International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:15, No:1, 2021

Knitting Stitches' Manipulation for Catenary Textile Structures

Virginia Melnyk

Abstract**—**This paper explores the design for catenary structure using knitted textiles. Using the advantages of Grasshopper and Kangaroo parametric software to simulate and pre-design an overall form, the design is then translated to a pattern that can be made with hand manipulated stitches on a knitting machine. The textile takes advantage of the structure of knitted materials and the ability for it to stretch. Using different types of stitches to control the amount of stretch that can occur in portions of the textile generates an overall formal design. The textile is then hardened in an upside-down hanging position and then flipped right-side-up. This then becomes a structural catenary form. The resulting design is used as a small Cat House for a cat to sit inside and climb on top of.

Keywords**—**Architectural materials, catenary structures, knitting fabrication, textile design.

I. Introduction

CATENARY structures have a variety of advantages. These parabolic structures are strong, light-weight, and can be considered aesthetically pleasing. Computational methods, such as Grasshopper and Kangaroo make the design of these structures on the computer easy. Quick simulations can be used to create and develop a variety of iterations and design outcomes. The idea of using a knitted textile for this type of structure is novel and experimental. Textiles are a soft and flexible material; this often leaves them to be overlooked as an architectural material as they do not usually provide any structural properties, although textiles have been common in architectural as building skins, not as structural elements. Gottfried Semper wrote about textiles in *The Four Elements of Architecture*. He describes weaving as for enclosure and walls; only when they need to provide structure, walls become solid and made from tectonic elements [5]. This project hopes to create a new use for textiles in architecture, as a light-weight thin-shell structure, when it is hardened with resin. The design process involves translating the information from the simulated design on the computer into a pattern that can be made on a knitting machine. This takes a bit of hand-work and back and forth between the digital tools and the physical process of making. Material culture and craft-based making is part of this construction process as it ultimately relies on the hand-work and craft based knowledge knitting stitches. The result of this experimental research is a small catenary structure that is used as a Cat House.

V. Melnyk is PhD Student at Tongji University DigitalFUTURES international PhD program, College of Architecture and Urban Planning, Tongji University , 1239 Siping Rd, Yangpu District, Shanghai, China and lecturer at Clemson University Department of Architecture. Fernow Street, Lee Hall, Clemson, SC 29634 USA (e-mail: vemelnyk@gmail.com).

II. Catenary Architecture and Knitting

Antoni Gaudi developed his catenary structures for many of his designs by physically hanging chains and weights to get the perfect parabolic structural forms [2]. His work has inspired architects for many years after his death, and as his most famous work, La Sagrada Familia is currently still under construction. The forms and geometries that he designed in this building have relationships to computational design [2]. La Sagrada Familia is one of the first buildings to utilized parametric software tools for architectural design, as Mark Burry developed parametric and computational ways to translate the few drawings and models, left after Antoni Gaudi died, into a system of understanding the forms and geometry that was implied throughout the building [2]. Currently, easy-to-use programs like Kangaroo for Grasshopper can generate physics simulations for gravity and material properties. These simulations work well for creating catenary structures as they can make similar models to the ones Gaudi made, with hanging chains, inside the computer. These advances to the design process allow for designers to produce many quick models that can then be easily translated to modes of digital fabrication although for this project computer controlled knitting (CNC) was not used. Therefore, the simulated model needed to be translated into a pattern for hand manipulated knitting machine stitches. But the computer still proved to advance and increase speed in the design process.

Other advantages of catenary structures are that they are thin and light. This results in fewer materials used in the final built project which are good for the environment. Resulting in less material needed in production, less waste created, and less energy wasted on transportation of materials to the construction site. This is good for the overall need to reduce the environmental impacts during the construction process.

Knitting is useful for catenary structures because it is a light-weight, thin material. A single strand of yarn might break under a large force, when knitted together the fibers gain strength as a grouping and can hold more weight. In this project, the yarn used is cotton, which is a natural renewable resource although cotton farming does have its draw backs, with large amounts of water consumption and high use of pesticides. In return cotton is bio-degradable, which is better than other synthetic yarns like acrylic or polyester [1].

Knitted textiles are made by connecting loops of yarn through other loops of yarn. These loops intertwine with one another creating stitches from one row to the next. Unlike woven fabric which has different warp and weft threads, knitted textiles are made out of one continuous string, which creates stretchy textile. When stress is added to the textile to force it to stretch, the loops can expand and contract, as the yarn can slide from one switch to the next effecting the size of the neighboring loops. The textile works as a whole and this slippage of yarn makes knitted textiles able to create deformations and stretch many times their original size [4]. The physics of how knitted structures stretch is dependent on many material qualities, such as the fuzziness of the yarn, the material the yarn is made out of, the yarn thickness, and the size of the knitted loop.

Knitting machines were developed during the industrial revolution and utilize a bed of latch hook needles to loop the yarn around, and a carriage cartridge the brings yarn back and forth across the needles. This produces very quick rows of knitting much faster than by hand with regular knitting needles. Although today there are digital CNC knitting machines that can be directly coded, this project was done on an older home punch card model with hand manipulation techniques to create the patterning.

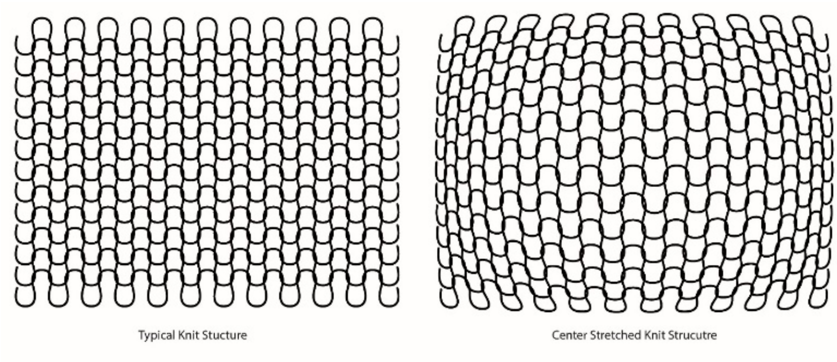

Fig. 1 Kitted structure stretched to create curvature

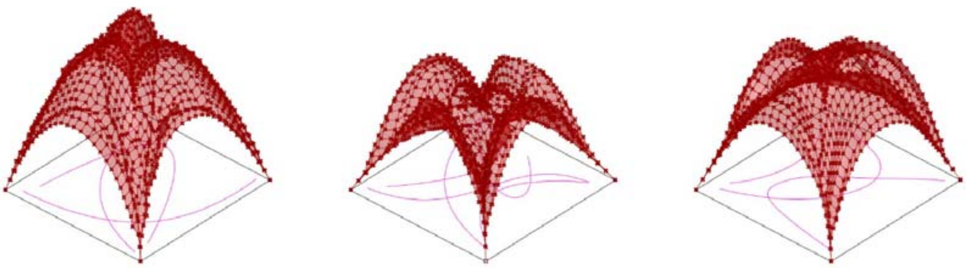

Fig. 2 Catenary structure in Grasshopper

Using knitted textiles works well for catenary forms because they easily can stretch in various ways and create the desired doubly curved surfaces by expanding and contracting, shaping individual stitches of the textile to create an overall three-dimensional form, see Fig. 1.

III. The Catenary Cat House

The Cat House started as a design in Kangaroo for Grasshopper. The design implemented base rectangular mesh, placing four anchor points on each corner. A negative gravitational force is applied and the mesh is then able to relax into a natural parabolic arched shape. By applying a negative gravitational force, there is no need to imagine the structure upside own, as on the computer you can visualize the results of the righted up model, and your desired design proposal. The base of a catenary design is a simple parabolic arch, and does not have any design or variation to it. To take advantage of different knitting stitch types, the hypothesis was to manipulate the stitching to create hills and valleys in the overall form, and create an asymmetrical design. To generate this design, a set of attractor curves was drawn on the base mesh to cull out a set mesh edges of the design in a pattern. This set of edges was given a length constraint to prevent them from stretching as much as the other mesh edges. In the Grasshopper simulation, this created the desired various ridges and bulges on the roof of the structure, see Fig. 2. The mesh and the desired set of culled edges were then translated into a knitting pattern where the edges that were intended to not stretch were to use tuck stitches. A tuck stitch pulls out a needle on the bed from the regular knitting rhythm and holds it for as many rows as desired, preventing it from making new stitches at that point. This results in a pucker in the fabric, similar to a cinch or gather which creates tightness and a restriction in the ability for the loops to stretch. By using this stitch strategically in the determined spots the textile will form the type of geometry predicted in the Grasshopper simulation.

A hand manipulated knitting pattern uses a grid and special symbols to tell the knitter when to make certain manipulations on the machine [3]. In this case, regular stockinet knitting stitches are used throughout the textile and a tuck stitch that would hold for eight rows would be used. The desired size of the textile for the design required using 180 needles on a 4.5

mm kitting bed and to knit 220 rows at a tension of six. This setting creates an even sized knitting stitch that with a fingering weight cotton yarn and still have room to move for desired stretching. The cotton yarn does not have very much fuzziness as wool or some acrylic yarns. This creates less friction to allow for stitches to slide from one to the next when stretching. As well as the cotton yarn itself does not have much stretch, leaving most of the textiles' stretchiness to be dependent on the knitting style rather than the yarn itself. A typical hand manipulated knitting pattern is usually a small grid of rows and columns, as typical designs for patterns can be repeated or for an individual design that is only desired in one spot in the knitted textile. For this pattern the design was larger as it had to occur over the whole size of the textile. That would be 20 inches by 18 inches, making the pattern match the individual stitches of a 180 x 220 grid. The pattern was simplified to call out just the row numbers and the needle number that would need to be moved to into action create the tuck stitch, rather than showing every grid square for the normal stockinette stitches. For a tuck stitch the symbol is similar to a lowercase looking "n". The "n" stretches over the number of rows in which the tuck stitch is meant to occur, in this case each tuck stitch was planned to hold for eight rows. Thus, the resulting pattern is a simplified version of a typical knitting pattern showing the elongated "n's" and called out with numbers at each row and needle number that express when these manipulations are to be made in the knitting process, see Fig. 3. The needles on the knitting machine bed are numbered from zero at the center and out, with negative numbers to the left and positives to the right.

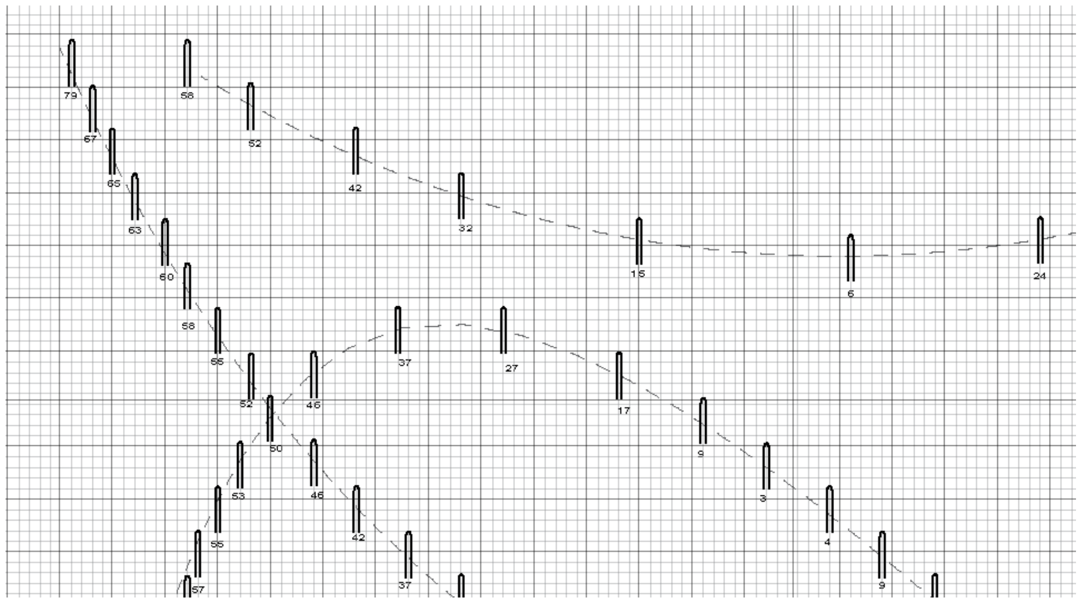

Fig. 3 Pattern drawing designed to create the hand manipulated knitting

Fig. 4 The resulting flat knit before being stretched into shape

The knitting took just over an hour as knitting each row is quite quick on a knitting machine. The difficult task of the knitting was to follow the pattern and watch the row counter to know when to make the hand manipulations to create the tuck stitches. Once the textile was completed, the overall pattern of the tuck stitches can be seen as little puckers in the fabric, see Fig. 4. At this point in the process the fabric is still flat, and it will need to be held with weights to force the stitches and yarn to stretch and shift to form it into the desired curved parabolic shape.

IV. Fabrication

A wooden box framework was built to temporarily hold the textile upside-down during the shaping and hardening process. The fabric was attached at the corners where the anchors were added in Kangaroo. Gravel rocks were used to add weight to the fabric to force the knitted loops into full stretch. The gravel rocks were placed specifically in the zones between the tuck stitches to force those pockets to shape. As more rocks were added the shaping of the stretched fabric and the restrained stitches in the fabric became visible. Once enough rocks were added as weights, you could see the desired resultant shape of the structure formed, see Fig. 5. The next step was to coat the textile in resin to permanently harden it in this form. In the interest of being environmentally conscious a bio-resin was used. Bio resin is a resin that derives some or all of its monomers from biological sources. These types of resins can be biodegradable, which can eventually be reduced back down to basic biological materials. Combined with the cotton yarn the whole final structure could eventually be biodegraded. The resin was brushed on the underside of the fabric and was left to dry for 24 hours to affirm hardness. Then the rocks and framework were removed and a second coat of resin was applied to the inside surface of the textile which was not reachable in the first coating. Once this second drying process was completed the textile was hard enough to be removed from the frame and flipped over.

Fig. 5 Textile hung with rocks to weigh fabric into parabolic shape

V. Results

The resulting structure kept its shape when flipped back over and all the design and form was visible. The structure was strong enough to support the weight of an average sized cat. The various bulges and creases created by the knitted textile loops to stretch under the force of the rocks resulted in a form to be quite similar to the simulated Grasshopper model, see Fig. 6. Although it was necessary at the base anchor points to add a string to keep the form from splaying out when a lot of weight was added to the top of the structure, it was overall free standing. In the simulation these points were set with anchor points, and would in a larger structure or permanent structure be made with a foundation or nailed down anchor points into the ground. But given the small scale of this structure and since it was a cat house that may want to be portable like a piece of furniture, the use of string was sufficient to pull the forces back from causing the structure to splay out.

Fig. 6 Final result of Catenary Knitted Cat House

Resultantly, the texture of the final design removes all the softness of the cotton yarn and has become a hard ridged shell. The knitted loops create a bumpy texture that is still apparent in the resin, as the yarn moves in and out of the various loops. The surface also visibly shows the stretch of the fabric as the scale of loops and hole sizes change as it stretched into full tension at the peaks of the form and become smaller and more constricted in the valleys. Overall, the shape is at a perfect size for a cat to hide and feel protected inside. Yet it has a playful roof scape allowing the cat to climb and explore as if on top of a rock. The cat ultimately seemed to enjoy the overall design.

VI. Conclusion

From this project it is clear that the possibilities of using different knitting stitches can successfully manipulate the way in which a knitted textile can stretch and form parabolic doubly curved geometry. This work developed a successful workflow and proved that by adjusting the knit stitches it is possible to create structural catenary forms and double curved thin shell structures. The use of Kangaroo in Grasshopper offered the ability to simulate designs and prepare a pattern for the production of the textile. The final resulting structure was visually quite similar to the simulated proposal and ultimately structurally successful. The resulting texture of a resin coated textile removes all the softness and flexibility typically associated with knitted fabric and provides a strong thin-shell structure. Still, visually and through the bumpiness, displays of some of the characteristics of the knitting are still apparent. The ecological advantages of this project is in the use of light-weight designs, reducing overall materials needed and the use of materials that are more environmentally friendly by being bio-degradable. Overall this research is successful, but it is in its early stages and could be explored with many different types of knitting stitches and in larger scales.

Acknowledgment

The author thanks PhD advisor Professor Philip F. Yuan at Tongji University.

REFERENCES

[1] Blackburn, Richard S. Sustainable Textiles: Life Cycle and Environmental Impact. Oxford: Woodhead Publ. Ltd., 2012.\
[2] Burry, Mark, and Gaudí Antoni. Expiatory Church of the Sagrada Familia: Antoni Gaudi. London: Phaidon, 1993.
[3] Guagliumi, Susan. Hand-Manipulated Stitches for Machine Knitters. North Charleston, SC, sc: CreateSpace Independent, 2016.
[4] Poincloux, S., M. Adda-Bedia, and F. Lechenault. Geometry and elasticity of a knitted fabric. Physics Review X 8:021075. 2018.
[5] Semper, Gottfried, and Harry Francis. Mallgrave. The Four Elements of Architecture: and Other Writings. Cambridge: Cambridge Univ. Press, 1989.

Virginia Melnyk (M-2020) Born in San Francisco California USA in 1985. Graduated from the University at Buffalo School of Architecture and Urban Planning with Bachelors of Science in Architecture in 2007. Graduated with Masters of Architecture from the University of Pennsylvania School of Design in 2010.

She has worked as an architect at Studio Pei Zhu in Beijing China. As well as taught at University of Pennsylvania as a lecturer and research assistant. Taught as a Adjunct Instructor at the University at Buffalo. And Currently is a Lecturer at Clemson University, in Clemson South Carolina, USA. She has presented at conferences at Georgia Tech, University of Kansas, and CAADRIA. Current and research interests include knitting, digital and parametric design, and architectural structures. As well as research in machine learning and AI.

Miss. Virginia Melnyk is a member of DigitalFUTURES association, and ACADIA