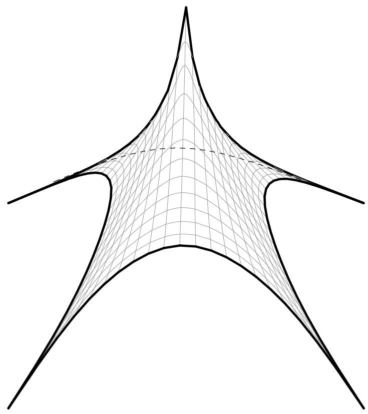
Tension active form

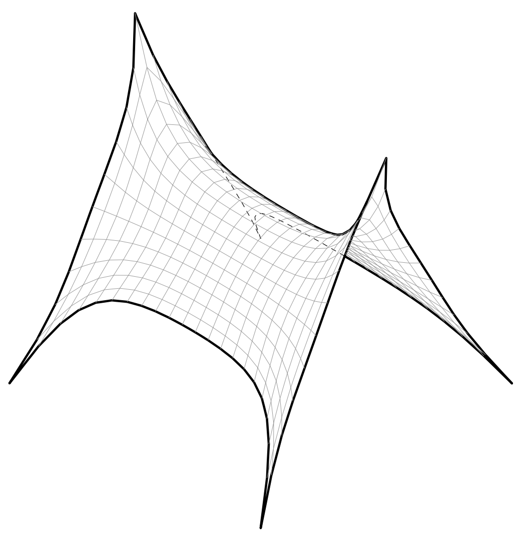
Basic geometries

The use of textile as form can be done in different ways. In this thesis I focus on form created by mechanically stressed tension structures, which are characterized by their anticlastic shape. The doubly curvature is what ensure that all loads is carried through tension (Hörteborn, 2020)

These structures can be divided into three basic types, the saddle shape (top), the point supported (middle) and the ridge and valley (bottom) (Bechthold, 2008). These types can be combined and work together in various ways.







Textile properties

Basics principles

There are three different techniques for creating a textile from yarns, interweaving (weaving), intertwining (braiding and knotting) and interloping (knitting). In architecture, it is most common to use woven textiles since the thread strength and stiffness of the woven textile provides a direct stability (Hörteborn, 2020).

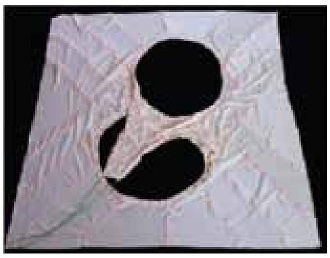
Textile structures

Woven textiles are built up by a warp that is crossed by wefts that are locked by going under and over the warp. The knitted textile is instead built up of linked loops (see next spread), which gives elasticity to the final fabric.

Create form in textile

To create shape in the woven textile, patterning, sewing, welding or gluing is required to create a 3dimensional shape. In the knitted textile, shape is instead created by increasing and decreasing stitches and rows (see next page) and/or use a circular needle, which makes it possible to make a 3-dimensional shape in one piece.

The pictures is from Popescu et al. (2016) and shows two surfaces with the same geometry, were the top one is done by stitching and the bottom one is done by knitting. The knitted one could be done in one piece and the stitched one had to be patterned and sewn together.

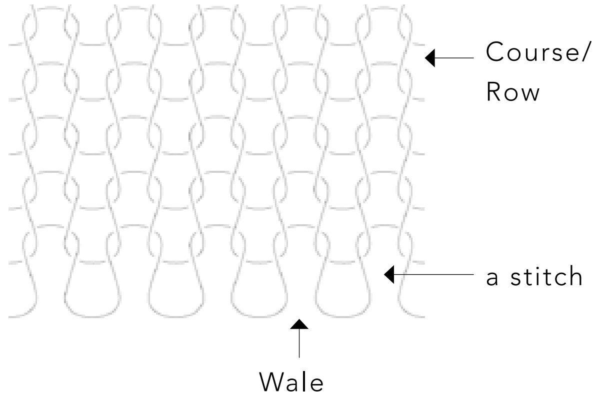


Stitched geometry

Knitted geometry

Knitting

Basics principles



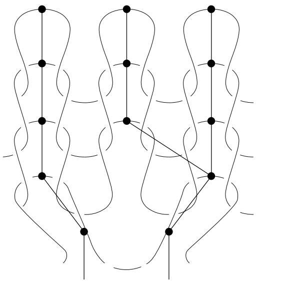
The knitted structure

The knitted textile is built up of linked loops (stitches), these loops are firstly linked together horizontally, creating a row (course direction). When a row is complete, the work is turned over and the stitches from the first row is linked with loops in a vertical direction. In this way a fabric is created stitch by stitch.

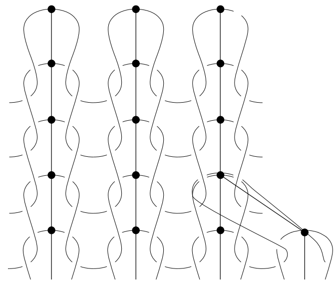
Knitting instructiones

Knitting patterns is often described with a circular or horizontal diagram explaining the sequence of stitches. In this thesis the knitting pattern will be illustrated with connected lines in a support grid, where every intersection with the grid is eaqual to a stitch. Increases and decreases is illustrated with a new or a joined line (se fig.).

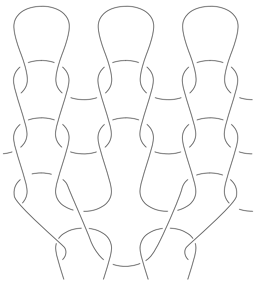
Since the knitting motifs are more complicated, including a variation of stitches, these are illustrated through color and symbols.



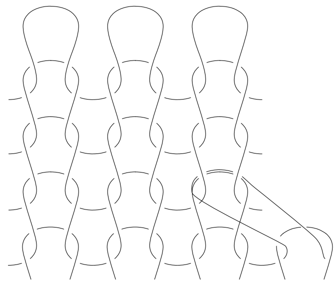
Knitting instruction:
Increase



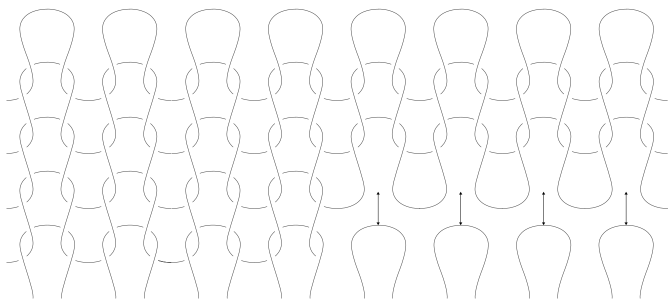
Knitting instruction:
Decrease



Increase



Decrease



Decrease a row/ short row

Knitting as form and scaffolds for other materials

This chapter introduces three techniques that use knitting as scaffolding. It begins with a brief description of Kneu-Crete and KnitFlatable and ends with this thesis main method resource, KnitCrete.

Kneu-Crete

In this research project from University of Michigan they work with CNC-knitted, inflatable formwork as a mould for concrete. The result is a negative form of the inflated knitted formwork since the knitted textile is removed after the casting (AlJomairi, M. et al. (2019).

KnitFlatable

Baranovskaya et al. (2016) creates a system where the knitting creates a boundery or a cushion for latex inflatebles. In the inflated state, the system bends according to the knitted fabrics surface.

KnitCrete

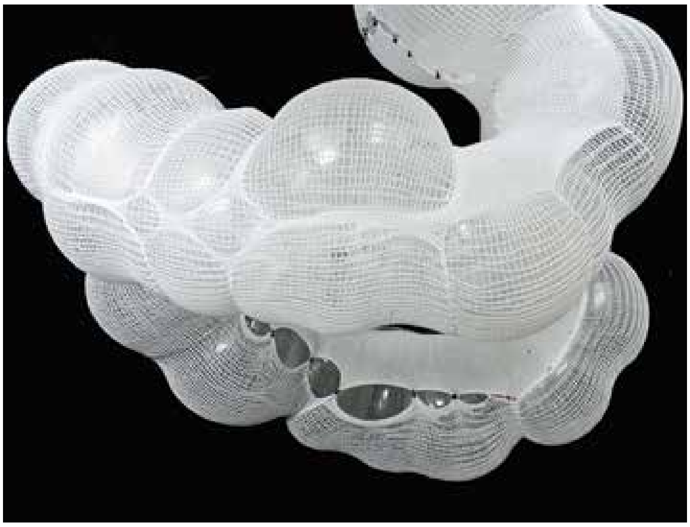
Knitcrete is a stay-in-place formwork system for the casting of doubly-curved geometries in concrete (Photo: Allegre, J. P. (2019). Unlike Kneu-Crete, the knitted scaffold becomes part of the final result. This system is presented futher in the *Method* chapter.

1. Kneu-Crete prototype (AlJomairi et al. 2019)

2. KnitFlatable prototype (Baranovskaya 2016)

3. KnitCandela, Zaha Hadid Architects in collaboration with BRG research Group (Allegre 2019)

1.



2.

3.

Textile and textile form in architecture
In the 1900s

Tension active structures

Aleksandra Kasuba

Kasuba (1923 – 2019) was a Lithuanian-American artist, who worked, inter alia, with innovative environments of tensile fabrics (www.kasubaworks.com).

In *The 20th century environment* Kasuba (1973) showed a 400m^2 fabric environment, the exhibition was commissioned by the Carborundum Museum of Ceramics in Niagara Falls. The fabric is attached to upper and lower frames and joint with Valco tape.

At the Philadelphia College of Textile and Science Kasuba (1977) did 21 self-enclosed tensil topologies. In 1983 she continued this work and the surfaces where harden with resin..

Shell structures

Heinz Isler

As a structural engineer Isler focused on creating structures of high efficiency with the lowest possible environmental impact. He did this by investigating the physical model instead of the engineer's classic way of working with mathematics and engineering. This led him to explore formworks such as molded earth, inflated rubber membranes and draped fabrics.

Félix Candela

Candela used hyperbolic paraboloid surfaces (hypars) to produce reusable formworks in order to reduce construction waste.

1. Aleksandra Kasuba, *The 20th century environment (1973)*

2. Aleksandra Kasuba, Work from the Philadelphia College of Textile and Science (1977)

3. Aleksandra Kasuba, coated geometries (1983)

4 & 5. Frei Ottos soap bubble experiments

6. Heinz Isler, *Deitingen Service Station*, Solothurn Switzerland, (1968)

7. Félix Candela, *Los Manantiales*, Mexico City, (1958)

1.

2.

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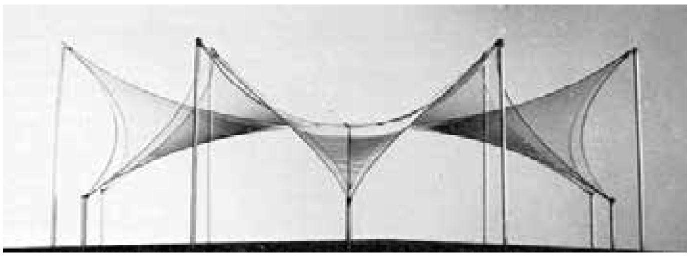
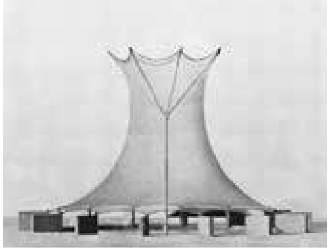




4 & 5.

6.

7.

Textile and textile form in architecture
Today

Tension active structures

Jenny Sabin

Jenny Sabin Studio, Ithaca, NY, investigates the intersections of architecture and science. Their projects uses theries from mathematics and biology in their design and production. The studio makes adaptive materials, installations, building facades, pavilions, rugs, tapestries and architectural interventions.

Sean Ahlquist

Ahlquist is an Associate Professor of Architecture at the University of Michigan and his research addresses the need for architecture to generate inclusionary spaces, especially for communities identifying as disabled. He is doing this by connecting architecture with other technologies such as performing arts technology, computer science and material science.

Doubly-curved geometries

NEST HiLo roof

The full-scale construction prototype of the NEST HiLo roof (top) was built by the Block research Group (BRG), ETH Zurich, 2017. It is built with a cable-net and fabric formwork system, a lightweight flexible formwork, made of tensioned cable net as falsework and tailored fabric as shuttering, sprayed with concrete. The result is a textile reinforced thin concrete shell.

KnitCandela

Zaha Hadid Architects (in collaboration with BRG research Group), 2018-2019, Mexico City, Mexiko

KniteCandela is an experimental structure constructed at the Museo Univeritario Arte Contempoáneo (MUAC), Mexico City. It is inspired of and a homage to Félix Candela's concrete shell structures but made with new computational design methods and KniteCrete formwork technology.

1. Jenny Sabin, Lumen, MoMA PS1, New York City (Enriquez 2017)

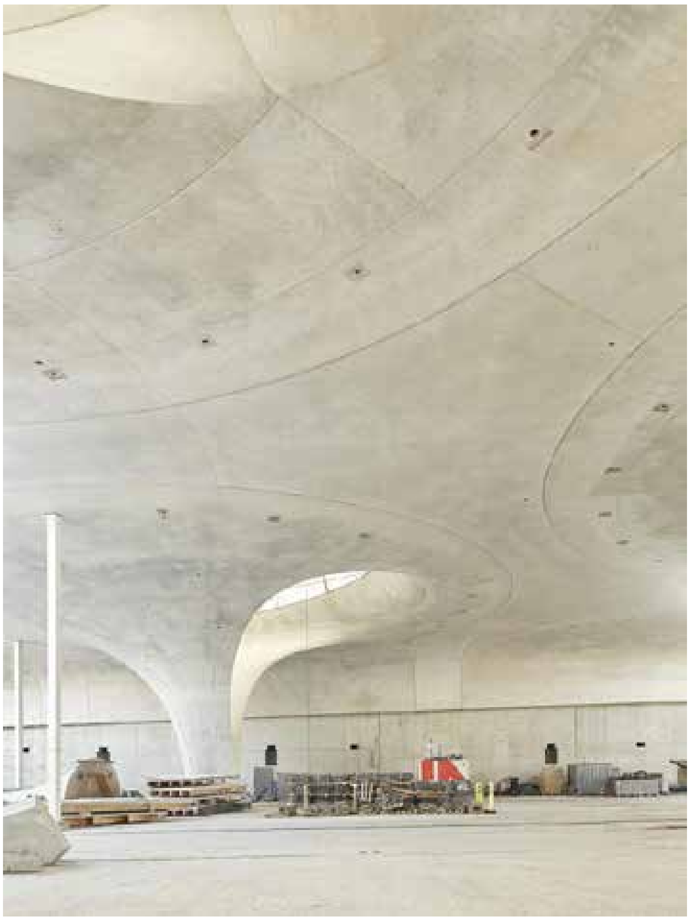
2. Sean Ahlquist, sensoryPLAYSCAPE (v1.0) textile hybrid prototype (2015)

3. Full-scale construction prototype of the NEST HiLo roof (Lyrenmann 2017)

4. KnitCandela (Allegre 2019)

5. Main Station Stuttgart, Stuttgart, Ingenhoven Architects (ongoing project) (Birnbaum 2021)


MoMA PS1



Method

For, me, it is important to use my hands in order to really understand a technique, a form etc. In the process of making, you think and discover possibilities and limitations, and you gain new ideas of how the material can be transformed.

Therefore, the explorations of this thesis, the knitting, the casting and the modelmaking has all been done by hand.

In these explorations I have used the knitting's inherent properties and attributes as a design tool. I have strived to work with the material, not against it, especially in the choice of ornamentation in relation to the doubly-curved geometry.

During the process references have come to mind, I have then brought them into the booklet and read literature about them. Not all of them might be part of the thesis when its done.

In the design phase, when the explorations transformes into an architectural design the material was brought into the computer where faster tests could be made. Rhino, Grasshopper and Kangaroo2 was tools used in this process.

KnitCrete

In the research of a stay-in-place formwork for doubly-curved geometries Popescu et al. (2018) did a prototype of a concrete shell bridge to try out their findings. Here is a brief summary of their approach and the method.

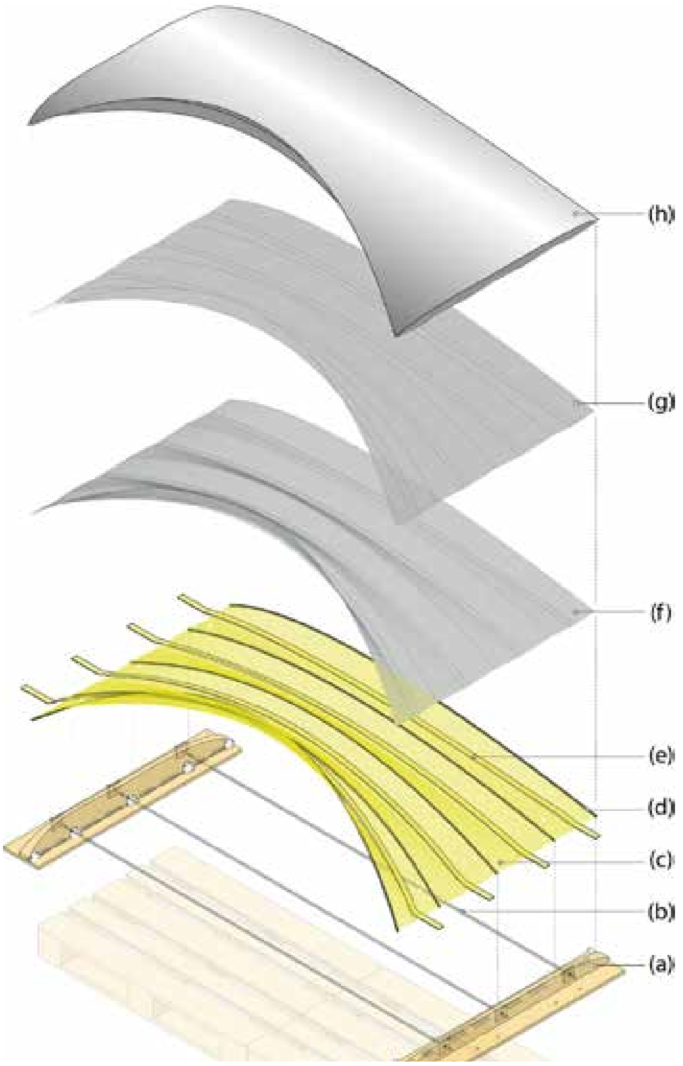
Preliminary studies

A tryout of coating the knitted fabric with concrete-paste where made on a plain knit and a ribbed one. The ribbed knitted fabric performed better as it clogged the flow of the cement-paste from passing the loops. A ribbed knitted fabric could be coated with ease with holes up to 5 mm in diameter.

Knitting

To generate the knitting pattern, they used the open-source package compas_knit (https://compas-dev.github.io). The program generates the loop topology to create a given 3D geometry based on knitting direction and input data of loop dimensions.

A knitting machine, Brother KH-970 equipped with a second needle bed (ribber) was used with Aramid yarn (160 TEX), which works as reinforcement for the first layer of cement-paste. Channels were knitted into the fabric for the insertion of shaping elements.



The formwork system

The formwork system is based on four "layers" supported by a timber edge (a). Threaded rod ties (e)(30 mm wide ribbons made by aramid-fibre) and bending active rods (d)(8 mm glass-fibre reinforced polymer) is inserted in the channels. The fabric (c) is then tensioned into shape on the support. A 1.5 mm thick cement-past (f) is coated on the fabric, then a 4 mm layer of mortar (g). Finally, a 5-10 cm thick layer of structural concrete (h) is applied.

This procedure makes the construction stronger by each layer: the cement makes the form able to take the mortar which in turn allows the final structural concrete to be applied.

Theory

Method
The KnitCrete method is an ongoing research field developed at at ETH Zurich by the Block Research Group (BRG) in collaboration with the Chair for Physical Chemistry of Building Materials, as part of NCCR in Digital Fabrication. Therefor, publications, thesis and articles about the method comes from their research. Mariana Adriana Popescu have been my main source and her thesis *KnitCrete: Stay-in-place knitted formworks for complex concrete structures* (2019) was the starting point for this thesis. The problem statement of her thesis is very convincing and her solution (KnitCrete) very intriguing to me.

Form
For the understanding of tension active forms Engels' *Tragsysteme, structure Systems (2009)* have been very useful.

I have used Engels as a dictionary of form and returned to the book every time I felt uncertain about definitions etc.

Knitting
In the exploration of knitting and ornamentation two books on knitting stitches have been of great importance: Stanfield and Griffiths' *Stickarens stora mönsterbok* (2012) (The knitter's large pattern book) and Vogues' *1000 Japanese knitting & crochet stitches: the ultimate bible for needlecraft enthusiasts* (2020). Both have been a source of inspiration for the knitted pattern/ ornamentation in this project.

When feeling insecure about how to knit a special stitch, I have turned to Wincent-Gelinder, E. (trans.). *Bonniers stora bok om stickning* (2007) (Bonnier's big book on knitting).

Delimitations

Knitting is the core in this thesis, it is the possibilities and limitations with knitting that is the framework for what this thesis can be.

Using the KnitCrete method as a principle

In order to be able to use knitting as formwork for concrete casting, certain requirements are placed on the concrete composition. The concrete needs additives for the curing and applicability to be correct. Much of the research available on KnitCrete today focuses on the construction aspect in order to make the method suitable for the construction industry.

In this thesis, nor the strength of the concrete or the construction requirements are in focus. The method is therefor used as a principle in my investigations. Instead of concrete, I use Jesmonite, a composite material that dries in 15 minutes, can be colored in, thickened and reinforced with fiberglass fabric. This gives me the opportunity to investigate form and ornamentation in an effective way. Since the same principle is used, almost the same result could be created with concrete.

Knitting

The knitting is done by hand but could be knitted on a knitting machine.

Knitting pattern software limitations

Knitting patterns are actually very simple, you have a starting point and know how high a row is and how wide a stitch is, then you can find out how many stitches are needed in each row.

On a doubly-curved geometry in the computer, this principle was not easy to apply. Several programs exist as open source, such as Cockatoo (a plugin for Grasshopper) (Popescu et al., 2018) and Autoknit (Narayanan et al., 2018), but these are in a development stage. The installation of the softwares is complicated and there are few instructions and even less tutorials.

Part II

Investigation

Knitting as texture and ornamentation

Part I Knitting

This chapter is divided into two in which I investigate the design possibilites of the knitted fabric in the framwork of this thesis. Part one is focusing on the knitted fabric and explore how the stitch composition creates motifs and texture in the knitted fabric. The knitting instructions used in this chaper is described in full in *Appendix I: knitting instructions.*

Basis for design choices

When designing a knitted fabric, the properties and appearance of the outcome is determined by three parameters: the fiber, the yarn and the fabric. The fiber, such as wool, cotton, linen or glass-fiber have different characteristics. The yarn is more or less twisted, where a high twisted yarn has more elasticity then a low twisted. The fabric is determined by the stitch-composition that creates the structure (Scott, 2013).

The fiber

The choice of fiber is determined by the requires of the mould. In my tests, which are knitted by hand, I chose to use linen yarn. The main reason for this was linens ability to sustain pre-stressing. Linen yarn has low elongation, low elasticity, (i.e. the fiber's ability to recover after stretching) and high tensile strength which increases when wet (Brindner 1975).

In more complex moulds, the yarn can serve as reinforcement by using glass-fiber, carbon fiber or aramid yarn.

The fabric

It is possible to create various motifs using color, texture or a combination of these in knitting. Yet, the doubly-cuved shapes this thesis aims at, creates limitations in terms of motif selection. With these complex shapes, decreases and increases of stitches become unavoidable, this means that graphic motifs would be deformed in the making. When choosing a motif, there must therefore be possible to increase and decrease the number of stitches without affecting the motif, or alternatively that it reinforces the motif.

Furthermore, the knitting in this project will be coated with Jesmonite, which add an additional color to the knitted textiles. The application of the concrete will also cover the cavities in the knitting to varying degrees and create an extra texture. How the concrete effects the knitted fabric needs to be considered in the design of the knitted fabric.

Gauge

The size of the hole in the stitch is important for this project. The casting material should easily cover all the holes after one layer and the stitches can therefore not be too large in tension. In Popescus' et al. (2018) research, they did material tests that showed that holes up to 5 mm are easely covered by the concrete.

To determine the gauge, tests in stockinette stitch were done. Throught these tests I decided that needle-size 3.5 gives the best gauge for this project. This means that the gauge of the fabric in its normal state in a square of 10 x 10 cm is 25 stitches and 33 rows and in tension 22 stitches and 25 rows. The holesize in the tensioned fabric is then 2 x 3 mm, which gives room to create lager holes as part of the ornamentation.

Conclusions

Based on these explorations I found that lace knitting patterns were interesting to work with. These patterns are created with larger and smaller holes that are combined in different ways. Since the knitting is coated in this project, the variation in hole size creates a varying texture, the holes can also be used as light inlets if they are large enough and not completely covered.

The leaf vine pattern is especially good for this project. All deformation can take place between the tendrils, and the deformation will just increase the winding whitch strengthens the pattern.

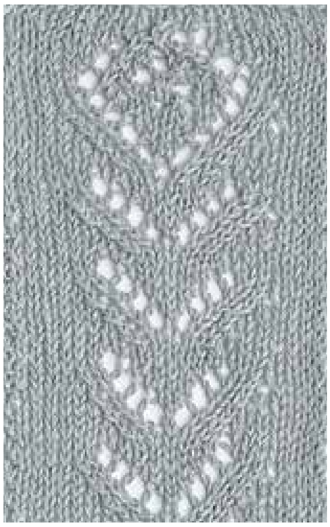
This conclusion made me try out other patterns from the nature, which I later on can combine into one big pattern/ornamentation.

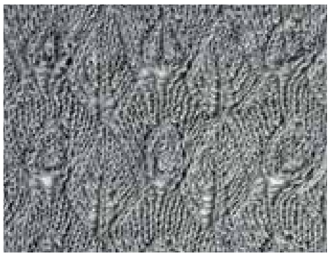
Stockinette stitch

Top and bottom right: right side of the work
bottom left: wrong side of the work

The stockinette stitch is the basis for knitting. It is done with the basic knitting stitches knit and purl. It is done by knitting knit (k) och the right side of the work and purl (p) och the worg side of the work.

Lace knitting motifs

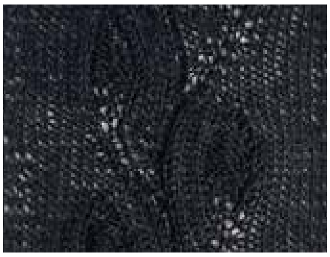




The lace knitting is created by increasing stitches with yarn over and decrease stitches. The yarn over is creating a (bigger) hole in the fabric whitch make it look like lace.

In the next row, the yarn over can be knitted with a normal stitch or knitted in the back of the stich, whitch creates a twisted stitch. If the stitch is knitted normal a bigger hole is created then if the stitch is twisted, but both creates bigger holes then an average stitch.

Leaf vine lace



Top and bottom right: right side of the work
bottom left: wrong side of the work

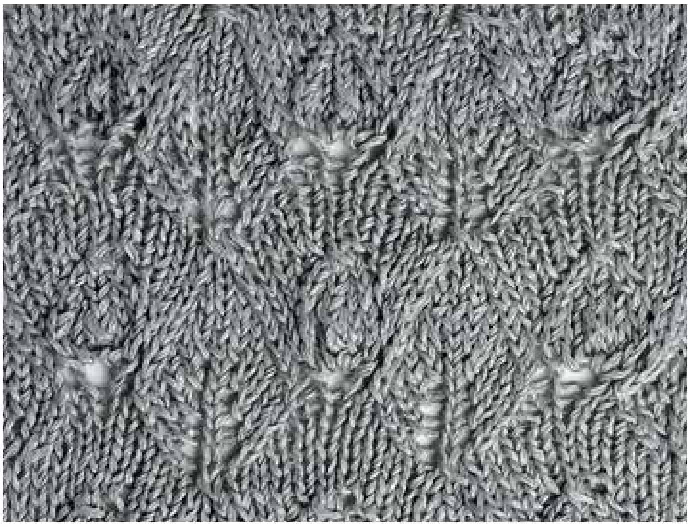
The motif is done by knitting knit on a bed of purl. The curved stem is done by moving stitches and the leaves are created by adding stitches using yarn over.

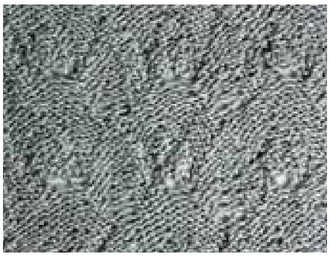
Flower lace

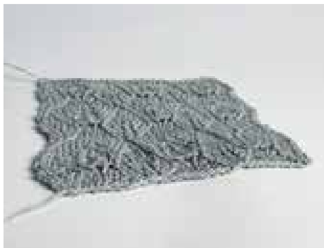
Top: right side of the work
bottom: wrong side of the work

In this case, two yarn over is done after each other which increase the size of the hole further.

Buds and leaves lace



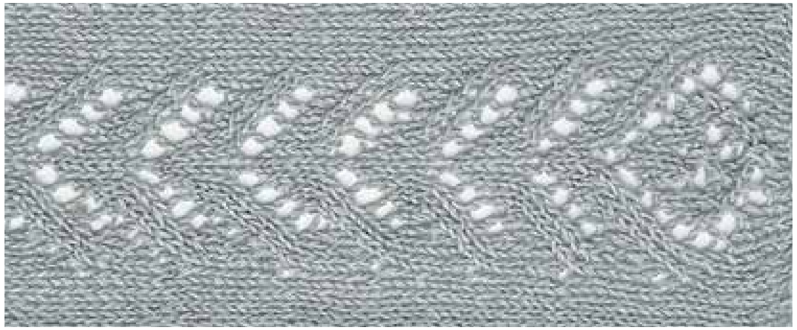




Top and bottom right: right side of the work
bottom left: wrong side of the work

The bud in this motif is created by adding 5 stitches in one.

Flower on stem lace



Left and bottom right: right side of the work
top right: wrong side of the work

Knitting as texture and ornamentation

Part II Casting

This part of the chapter focuses on what happens when the knitted fabric is casted. I explore what effects can appear depending on: the stitch composition of the knitted fabric, the holesize of the stitches and the color difference between yarn and casting material. The casting process is described in full in *Appendix II: casting process.*

Casting

The knitted textiles were stretched against a wooden frame with warp thread (cotton). Depending on the knitting pattern and how the fabrics were stretched against the frame, larger and smaller cavities were formed in the stitches.

The back of the tensioned textile was then coated with Jesmonite. The mixing of Jesmonite was done according to the instructions of the supplier: 2.5:1 in weight ratio (Jesmonite Base / Jesmonite AC100). In addition to that, black pigment was added.

The first layer was puttyed on the textile. The second layer was brushed on. After the second layer, Jesmonite was alternated with fiberglass fabric to stiffen the surface. Three layers were applied in total and 2-3 layers of fiberglass fabric.

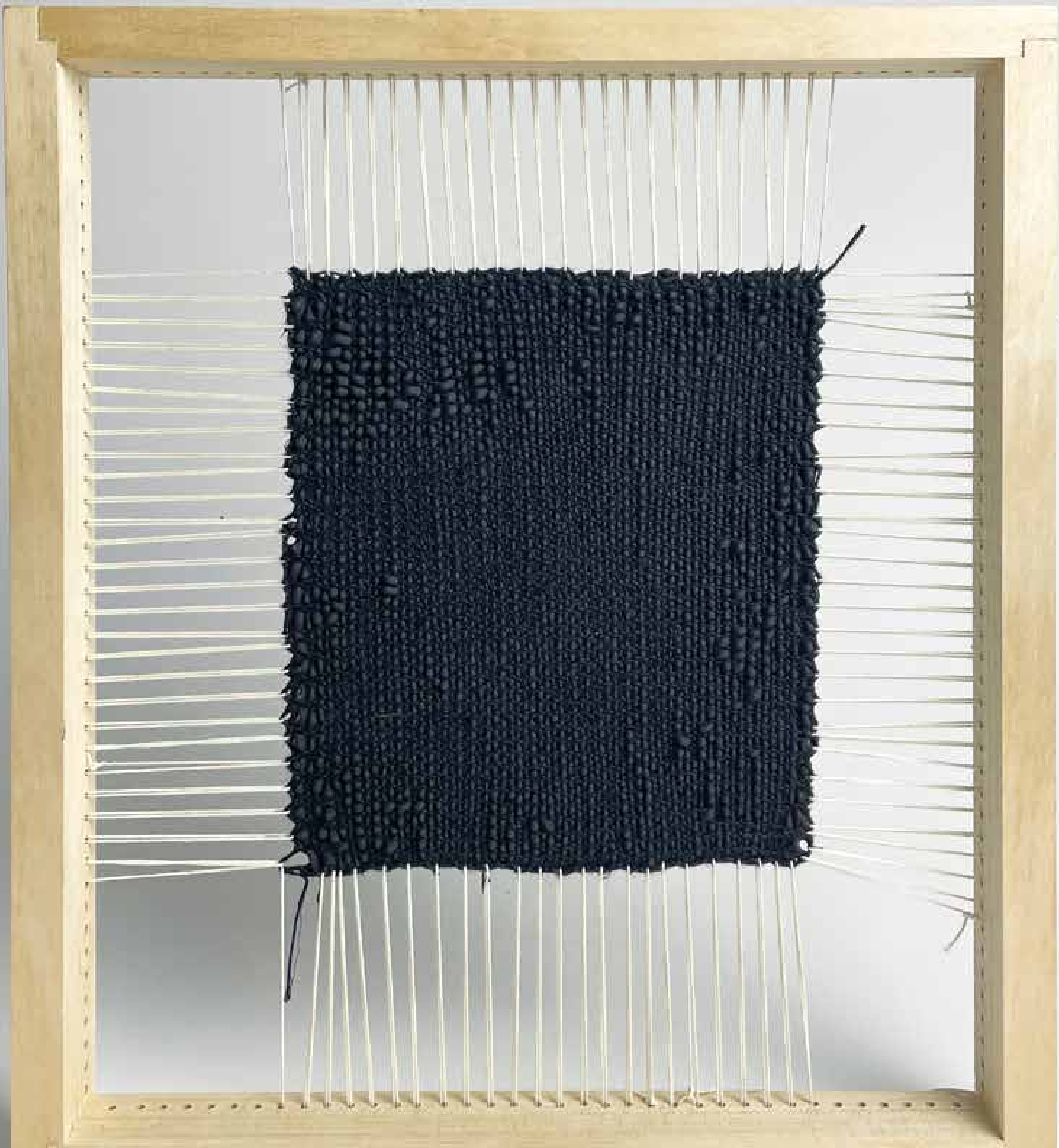
General analysis of the result

When applying Jesmonite, the mixture is pushed out through the holes and forms bulges of different sizes, depending on the size of the holes. The bulges gives the surface a 3-dimensional texture.

The yarn becomes like a joint between the Jesmonite, the effect can be compared with the joint between tiles. The difference in color/ tone of the yarn and Jesmonite therefor creates diverse outcomes.

Knitted fabric

Coated fabric

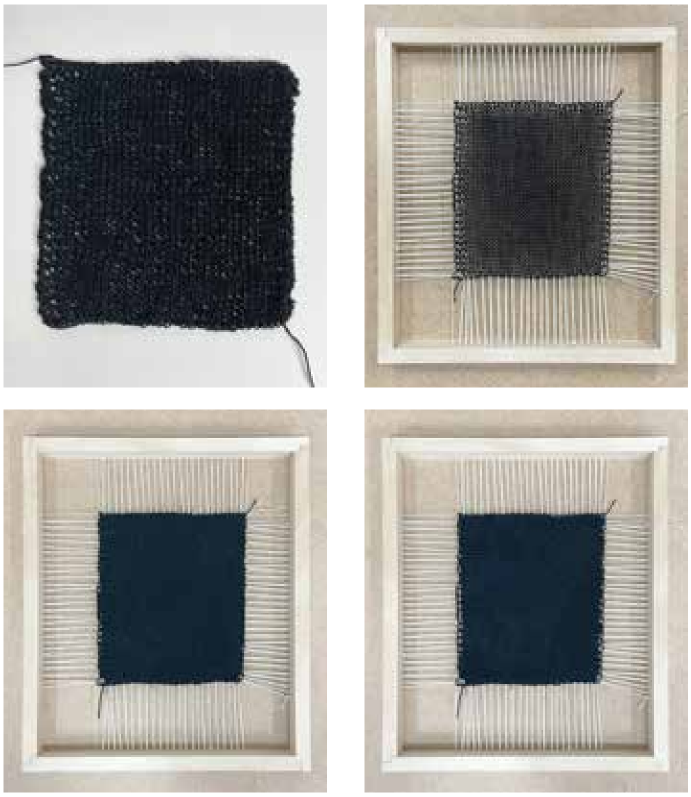


Stockinette stitch

The knitted fabric (top left) was tensioned by threading the warp thread through each stitch (top right). The stitches the thread goes through are tightened extra and larger holes are formed there.

The smaller holes are 2x3 mm, while the larger holes along the edges are up to 4x6 mm in size.

1% black pigment was added to the Jesmonite. The first layer covered all the smaller holes, but some of the larger holes along the edges were not covered (bottom left). Most of the larger holes were covered after the second layer (bottom right).



By tensioning the textile through each stitch, the fabric was evenly stretched in the inner parts, but the edge stitches were pulled extra.

The shade difference between yarn and jesmonite became relatively small (1% pigment), this makes the texture stand out more than yarn/jesmonite.

Leaf vine

The knitted fabric (top left) was tensioned by threading the warp thread through a smaller number of stitches (top right).

The variation of hole size here mainly depends on the design of the pattern. The smaller holes are 2x3 mm while the larger ones are up to 6x6 mm in size.

1% black pigment was added to the Jesmonite. The first layer covered all but three of the larger holes (bottom left). After the second layer, there was only one hole that was not covered (bottom right).

By tensioning the textile through a smaller amount of stitches, the bigger holes alonge the edges where removed. Instead, arches were formed along the edge when the fabric was tensioned at a few points. The hole size in the stitches varies over the arch when the fabric is tensioned in this way, creating an effect in itself.

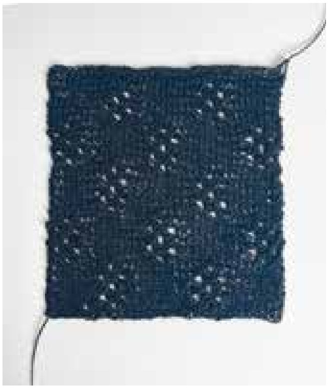
The shade difference between yarn and jesmonite became relatively small (1% pigment), but in this case the knitting pattern comes into focus rather than the texture.

Flower lace

I continued to tension the fabric (top left) through a smaller number of stitches (top right).

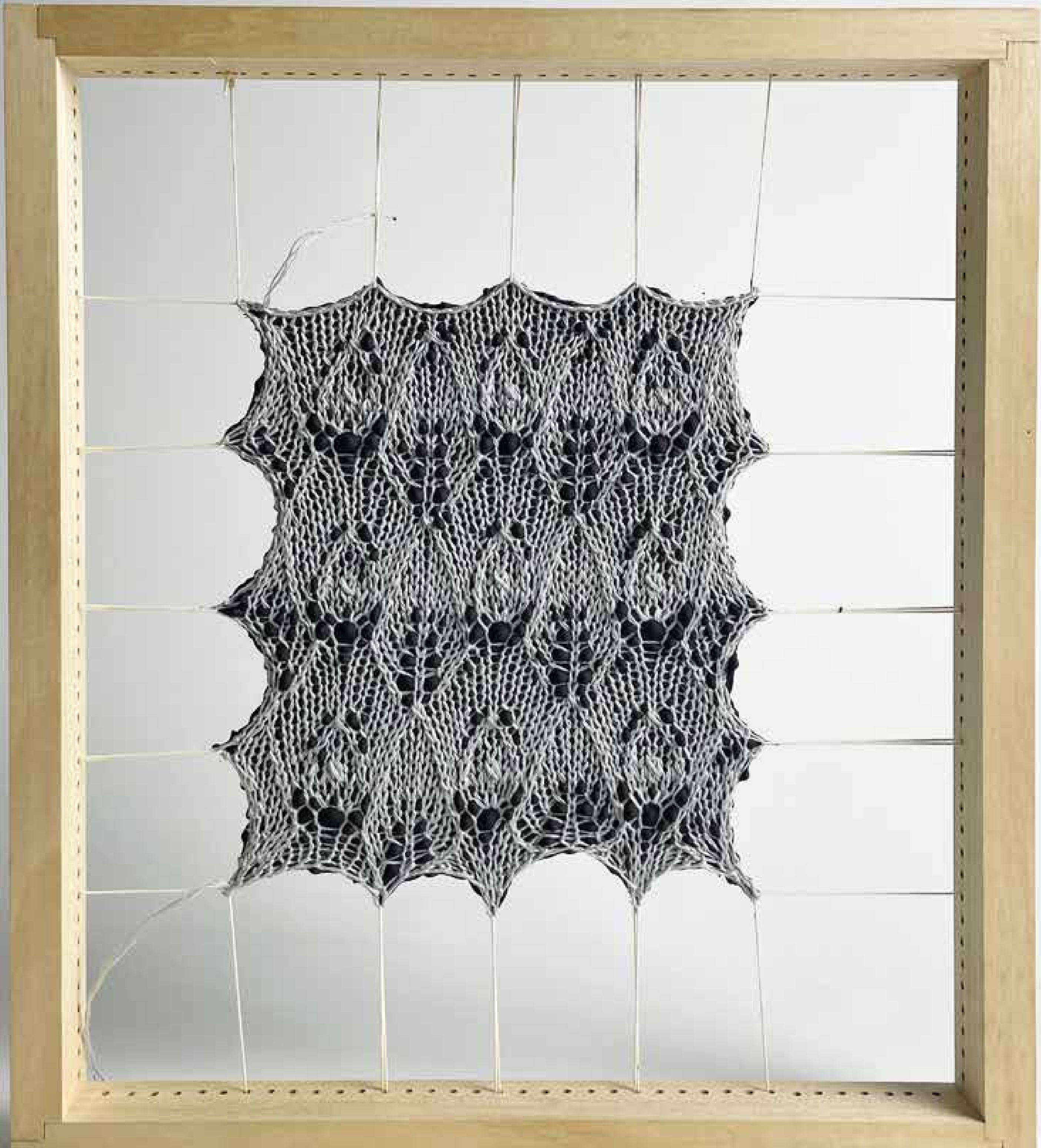
In this fabric the variation of hole sizes mainly depends on the design of the pattern that consistes of bigger holes and stockinette stitch. The smaller holes are 2x3 mm while the lager ones are 7x7 mm in general, but due too the tensioning some of the larger ones are up to 8x9 mm.

0,5% black pigment was added to the Jesmonite. The first layer covered all the smaller holes but only a small amount of the bigger ones (bottom left). The second layer covered all but 4 of the holes (bottom right).



Not all the holes were covered after one layer and that is not optional for the aim of this project.

The shade difference between yarn and jesmonite became bigger with 0,5% pigment, whitch makes the yarn (and Jesmonite) more visible than in the tests made with 1 %. When the holes creates the pattern, as in this case, there could be a point to work with a bigger difference in color to highlight the pattern.



Buds and leaves lace

In this test, I wanted to see what effect a huge color difference between yarn and Jesmonite created. Therefor a lighter, gray linen yarn was used.

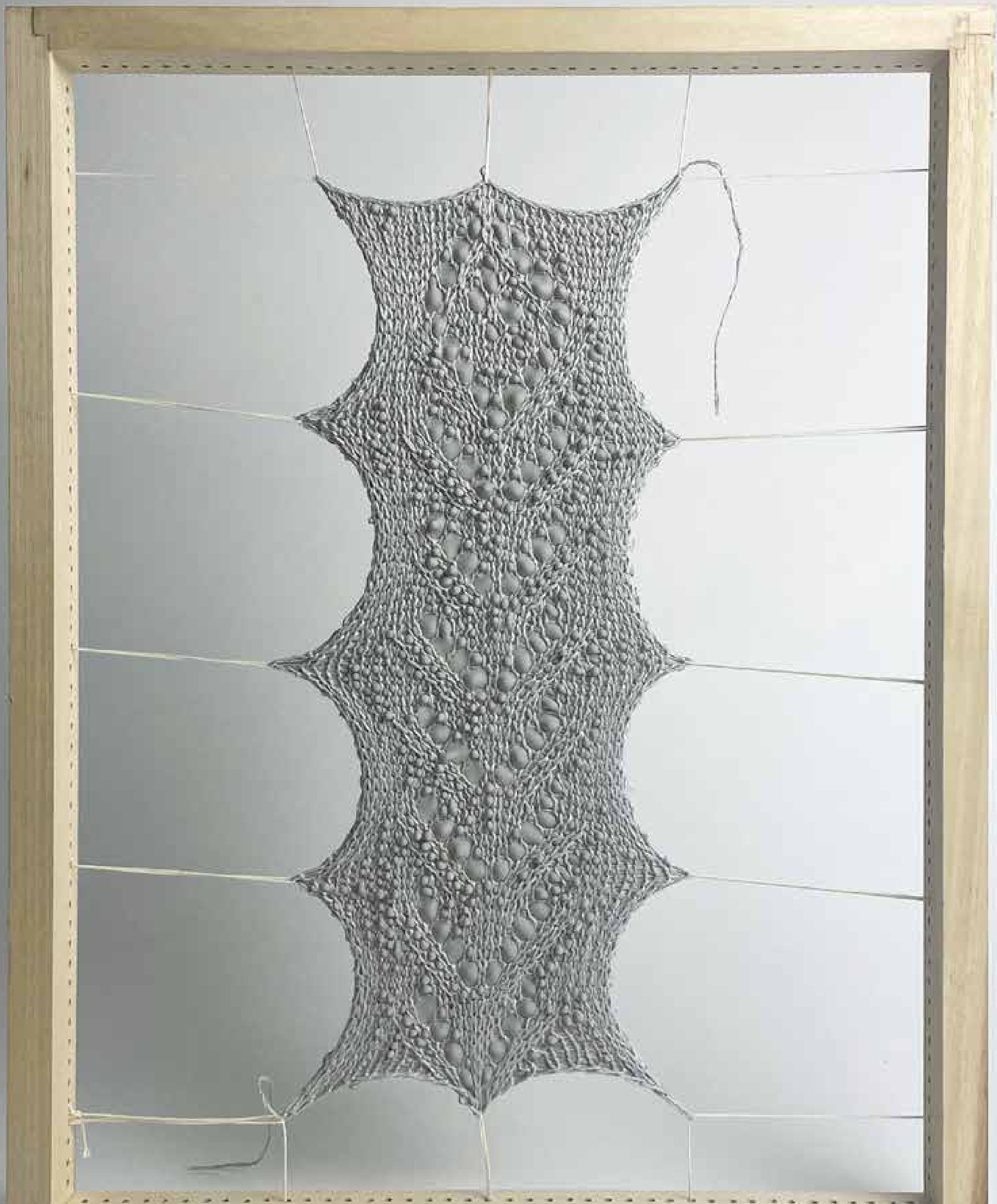
I continued to tension the fabric through a smaller number of stitches (top left).

The variation of hole size here mainly depends on the design of the pattern. The smaller holes are 2x3 mm while the lager ones are up to 7x6 mm.

0,5% black pigment was added to the Jesmonite. The first layer covered all the holes (top right).

The size of the bigger holes in this pattern is on the right side. It is not optimal that so few of the holes were covered after one layer.

The big shade difference between yarn and jesmonite makes the yarn (and Jesmonite) in focus. The texture from the bulging Jesmonite almost disappears in favor of the color difference (r.s. bottom right).



Flower stalk lace

Summary

In this chapter I have found that the color of yarn and coating, how the knitting is tensioned, size of the cavities and knitting motif determine how the final visual expression will be.

Light entry

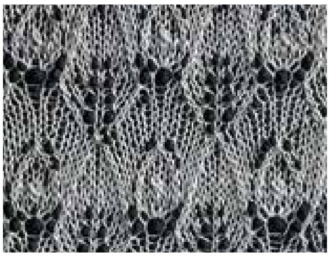
When the holes in the stitches are larger (here up to 8x9 mm), the first layer do not cover all the holes. If not all the holes are covered, it could be used to bring in light into the structure and create an effect in itself.

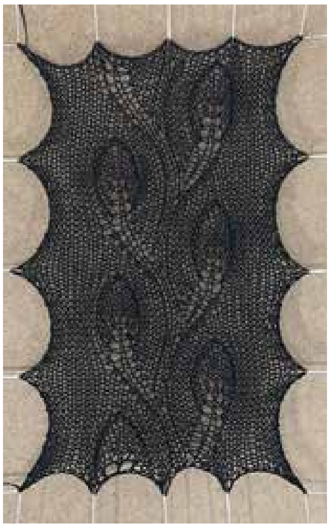
Tensioning effect

As the knitted fabric is elastic and always seekes for an even distribution of forces, there are different effects depending on how the fabric is tensioned.

By tensioning the textile through each stitch, the fabric was evenly stretched in the inner parts, but the edge stitches were pulled extra.

By tensioning the textile through a smaller amount of stitches, arches were formed along the edge. The hole size in the stitches varies over the arch, creating an effect in itself.





The interplay between fabric and formwork in the creation of form

In this chapter I investigate tension active form by tensioning high elastic fabric on metal formwork. Three wooden frames were built to allow for multipe tests but some free-form models where also made. Full documentation of the models can be found in *Appendix II: models*

The Wooden frames

Three frames were built to allow for multiple tests, but also to be able to combine them into one unit. The frames are 30 x 30 x 30 cm.

In scale, this means:
1:10 3 x 3 x 3 m
1:15 4.5 x 4.5 x 4.5 m
1:20 6 x 6 x 6 m
1:50 15 x 15 x 15 m

Process

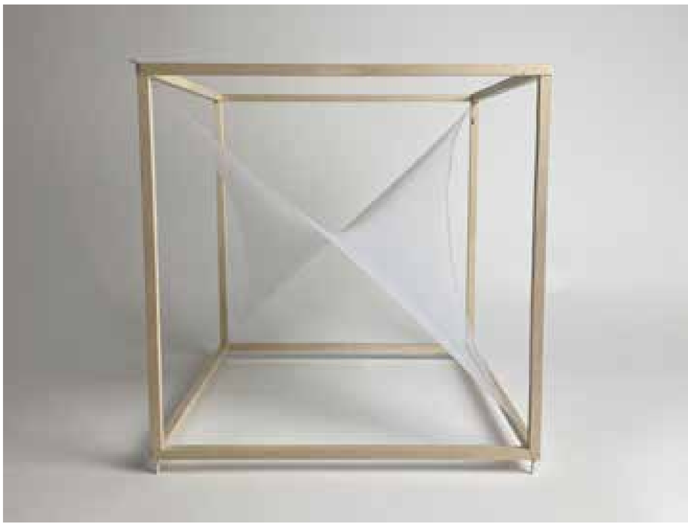
The metall framework was bent and glued to the wooden frames. Most of the explorations where made with a mesh fabric, that is highly elastic in all directions. The fabric was tensioned on the framework by twisting thread through the fabric and around the framework.

Since doubly-curved geometry using fabric as a form-creater is relatively new to me I decided to start with the basic shapes. The point- and ridge valley shape where made.

Ridge and vally

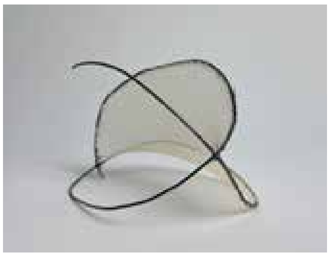
The ridge and valley shape is one of the basic geometries of tension active structures and is created by forcing down the corners of a rectangle and pull from two points in the centerline of the rectangle.

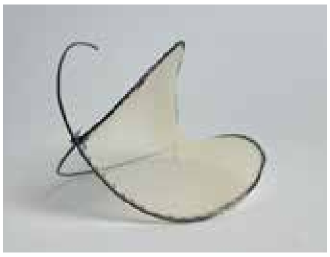
Saddle shape



The saddle shape is also one of the basic geometries of tension active structures. It is created by altering push and pull in every other corner. This try-out were later coated with Jesmonite and reinforced with glasfibre (bottom right).

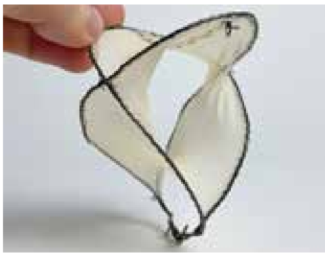
Free form 1





In this basic free form geometry I could bend the metall frame around and find new spatialities.

Free form 2



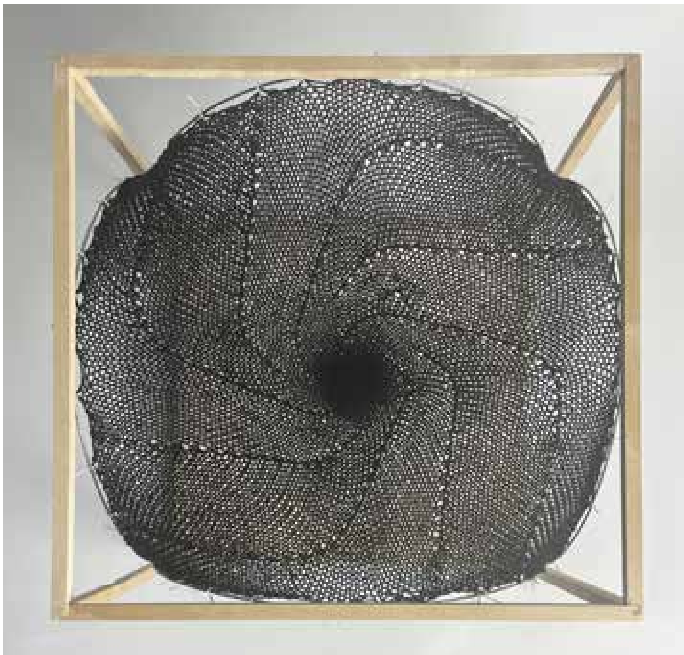
This free form geometry was inspired by Sean Ahlquists *sensoryPLAYSCAPE*. It is a complex shape using a tensioned cylinder. The tensioning did not succed fully in this modell since there is to much fabric where the fabric intersect.

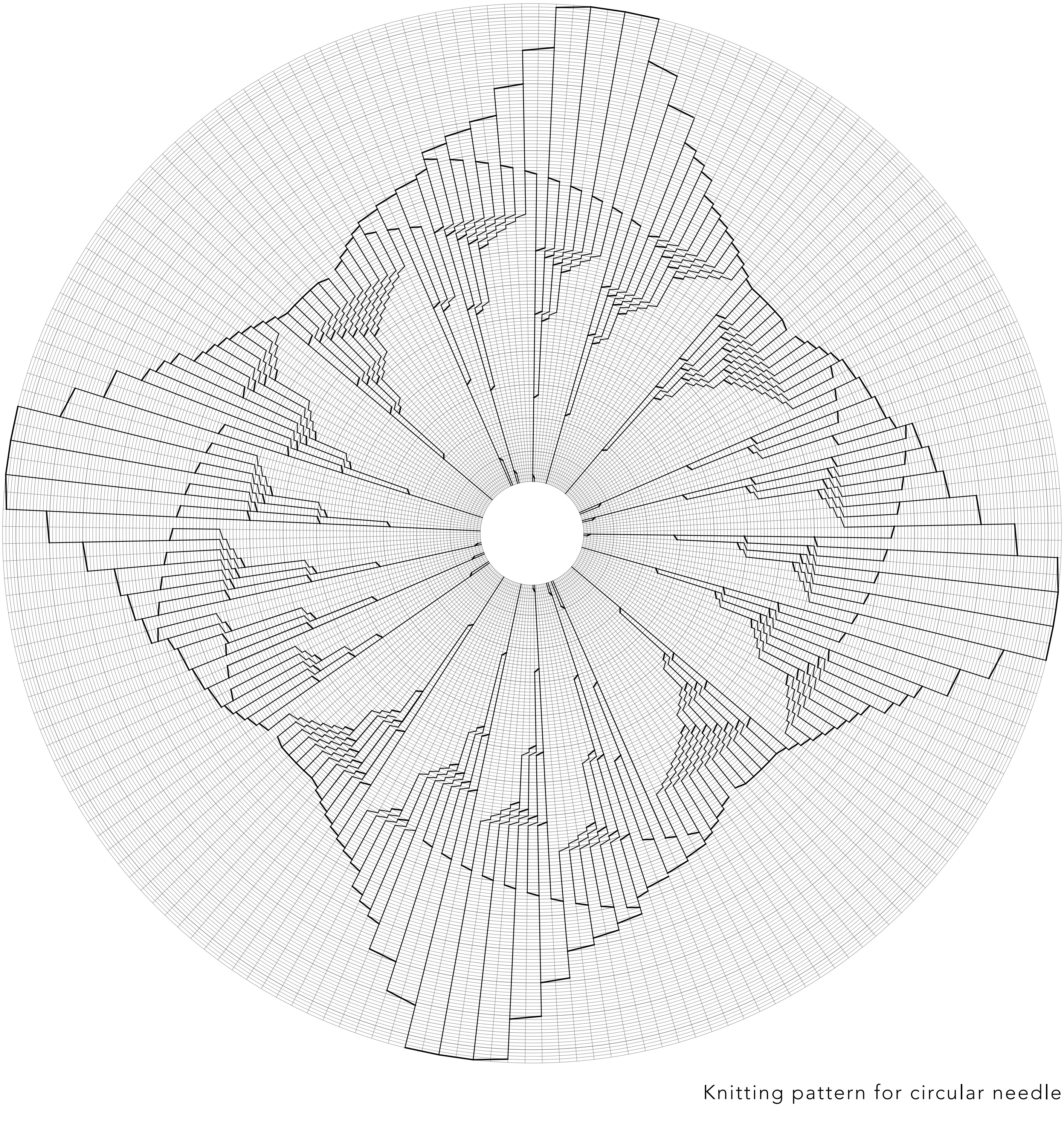
Wooden frame, white mesh

This model is ispired by the NEST Hilo roof. It is made with a white mesh fabric, highly elastic in every direction. The fabric is tensiond to metal splines mounted on the wooden frame.

Wooden frame, circular needle

In this model, the possibility to knit a cylinder in one piece using a circular needle was investigated further. The decreases and increases are done in a spiral shape creating a ornamentation in the fabric.





Knitting pattern for circular needle

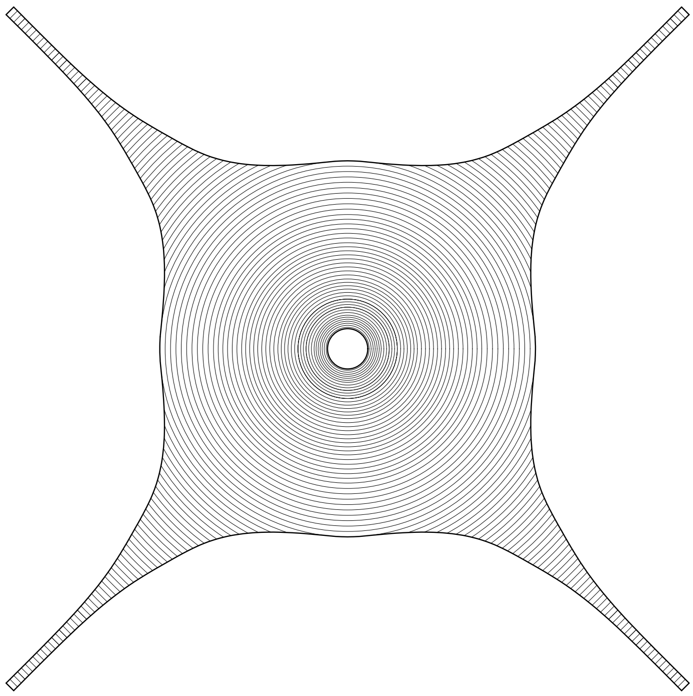
Knitting pattern

Wooden frame, circular needle

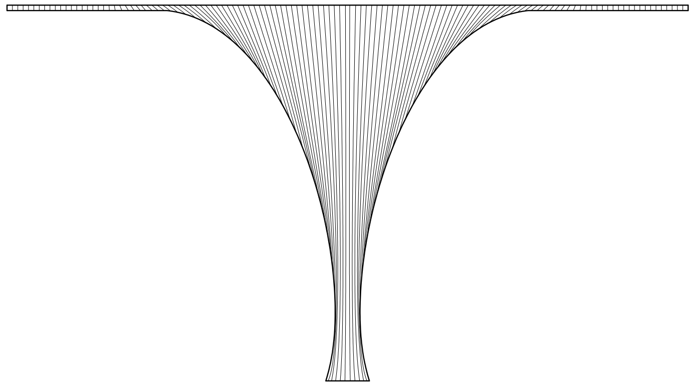
The fabric is done with a circular needle and starts from the center of the circle.

The circles in the support grid represent rows. The intersection between a thicker line and the support grid represents a stitch.

Thickest line: decrease or increase
Knitted with needle 3.5



Textile pattern, top view, 1:5



Textile pattern, side view, 1:5

Part III

KnitCrete in practice

Generating knitting patterns

The principle of a knitting pattern is actually very simple. You need to know the gauge (how wide a stitch is and how high a row is), and decide on a starting and end point. With this information you can find out how many rows you need to do and how many stitches are needed in each row.

Gauge in this project

In this thesis the knitted fabric is tensioned and the gauge therefor needs to be the gauge of the tensioned fabric. I used the findings from tensioning the stockinet stitch test to find out the gauge. In a square of 10 x 10 cm there is 22 stitches and 25 rows in the tensioned fabric, that means that a stitch is 4.54 mm and a row is 4 mm.

In the computer

This principle is simple to use if the outcome is flat, on a bespoke, doubly-curved geometry in the computer, this principle was not as easy to apply. Several programs exist as open source, such as Cockatoo (a plugin for Grasshopper) (Popescu et al., 2018) and Autoknit (Narayanan et al., 2018), but these are in a development stage. The installation of the software's is complicated and there are few instructions and even less tutorials.

In this thesis

Since the software available did not work, I decided to create the knitting patterns by hand. The pattern for the Wooden frame: circular needle was easy to make since I did it wail creating it. There were simply no original to copy, and the result could therefor not be wrong.

The Wooden frame: white mesh pattern turned out to be more complicated since I there had a bespoke geometry that I wanted to generate a pattern from.

I generated the original model in Grasshopper and found that geometry more interesting then the original model, I therefore wanted to generate the knitting pattern from the grasshopper generated model.

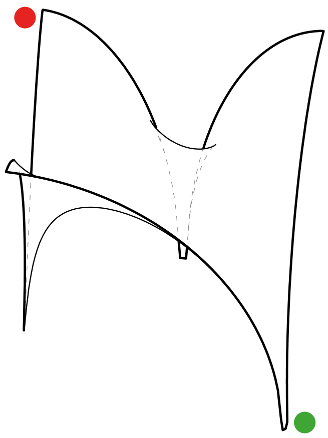
The start and the end were decided, here demonstrated with a green (start) and red (end) dot.

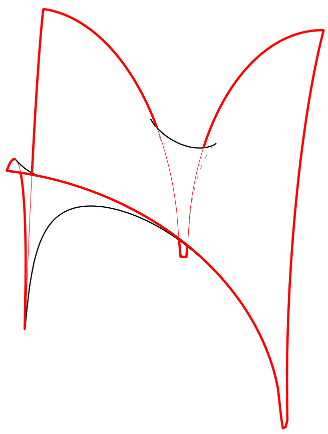
Main measurements
The measurements of the model's edge (middle image) were used to gain the outline of the knitting pattern.

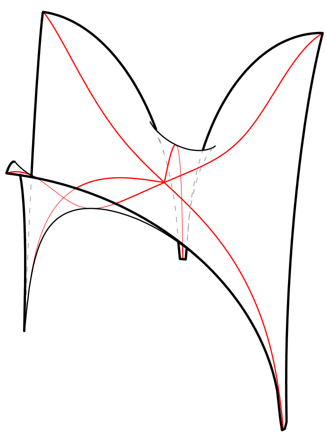
The measurement from start to end point gave me how many rows the central part of the fabric had to be. I also measured the length between of the widest part of the model, this gave me how many stitches were needed in that specific point (bottom image).

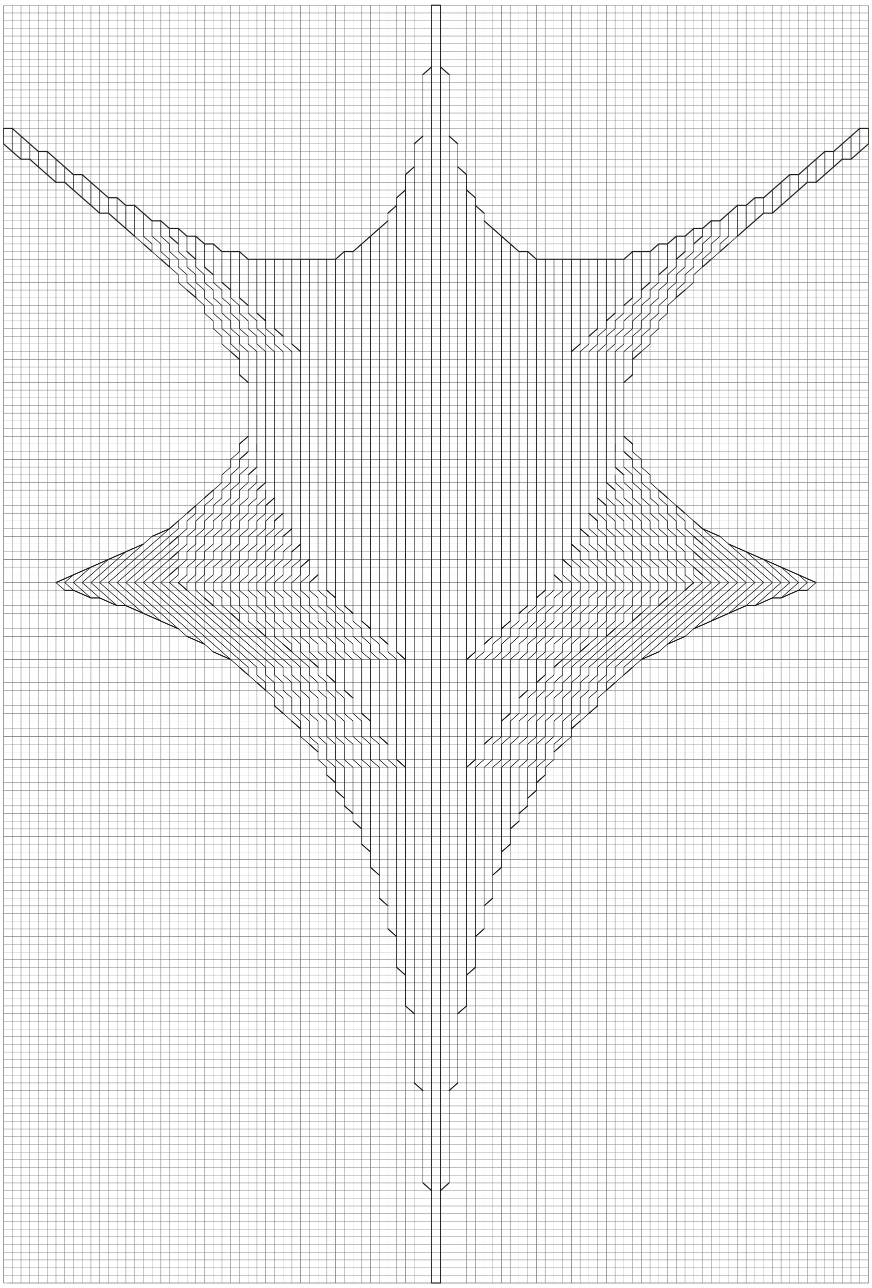
I also took the measurement from were the fabric is pulled down, since this is what creates the form.

From these measurements I could generate a knitting pattern. The two first patterns did not become right, but I used the findings from these tests to get the third and accurate knitting pattern.



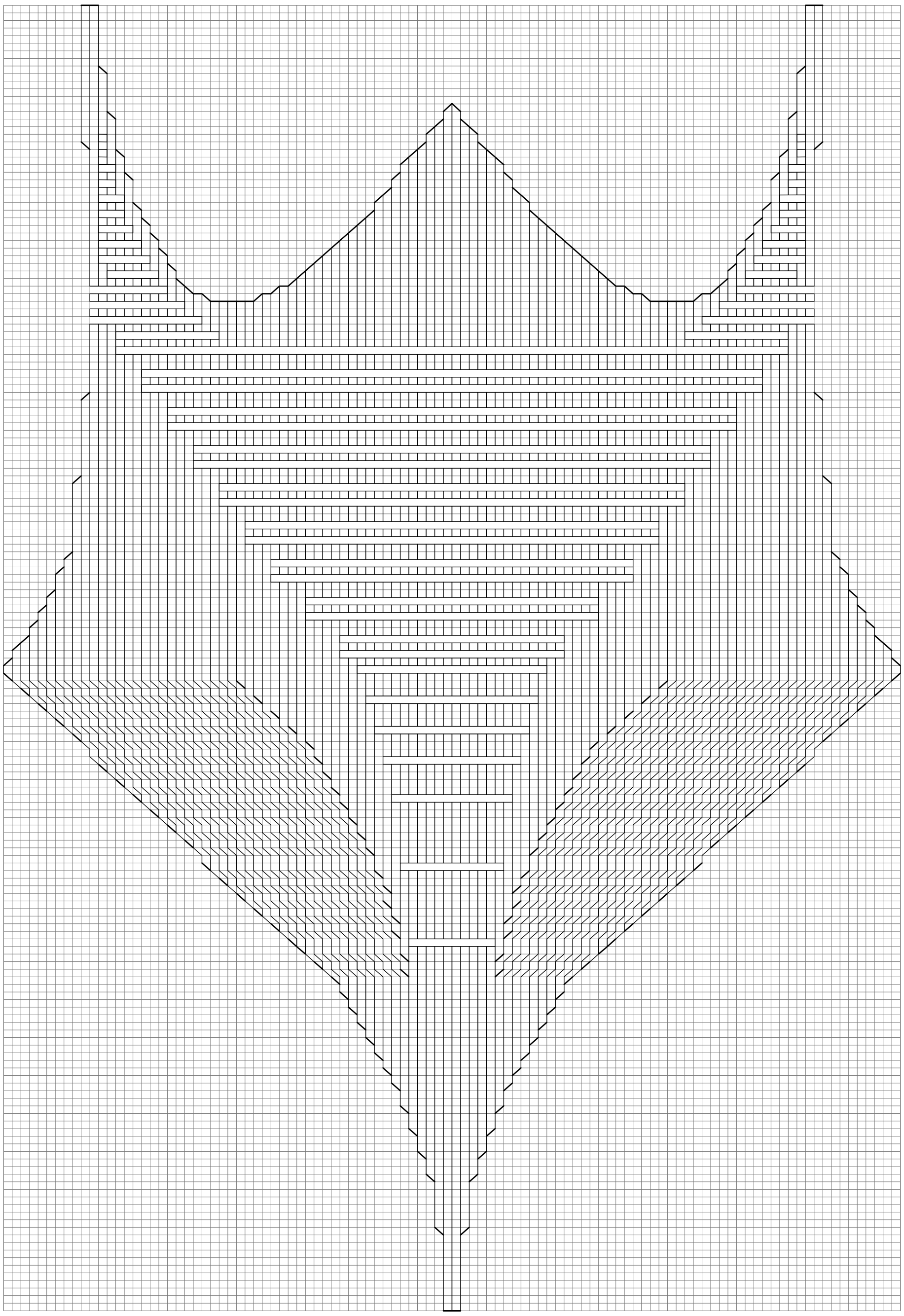






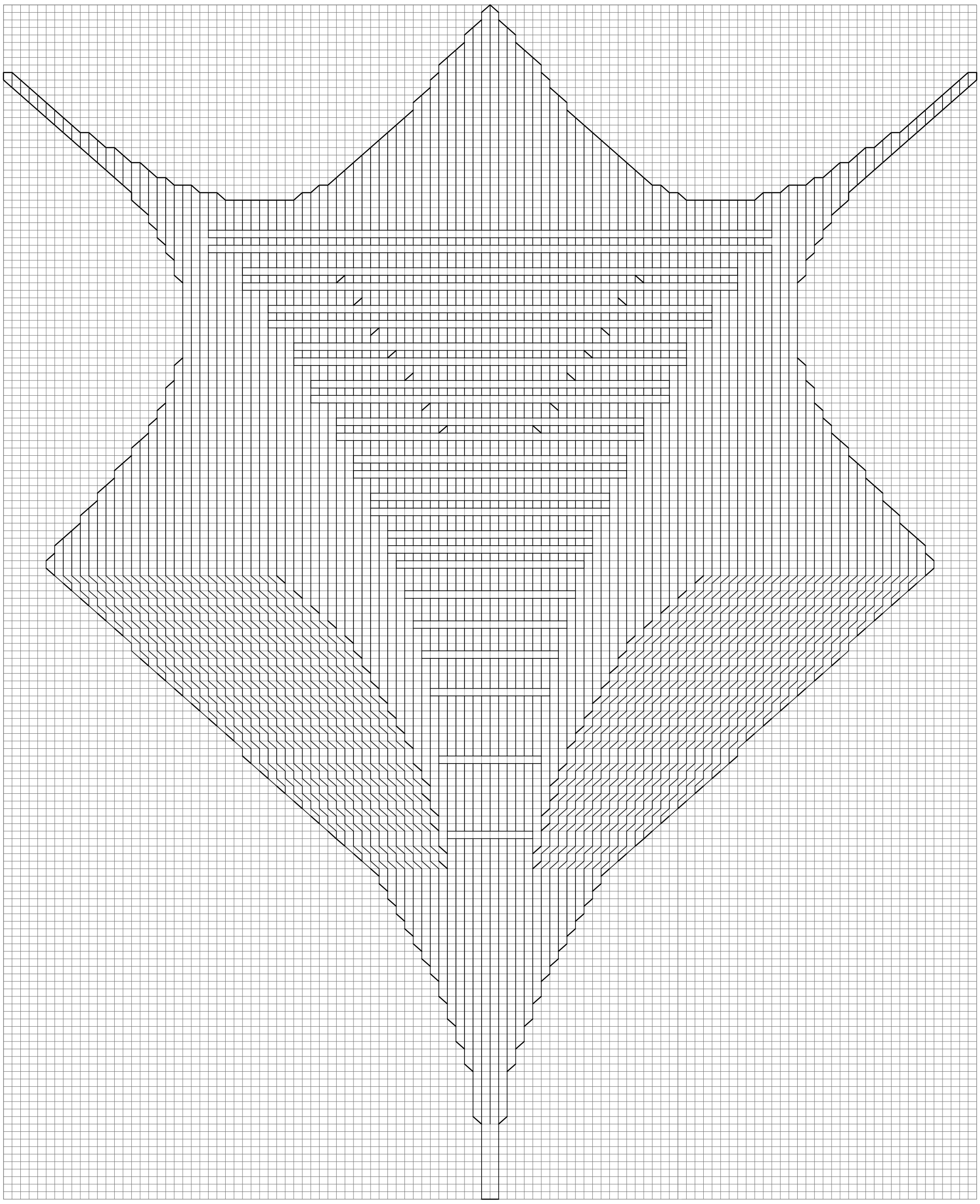
First try, knitting pattern for White mesh

In this first test I mainly focused on the outline of the fabric, which resulted in too little fabric inside the knitted fabric.



Second try, knitting pattern for White mesh

In this second test I used all the measurements described on the previous page. A lot of short rows had to be used were the fabric is pulled down, which means that there is less rows and fabric in this part of the fabric.

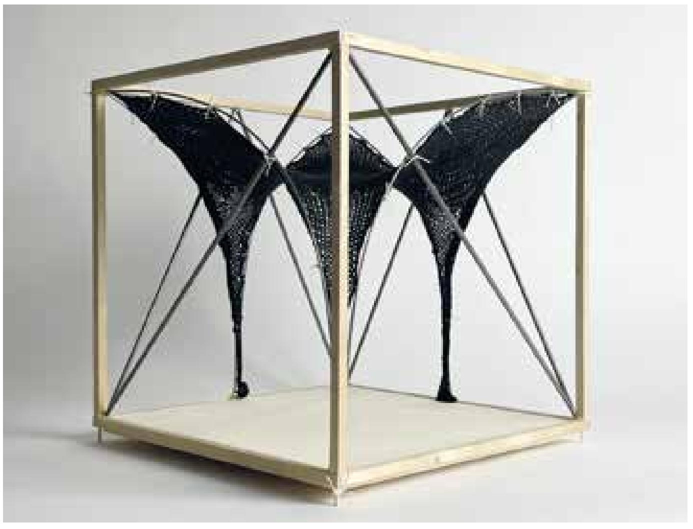


Knitting pattern for white mesh model

Knitting pattern

Wooden frame, white mesh

In the final pattern, decreases was aded in the triangulated short-row section. The position and shape of the two centerplacerade "arms" where also done.



An architectural design

A pavillion

In order to effectively test different shapes, the two main models (wooden frame: white mesh and wooden frame: circular needle) were modeled up in Rhino using Grasshopper and the Kangaroo2 plug-in.

The 3d models were then copied and combined in different ways. In this process, I found a flowery/leafy shape which I continiued working with. Since this organic geometry is related to the ornmentation motifs of flowers and leaves developed in this thesis, it was logic to continue this nature inspired theme also in this shape.

As I found the shape, I also decided that the end result would be a pavilion.

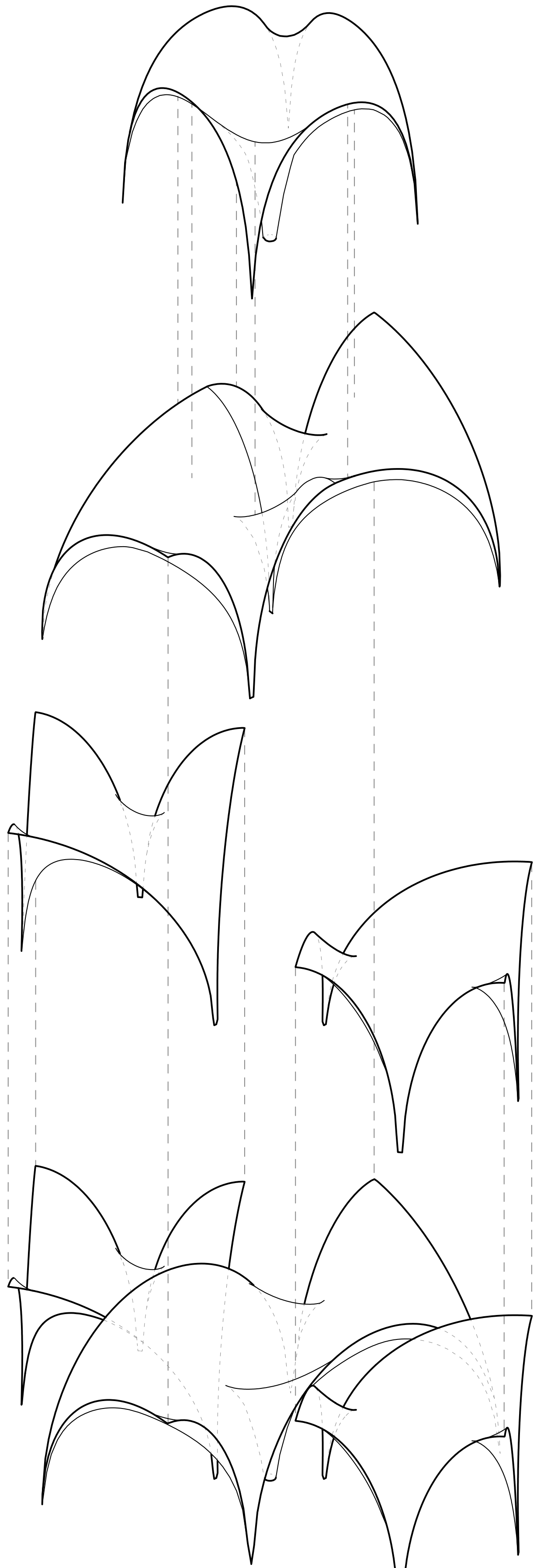
The Knitcrete method, where the coating is done in several layers, gives opportunities to use a color difference between the different layers. In my pavilion, I have chosen to use this possibility and leave the inside in the original gray tone of the cement, while the outside is colored in a shade of green.

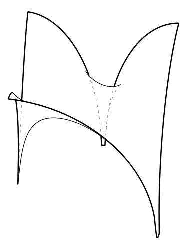
The pavilion is placed by the water close to Röda Sten, here it can be seen as both an architectural element, protecting against sun and rain, but also as an artistic sculpture corresponding with Röda Stens Art space.

Finding the flower form

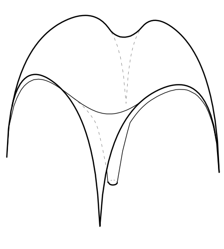
Model 1 was mirrored onto itself so that the center point between them could be "swap-ped" to the pillar created in Model 2.

On each side of the new, mirrored geometry, Model 1 was placed at a 45 degree angle from the larger geometry. These are then pu-shed under the roof of the larger geometry

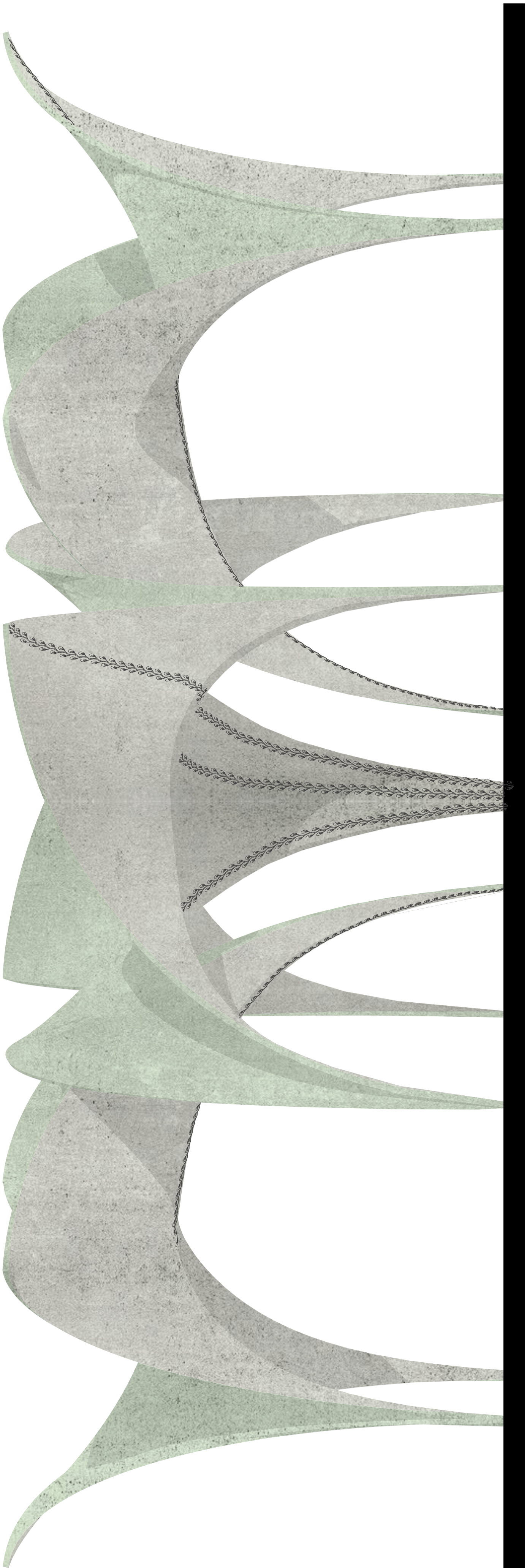




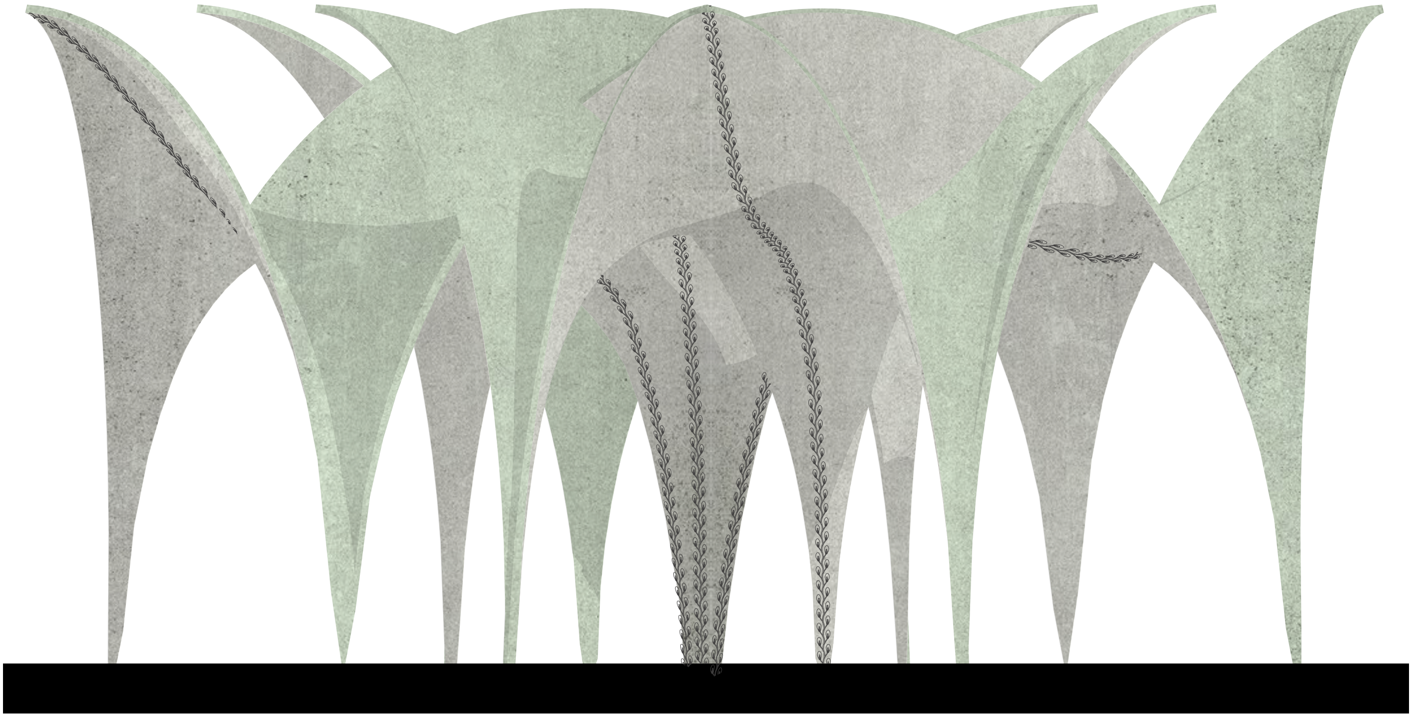
Modell 1
(Wooden fram: vit mesh)



Modell 2
(Wooden frame: circular needle)

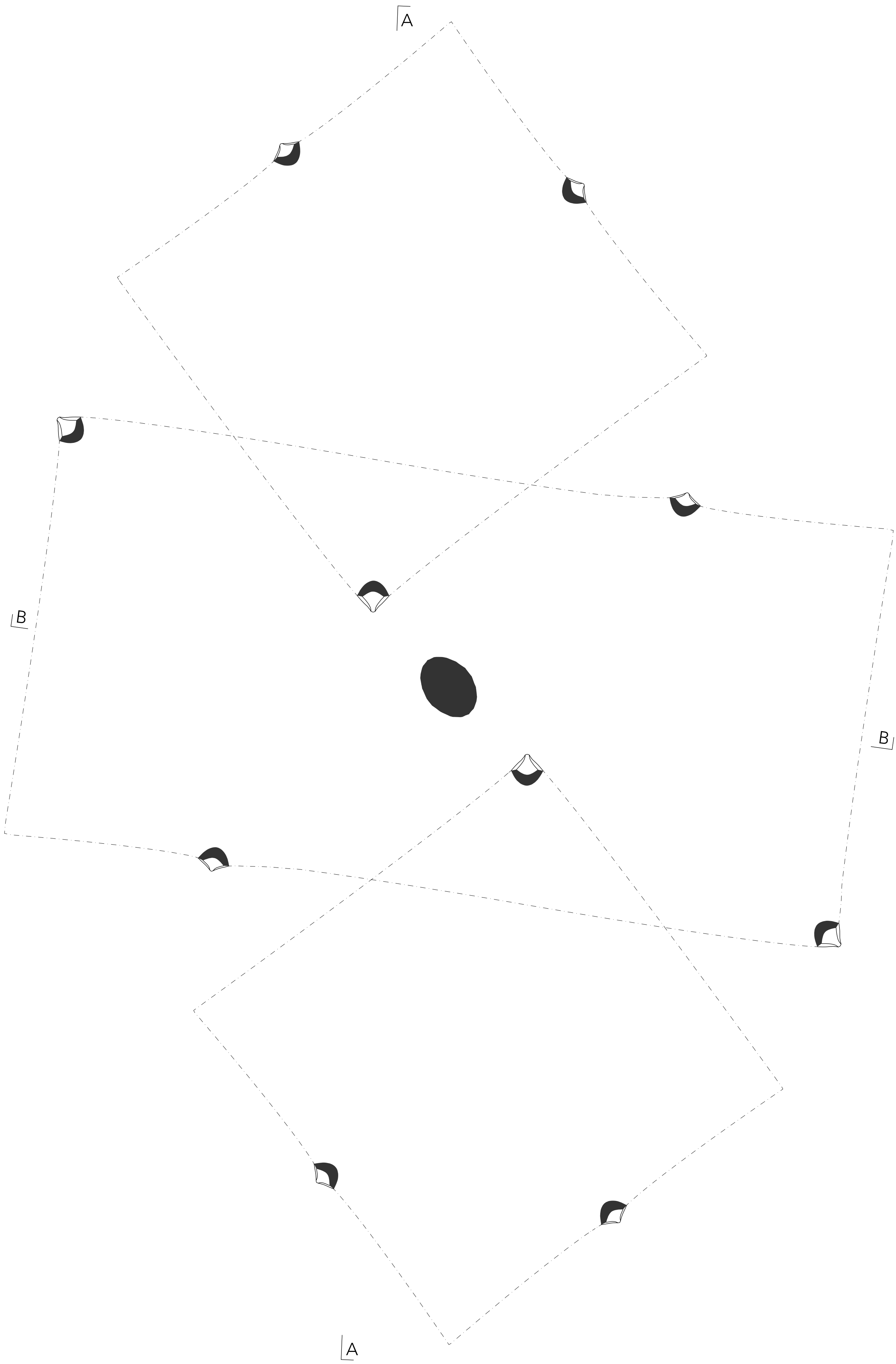


Facade facing south 1:50

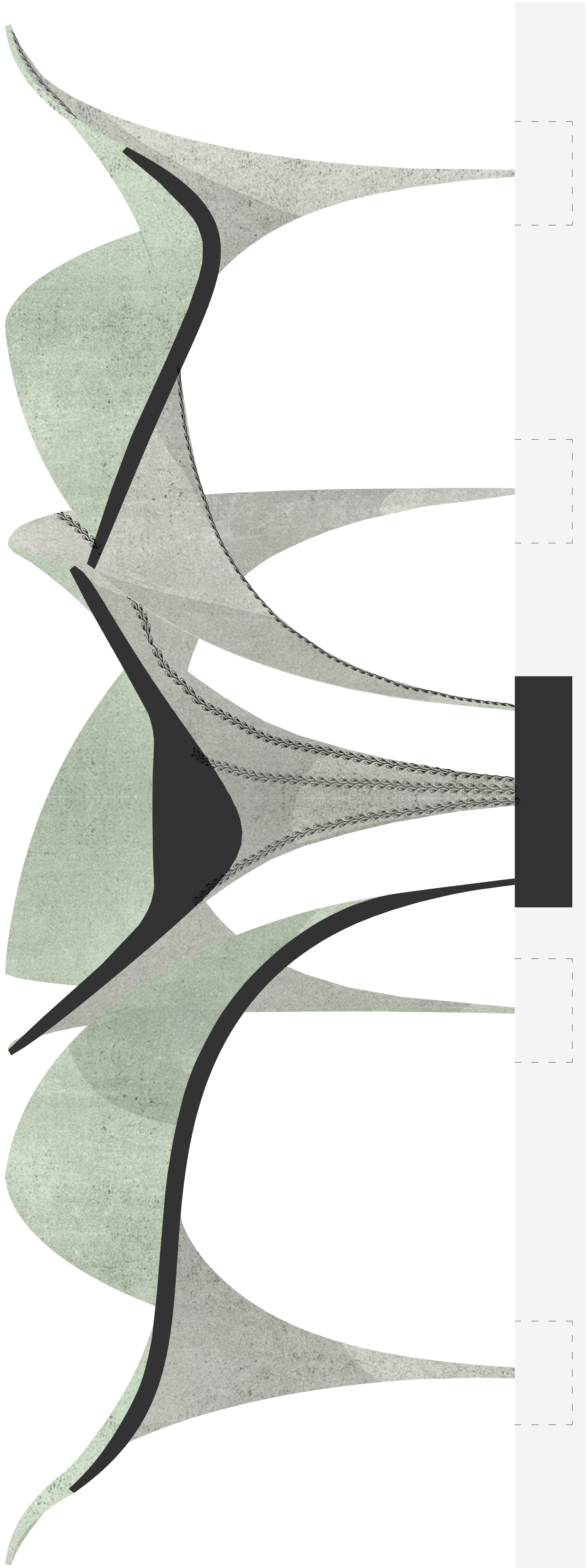


Facade facing west 1:50

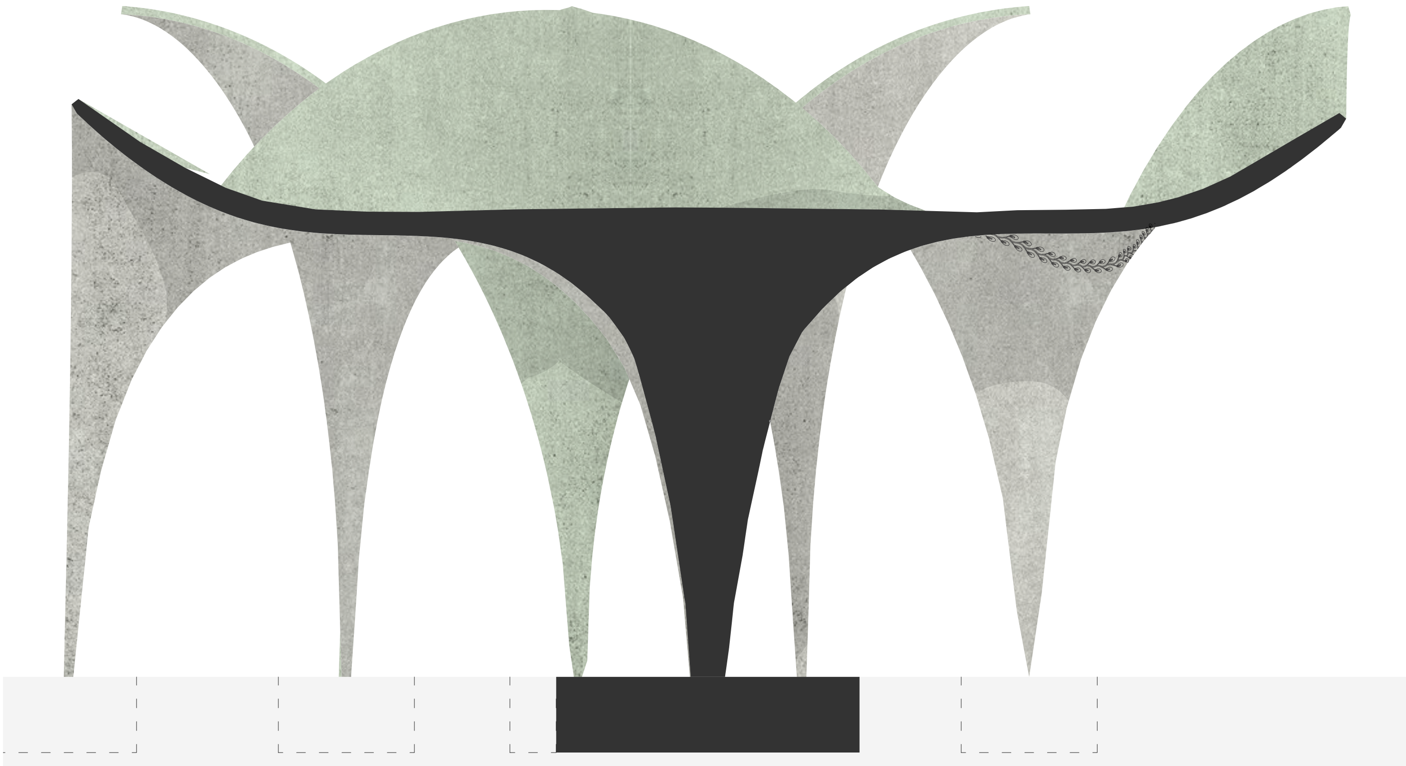
The ornamentation used for the pavilion is the leaf vine motif. The leaf vine starts on the center pillar and moves up over the ceilings.



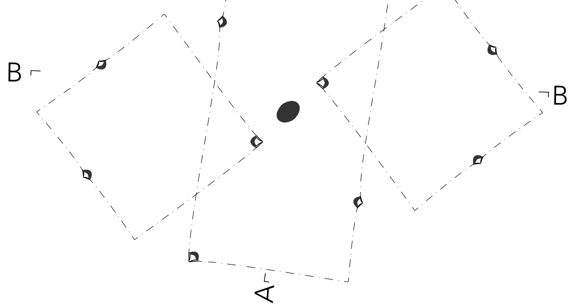
Plan 1:50

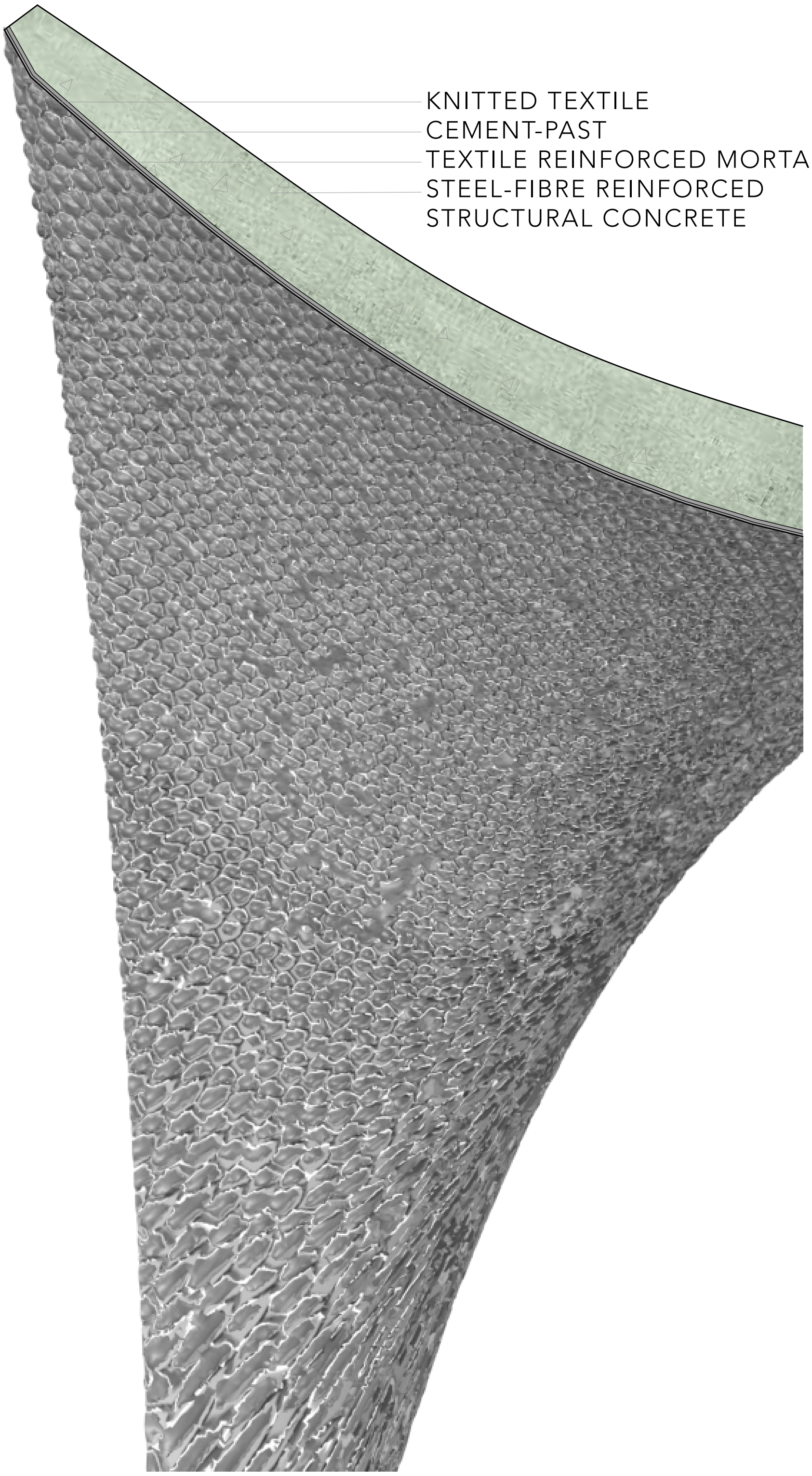


Section A - A 1:50



Section B - B 1:50





Detail section 1:10

Discussion | Summary

That knitting is an excellent formwork for other materials has been proven, and KnitCrete as a cost- and material-efficient method for doubly-curved geometries has been demonstrated through various prototypes and the KnitCandela shell-structure. However, there is more to explore when it comes to integrating knittings inherent properties as part of the design.

In this thesis I have contributed to this field mainly by showing how lace knitting patterns can work as both ornamentation and create a texture in these systems.

Using knitting's inherent properties as a design tool

The knitting's inherent attribute has its foundation in the looping stitch. It's the one that stitch by stitch builds up the structure that forms a fabric. This structure, created from small united loops, is also the reason why it is possible to shape a knitting at the same time as it is created (by increasing and decreasing stitches/rows anywhere in the knitting, and/or by using circular knitting). The linking stitches are also what makes the fabric elastic.

In a KnitCrete construction, these properties, the ability to create shape and the elasticity of the final fabric, are beneficial when the fabric turns in to a formwork. The individual stitches are then stretched and the cavities in the fabric become prominent. These are then covered by a coating and a texture arises where the yarn of the knitting becomes the basis for the bulging coating-material. Visually, the knitting can be seen as a joint between the bulging coating-material.

Through hands on explorations, I have showed that the color of yarn and coating, how the knitting is tensioned, size of the cavities, knitting pattern and where you choose to place increases and decreases determine how the final visual expression will be. Lace knitting patterns have been of special interest since they are created by alternating between smaller and bigger cavities. These patterns not only create an ornamentation, but also give the surface a varying texture when coated.

Knitting as ornamentation, form and formwork in an architectural design tool

In the design process of combining my findings in to an architectural design, I realized I could make a flower from the hand made models I had made. Since the ornamentation made in this thesis has flower motifs, it was logic to me to use this flower geometry in my proposal.

This geometric finding made me think that this could have turned in to a biomimicry inspired project. Since tension active form so clearly it's connected with geometric efficiency, and the nature is as well.

The Knitcrete method, where the coating is done in several layers, gives opportunities to use a color difference between the different layers. In my pavilion, I have chosen to use this possibility and leave the inside in the original gray tone of the cement, while the outside is colored in a shade of green.

To create an architectural design out of my findings turned out to be the most difficult part of this essay. As an architectural design involves a larger scale I wanted to do this work with the help of the computer. The doubly-curved geometry complicated this work in many ways and a lot of, to me, new software where used, such as Kangaroo2, Autoknit and Cockatoo.

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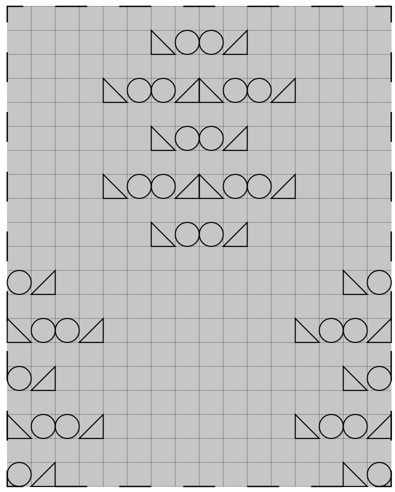
Appendix I

Knitting patterns

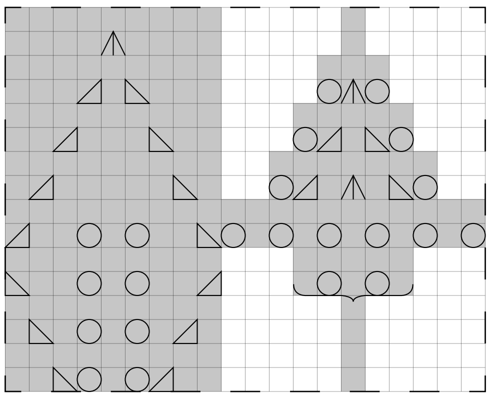
Flower lace



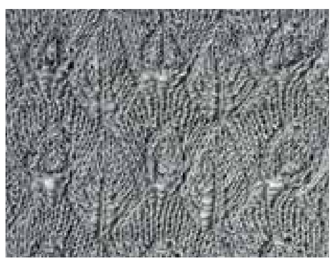
- ■ knit (k) on RS, purl (p) on WS
- ○ yo (yarn over)
- ◺ k2tog (knit 2 stitches together)
- ◿ skp (slip 1, knit 1, psso)

Källa: Wincent-Gelinder, E. (övers.) (2007)

Buds and leaves lace

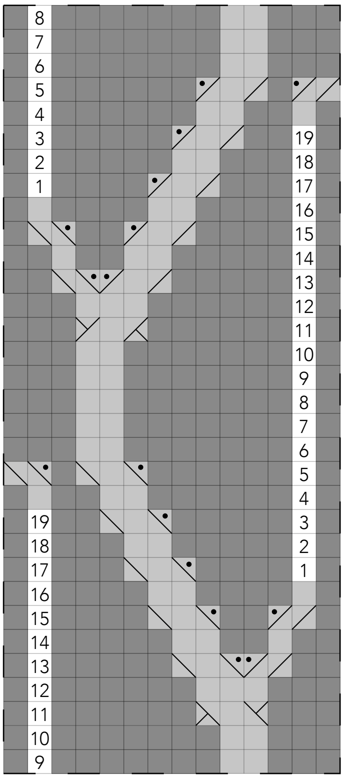


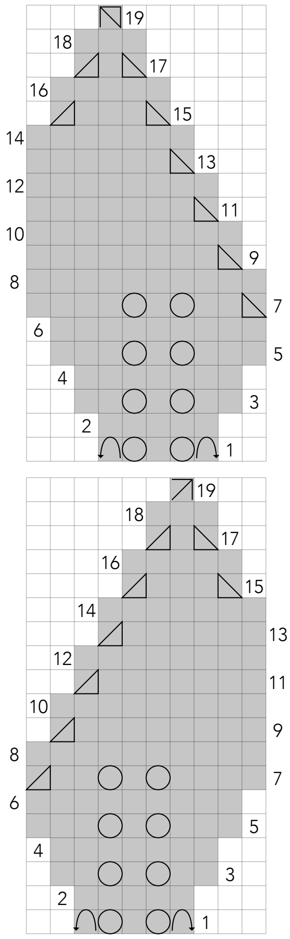
- ■ knit (k) on RS, purl (p) on WS
- □ no stitch
- ○ yo (yarn over)
- ◺ k2tog (knit 2 stitches together)
- ◿ skp (slip 1, knit 1, psso)
- ⋀ cdd (center double decrease)



Källa: Stanfield, L., Griffiths, M (2012)

Leaf vine

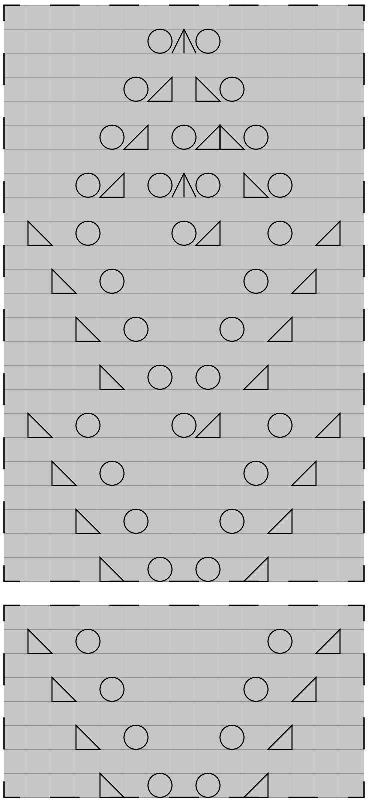




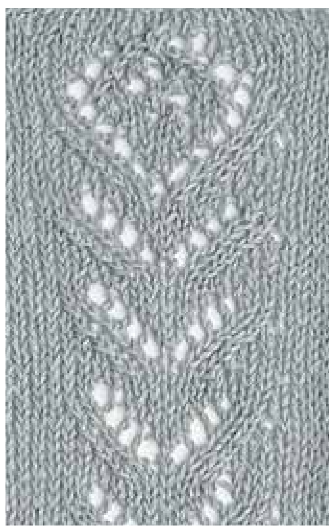
- purl (p) on RS, knit (k) on WS
- knit (k) on RS, purl (p) on WS
- yo (yarn over)
- k2tog (knit 2 stitches together)
- skp (slip 1, knit 1, psso)
- k3tog (knit 3 stitches together)
- m1l (make 1 left)
- m1r (make 1 right)
- cross 1 to left over purl (1 stitch on auxiliary needle in front of the work, 1p, 1k from auxiliary needle)
- cross 2 to left over purl (2 stitches on auxiliary needle in front of the work, 1p, 2k from the auxiliary needle)
- cross 1 to right over purl (1 stitch on auxiliary needle behind the work, 1k, 1p from the auxiliary needle)
- cross 2 to right over purl (1 stitch on auxiliary needle behind the work, 2k, 1p from the auxiliary needle)
- cross 2 to left (2 stitches on auxiliary needle in front of the work,1k, 2k from the auxiliary needle)
- cross 2 to right (1 stitch on auxiliary needle behind the work, 2k, 1k from the auxiliary needle)

Källa: Stanfield, L., Griffiths, M (2012)

Flower on stem lace



- knit (k) on RS, purl (p) on WS
- yo (yarn over)
- k2tog (knit 2 stitches together)
- skp (slip 1, knit 1, psso)
- cdd (center double decrease)



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