Visualization of Three-Dimensional Knit Textiles

Multi-Material Fabrication and Design Iteration

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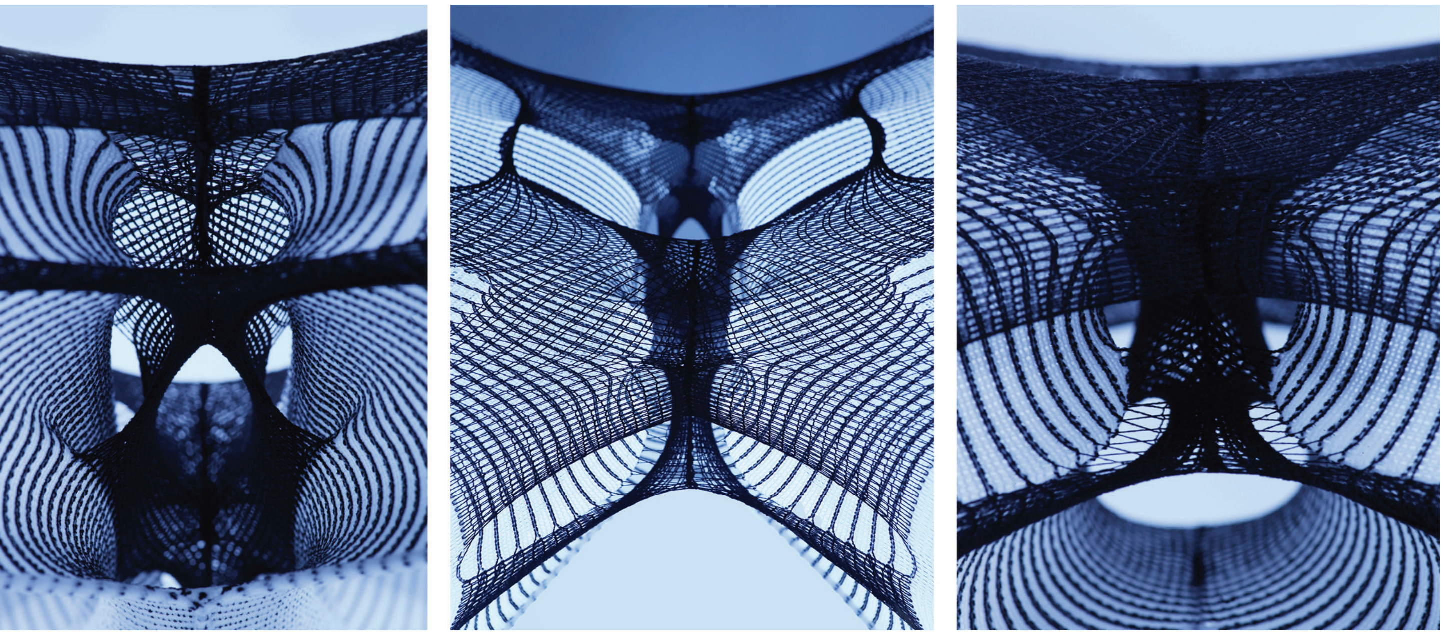


1 Examples of three-dimensional, multi-layered knit textiles addressed in this research

ABSTRACT

Virtual domains in digital fabrication such as simulation and digital visualization often prioritize values such as geometric accuracy and precision. Simulation methods are evaluated by comparing physical and virtual objects, measuring discrepancies in tolerance and geometric form. However, the ability of simulation to inform the design process extends to intuitive decision making and exploratory iteration, independent of geometric fidelity. This paper explores the role of simulation through the lens of textile fabrication, which is uniquely resistant to accurate geometric characterization but offers clear opportunities to consider the role of simulation in the design process. The research outlined in this paper establishes a new design workflow that incorporates material properties, stitch structure, and varied knitted architecture to create a powerful new way to design and fabricate textiles.

INTRODUCTION

Textile fabrication has recently enjoyed increased interest across many academic fields and as a result, there have been efforts to better integrate these machines into normative digital fabrication workflows. Though the technologies of early CNC machining have often been compared to the mechanical automation in early textile punched-card systems, textiles offer a fundamentally different mode of design. In contrast to the geometric inputs employed in typical digital fabrication workflows, textiles are designed and manufactured topologically as a network of interconnected elements, and textile designs are represented digitally by a spatial sequence of machine actions that define a pattern of physical interaction between linear materials (Fig. 1). This presents a unique challenge when integrating textile-based instructions with 3d modeling tools that enable display and interaction with surface geometries.

While there are many promising research strategies that expand the way designers interact with textile machines, many of these tools limit design feedback related to the material, textural, and behavioral elements of fabric. In particular, industrial knitting machines are highly capable of complex three-dimensional surface topologies, but interfaces of existing software tools primarily represent the fabric in two dimensions, consisting of front and back fabric faces.

While there is no replacement for true tactile feedback from fabric samples, digital visualizations can provide significant insight within a fabrication process. This research establishes a design tool and simulation workflow centered around the three-dimensional aspects of knit fabric that result from knit structure, multi-material interaction, and multi-layered fabric construction.

BACKGROUND

CNC flatbed knitting is a highly automated industrial textile process unique in its ability to embed multiple materials and properties into a single fabric at a high resolution of control. In the design process for knitting, stitches refer to the individual loops, tucks, or floats formed by the machine's needles, while knit structure refers to the pattern in which the needle actions relate to one another (Spencer 2001). Knit fabric is challenging to characterize geometrically, and current design tools provide limited design feedback through visualization. Mechanical characterization is also difficult due to the enormous topological design space of materials and knit stitches, which are also subject to constant variation in environmental conditions (Kyosev and Renkens 2010).

Current Research Strategies

Responding to these challenges, knit textile researchers share several common goals. These include expanding the types of information that can be visualized and predicted before knitting as well as adapting the typical workflow of industrial textile fabrication for specific purposes often outside the norm of the apparel industry. Current research also focuses on innovation to the design and production workflow that can enable design iterations to become less time consuming and reliant on repeated physical prototyping (Baytar and Sanders 2020).

Current strategies can be broadly summarized in three different directions. First, in the field of computational fabrication and architecture, researchers seek to adapt existing knitting processes to more closely resemble on-demand workflows such as 3D printing or CNC machining (Dooner, Lourie, and Velderman 1974; Kaspar, Makatura, and Matusik 2019; Narayanan et al. 2018). Second, architects and designers employ novel strategies informing three-dimensional membranes through simulation of knit structure with a desire to connect digital form-finding with accurate prediction of physical results (Sabin 2013; Ahlquist, Erb, and Menges 2015; Popescu 2018; Ramsgaard Thomsen et al. 2019; Sinke Baranovskaya 2020). In a third strategy, textile researchers develop detailed topological representations of knit structures as a stepping stone to enable more accurate mechanical simulations in the future (Kyosev 2019; Kapllani et al. 2021).

Current Limitations

While the existing research represents significant advancements that expand the ways of interacting with a knitting machine, they are often limited by a narrow specificity of which types of patterns and structures can be addressed within each workflow. In these cases, functionality relies on limiting the rich variation that occurs because of knit structures and fiber behaviors. Furthermore, workflows that enable textile fabrication from geometric surface inputs completely ignore that the geometry of a textile is often a result of the behavior and interaction of materials rather than a fixed representation of a rigid shape.

While all these strategies offer significant contributions to expanding the current tools for textile fabrication, many existing visualization strategies – particularly in engineering and computer science – focus on attaining higher levels of simulation accuracy at the detriment of the size of design space addressed by the technique. Such methods limit the engagement with knit structure and material parameters to prioritize a geometric understanding of three-dimensional form. In contrast, this research focuses on insights afforded to the designer about the three-dimensional elements of the textile belonging to knit structure, material parameters, and multi-layer surface topologies. The research outlined in this paper reimagines these tradeoffs, creating a highly adaptable tool for assisting the designer with qualitative feedback while maximizing the potential of experimentation.

OBJECTIVES

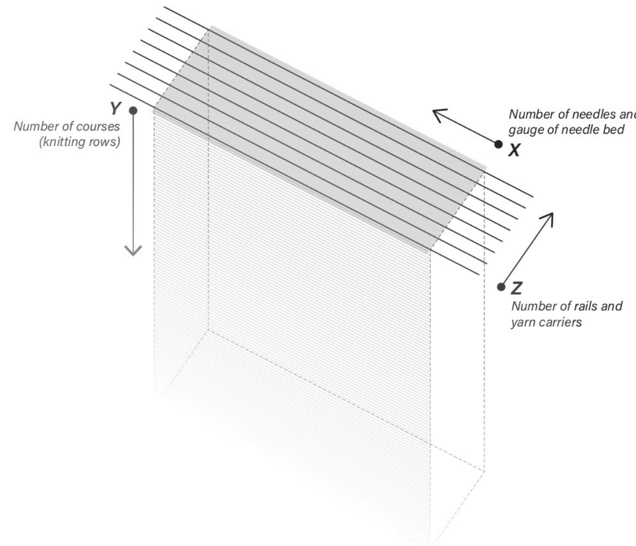
The primary objective of this research is to demonstrate a versatile workflow that generates design feedback about the basic interaction of materials and behavior of knit fabric while conveying different types of three-dimensional information. The workflow is intended to accept a wide range of input patterns and potential material combinations, while visualizing design outcomes. An additional goal is to employ the tool to speculate about how it can enable exploration of three-dimensional textile design.

METHOD

This research borrows from existing strategies for the visualization and simulation of knit fabric, and employs elements of stitch meshes, geometric models of knit loops, and existing particle-spring solvers (Ahlquist, Erb, and Menges 2015; Karmon et al. 2018; Yuksel et al. 2012; Wu, Swan, and Yuksel 2019; Narayanan et al. 2018; McKnelly 2015; McCann et al. 2016; Piker 2023). To achieve a new way to interact with three-dimensional information, these methods are adapted to apply to multi-layer fabric configurations that contain multiple materials and knit structures.

There are multiple ways to construct three-dimensional objects on a knitting machine. The elements of this workflow are organized by the idea of an abstract volumetric bounding box situated within the physical constraints of the machine. The x-axis belongs to the horizontal area of the needle bed, while the y-axis is generated in the vertical plane as the fabric exits the machine. The imaginary z-axis consists of the rails on which the yarn carriers move and is constrained by the number of yarns that can be sequenced from front to back (Figure 2).

The workflow begins with two inputs: a bitmap image representing an abstracted knitting pattern, and a library of stitch types that correspond to each pattern color. The image can be created in the existing design interface belonging to the knitting machine such as M1Plus or Create+ or developed in an image-editing software such as Photoshop ("M1PLUS" 2021; "Photoshop" 2023). To ensure that image files are transferable between each interface, a custom color palette containing sixty-four unique RGB values is established both as a STOLL palette (.scpx) file



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and a corresponding Adobe Creative Cloud library. Upon loading a pattern image into Grasshopper, a data structure is assigned to the workflow based on the order and presence of specific input colors. The color-ID data structure serves as the primary organizing strategy throughout the workflow. Input images can be drawn in the same resolution as the knitting file or assigned a higher or lower resolution at the start of the workflow. The adjustment enables the user to explore the effect of pattern and scale on the behavior of the fabric, and to manage the complexity of the simulation for large knitting files.

Next, a stitch library contains sets of information that geometrically describe the stitches in addition to settings and values that determine aspects of their behavior (Figure 3). The stitches consist of simple needle actions that are executed individually in addition to compound actions that occur as a sequence within one cell of the pattern representation. Examples of simple stitches include front and back knit stitches, while compound stitches include held stitches with floats or tucks as well as transfers of held stitches between needle beds. Each stitch contains a corresponding set of information: this includes its geometry, bounding box, connectivity in x, y, and z directions, and indication of presence and direction of asymmetry (Figure 4). For example, front stitches and back stitches both have fabric connectivity in the x and y direction while having no connectivity in the z axis (Figure 5).

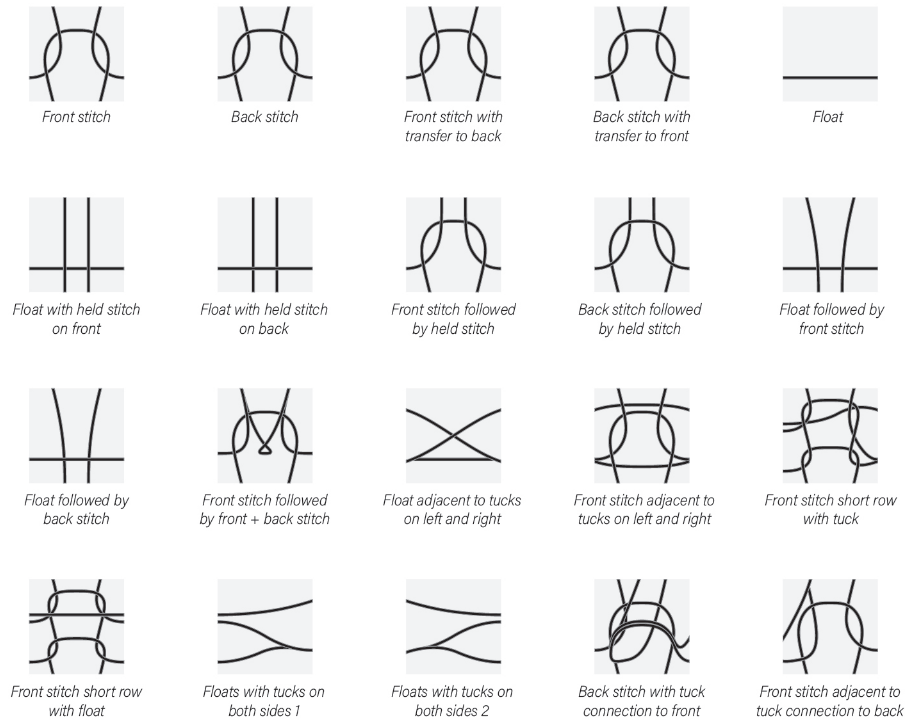
Basic knit stitches are asymmetrical on the front and back fabric face which results in an overall curling behavior which is approximated by assigning opposing forces assigned to each stitch type. Floats, which do not form any interconnected loops within the fabric, have only x connectivity; they are symmetrical and therefore do not

2 Abstract three-dimensional bounding box of a flatbed knitting machine

3 Examples of stitches in library

4 Constructing simulation behavior from stitch types

5 Determining basic stitch connectivity



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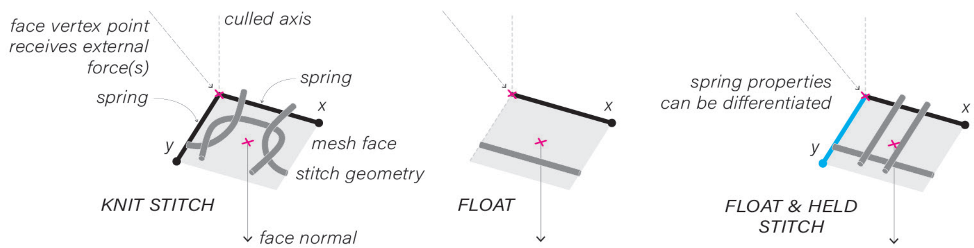

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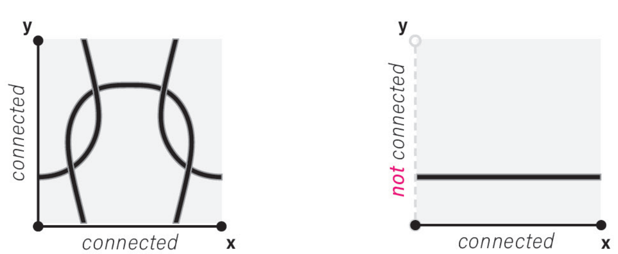
tend to move out of plane. Each stitch stored in the library is generic and does not contain any information related to the arrangement of stitches in any knitting pattern. As such, they function as building blocks that can be deployed into any visualization.

Next, the user determines which stitches from the library should correspond to each pattern color by assembling them into the same data structure as generated from the input file. Stitches can either be arranged to directly



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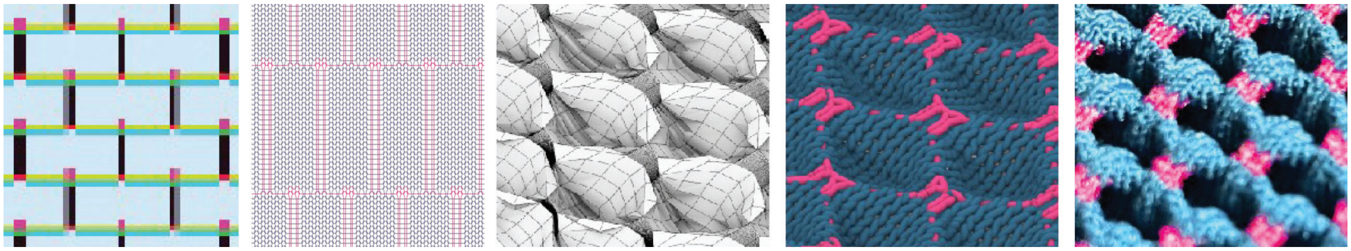
match an existing knitting program to be visualized, or in a different arrangement as a form of experimentation. The information representing the stitch's geometry is assembled along with the rest of the information that describes its other attributes.

A unitless rectilinear mesh is constructed in the same number of pixel-stitches as the input pattern, which is then scaled to approximate the physical dimensions of a hypothetical knit sample. The mesh is deconstructed according to the stitch information stored in the data tree, which is used to influence the strengths of Kangaroo solver goals within the Rhino and Grasshopper interface corresponding to edge lengths and normal forces (“Rhinoceros 3D” 2020; “Photoshop” 2023; “Kangaroo” 2023). After the mesh is deformed by the solver it is used to create a target surface for mapping the final visualization of stitch geometry. The stitch geometries are arranged on the original two-dimensional mesh according to the input pattern, then mapped to the three-dimensional target surface (Figure 6). At this



6 Elements of the design, visualization, and fabrication workflow. Right to left: 2D input pattern, unitless assembled stitch matrix, deformed mesh, stitches mapped to mesh, physical output from knitting machine

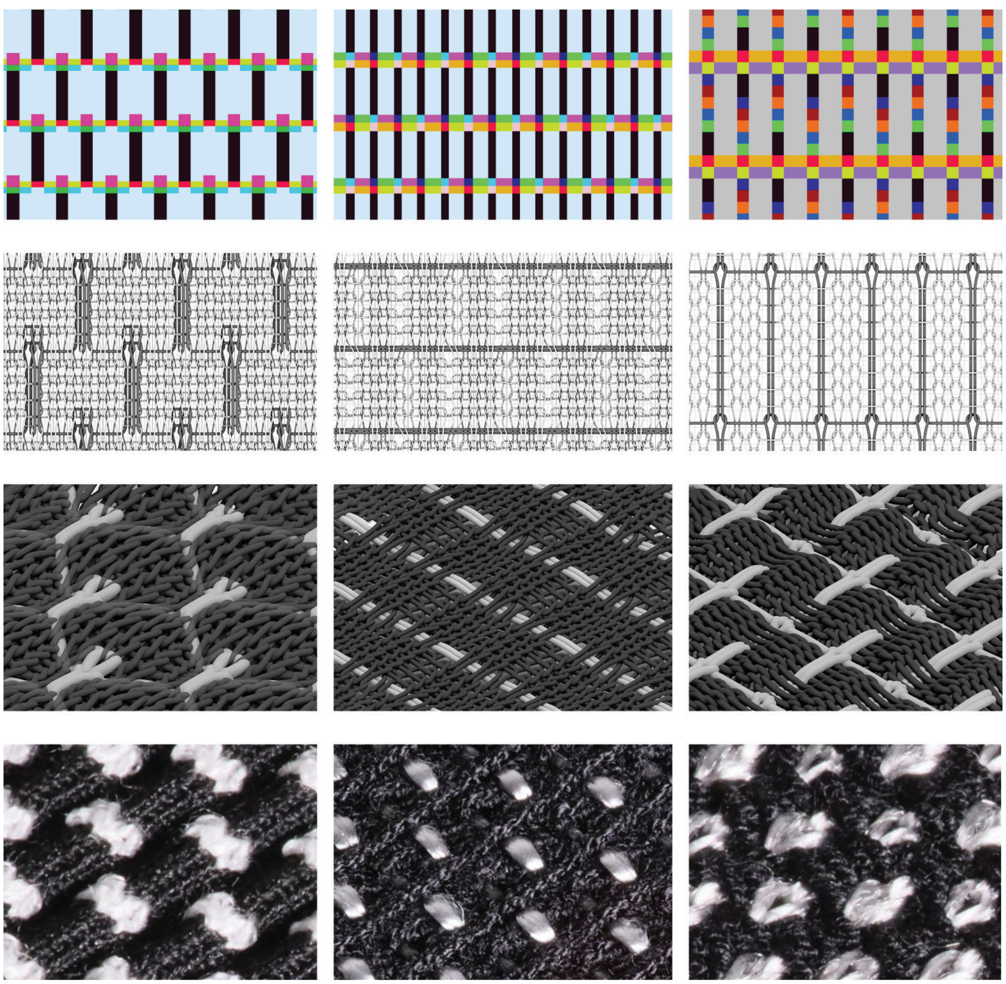
stage, the stitch geometries are organized into a new data structure according to the number of different yarns to be visualized.

RESULTS

The workflow was tested with a range of different input bitmaps and knitting files, exploring its ability to visualize different knit structures, design parameters, material interactions, and multi-layer fabric constructions. In the tested examples, the two-dimensional patterns employ two separate yarns, and the four-layer patterns consist of up to four yarns. The input patterns were initially designed as bitmap images in Photoshop, then output to the knitting machine software interface. In some cases, minor revisions were made to the pattern files to refine the knitting process.

Knit Structures

A first set of experiments demonstrates the capability of the workflow for visualizing simple knit structures as well as more complex knit structures that contain two yarns within the same pattern. The patterns employ a small set of different stitches from the stitch library configured in different ways to demonstrate variation in the resulting three-dimensional textures. (Figure 7)



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7 Examples of three knit structures visualized and fabricated with the workflow

Design Parameters

A second set of samples shows that the workflow can accommodate a design exploration through different pattern elements, each resulting in fabric variation. Here, a set of four input patterns that are used to generate visualizations and knit samples. The visualization is able to provide feedback about the potential textural differences that result from adjustment to the pattern proportion, which is not easily predictable in the absence of the simulation (Figure 8, Figure 9).

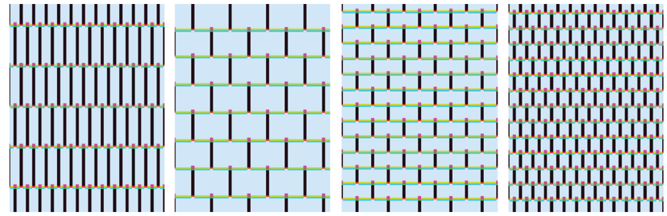
Material Variation

Next, a pair of samples explores the ability of the visualization to inform the designer about the effects of material properties. Fabric that is knitted with a combination of elastic and non-elastic fibers will gain part of its final geometry as result of the interaction between the two materials in combination with the choice of knit structure. Here, the same sample is visualized and knitted twice, with the first sample containing two elastic yarns, while the second sample is composed of one elastic and one non-elastic yarn. (Figure 10).

Multi-Layer Fabric

So far, each of the knit patterns has focused on single-layer fabrics, but the tool applies to multi-layer fabrics as well. Such fabric constructions are completely out of reach in current visualization tools, creating a significant opportunity for the application of this method. While the textural results of the knit structure are three dimensional, the connectivity pattern within the stitch library only contains information about the x and y axes.

The final set of knit patterns explores the ability of the tool to visualize multi-layer fabrics that can be viewed through



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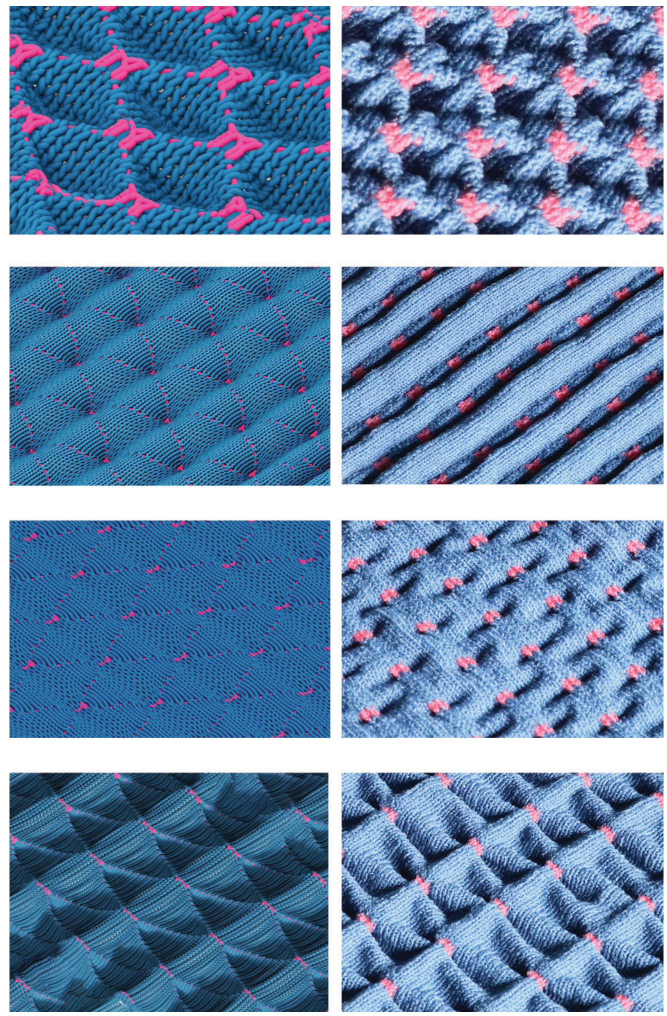

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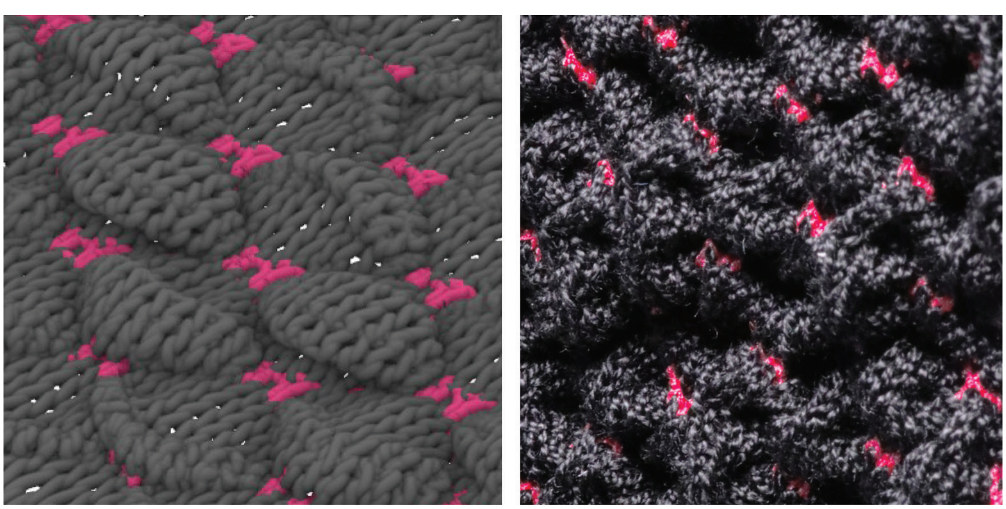

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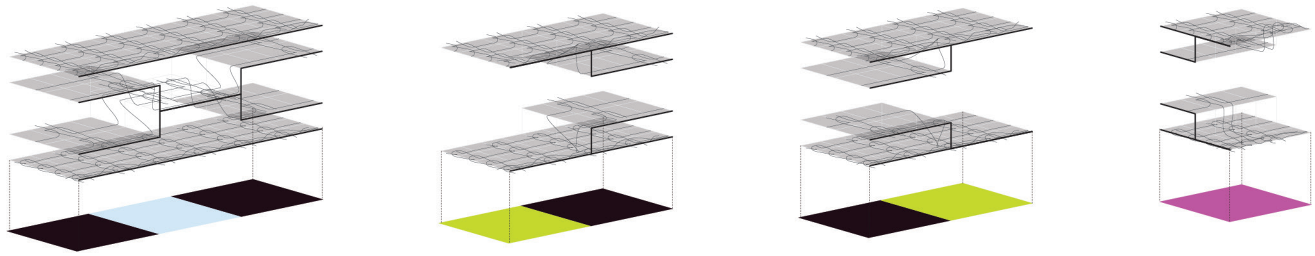
8 Input patterns with adjustments to design parameters such as scale, width, and height of pattern repetition

9 Simulation and fabrication outcomes for the four pattern variations

10 Exploration of material parameters using elastic (pink) and non-elastic (black) yarns in the main body of the fabric



11 Multi-layer surface and corresponding stitch topologies expanded from a two-dimensional pattern representation

the simulation of three-dimensional networks. These patterns utilize only the simplest stitches from the library but employ a more complex physical execution on the knitting machine, allowing four different surface topologies to be assembled from single stitches. The fabric consists of four separate knitting layers that can be attached or detached following four configurations which can be used individually or placed in a series (Figure 11, Figure 12, Figure 13).

Finally, the workflow is used to demonstrate the process of three-dimensional design iteration for multi-layer fabrics. A starting design is used as an initial input, and subsequently modified to test and improve the results of the input pattern. The final design is then created physically, showing potential for the digital tool to inform the iterative process (Figure 14, Figure 15, Figure 16).

DISCUSSION: LIMITATIONS AND NEXT STEPS

Overall, the workflow is successful in providing three-dimensional feedback in the absence of physical iteration. In some cases, visualization generated surprising results that closely mimicked conditions in physical samples. The results show that many elements of fabric behavior are embedded in stitch-level decisions, which can be leveraged with simple approximations to create effective visual feedback. The simulation tool had the most benefit for the design of multi-layer fabric since iteration in this case is particularly arduous and time consuming.

However, the weights of solver goals were finicky and required minor adjustments on multiple patterns, and the stitch library does not allow information stored within a one-layer stitch to separate into multiple layers as it deforms. While this is insignificant for many knit structures, it is a key behavior of some fabrics when multiple materials are combined. Finally, more work is needed to map stitch geometries to multi-layer fabrics. Next steps include expanding the stitch library, including additional types of fabric constructions, and considering how the tool can become more user friendly, either for a user with limited knowledge of knitting or for a user with limited knowledge of Rhino or Grasshopper.

CONCLUSION

Today's textile design and fabrication workflows are based on software tools that limit the exploration of surface topologies, stitch structure, and material engagement, severely constraining the design and application of textiles. Existing research in the field has attempted to create design tools that help interface with knitting machines, butthese tools lack the ability to model material behaviors of the textile, ignore material properties or the natural stretch of a knitted fabric, and exclude multi-layer and complex topologies that are possible on industrial knitting machines. The research outlined in this paper creates a new design workflow that incorporates material properties, stitch structure, precise knitted architecture as well as complex textile topologies to create a powerful new way to design and fabricate textiles.

With this work new opportunities arise to design and create multi-layered and multi-functional knitted structures where the aesthetics, functionality and behavioral change of the textile can be incorporated into the design process. This paper has outlined several knitted samples that have been tested and correlated to the software tool while also demonstrating variation in material property, stitch type, knitted architecture and differential topologies. Today's interface with industrial knitting machines is very much like the 0s and 1s of early computing where individual stitches are designed in a 2-dimensional array. The proposed design tool can now be used to help designers, architects and others to design the behavior and functionality of the textile at a high-level, while also interfacing closely with the machine to directly produce physical fabrics.

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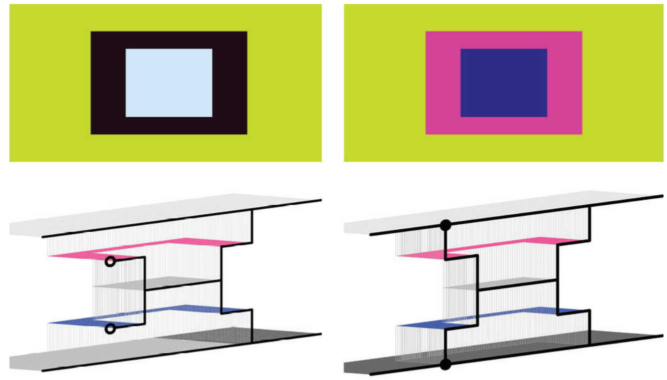

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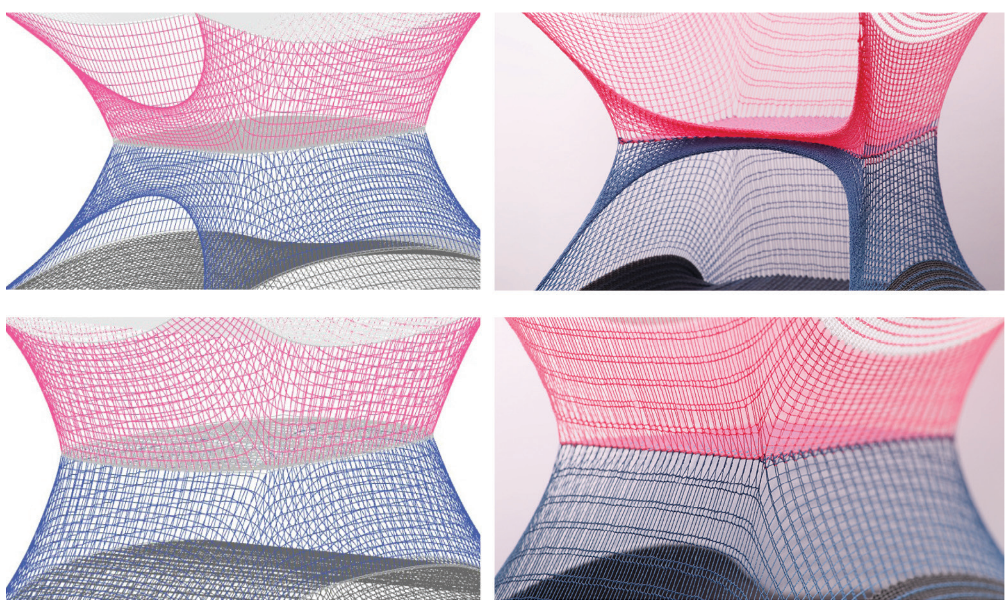

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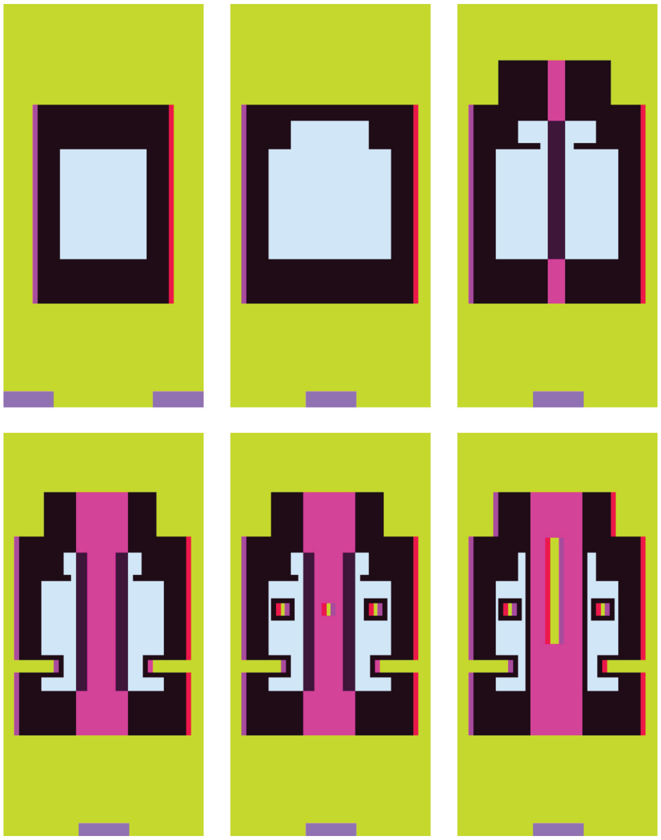
12 Knit patterns and meshes for two four-layer surface designs

13 Comparision of visualization and fabrication for both four-layer designs



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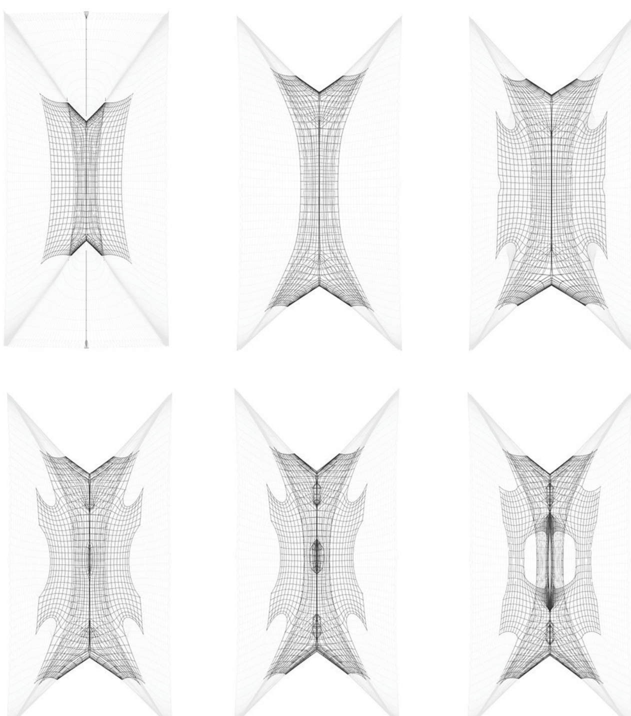

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14 Iteration in two-dimensional knit patterns drawn in Photoshop

15 Corresponding iteration of three-dimensional simulations

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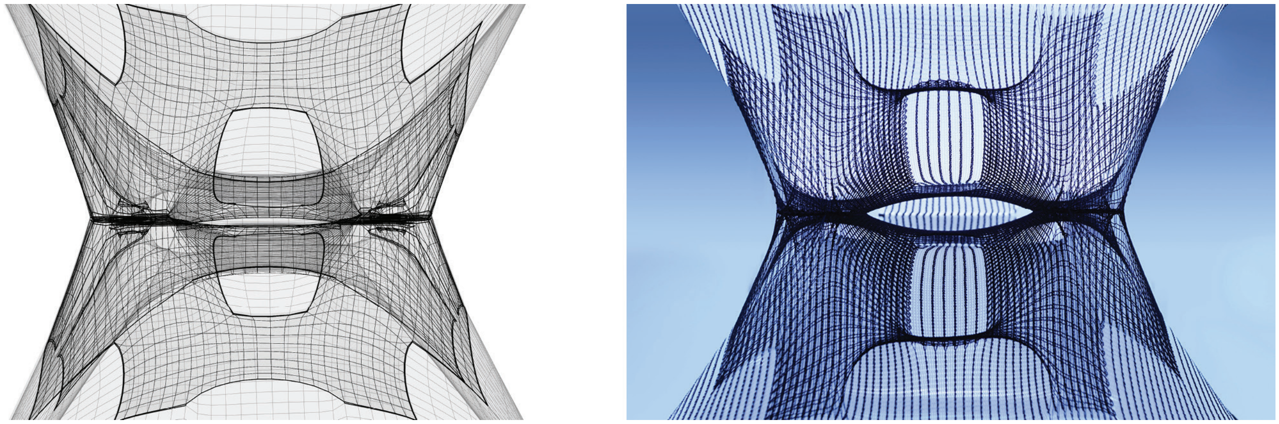

16 Final simulation and corresponding physical knit output

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