Computational Knitting in Architecture: an Experimental Design Process for a Performative Textile System

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Abstract

Today’s possibility to design the performance of fabrics thanks to computational tools has broadened the application of knitting techniques to AEC. This paper will introduce a practical and computational trial to produce a knitted shading structure for a pavilion through a preliminary experimental process. The first part of this paper will focus on the practical knitting technique, in which the geometry and derived properties of a knitted stitch will be examined. A rule is defined within the knitted pattern to increase the number of stitches per course, resulting in diagonal outer edges with specific slope. Using this rule, three distinct geometric textile modules are defined where the relationship between the edges of each module provides the possibility for their combination into different patterns. The second part of this paper will introduce possible pattern simulations of the combination of textile modules. Varying degrees of enclosures can be produced through the pattern simulation and adapted to the diverse program of the pavilion and its orientation within the project site. Various structural technologies will be examined in an effort to demonstrate the possibility of integrating such a textile system through existing technologies.

Keywords: (knitting techniques, geometric textile design, geometric patterns, shading structure, textile pavilion design, computational design).

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1. Introduction

Knitting is a traditional and complex method of manipulating fibers in which the loops of a fiber are gradually intermeshed in order to produce a fabric. The knitted pattern of the loops, referred to as stitches, brings elasticity to the fabric. Different stitch types, bringing different knitted patterns, introduce varied properties to resulting fabrics, allowing manufacturers to tailor the shape, rigidity, and consistency of their product, thus producing customized results.

Developments in computational design have expanded the possibilities of applying knitting techniques on an architectural scale. Traditional practices of knitting have been integrated and adapted through computational tools to move beyond their traditional methods and uses, providing incredible inspiration and innumerable possibilities to contemporary designers.

This paper explores the possibility of applying traditional knitting techniques through computational tools to the design of a prototype for an architectural pavilion. Through preliminary physical testing and investigation, three unique geometric textile modules are defined and later simulated using computational tools. The possible patterns that their combination creates produces the possibility of various “degrees of enclosure” that can be customized to accommodate different program for the pavilion. Integrated within the pavilion’s structural system, the combinations of textile modules appear as one “continuous” fabric, while creating multiple “interior” spaces defined by the separation of knitted fabric “walls.”

2. Knitting geometric modules

This section of the paper introduces practical knitting techniques that have traditionally been used to produce patterns within knitted fabrics. First, common pattern-producing techniques are presented, including the possibility to join two unique fabric pieces along a diagonal seam. The possibility of “scaling up” these joining techniques is presented through a physical trial that joins 10mm hemp rope and common stainless steel hardware.

The textile pieces presented here are simulated through the “Stockinette” stitch. One of the most common knitted stitches, “Stockinette” is produced by knitting complete alternating rows of “purl” (or “under”) and “knit” (or “over”) stitches, giving the stitches a distinct “V” shape on the front of the fabric piece.

The second part of this section examines the geometry of the “Stockinette” stitch, producing a method to determine the length and weight of each completed stitch. After setting a rule to “increase” one stitch for every row of purl stitches, three unique geometric textile modules can be produced by “mirroring” the resulting base shape of a right triangle. Potential combinations of the three unique modules are explored to understand the possibilities of joining the textile pieces along their edges.
The proposed textile modules are investigated through physical trials and conceptual diagram during the design of the pavilion prototype. At a later date during a workshop held at the Politecnico di Milano, the pieces are computer simulated by a team led by Ingrid Paoletti (modeling the “Stockinette” stitch in Grasshopper and the textile modules in Kangaroo).

2.1. Pattern joining in traditional knitting

The diverse hand techniques that have evolved from traditional knitting permit a variety of patterns and designs for knitted fabrics.

2.1.1. “Picking up a stitch”

It is common practice in traditional knitting to create multicolored geometric patterns by “picking up the stitches” of a completed fabric section (see Figure 1.). This is accomplished by looping a new strand of yarn through the crossed “end stitches” of the completed piece, thereby creating a new row of loops that permit a new fabric section to be attached to the existing piece.

Often this is accomplished by using strands of contrasting colors, in order to create a pattern that is embedded within a knitted fabric and creating a “knitted seam” between the two distinct fabric pieces. A variation of the technique can also be applied to join two fabric pieces that have already been completed.

![Figure 1: Hand trials of “picked up stitches” along a vertical edge, using two different colors and strands of yarn. 10mm knitting needles are used.](image)

2.1.2. Creating a diagonal seam

A diagonal seam can be created along the edge of the knitted fabric by either “increasing” the number of stitches in a row (or by “decreasing” them). “Increasing” a stitch is accomplished by “knitting twice” on one stitch. “Decreasing” is accomplished by knitting two stitches together. Physical trials with Stockinette stitch were completed by increasing one stitch for every purled row (so alternating rows of stitches increase by one). This method produces a diagonal on a single side of the fabric piece (while the opposite side remains straight, see Figure 2.). Other methods (such as “knitting twice” or more on every row – which causes opposite sides of the fabric piece to simultaneously increase) produce diagonals of different slopes.

![Figure 2: Hand trials of “picking up stitches” along a diagonal seam, using two different colors and strands of yarn. 10mm knitting needles are used.](image)
The method used (increase one stitch every other row) produces the possibility of a right triangle (increasing only along one edge). By “knitting twice” with the first stitch of every purled row, a crossed loop shape is produced along the diagonal seam, similar to the crossed ends of a straight seam. These loops can then be “picked up” to join the diagonal seam to a new piece of fabric in the same way that straight seams can be joined (described in 2.1.1).

2.1.3. Possible attachments to existing hardwares

Traditionally, these methods are used to produce flat patterns that are integrated within a single knitted fabric. This project however, investigates whether these joining methods could produce a joint between unique large-scale fabric pieces that could then be folded along their seam to produce inhabitable space.

At an architectural scale, modular textile pieces would likely be produced as completed fabric sections (easily transportable from manufacturer to the project site) and then integrated within a cable system (a common structural system for tensile fabrics and one that could be used, in this case, to create large-scale “seams”). Here, the possibility of looping the closed stitches of a completed textile piece to a piece of closed steel hardware are explored. Using hardware to attach the ends of the textile modules along a structural cable (versus attaching the ends directly to the cable) produces a structural “break” (that can help to prevent the textile from deforming during installation and also enables the piece to be more easily installed, removed, or replaced). The principle of “picking up the stitches” of a completed knit fabric (common in traditional knitting techniques) is used to loop the closed end stitch of the textile to the hardware.

Figure 2: Hand trials of “picking up stitches” along a diagonal seam, using two different colors and strands of yarn. 10mm knitting needles are used.

Figure 3: Physical trial to test attaching a “closed stitch” to a closed hardware. Completed with 10mm three-strand synthetic hemp rope and a stainless steel swivel eye hook loop.
2.2. Determining proportions for three geometric modules

Three geometric textile modules are defined by examining the proportions of and the diagonal slope created by “increasing” with the Stockinette stitch.

2.2.1. The geometry of the stitch

The geometry of the Stockinette stitch is explored through its proportions, understanding that each stitch has an “optimal geometry” to produce optimal stretch. In terms of material, three-strand synthetic hemp rope of 10mm diameter is considered (which has its own elastic material property that must be taken into consideration). Recalling that the properties of manufactured fabrics is dependent on the type of stitch used (see Introduction: different stitches in knitting produce different fabric properties), a single “V” stitch is diagrammed. The proportions of a single stitch will be used to determine maximum and minimum areas of stretch and also to determine the diagonal slope achieved by increasing by one stitch.

This diagram allows multiple stitches to be considered through their proportions to produce a method of counting that can be used to estimate the length of 10mm rope necessary to produce a Stockinette stitch (a necessary consideration in the manufacturing of the textile pieces, and one that also allows the weight of each module to be determined).

![Figure 4: Diagram of the proportions of the Stockinette stitch. (Note: the length of rope needed to “loop under” and create a new stitch is not pictured in this diagram, but was taken into consideration).](image-url)
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2.2.2. Defining shape based on set slope

Using the rule of increasing one stitch for every purled row (see 2.1.2), a specific slope is defined, creating a right triangle. By “mirroring” the same right triangle in two different positions, three geometric modules are produced in proportion to one another (see Figure 5.). The slopes of the geometric modules match, allowing for the possibility of their combination into various fabric “patterns.” These fabric modules are imagined to be arranged in combinations along their edges, and attached along their seams, in order to create inhabitable space in the pavilion prototype.

![Figure 5: Three geometric textile modules are defined by “mirroring” a single right triangle. For clarity of drawing, dashed lines show the “direction” of the Stockinette stitch.]

2.2.3. Exploring geometric combinations

Possible pattern combinations of the proposed textile modules are explored by understanding the relationships between the edges of their geometries (see Figure 6.).

Once the length of the straight edge of each geometric module has been set, the maximum and minimum values achieved through stretching the fabric can be determined for each textile module (this must, of course, take into consideration the elastic properties of both the Stockinette stitch and also the material properties of 10mm three strand synthetic hemp rope). This can be determined by calculating maximum and minimum areas, using the resulting calculations to determine maximum and minimum lengths of the sides. Additional pattern combinations of the fabric modules then become possible through the range of length possible from stretching each side.
3. Combination of textile modules for a prototype design

This section explores the possibility of combining the three geometric modules into various pattern combinations to create space suitable for different pavilion program. The resulting open shading structure is a seemingly continuous patterned fabric that acts as to delineate space both through overhead shade and also through vertical fabric “walls.” The possibility of securing the patterned fabric between an external frame (composed of four curved triangular space trusses) and a system of curvilinear steel bars “hidden” beneath a raised wooden deck is investigated and developed through the adjustment of existing structural technologies.

The prototype proposed is for a country pavilion for the 2020 World Exposition in Dubai. The site is situated within the Dubai Expo with its main entry facing North/Northwest. The knitted composition of the textile modules produces a porous condition, allowing wind to traverse through the pavilion site and also reducing wind loads considerably. The tropical desert climate of Dubai is taken into consideration, and low-consumption cooling systems are explored.
3.1. Meeting programmatic needs through textile patterns

Programmatic activities are diagrammed to understand their “shading” needs, in order to simulate a textile design that meets these through its pattern combinations.

3.1.1. Simulating patterns to enclose pavilion program

The potential program of the pavilion is investigated by exploring the lighting and shading demands of each (referred to as “degrees of enclosure,” see Figure 7.). Program is then arranged such that “more enclosed” (or “more shaded”) program is situated appropriately within the site. “Degrees of public access” are also taken into consideration when arranging the program. Possible combinations of the textile modules are then simulated to “wrap” various pavilion program (see Figure 9.). Based on the “degree of enclosure” necessary and the program’s position within the site, the fabric conditions can be layered to create more shade for the program inside.

Figure 7: Diagram of “shading needs” of pavilion program.

Figure 8: Ground floor arranged according to degrees of public access and degrees of enclosure.
3.2. Integration of textile modules through existing structural technologies

3.2.1. Hardwares and connections

Early physical testing explored the possibility of attaching completed fabric pieces to a stainless steel swivel eye hook loop (a common hardware used to secure ropes—see Figure 3.). In this section, the possibility is presented of modifying one end of this common hardware so that it has a flat metal plate that can be screwed into cable clips (to secure textile pieces to structural steel cables) or to a membrane plate (used to secure corners of tensile fabrics).

The knitted end stitches of the textile modules, once looped to the hardware, can be secured to adjustable cable clips (see Figure 11.). These cable clips can be secured in multiple positions to accommodate the direction of the textile stitching, and they can be easily replaced if necessary without disturbing the adjacent textile piece. At the ground, the end stitches of textile modules (once looped to hardware) can be secured at their corners to a membrane plate.

Figure 9: Exploded axonometric drawings simulating possible pattern combinations of the textile modules into geometric nodes that “wrap” various pavilion program.
3.1.2. Wrapped enclosures and fabric “walls”

The geometric textile modules are attached to one another through connecting structural cables. At the ground, the textile modules are secured at their ends and then along their edges by a system of curvilinear steel bars hidden beneath a raised wooden deck. This way, the textile “meets” the inhabitable ground, creating the appearance of fabric “walls.” The textile modules are held in tension above by structural cables that connect the consolidated modules to an external frame composed of four triangular curved space trusses.

Figure 9: Exploded axonometric drawings simulating possible pattern combinations of the textile modules into geometric nodes that “wrap” various pavilion program.

3.2. Integration of textile modules through existing structural technologies

The adjustment and modification of existing structural technologies is explored in order to demonstrate the possibility of integrating the textile modules into a larger system.

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membrane plates and structural steel cables can then be consolidated and attached to foundations through a semicircular steel anchor plate (see Figure 12.). Along its edges at the ground, the end stitches of the textile modules (once looped to hardware) are secured along a curvilinear steel bar using an adjustable nylon rope (see Figure 12.). These adjustable systems are necessary in order to “tighten” the fabric system (which inevitably stretches over time).

Figure 11: Diagrams depicting the adjustable connection of textile modules to structural cables.

3.2.2. Making use of a raised deck

The raising of the inhabited ground plane by a wooden deck allows for the integration of a fan system embedded in the floor. Integration of geothermal cooling can cut energy costs, to create a low-consumption cooling system that is integrated into the pavilion design. A fan system releases cooled air through perforated wooden panels embedded in the deck.

3.2.3. Integrating connections with an external frame

An external frame of four curvilinear space frame triangular trusses holds the textile modules in tension. The steel cables that secure the textile modules to one another are consolidated at the top corners of the fabric pieces, along with the corner membrane plates, and secured to a structural cable that is anchored to one of the exterior trusses.

The resulting structure holds the combined textile modules in tension between the embedded steel bars in the “ground” of the raised wooden deck and the “sky” of the external framing system.

References


4. Conclusion: experimental possibilities

The experimental prototype design presented here uses the geometric and material properties of knitted fabrics to inform the design and production of an architectural pavilion through the combination of knit textile modules. In particular, the process intends to explore and analyse an experimental process that allows to collect data to transform the control-by-hand work into digital modelling. Developments in computational tools in recent years have produced the possibility to incorporate traditional knitting techniques into large-scale productions, enhancing existing innovative technologies. Students at the ETH Zurich in collaboration with ZHCODE and R-Ex have worked in the past year to produce a four meter tall installation through a 3D-knitted design. As the development of computational knitting continues to progress, the experimental possibilities of applying knitting techniques at an architectural scale will expand, extending the opportunity for the integration of textiles in large-scale innovative designs and giving designers the opportunity to develop their own skills by challenging a very old technique like knitting in an innovative way.

References


