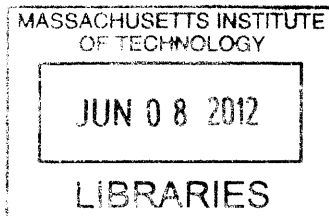


Knit Architecture: Low Tech Fabrication Techniques in Modern Design

thesis by Kimberly I. Mennel



ARCHIVES

June 2012

Submitted to the Department of Architecture in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Architecture at the Massachusetts Institute of Technology

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Abstract

This thesis aims to bring the handicraft of knitting into the realm of architecture as a low-tech means of fabrication in a world of high-tech design. This thesis attempts to break knitting down into its most essential components and use these to build a catalog of basic forms which can be generated through knitting. These basic forms will act as building blocks which can be combined to generate more complex geometries. It will be seen that virtually any form can be generated using knitting as a means of production. Furthermore, this thesis will explore the idea of composites in knitting. It contains a catalog of traditional knitting augmented by structural additives, and it speculates as to the repercussions of adding performative elements into the working fiber. Finally, this thesis addresses the approachability of knitting by exploring crowd-sourcing. It postulates that using knitting as a means of fabrication will allow people to actively intervene in their communities, giving them a way to construct solutions to problems in their own neighborhoods.

Thesis Advisor: Sarah Hirschman
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I'd also like to thank my thesis advisor, Sarah Hirschman for her constant energy and excitement regarding my project.

Finally, I'd like to thank my supportive family, especially my sister Pam, who got into knitting with me years ago, and who spent countless nights with me talking about this project and helping me to find my direction.

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0.0 Introduction

Bringing knitting into the world of architecture will allow for the architectural designer to capitalize on a few properties of knitting which are difficult to replicate through other means of production. For instance, knitting has very few geometric restraints. The process of knitting transforms an essentially one-dimensional medium, yarn, into a three-dimensional fabric by creating a series of knots which expand from the starting position in all three physical dimensions. This three-dimensional flexibility enables knitting to generate forms which are difficult to create with traditional construction materials and methods. Knitting can easily create instances of double curvature or even hyperbolic planes.

Agata Olek's Knitting is for Pus**** project [see figures 0.0.1 (a-e)], in which she yarn bombed an apartment and all of its contents, is a good example of the many forms that knit fabric can take. All surfaces within the apartment, including its living inhabitants were covered with knitting, resulting in an installation comprised of thousands of custom knit pieces perfectly conforming to the objects they



(a)



(c)



(d)



(b)



(e)

Figure 0.0.1 (a-e): Agata Olek's Knitting is for Pus****

Olek covered all surfaces within an apartment, including its living inhabitants with knit fabric. This project shows the versatility of knit fabric and its ability to generate any form which can be created via other means of production.

covered. Olek clearly demonstrated the power of knitting to generate form by covering everything from a flat table to a human body, knitting flat pieces and double curvature.

Additionally, several crafters are using knitting to illustrate complex mathematical forms which cannot be produced through other means. Mathematicians realized that knitting could be used to create the hyperbolic plane, a physical representation of “four-dimensional space.” This refers to the mathematical concept where a plane cannot be compressed into two dimensional space, but when folded, a straight line can be traced over its surface.

Margaret Wertheim, who is both a mathematician and a knitter, decided to capitalize on this property of knitting by organizing the Knit Coral Reef project [see figures 0.0.2 (a-e)] with her sister. Together with other knitters from the Institute for Figuring, they attempted to replicate a section of Australia’s Great Coral Reef with knitting, using hyperbolic forms to create the coral.

Wertheim enlisted several knitters to complete her Knit Coral Reef Project. This is possible because knitting is a highly approachable craft. It is simple to learn, as is illustrated by the sheer number of knitters in America. As of 2004, following the resurgence of knitting’s popularity in the early 2000’s, twenty-two percent of the American public had learned how to knit. A knowledge of knitting is easily passed down among friends and families, and there are countless books and videos available which attempt to teach knitting to the inexperienced.

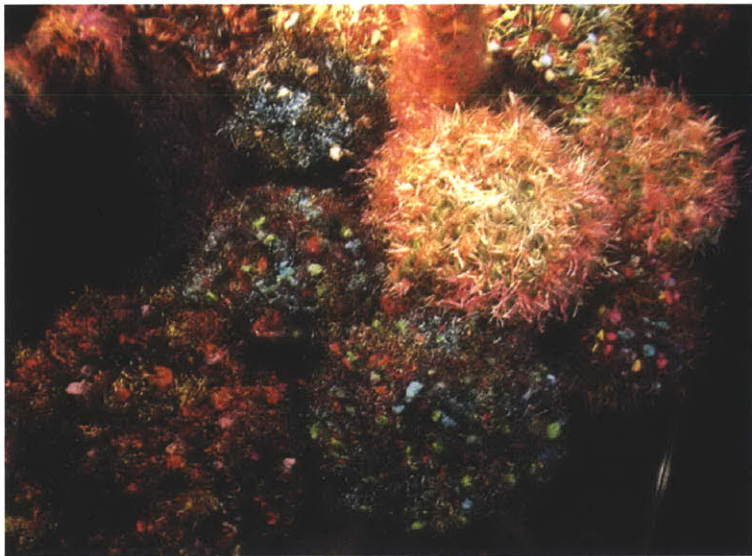
This idea of approachability has been much explored in recent years, with the emergence of the “craftivism” movement. Craftivism attempts to use craft to call



(a)



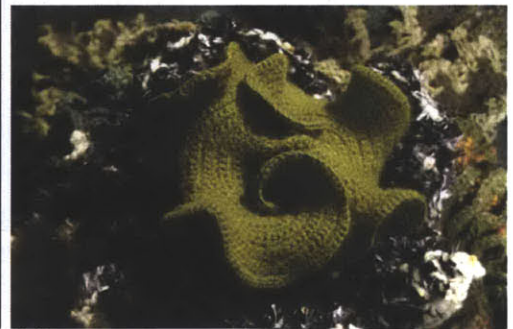
(c)



(b)



(d)



(e)

Figure 0.0.2 (a-e): Margaret Wertheim's *Knit Coral Reef*

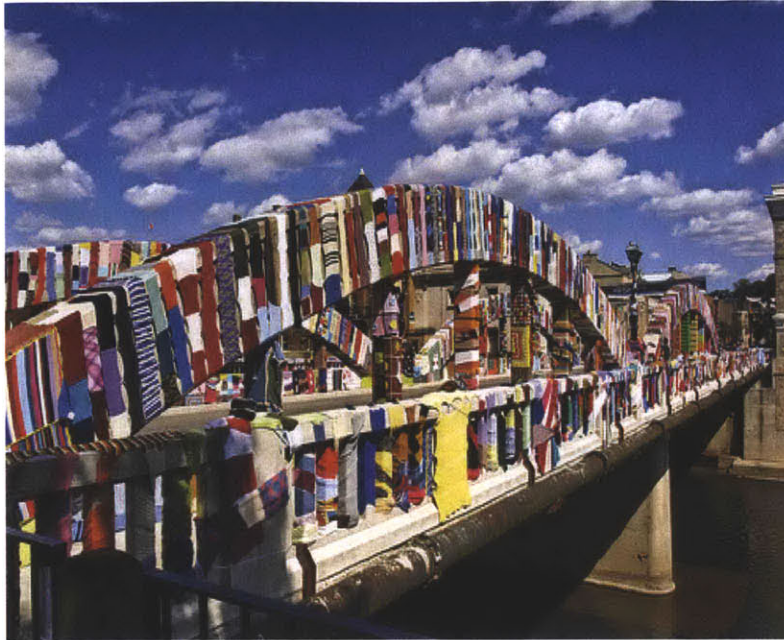
Wertheim united her mathematical and crafting background in the creation of her *Knit Coral Reef* project, in which she and a team of knitters from the Institute for Figuring replicated a section of Australia's Great Coral Reef. This project is produced primarily from knit hyperbolic forms.

attention to problems facing society, or even to attempt to solve them.

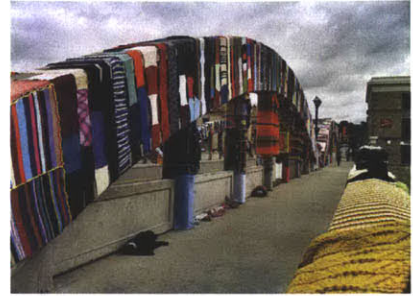
The Knit CamBRIDGE project [see figures 0.0.3 (a-c)], organized by Sue Sturdy, for instance, is an example of a project meant to raise awareness on an issue. Sturdy organized for a dilapidated bridge in Cambridge, England to be completely covered in knit fabric. The project was crowd-sourced, with Sturdy seeking help from knitters in and around her community. Each knitter who contributed to this project was encouraged to knit a flat panel, and these were then combined to cover the bridge in its entirety. This process generated community interest, and in this way, helped to raise money for the bridge's repair

The Skeinz Yarn Store of New Zealand took this idea of crowd-sourcing one step further with the Penguin Jumpers Project that they organized [see figures 0.0.4 (a-c)]. Hundreds of penguins, along with other marine life, had been affected by an oil spill off the coast of New Zealand, and Skeinz decided to take action to help these animals. It created a pattern for a sweater for penguins, which, when worn by the affected birds, would prevent them from eating the oil off of their feathers until they were healthy enough to be cleaned properly. This pattern was digitally distributed. There was a huge response to the project. Word spread, and eventually, there was even major network news coverage of the campaign. The project was widespread, and Skeinz received sweaters from every continent except Antarctica, making this one of the most successful crowd-sourced crafting projects to date.

While the versatility and approachability of knitting makes it a potentially powerful means of construction, the addition of structural or functional elements into the fiber could make it even more powerful. By incorporating wire, for instance, the knit



(a)



(b)



(c)

Figure 0.0.3 (a-c): Sue Sturdys Knit CamBRIDGE

This project is an example of yarnbombing on a massive scale. An entire community was encouraged to knit pieces to cover a bridge which was in need of repair, drawing attention to it and thus earning money to fix the problem.



(a)



(b)



(c)

Figure 0.0.4 (a-c): The Penguin Jumpers Project by Skeinz Yarn Store of New Zealand

Skeinz mobilized the worldwide knitting public, by digitally distributing a pattern for a penguin sweater. They received contributions from every continent except Antarctica.

structure can become a means of redirecting electricity, and if energy harvesting elements are also incorporated, the knit object can become a completely self-sufficient electrical object.

This process becomes a good way to get the public involved in construction in their communities. Theoretically, they can solve problems like underlit streets in their neighborhoods by knitting street lamps, or they could erect temporary structures for events or as a means of disaster relief [see figure 0.0.5].

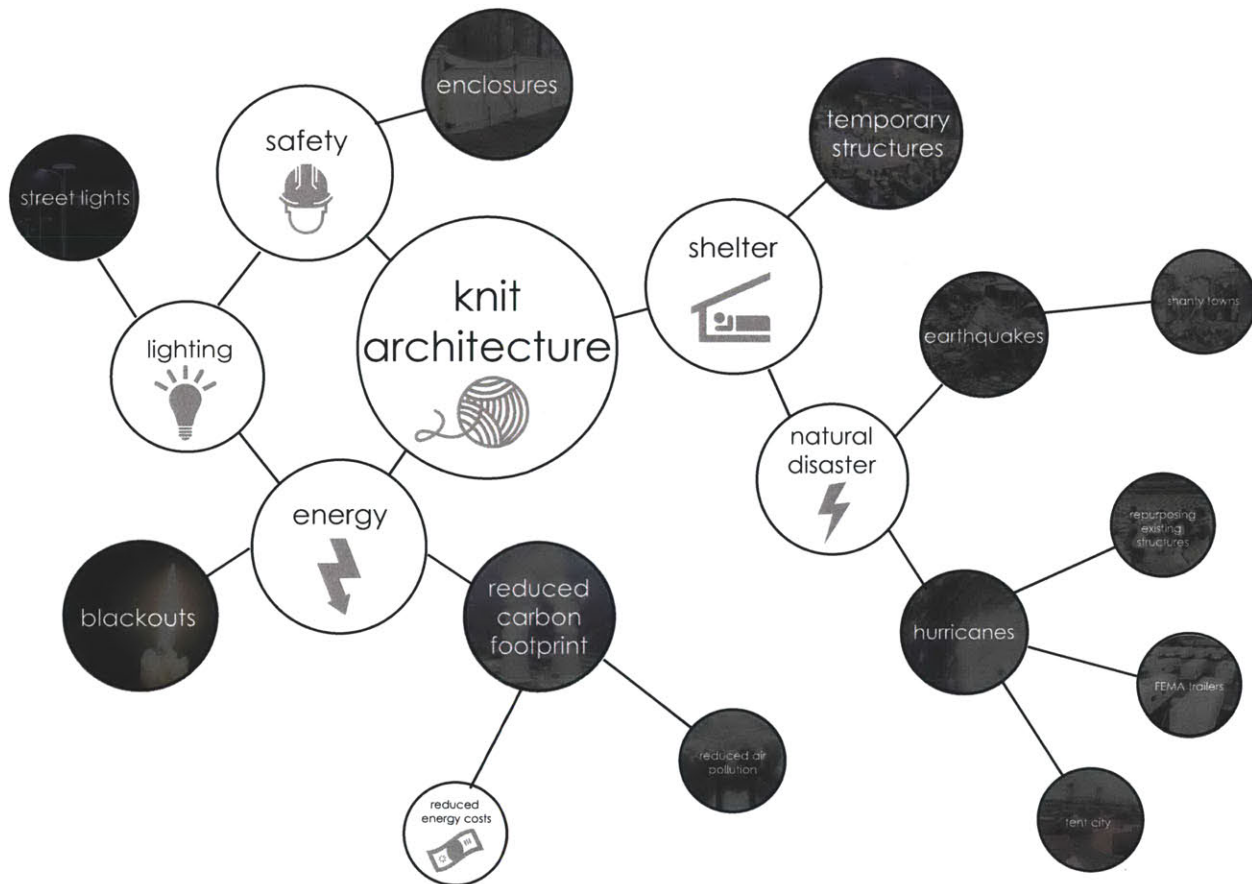


Figure 0.0.5: Potentials of a Knit Architecture

This diagram speculates about the types of problems which a knit architecture could solve if implemented. By placing the power of construction in the hands of a the community, those individuals are allowed to become architectural problem-solvers. By incorporating performative elements into the working yarn, a knitter could create a functioning street lamp to combat the problem of underlit streets, or a temporary shelter as means of disaster relief

Virtually any form can be generated through knitting by breaking it down into its component parts [see figure 0.0.6]. The resultant knit object can be knit by anyone with a basic understanding of the craft. No special tools or machinery are needed to create complex curvature. The fiber is adaptable, and with the addition of structural or performative elements, the piece can become highly specialized and self-contained. Knitting has the potential to become a really innovative means of construction and fabrication.

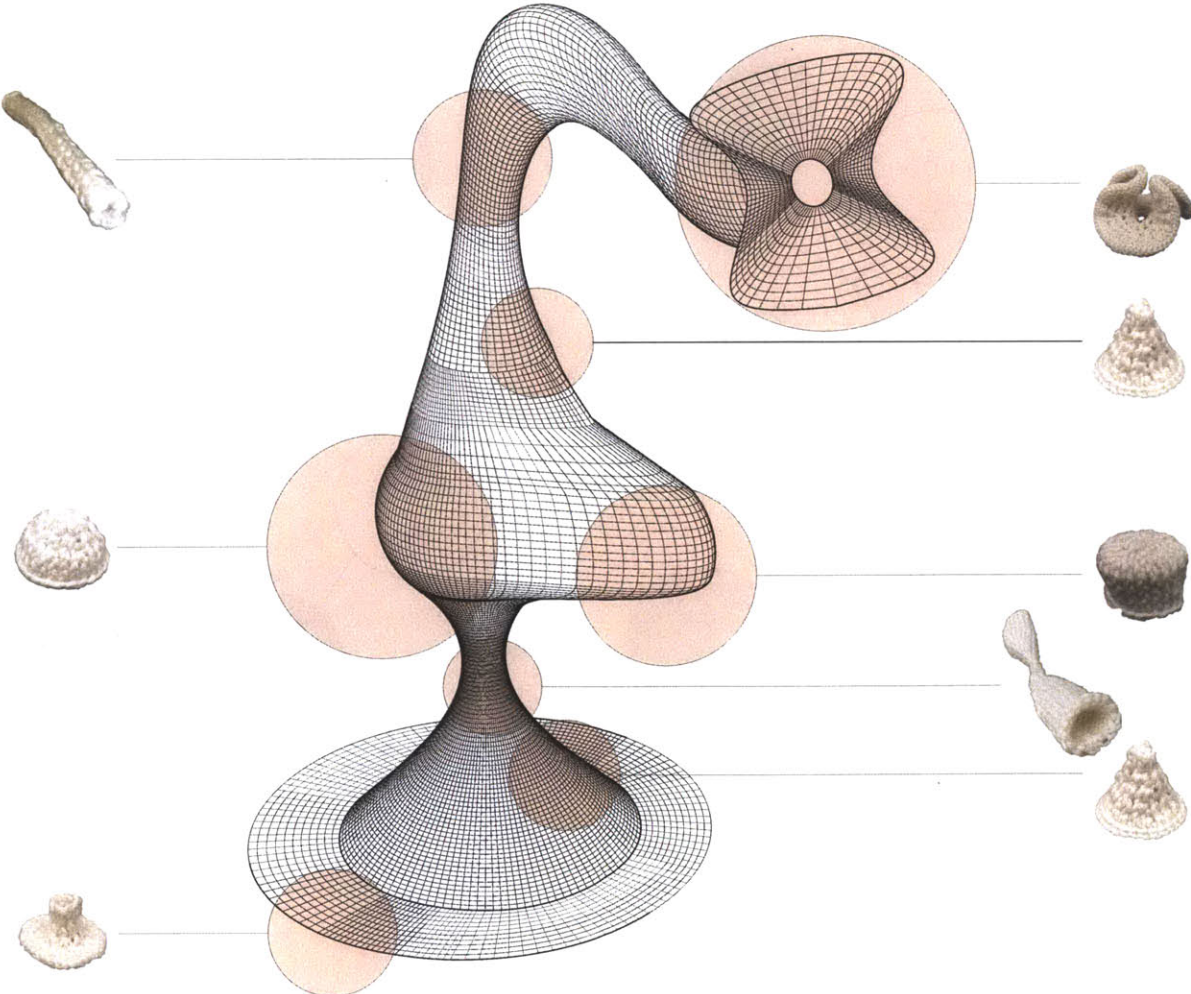


Figure 0.0.6: Anatomy of a Knit Object

This diagram shows that even the most complex shapes can be broken down into the easily understandable parts, like those shown here, which will reappear in section 2.0.

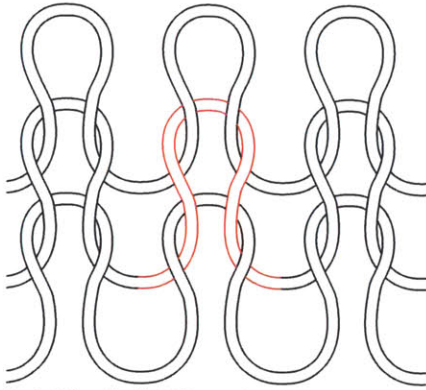
1.0 Essentials of Knitting

To make knitting more approachable to an architect without a knitting background, it becomes necessary to distill knitting into its most essential elements. Knit stitches fall into three general categories: static stitches, increases, and decreases.

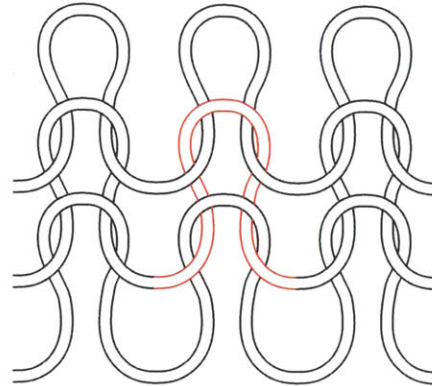
Static stitches do not alter the density of stitches in the knit fabric. Two static stitches will be used throughout this project: the knit stitch [see figure 1.0.1 (a)], and the purl stitch [see figure 1.0.1 (b)]. These two stitches are the most basic stitches in knitting, and they form the basis for most knitting patterns.

Increases add to the density of stitches in the knit fabric. Two increase stitches will be used: the bar increase [see figure 1.0.2 (a)], which forms a solid fabric, and the yarn over [see figure 1.0.2 (b)], which leaves a hole in the knitting and will be useful in creating connection details.

Decreases reduce the density of stitches in the knit fabric. One decrease stitch will be used: knit two together [see figure 1.0.3 (a)]. This generates a solid fabric.



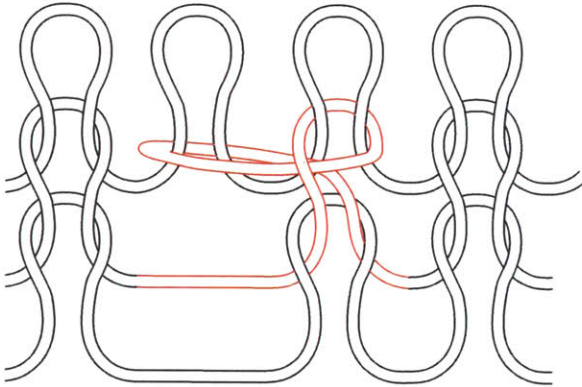
(a) The Knit Stitch (K)



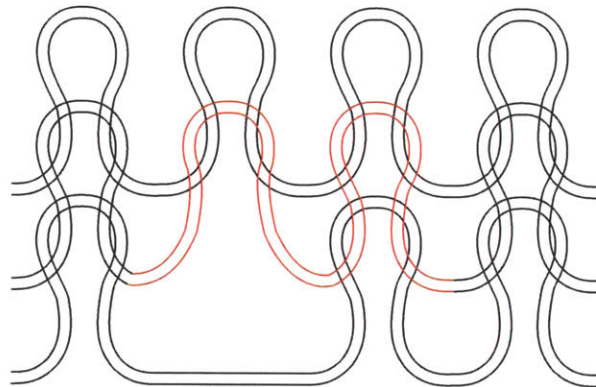
(b) The Purl Stitch (P)

Figure 1.0.1 (a-b): Static Stitches

These two stitches are the most basic stitches in knitting. They do not alter the shape of the fabric being constructed. (see Appendix A to learn how these stitches are made)



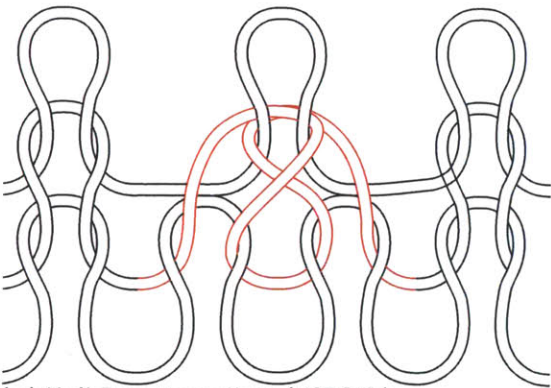
(a) Bar Increase (KFB)



(b) Yarn Over (YO)

Figure 1.0.2 (a-b): Increase Stitches

These are two basic increase stitches which appear in many knitting patterns. The bar increase is a dense increase, and it generates fabric without any holes. The yarn over stitch is the basic lacework stitch, and when used, it leaves a hole in the work. (see Appendix A to learn how these stitches are made)



(a) Knit Two Together (K2TOG)

Figure 1.0.2 (a): Decrease Stitches

Knit two together is a basic decrease used in many knitting patterns. It generates a dense fabric with no holes. (see Appendix A to learn how this stitch is made)

2.0 Catalog of Knit Forms

Traditional knitting patterns contain a large amount of information in only a few lines of text. While these patterns can be understood by the craft knitter, they cannot be understood by the architect who has no knitting background. To make these patterns intelligible to the architect, it is necessary to create a visual representation of this information. Since the form of a knit piece is directly related to the change of density of stitches around the area in question, it follows that the diagram of a knitting pattern should clearly demonstrate the density of stitches in any one given area. Tree diagrams are able to accomplish this goal. In the diagrams which follow, all static stitches are represented by a straight, unimpeded line. These stitches do not change the density of stitches in the knit fabric. All increases and decreases, stitches which do alter density of stitches in the fabric, are represented by a V-shaped branching node. Increases are shown as a “V” with the prongs facing the direction of expansion, and decreases are shown as a “V” with the point facing the direction of expansion. Each stitch carries with it a label indicating which type of increase, static stitch, or decrease is to be used at

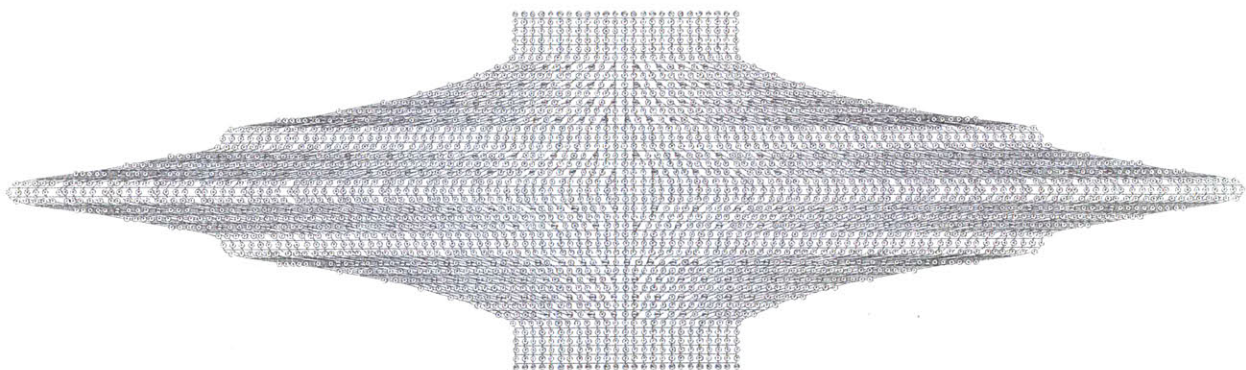
that point in the knitting.

Knit forms fall into four general families, which will be explored in the following sections: flatwork pieces, tube and plate forms, rotated curves, and hyperbolic forms. More complex geometries can be formed by the connection of pieces from these families

2.1 Flatwork Pieces

Flatwork knitting is what comes to mind for most people when they think of knitting. This is the type of knitting which is done on two needles, where the knitting is turned over at the end of each row. Flatwork knitting is very effective for creating large, flat panels. However, it is difficult to create volume without using seams to join pieces together. Without seamwork, a knitter can create amorphous bulging shapes, like those shown in figures 2.1.1 (a-e) and 2.1.2 (a-e), but can do little to create more regular forms.

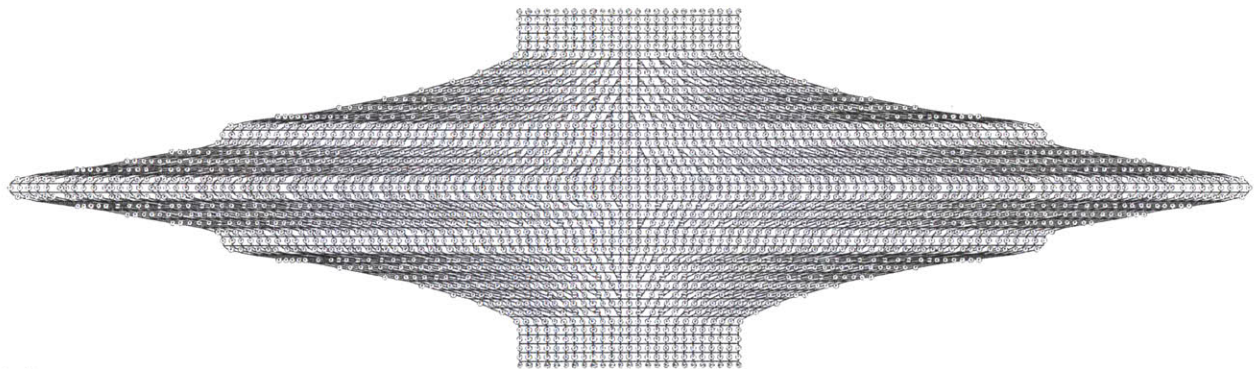
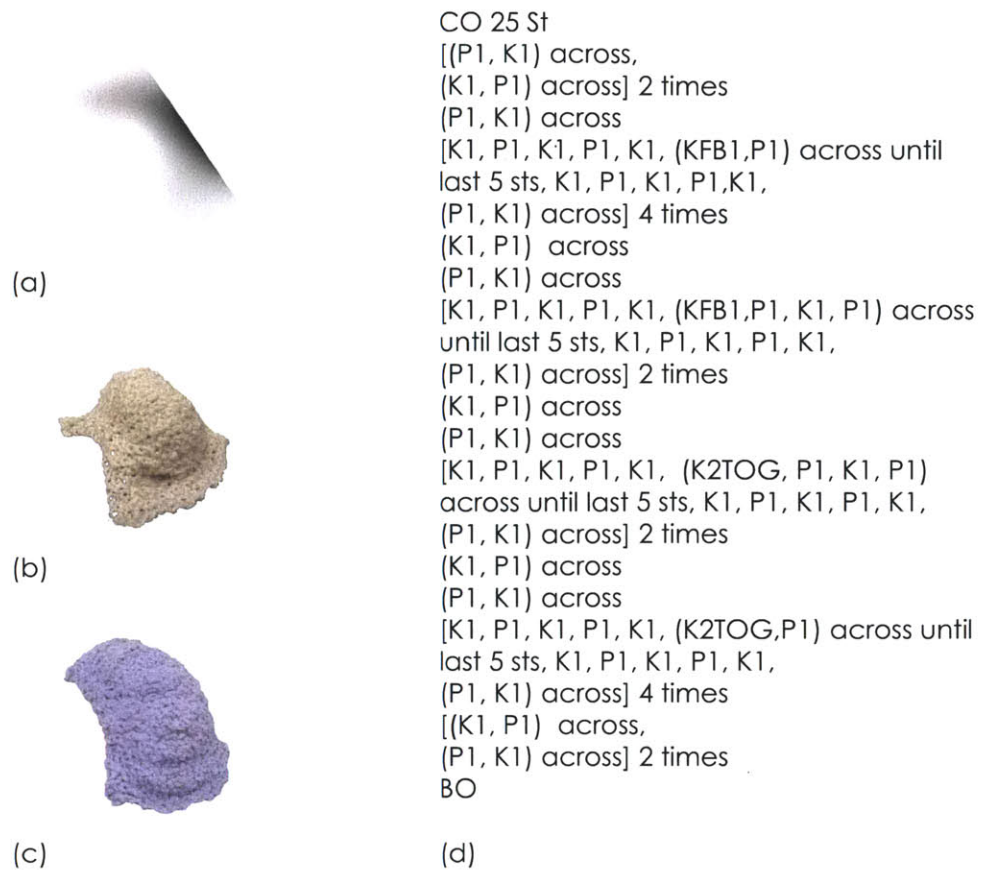
In order to create more rigid geometries, one must move away from flatwork knitting and instead begin knitting in the round. This technique generates radial pieces which possess an inherent volume. Rather than using two traditional straight needles, as in flatwork knitting, knitting in the round uses several double pointed needles. The piece is worked continuously, and it is never turned. The other three families of knitting listed above are generated through radial knitting. The different forms come from varying the density of knit stitches.



(e)

Figure 2.1.1 (a-e): Shaped Stockinette Stitch Flatwork Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using plaster (see section 3.0)
- (d) traditional knitting pattern
- (e) logic tree representation of knitting pattern



(e)

Figure 2.1.2 (a-e): Shaped Seed Stitch Flatwork Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using rubber (see section 3.0)
- (d) traditional knitting pattern
- (e) logic tree representation of knitting pattern

2.2 Tube and Plate Forms

In the first of the families, the tube and plate forms, increasing is restricted to either the vertical or the radial direction. This results in pieces which consist of rigid tubes and flat plates [see figures 2.2.1 (a-d), 2.2.2 (a-d), 2.2.3 (a-d), and 2.2.4 (a-d)].

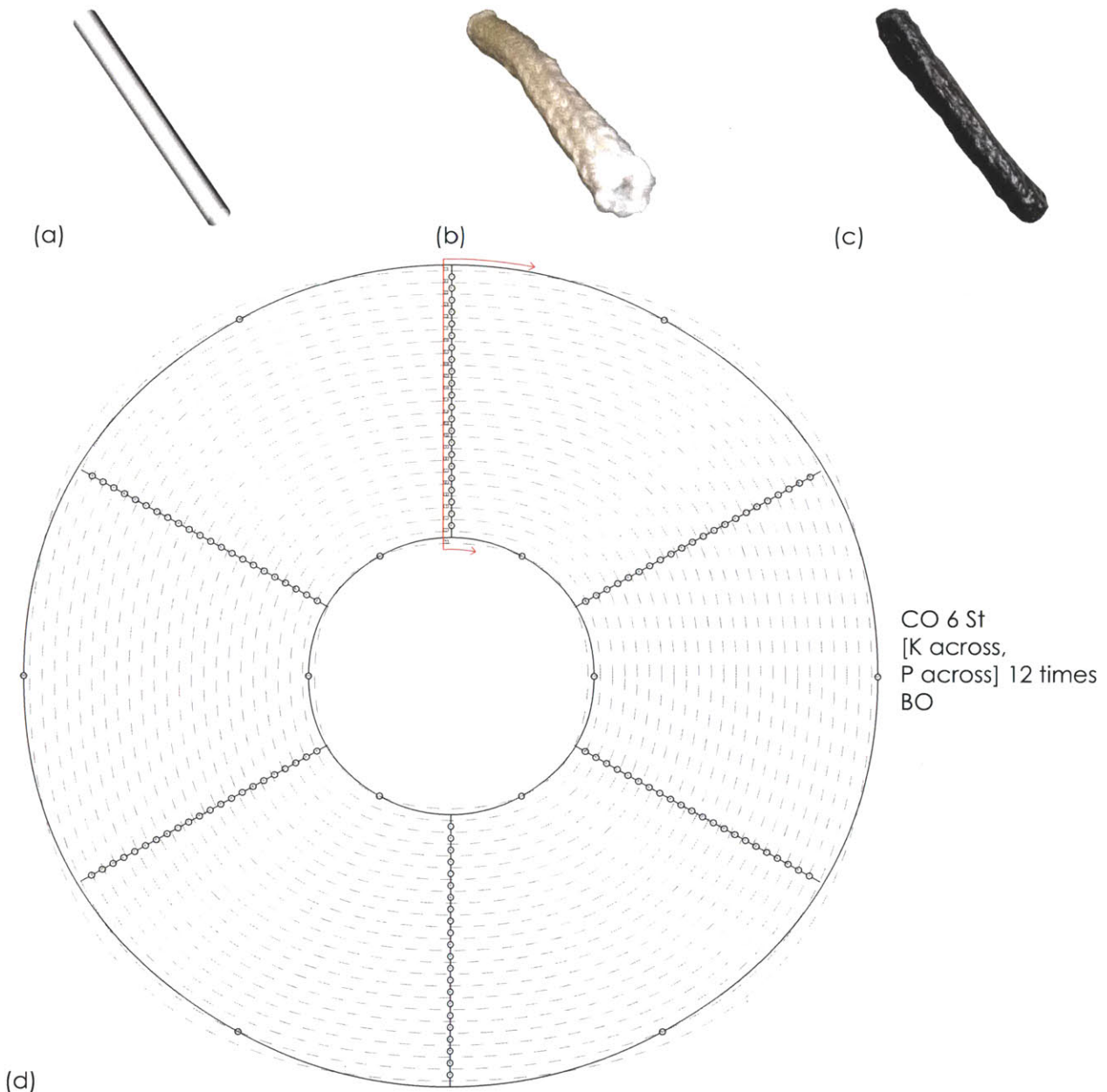


Figure 2.2.1 (a-d): Tube Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using plastic (see section 3.0)
- (d) traditional knitting pattern and the logic tree representation of knitting pattern

Tubes are constructed by using only static stitches as you progress through the work. To produce a plate, you must alternate between increase and static rows. To prevent the plate from expanding into the vertical direction, you must begin

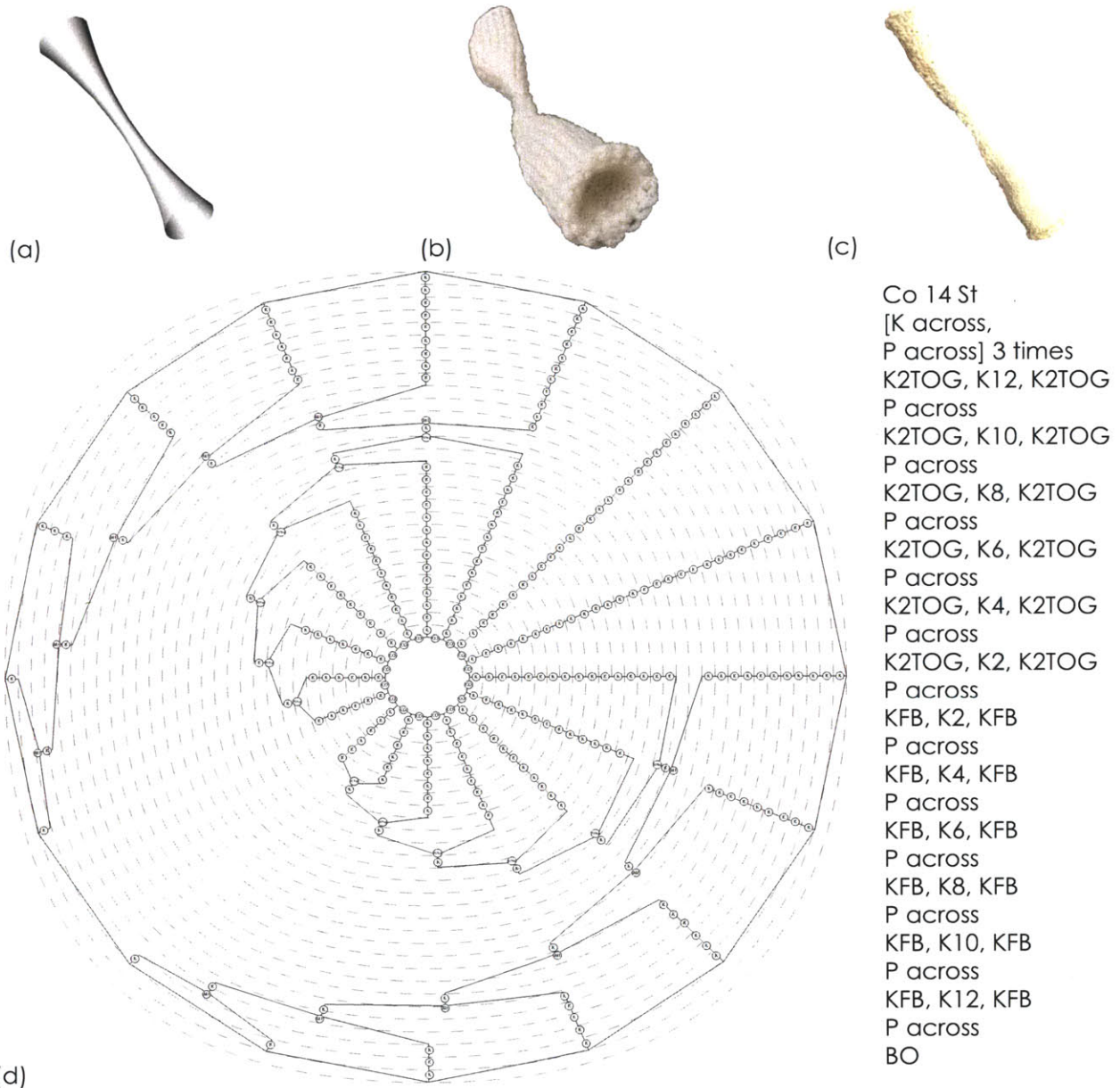


Figure 2.2.2 (a-d): Constricting Tube Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using latex (see section 3.0)
- (d) traditional knitting pattern and the logic tree representation of knitting pattern

with a relatively dense increase pattern on increase rows, and as you move out through the work, the percentage of increases per row must decrease, generally, in proportion to an inverse square law.

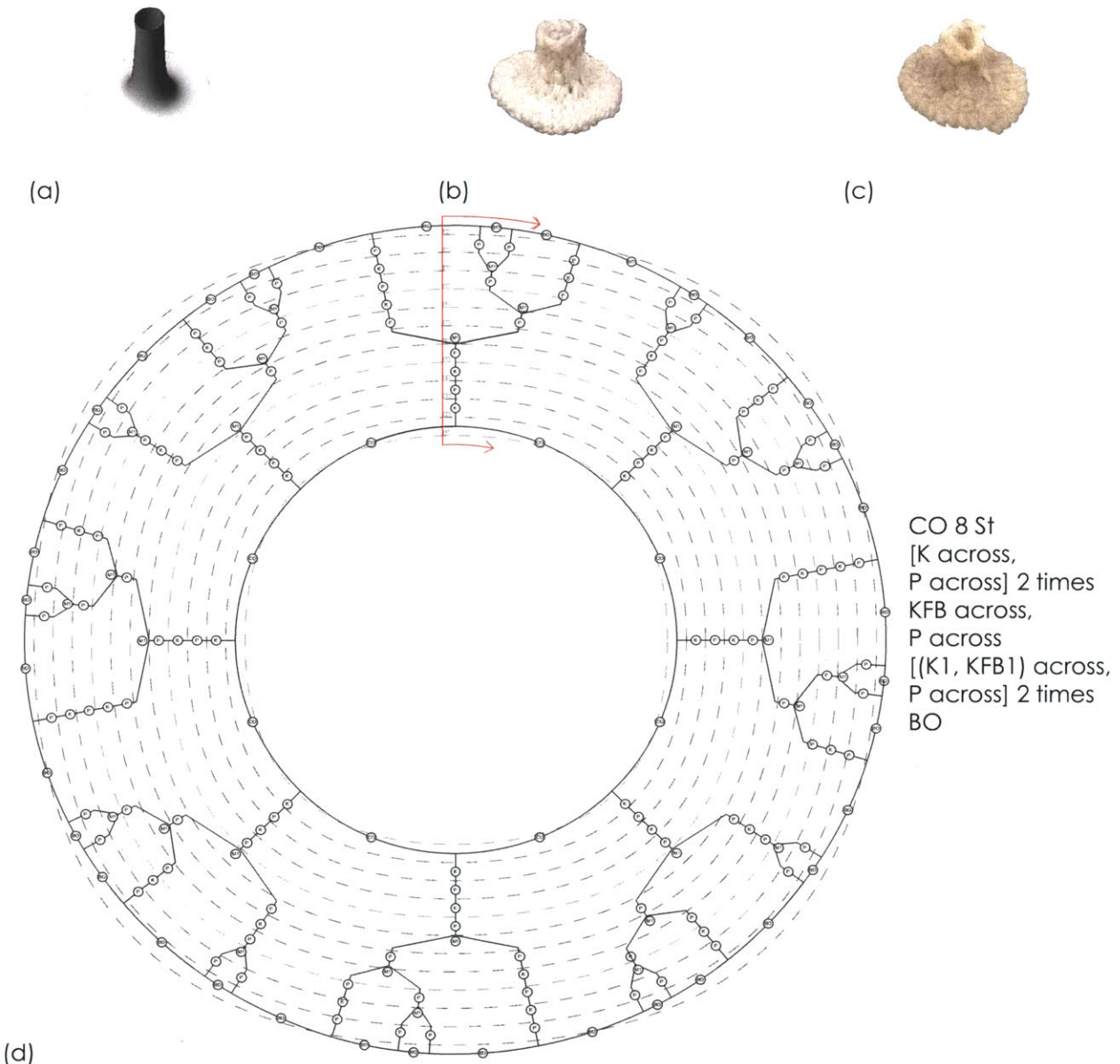


Figure 2.2.3 (a-d): Tube and Plate Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using resin (see section 3.0)
- (d) traditional knitting pattern and the logic tree representation of knitting pattern

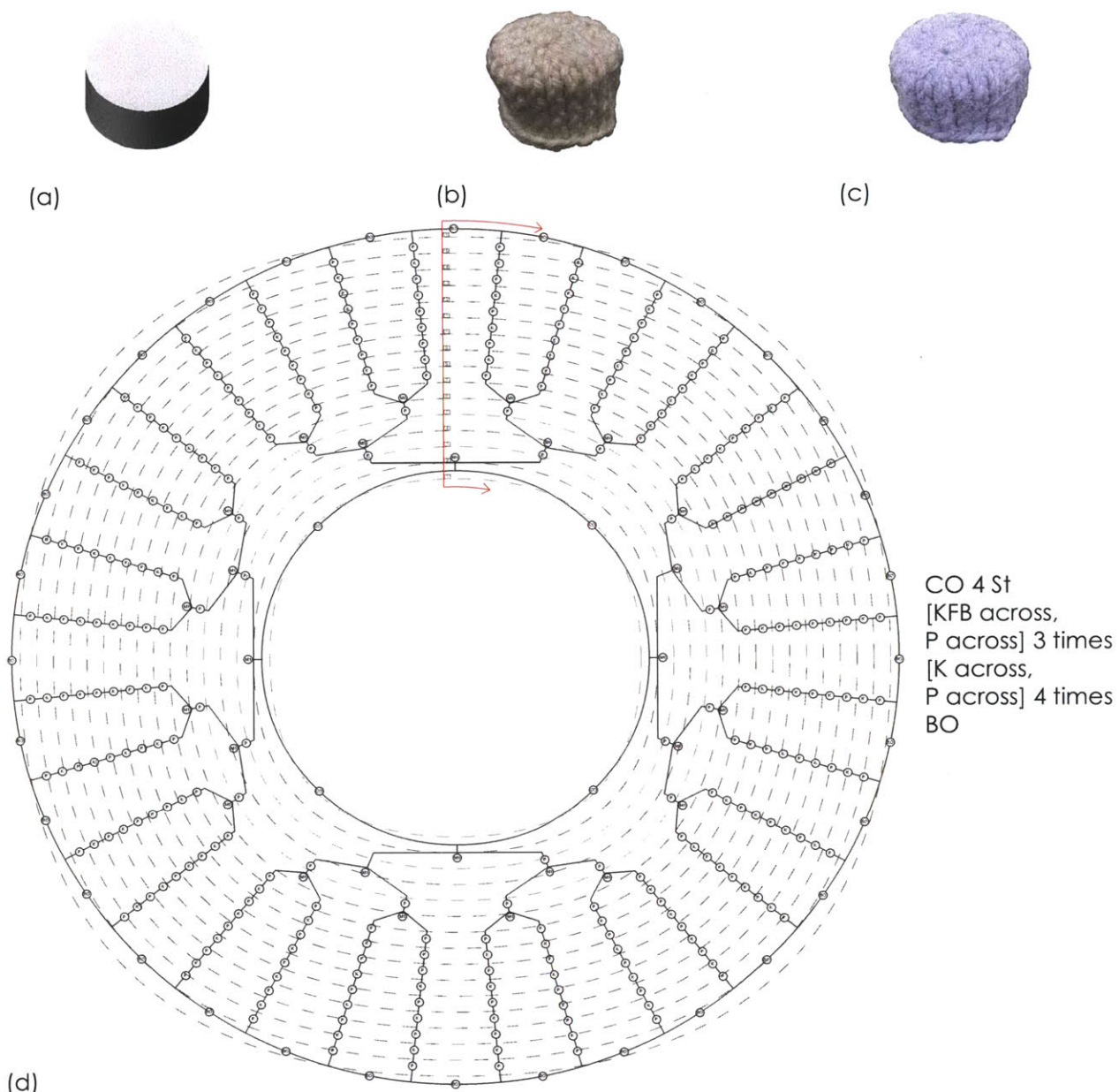


Figure 2.2.4 (a-d): Semi-Cylinder Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using rubber (see section 3.0)
- (d) traditional knitting pattern and the logic tree representation of knitting pattern

2.3 Rotated Curves

The second family of forms, the rotated curves, expand in both the vertical and radial directions simultaneously. This is the family of forms which generates double curvature. To knit a form such as a cone [see figures 2.3.1 (a-d) and 2.3.2 (a-d)],

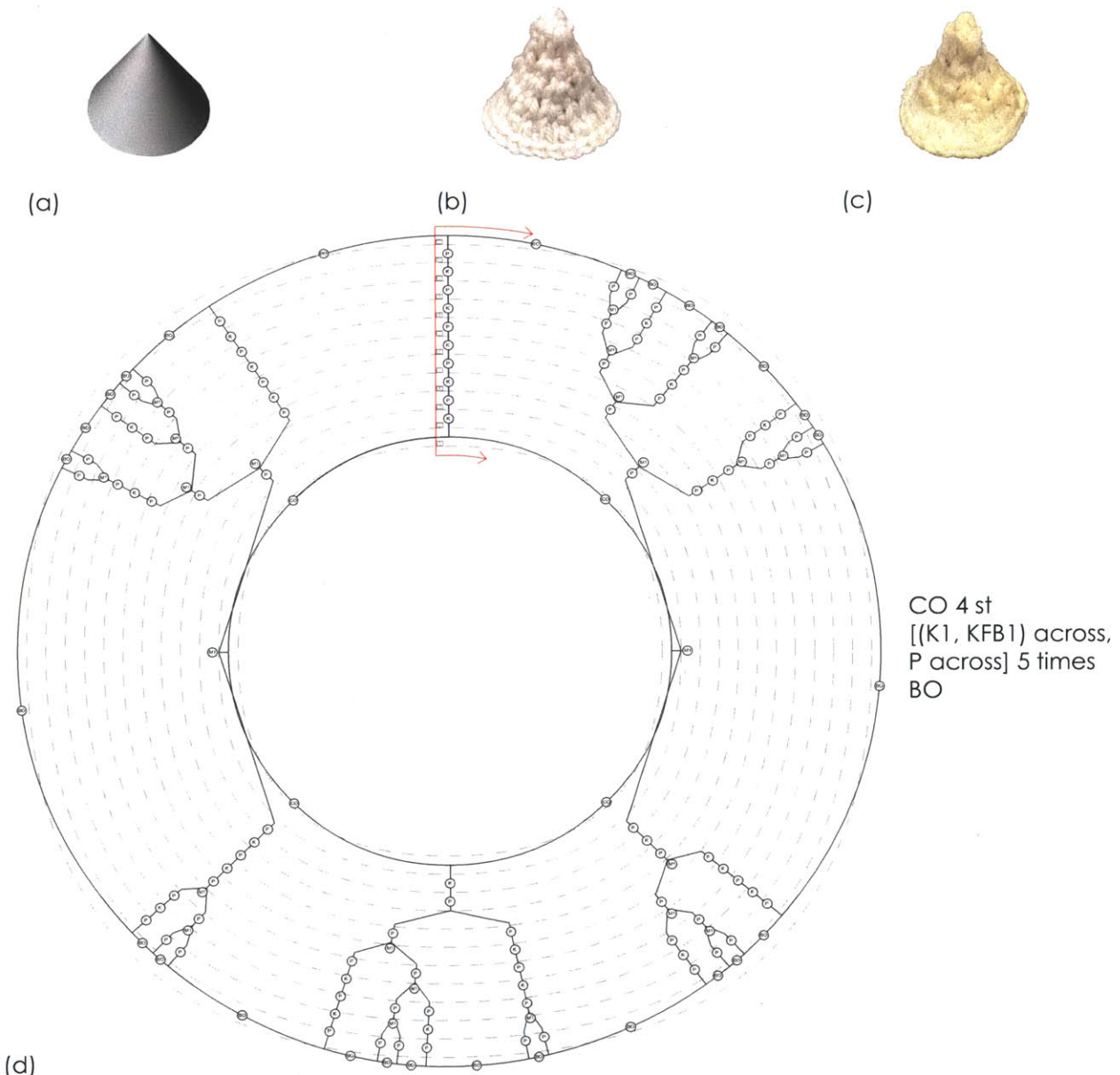


Figure 2.3.1 (a-d): Cone Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using latex (see section 3.0)
- (d) traditional knitting pattern and the logic tree representation of knitting pattern

where the profile of the rotated curve is linear, one must alternate increasing and static rows. Again, one must begin with a relatively dense increase pattern on increase rows, but this time, as the knitting progresses outward, the percentage of increases per row must decrease at a constant rate, not a rate which is in

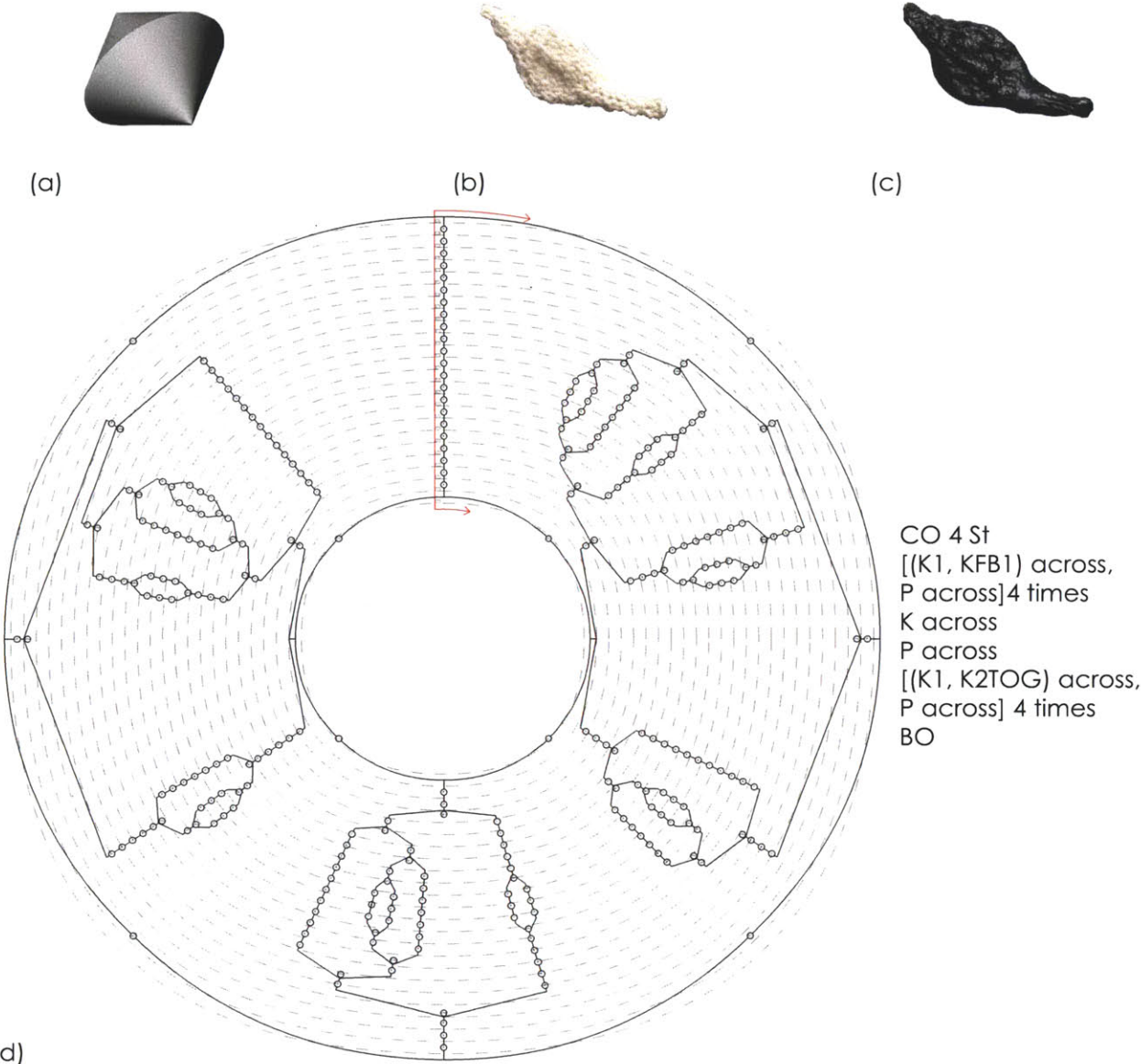


Figure 2.3.2 (a-d): Double Cone Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using plastic (see section 3.0)
- (d) traditional knitting pattern and the logic tree representation of knitting pattern

proportion to an inverse square law. To create a rotated curve with a curved profile, like the forms shown in figures 2.3.3 (a-d), 2.3.4 (a-d), and 2.3.5 (a-d), One must initially knit all increase rows. After about four to six rows of increases, one

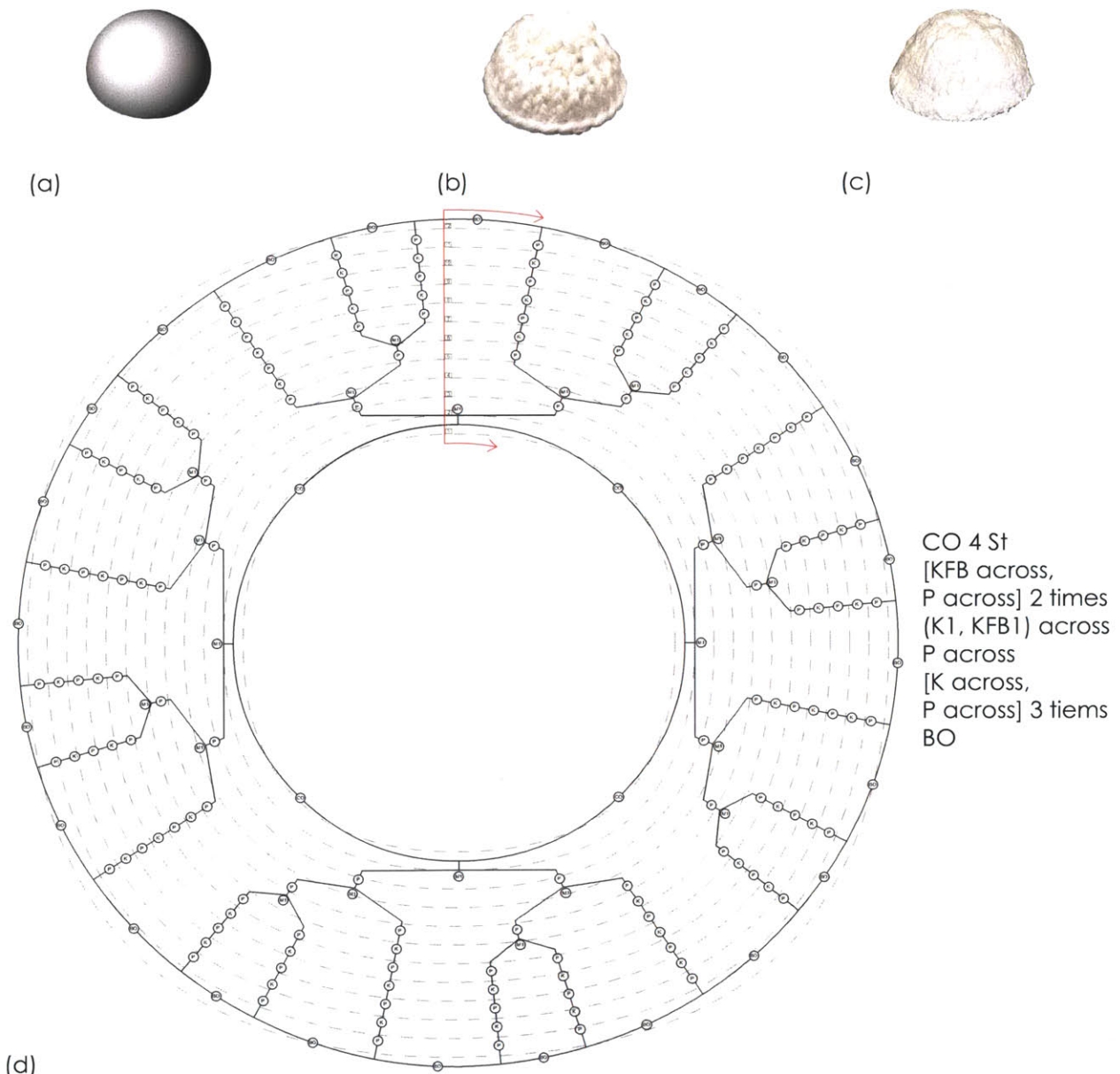


Figure 2.3.3 (a-d): Dome Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using plaster (see section 3.0)
- (d) traditional knitting pattern and the logic tree representation of knitting pattern

can begin to alternate between increase and static rows. The increase pattern in the increase rows will decrease as the work progresses radially outward from the starting position, but it will decrease at a rate which is not constant or constrained

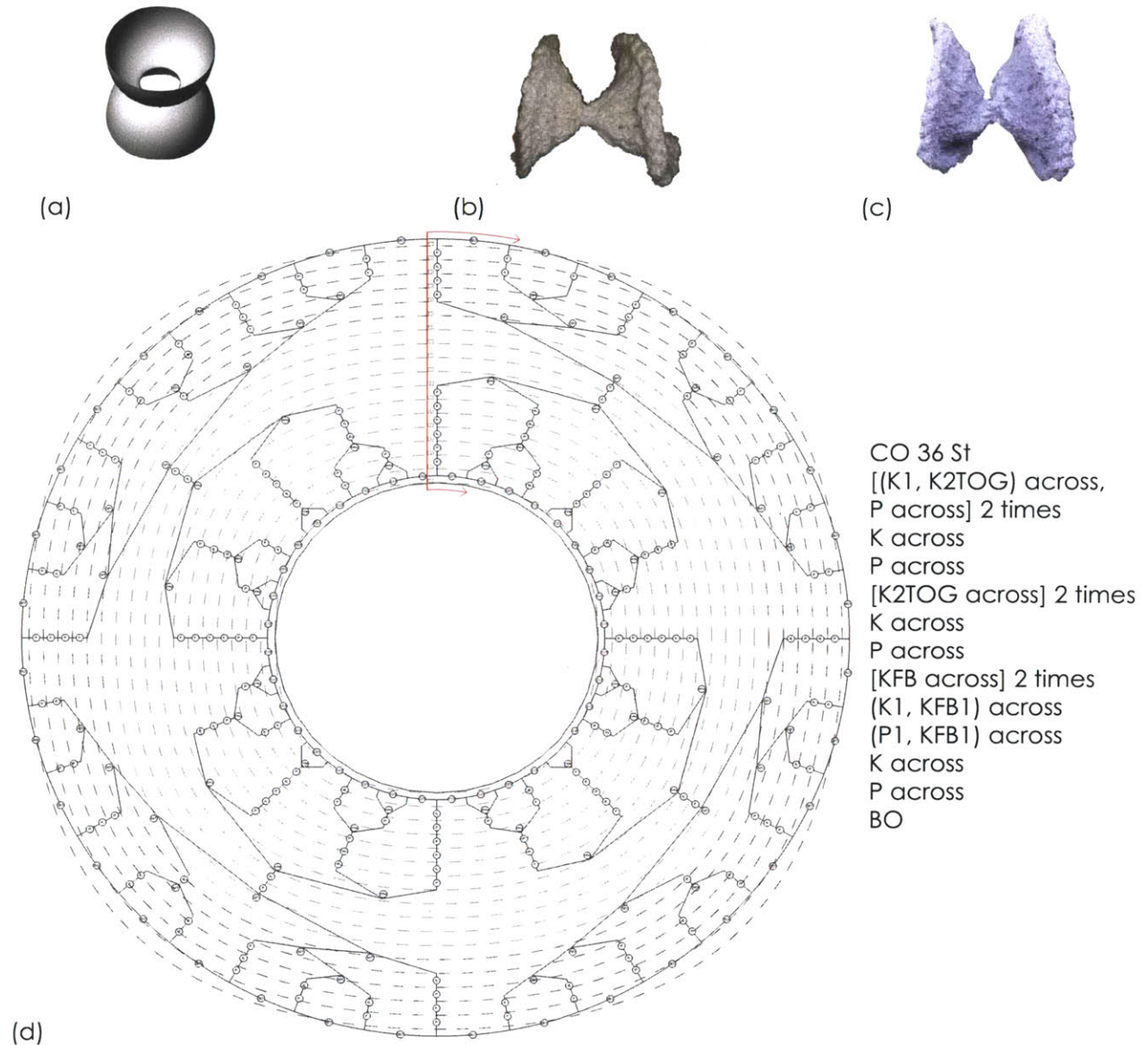
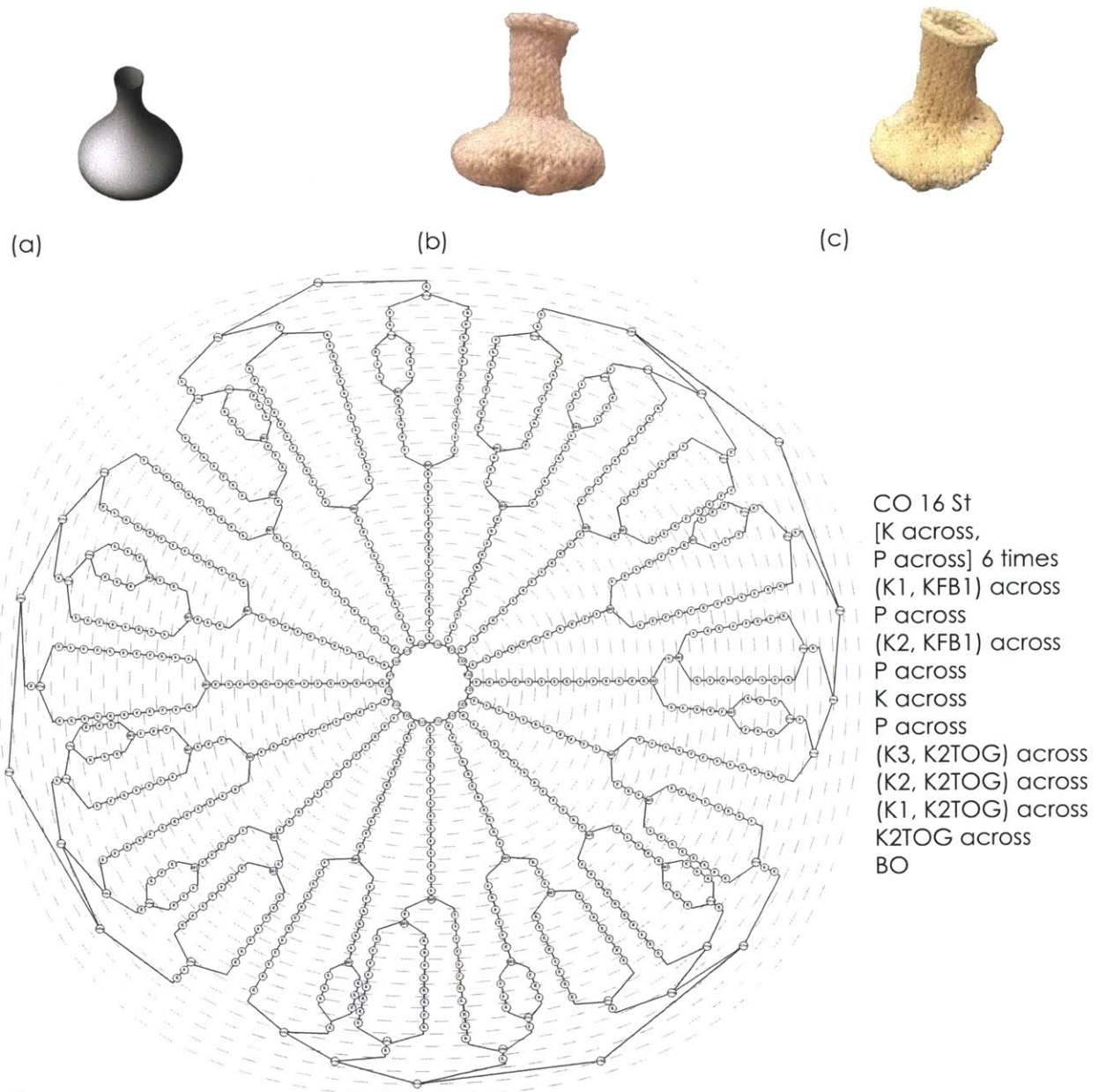


Figure 2.3.4 (a-d): Hourglass Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using rubber (see section 3.0)
- (d) traditional knitting pattern and the logic tree representation of knitting pattern

according to an inverse square law. Any other change in the ratio of increases to static stitches within the increase rows will begin to generate non-linear curvature.



(d)

Figure 2.3.5 (a-d): Bulb Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using latex (see section 3.0)
- (d) traditional knitting pattern and the logic tree representation of knitting pattern

2.4 Hyperbolic Forms

The final family of forms which can be created through knitting is composed of hyperbolic planes. These are forms which do not enclose a volume, and thus, possess all of the qualities of surfaces, yet, they cannot be compressed into two dimensions, as the plates from the tube and plate family of forms can be. To generate these forms, again, one must work with alternating increase and static rows. The work must begin with a dense increase pattern, but as it progresses outward, the ratio of increases to static stitches within the increase rows will remain constant.

Hyperbolic forms are highly demonstrative of knitting's formal power. These are

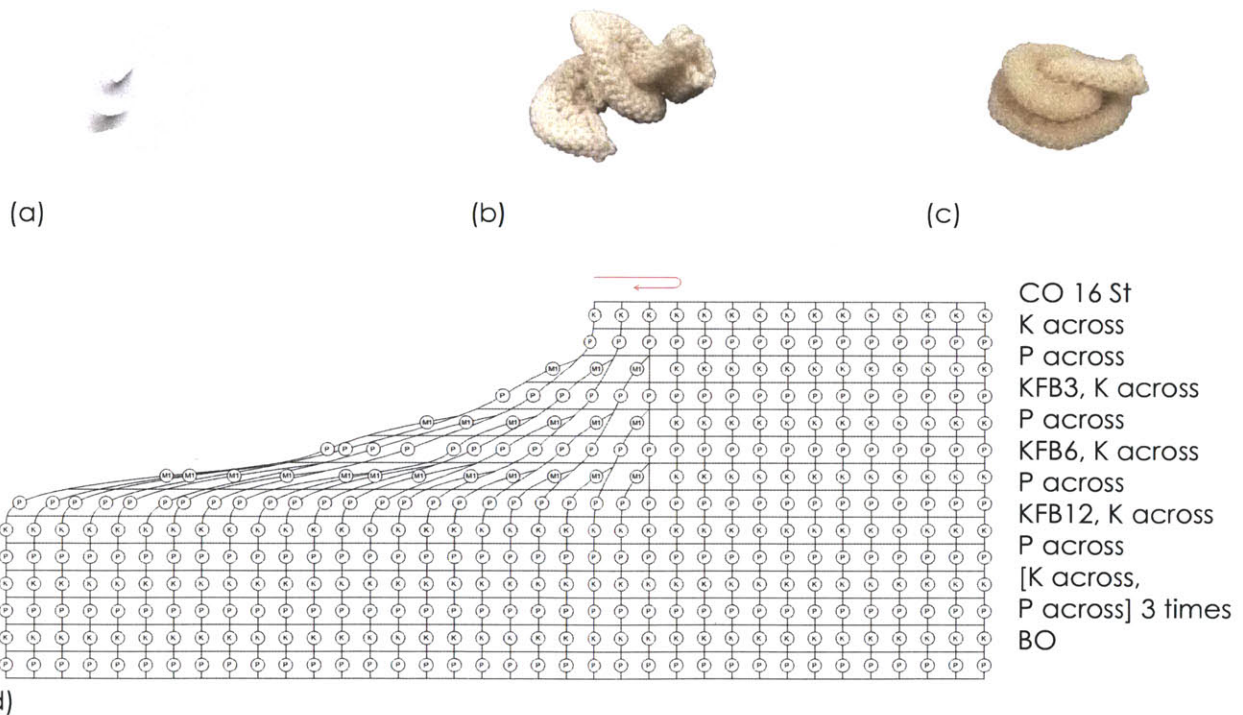


Figure 2.4.1 (a-d): Spiral Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using resin (see section 3.0)
- (d) traditional knitting pattern and the logic tree representation of knitting pattern

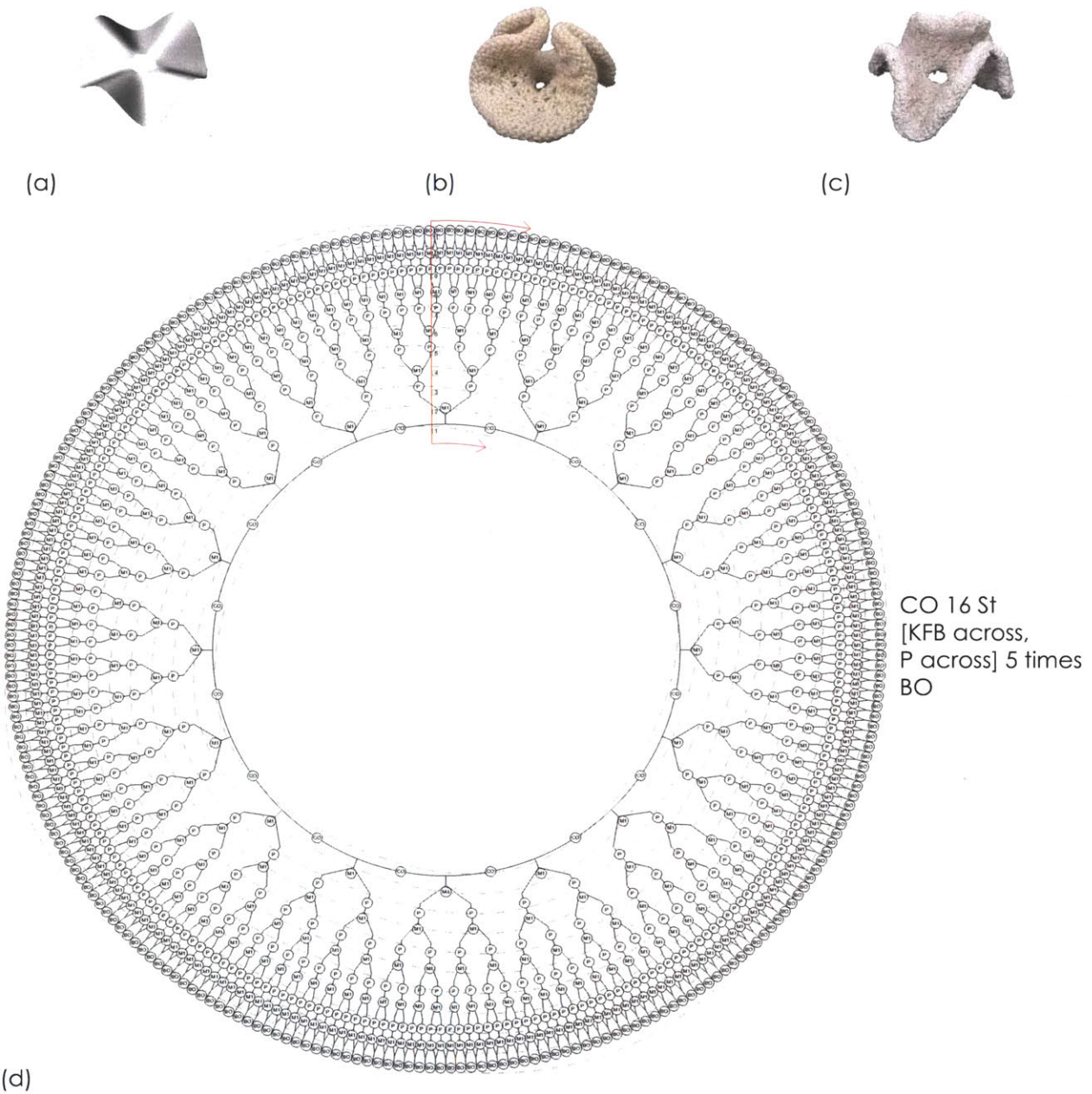


Figure 2.4.2 (a-d): Hyperbolic Plane Pattern and Resulting Forms

- (a) rendering of conceptual form
- (b) knit form, as produced following provided pattern
- (c) reinforced knit form, made into a composite using plaster (see section 3.0)
- (d) traditional knitting pattern and the logic tree representation of knitting pattern

forms which are difficult to replicate through any other means of fabrication. Additionally, these forms are versatile. They do not have a rigid three dimensional form, so they can be manipulated into various shapes, which, when cast as a composite (see section 3.0), will form completely different geometries. Additionally, this form is very simple to knit, as one does not need to keep track of how often an increase is needed in the stitch pattern.

These properties of the hyperbolic plane make it ideal for further exploration, as will be seen in section 4.0 on crowd-sourcing.

3.0 Material Studies

While radial knitting possesses some structural properties, the knit fabric is not inherently rigid. Knit fabric, just like the yarn from which it is made, performs well in tension, but is not strong in compression. Thus, knit pieces can benefit structurally by forming them into composites, which can add rigidity. The diagrams shown in figure 3.0.1 illustrate a few options for forming composites from knit fabric. One option is to dip the completed piece into a casting material, as is demonstrated through figures 3.0.1 (a, b, f, i, j, k, and l). Alternately, figures 3.0.1 (c and d) show the effects of coating the finished knit piece in a dry composite compound and spraying the result with water to activate the composite compound. Figures 3.0.1 (g and h) show the results of incorporating the dry composite compound into the fiber itself prior to knitting it into fabric. The composite compound can be activated with water following the completion of the knitting. Finally, figure 3.0.1(e) shows a technique for adding rigidity to a knit piece which takes advantage of natural properties of wool. Felting is a process of abrasively washing wool which causes the fibers to tangle with the other fibers around them, forming a dense, highly connected fabric.

Figure 3.0.1 (a-l): Composite Studies

These images show various forms of composites which can be formed with knit fabric. The circle diagrams which follow the images illustrate the penetration of the composite material into the yarn itself. Each exploration is accompanied by a list of advantages and disadvantages for using that type of composite

(a)



Chunky Acrylic Dipped in Concrete



Advantages:

- Strength
- Quick knitting due to yarn thickness

Disadvantages:

- Difficult for implementation on large scale pieces

(b)



Worsted Acrylic Dipped in Concrete



Advantages:

- Strength
- Better absorption of concrete

Disadvantages:

- Difficult for implementation on large scale pieces
- Slow knitting due to yarn thickness

(c)



Chunky Acrylic Covered in Concrete



Advantages:

- Quicker knitting due to thicker yarn
- Easier implementation by crafter

Disadvantages:

- Fragile
- Unpredictable structural properties (dependent on degree of coating)

(d)



Worsted Acrylic Covered in Concrete



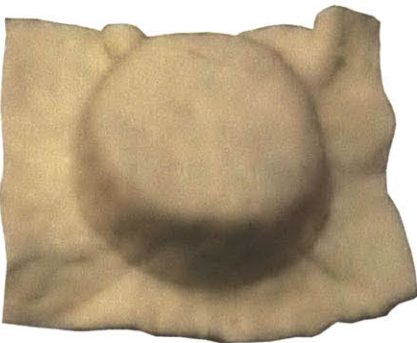
Advantages:

- Easier implementation by crafter

Disadvantages:

- Fragile
- slow knitting due to yarn thickness
- Unpredictable structural properties (dependent on degree of coating)

(e)



Felted Wool



Advantages:

- No concrete, in line with the spirit of handicraft
- Able to be produced from pre-existing material (natural, untreated wool)

Disadvantages:

- Weak
- Requires much material due to the shrinkage of the fabric
- Labor intensive, requiring a large knit area

(f)



Worsted Acrylic Dipped in Plaster

Advantages:

- Strength

Disadvantages:

- Fragile
- Difficult for implementation on large scale pieces
- Slow knitting due to yarn thickness

(g)

Handspun Wool with Concrete Incorporated



Advantages:

- No material mixing required by the crafter to become structural



Disadvantages:

- Fragile
- Long curing time
- Concrete absorbs natural oils of the yarn, making spinning consistent fiber difficult and eliminating the slippage of fiber when knitting

(h)

Wrapped Wool Blend with Concrete Core



Advantages:

- Strength (varied depending upon concrete content)
- Tulle-wrapped fiber prevents the fibers from clinging to each other and to the needles, making knitting easier
- Concrete incorporated into fiber allows for easier construction



Disadvantages:

- Labor-intensive, not realistic for mass-production

(i)

Worsted Acrylic Dipped in Latex



Advantages:

- Strength
- Maintains flexibility of knit fabric



Disadvantages:

- Difficult for implementation on large scale pieces
- Slow knitting due to yarn thickness

(j)

Worsted Acrylic Dipped in Resin



Advantages:

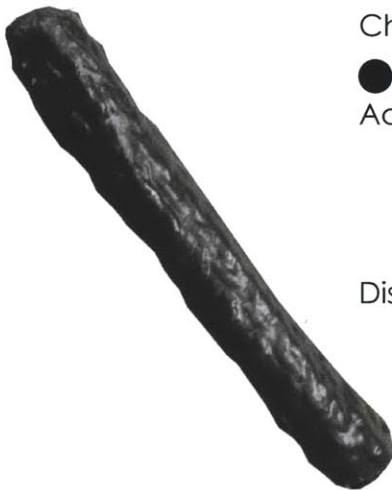
- Strength
- Rigidity

Disadvantages:

- Difficult for implementation on large scale pieces
- Slow knitting due to yarn thickness

(k)

Chunky Acrylic Dipped in Plastic



Advantages:

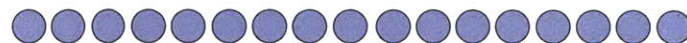
- Strength
- Rigid
- Quicker knitting due to thicker yarn

Disadvantages:

- Difficult for implementation on large scale pieces

(l)

Chunky Acrylic Dipped in Rubber



Advantages:

- Relatively rigid
- Maintains flexibility of knit fabric
- Quicker knitting due to thicker yarn

Disadvantages:

- Chunky yarn less absorbant than worsted
- Less strength

4.0 Crowd-Sourcing

In the early 2000's, knitting experienced a resurgence of popularity, and between 2003 and 2004, the percentage of the American public who knew how to knit jumped from eight percent to twenty-two percent. Since so many Americans already know how to knit, and the craft is easily taught to those who do not have a knitting background, this makes knitting an ideal medium for a crowd-sourced project. Patterns and guidelines for knitting particular pieces can be distributed to the public, either physically or digitally, and anyone with the proper materials and a basic knowledge of knitting can contribute to the project.

If this idea of crowd-sourcing is considered architecturally, it could mean that a knit architecture project would place the power of construction in the hands of members of a community. It could bring people without the typical background into the fields of design and construction. These people can become problem solvers within their own neighborhoods. For instance, if an enclosure is needed in a park for safety reasons, the members of a community could come together to

produce it. Collectively, they can knit temporary shelters to hold events. If the distributed material becomes more sophisticated, communities could theoretically solve problems such as underlit streets by knitting self-sufficient, solar-powered street lamps

Additionally, since most knitters are female, allowing knitting to become a means of fabrication will be a way to bring women into the male-dominated field of construction.

4.1 Overview of Respondents

To prove that a crowd-sourced architecture could work, this thesis has been distributed online through various crafting forums and social networking sites. It has a presence on Craftster, a forum geared toward the modern crafter which veers away from the more traditional uses of knitting, as well as on Instructables, which is a forum with a more technological slant which places much importance on the experimentation aspect of craft. Furthermore, it has a presence on Ravelry, one of the largest knitting databases on the internet. News of this project also spread through social networking sites such as Facebook, Tumblr, and Twitter. As time went on, and awareness of the project rose, it also began to spread via word-of-mouth. Within a few weeks, fifteen people had responded to this project.

These respondents were asked a bit about their backgrounds, and information about them can be seen in figures 4.1.1 through 4.1.3 and in Appendix B. Their responses showed that many of the respondents to this project were products of the resurgence in knitting triggered by the post-feminist revolution (see figure 4.1.4, 4.1.5, and Appendix C for a critical history of knitting related to its gender bias). Most of the respondents were female, with a large portion of them in their twenties and thirties. This is consistent with the overall population of knitters, as

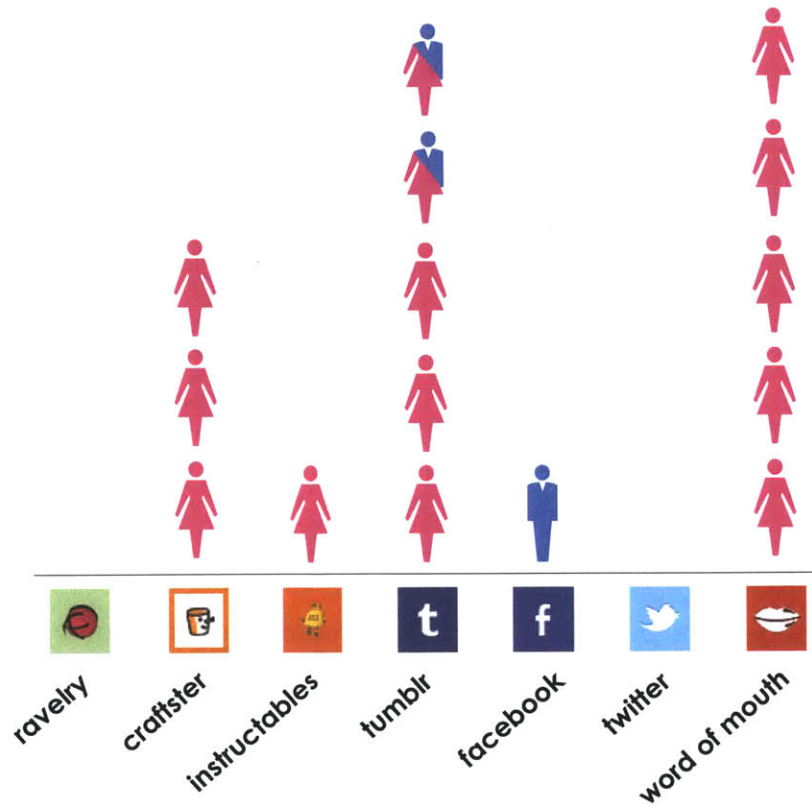


Figure 4.1.1: Information Distribution

Information about this project was distributed via various crafting forums, including craftster and instructables, as well as through several social networking sites. This chart shows how the respondents to the project first heard of its existence. (see Appendix B for full information on the respondents.)

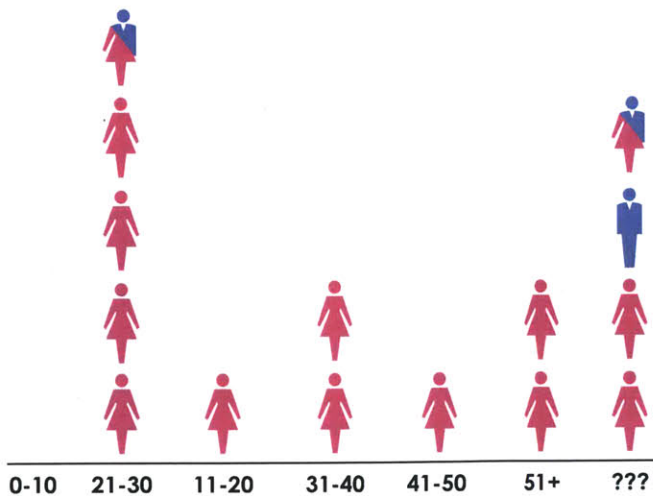


Figure 4.1.2: Age Distribution

This chart shows the relative ages of the respondents to this project. (see Appendix B for full information on the respondents.)

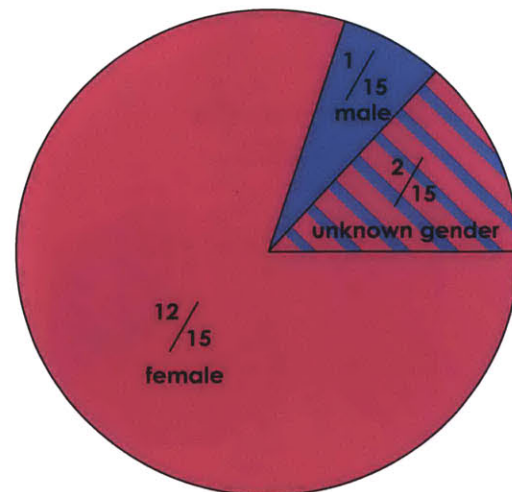


Figure 4.1.3: Gender Distribution

This chart shows the genders of the respondents to this project. (see Appendix B for full information on the respondents.)

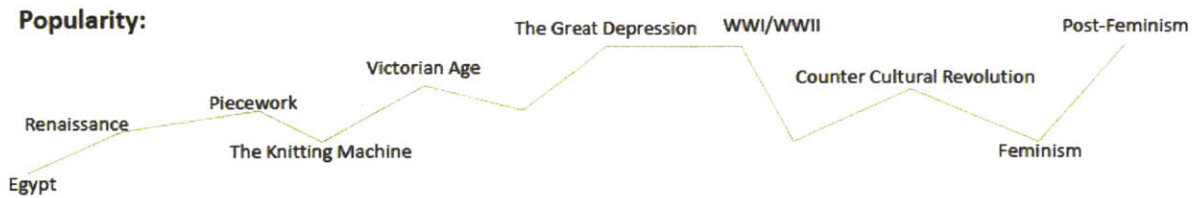


Figure 4.1.4: Timeline of Popularity of Knitting

This chart shows the relative popularity of knitting over time, relative to important events and developments in history. (See Appendix C for a more complete history of knitting.)

Inception	(-)
Guilds	♀
Piecework	♂→(-)→♀
Knitting Machine	♀
Victorian Age	♀
Countercultural Revolution	♂ & ♀
Feminist Revolution	→ (-)

Figure 4.1.5: The Gender Bias in Knitting

This chart shows the status of the gender bias in knitting at several critical points throughout its history. (See Appendix C for a more complete history of knitting.)

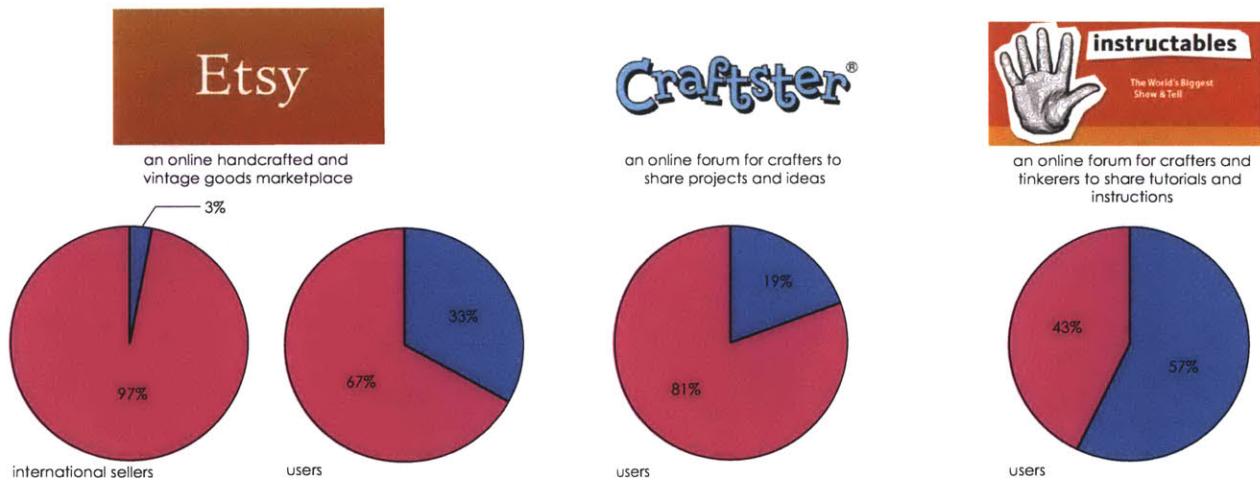


Figure 4.1.6: Residual Gender Bias as Seen Through Usage of Crafting Websites

These charts show the percentages of women and men who use popular crafting websites. Women form a majority of users of sites such as Etsy and Craftster, which emphasize the process of making things by hand. Even Instructables, a site which has a more technical bias than the others, has a large representation of women.

shown by the percentages of women using online crafting resources such as Craftster, Etsy, and Instructables (see figure 4.1.6)

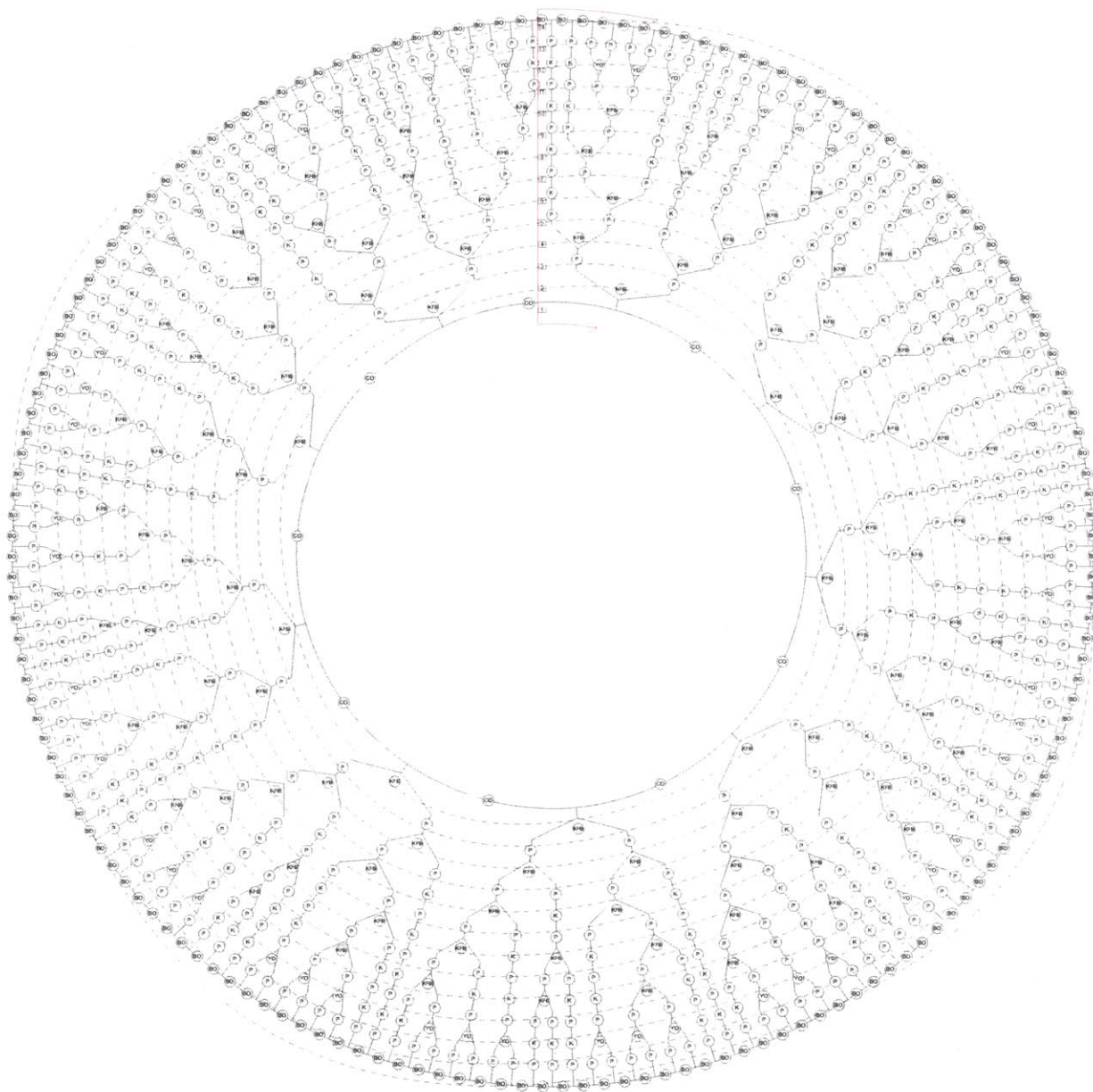
4.2 Distributed Module Pattern

Five of the women who responded to this project were particularly interested in helping, and these were the women to whom patterns and materials for knitting the module shown in figure 4.2.1 were sent. Each knitter was sent a set of size 8 double pointed needles with appropriately sized yarn, a prepaid return envelope, and a pattern like the one shown in figure 4.2.2. This pattern is for an adapted version of the hyperbolic plane shown in figure 2.4.2, but with connection details worked into the outer edge of the module which will allow for the casting of each module into three possible forms (as will be shown in section 4.4). Figure 4.2.3 shows a diagrammatic representation of the relationships between stitches in the distributed pattern.



Figure 4.2.1: Distributed Module

A pattern for the above module was distributed to the test knitters who responded to this project.



CO 9 Stitches, Split over 3 DPN
 KFB across>>18 stitches
 P across
 KFB across>>36 stitches
 P across
 (K1, KFB1) across>>54 stitches
 P across
 (K1, KFB1) across>>81 stitches
 P across
 (K2, KFB1) across>>108 stitches
 P across
 [K2, (YO,K) 3 times, K1] 18 times>>162 stitches
 P across
 BO

Figure 4.2.2: Traditional Knitting Pattern and Adapted Logic Tree Representation of Distributed Module

This is the pattern which generates the module shown in figure 4.2.1. It is an adaptation of the hyperbolic plane explored in figure 2.4.2, with yarn over connection details worked into the outer edge of the module. These connection details allow for each module to be cast into one of three basic forms, and also allow for the attachment of adjacent modules.

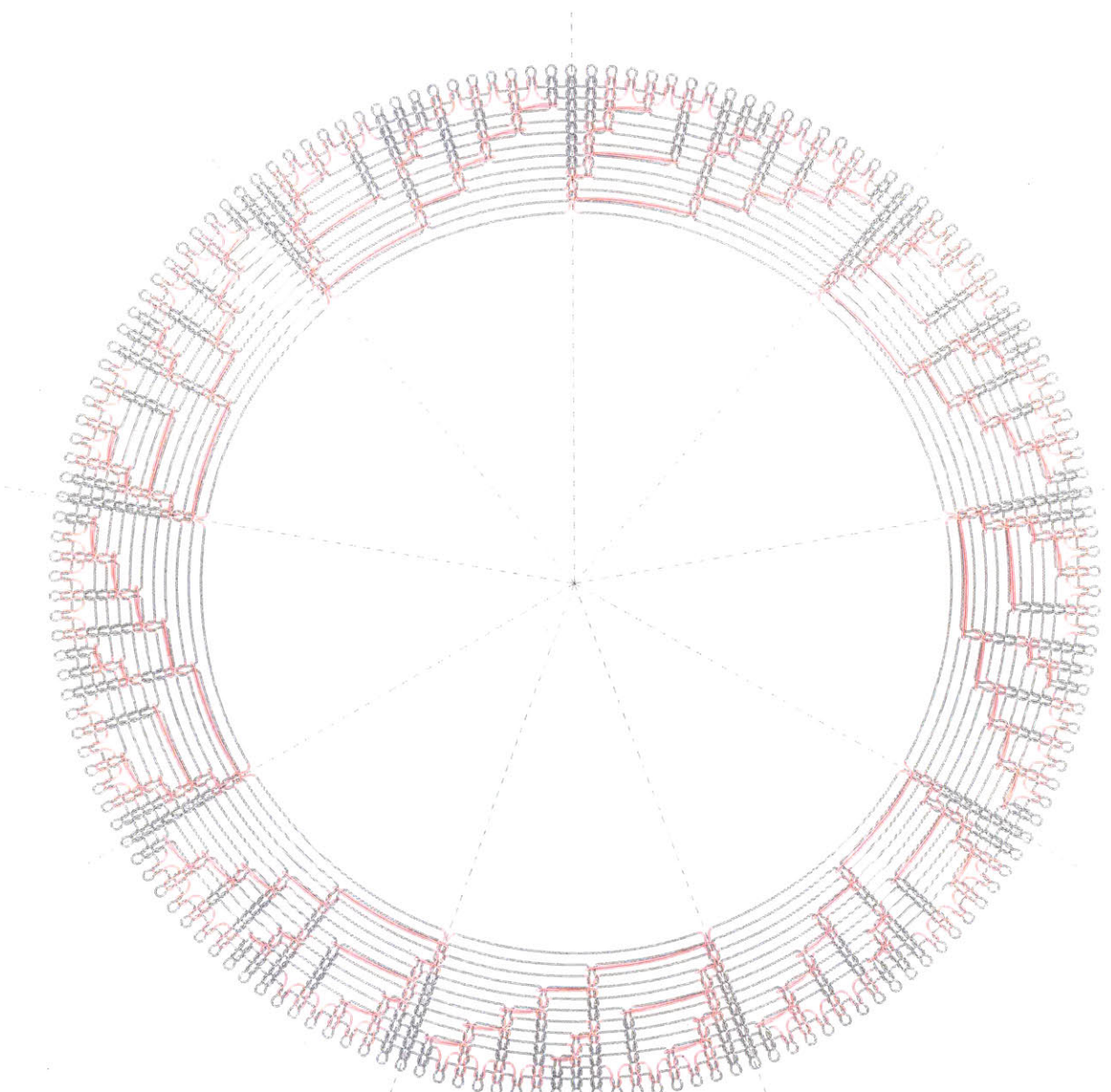


Figure 4.2.3: Diagrammatic Stitch Representation of Distributed Module

This diagram shows the relationships between stitches in the pattern for the distributed module. Increase stitches are shown in red, while static stitches are shown in black.

4.3 Recieved Modules

Each knitter was asked to knit as many modules as possible during the two week knitting period. They returned the modules shown in figures 4.3.1 (a-e) and 4.3.2 (a-f). There were a total of forty-eight modules. When seen next to one another, the differences between the modules begin to emerge. Each knitter followed the same pattern, so the differences which can be seen are a byproduct of the



Figure 4.3.1 (a-e): Received Module Packaging

(a) packaging containing the knit modules

(b-e) contents of received packages, labelled according to the knitter

handmade nature of knitting. The modules vary in density of fabric from knitter to knitter. Some pieces are larger, and more open, like those created by Jennifer, and some pieces are smaller and denser, like those knit by Sarah. In order for these pieces to attach to each other properly, they must be regularized through the casting process.

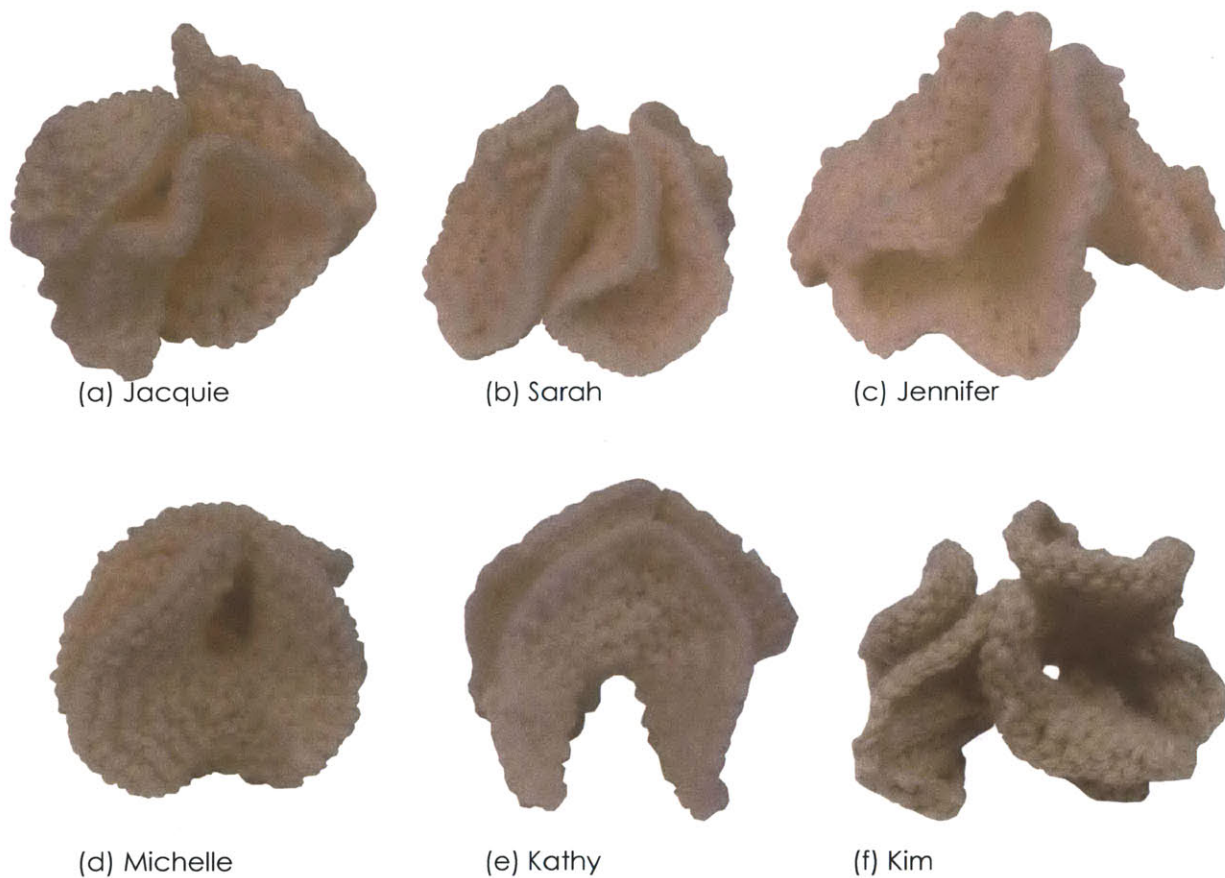


Figure 4.3.2 (a-f): Received Modules

Photographs of the uncast modules received from project respondents. It is interesting to note that, due to the handmade nature of knitting, each knitter constructed a slightly different module. Some were larger, with more open fabric, like those shown in (c), and some were more smaller and made of more dense fabric, like those shown in (b).

4.4 Casting and Regularization

Each module can be cast into one of three different formations: a form with three peaks on each side, a form with six peaks on each side, and one with nine peaks on each side. These forms are shown in figures 4.4.1 (a-c). Each form is derived from the placement of the yarn over connection details which were written into the distributed pattern. These connection details dictate where the still-wet cast piece can be sewn into a casting jig, as pictured in figures 4.4.2 (a-i). Not only does using a jig when casting these pieces help them to achieve one of the three designated forms, it also helps to regularize the diameter of each cast module. The jig stretches the smaller pieces to make it easier to attach them to some of the larger, more open modules.

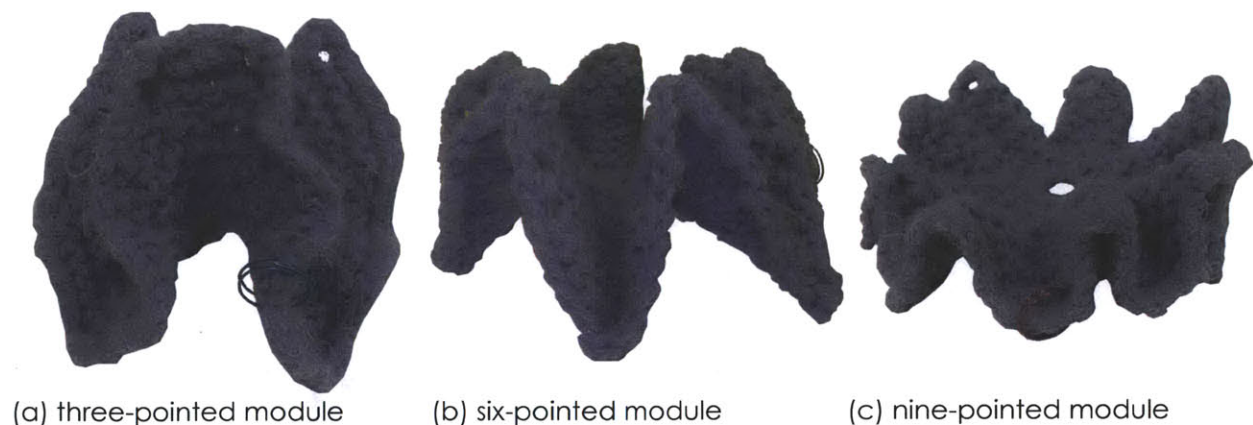
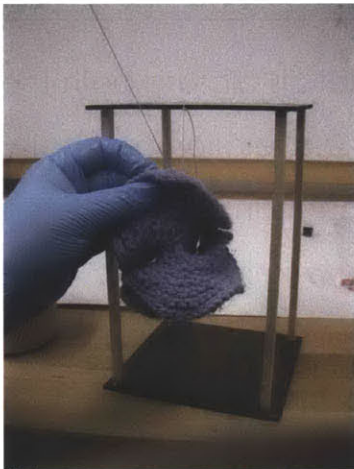


Figure 4.4.1 (a-c): Three Forms of the Cast Module

A series of photographs showing the three forms which can result from the different casting conditions of the distributed module, these forms are dependent upon the placement of the connection details in the pattern provided in figure 4.2.2.



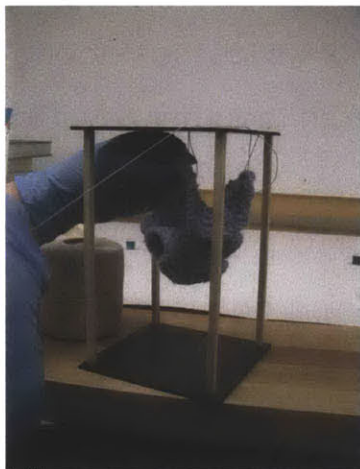
(a)



(b)



(c)



(d)



(e)



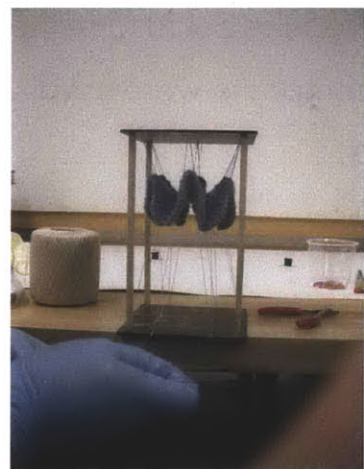
(f)



(g)



(h)



(i)

Figure 4.4.2 (a-i): Step-by-Step Casting Process

A series of photographs showing how the knit piece is suspended in the jig after being coated in the rubber compound.

4.5 Module Aggregation

These yarn over connection details dictate both the forms in which the modules can be cast and the connecting relationships between two adjacent modules. Figure 4.5.1 shows the forms that can be generated by exploring three different spatial relations for each cast variation on the distributed module. It also shows two ways in which different castings of the module can relate to one another. Since the module itself is geometrically complex, a series of simple aggregations of the module using the rotate rule were chosen to generate each layer of the aggregated form. Connections between layers were achieved using the two multiple-type-module connection rules shown in figure 4.5.1, as well as the stacking rule for the three-pointed module. These aggregations, taken together, result in the final, pillar-like form shown in figures 4.5.2 (a-c).

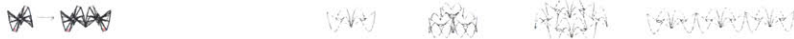
While this model was constructed using rubber as a stiffening agent to ensure that the modules were able to connect at the appropriate points, it is easy to envision the possibilities for the use of this form had it been cast in a more structural material like plaster (shown in figure 4.5.3), or even concrete. This aggregation of modules could form the base for a table, or even a structural column if the proper composite were used.

Figure 4.5.1: Aggregation Studies of Three Forms of Distributed Module

An exploration of forms which can result from three basic spatial relations for each of the three variations on the distributed module. The diagrams near the end show the ways in which non-similar module forms can relate.

3-Pointed Module

Rotate



Stack



Turn



6-Pointed Module

Rotate



Stack



Turn



9-Pointed Module

Rotate



Stack



Turn



3-6 Module Connection

Stack



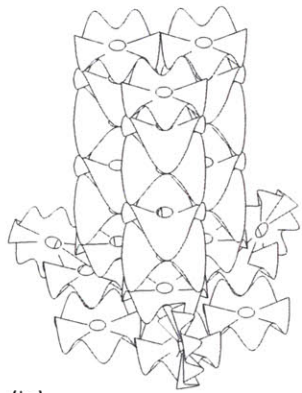
6-9 Module Connection

Pivot

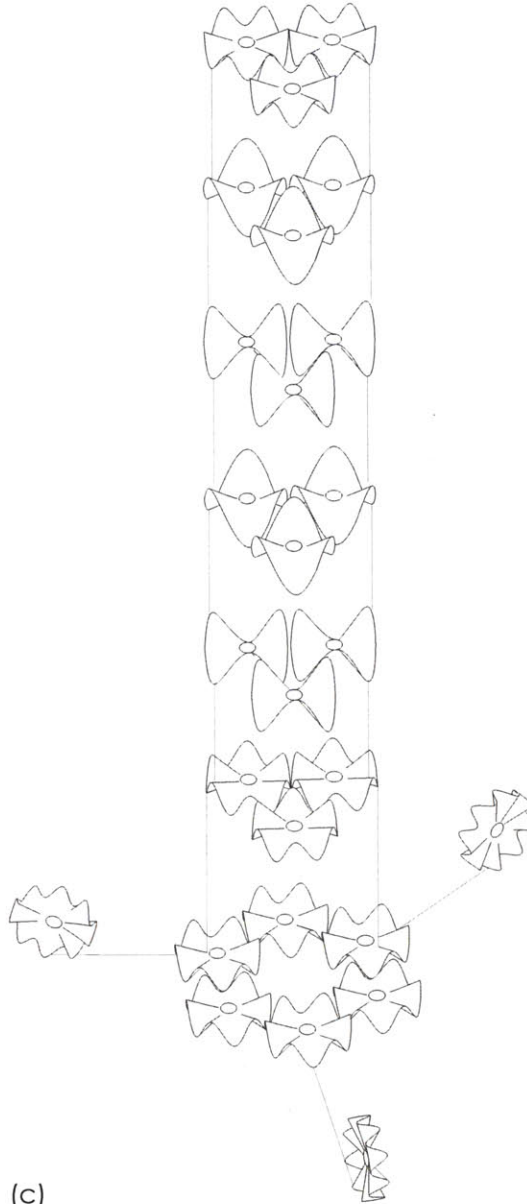




(a)



(b)



(c)

Figure 4.5.2 (a-c): Final Aggregation of the Distributed Modules

(a) photograph of the final aggregation of modules

(b) diagram of the final aggregation of modules

(c) exploded axon showing the assembly of the final aggregation by layers



Figure 4.5.3: Alternative Casting Material-Plaster

5.0 Conclusion

Embracing knitting as a means of fabrication can have vast architectural implications. Formally, knitting can be used to create virtually any geometry, even those which are difficult to create through other means of fabrication. Many knit forms have inherent structural properties, which, when the fiber is reinforced with a composite, can generate structural pieces which have architectural potential both individually and when aggregated. The architectural implications become even more tangible as the construction process is scaled up. Figure 5.0.1 shows the structural implications of scaling up. The fabric generated using rope is far denser, and thus, more structural than fabric made with fingering weight yarn.

Also, knitting has the power to bring a new audience into the fields of construction and design. Knitting is a handicraft, which makes it easy to learn. Knitting is highly accessible, and many Americans can already knit. Making knitting a form of fabrication can bring these individuals into the design world, and allow them to take action to solve problems in their own communities.

Figure 5.0.1: Table of Compatibility between needle sizes and yarn weights

yarn weight → fingering weight

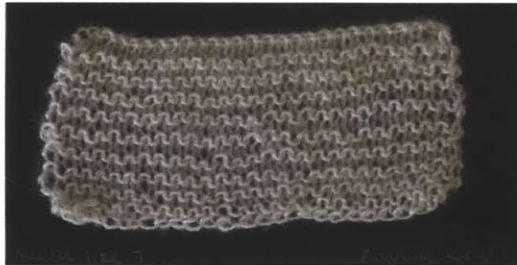
worsted weight

needle size
↓

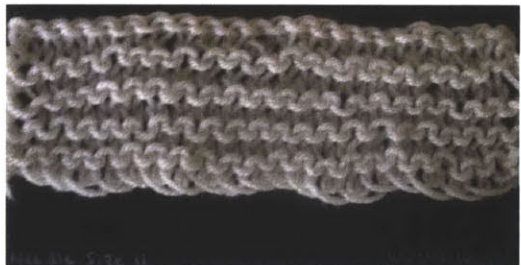
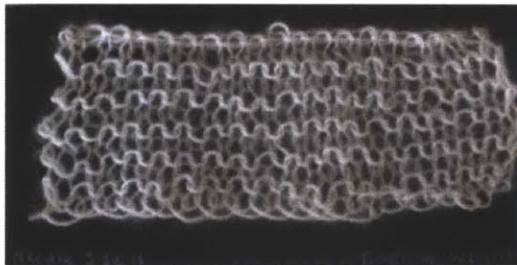
size 2



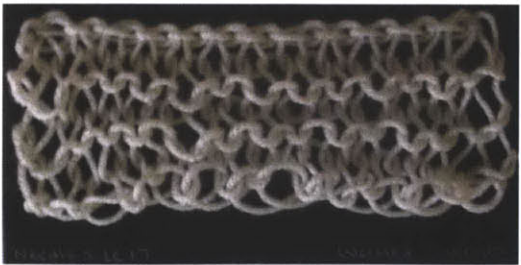
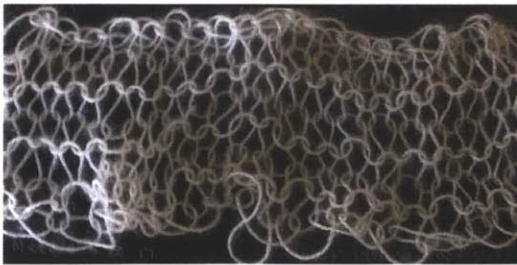
size 7



size 11

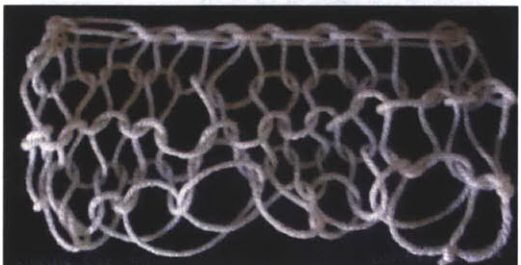


size 17



materials not compatible

size 35



chunky weight

rope

materials not compatible

materials not compatible



materials not compatible



materials not compatible

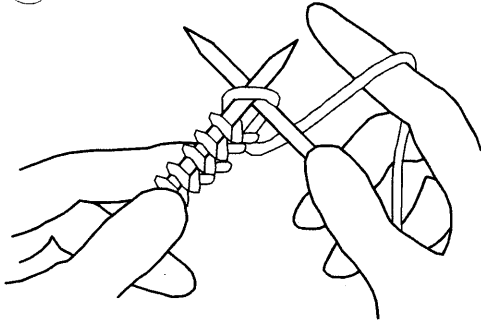


Appendix A
Constructing Knit Stitches

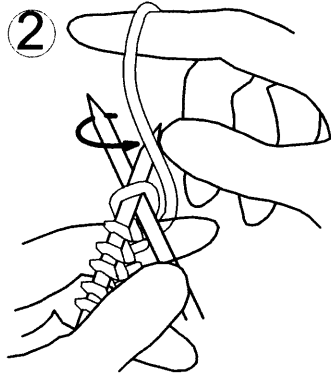
Static Stitches

The Knit Stitch [K]

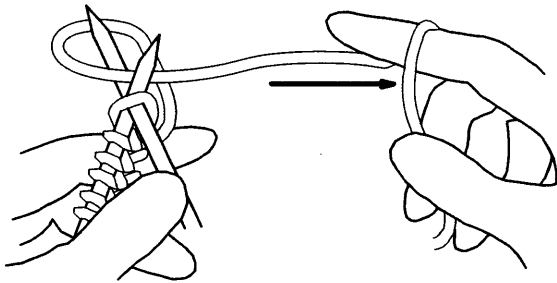
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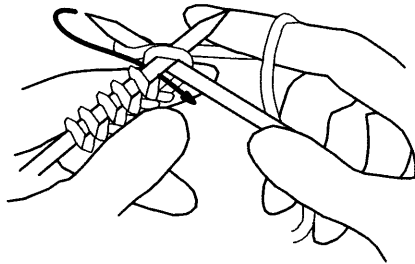
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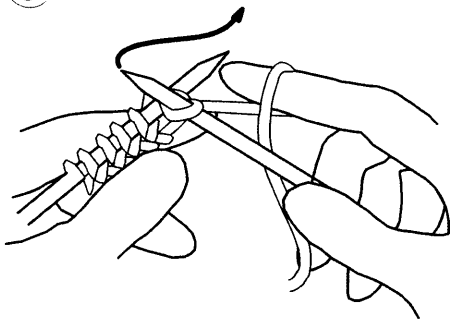
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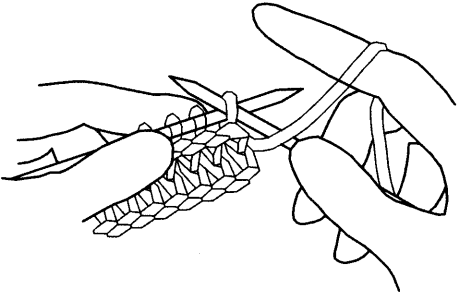


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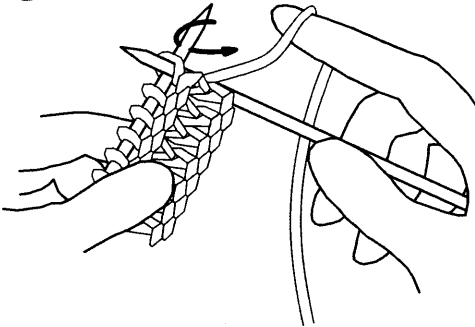


The Purl Stitch [P]

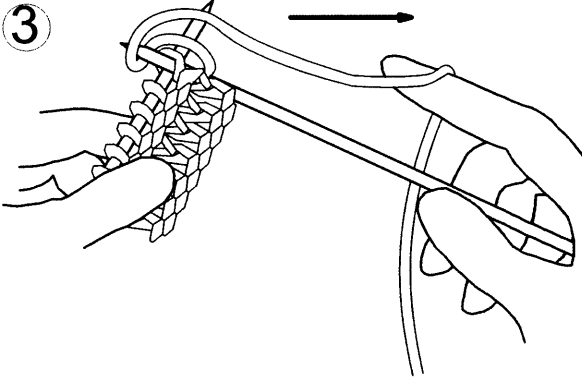
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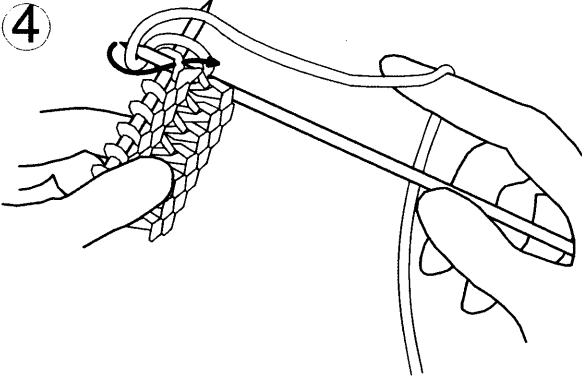
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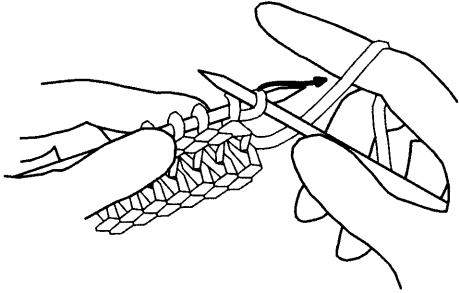
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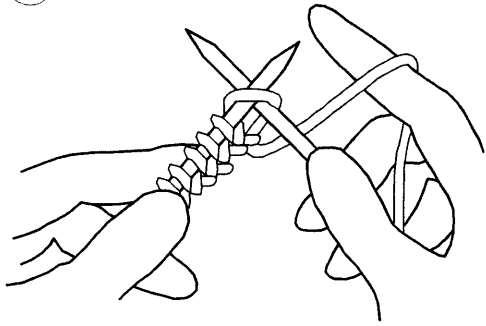
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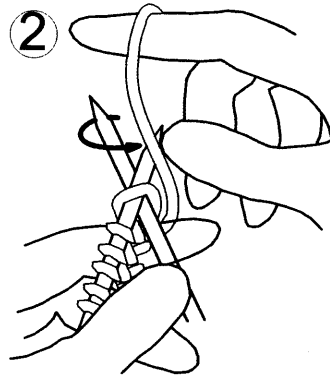
Increase Stitches

The Bar Increase [KFB]

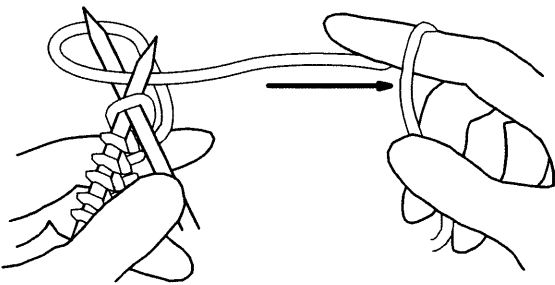
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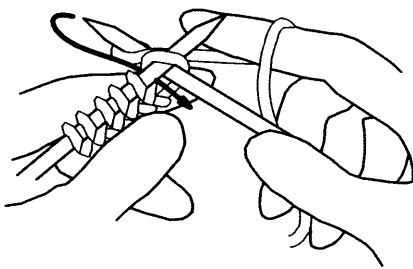
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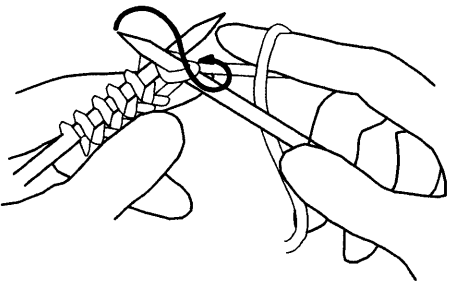
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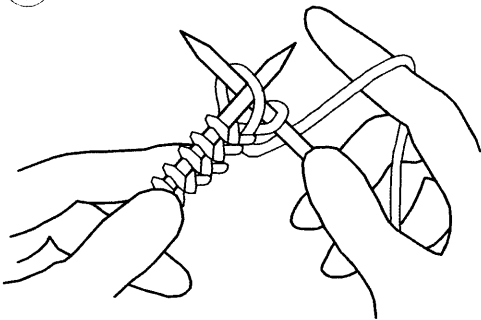
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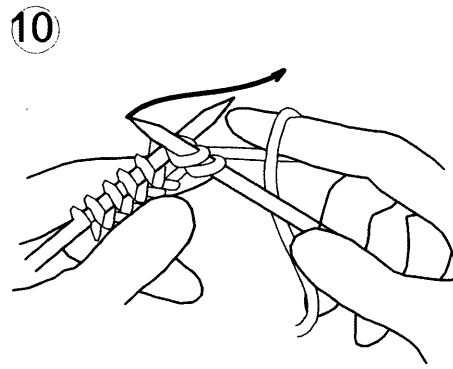
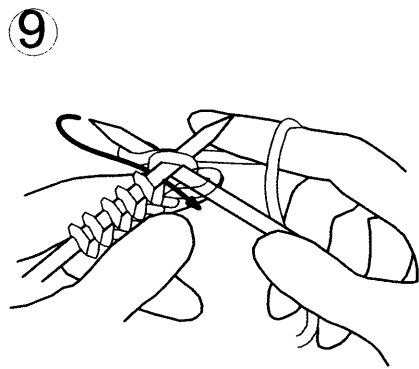
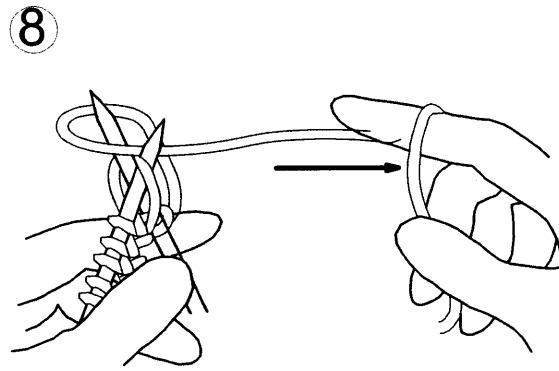
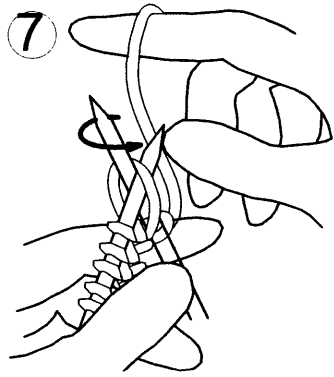
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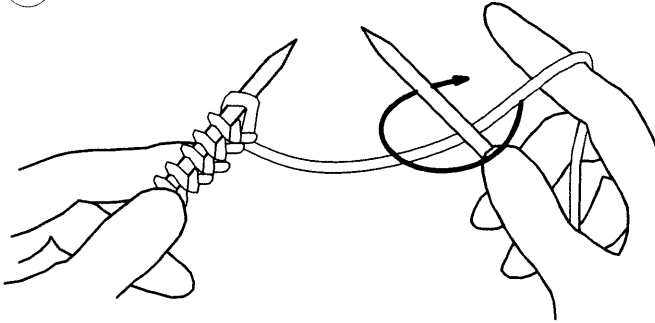


The Bar Increase [KFB] (continued)

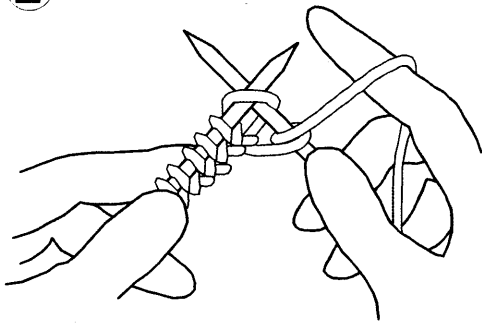


Yarn Over [Yo]

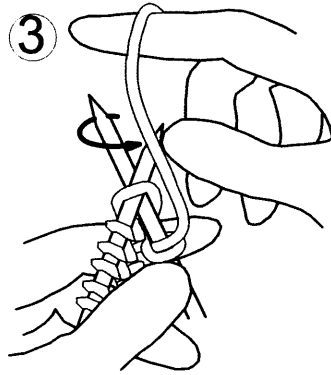
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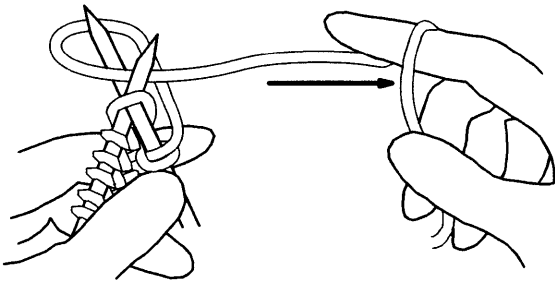
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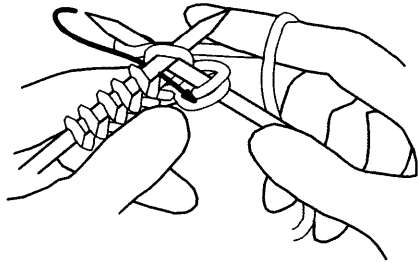
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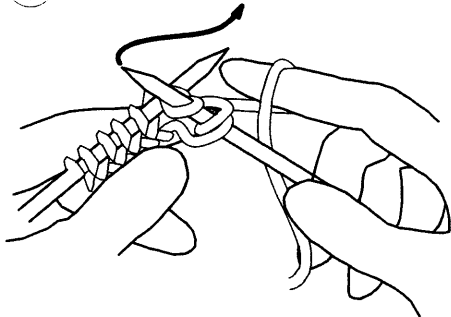
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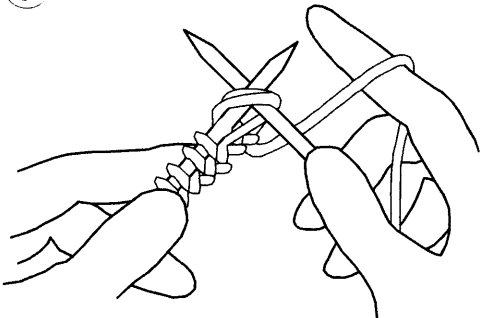
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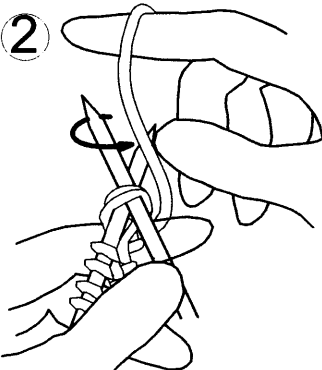
Decrease Stitches

Knit Two Together [K2TOG]

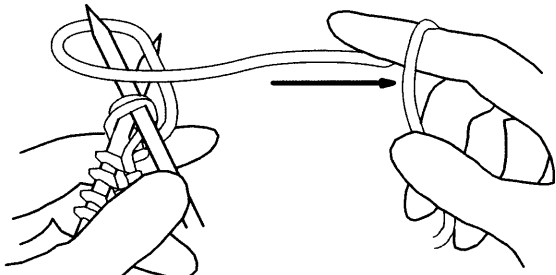
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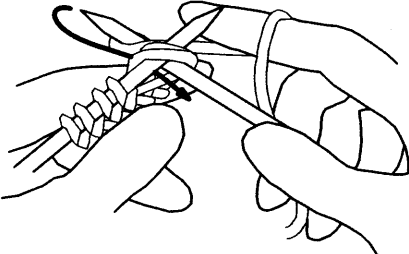
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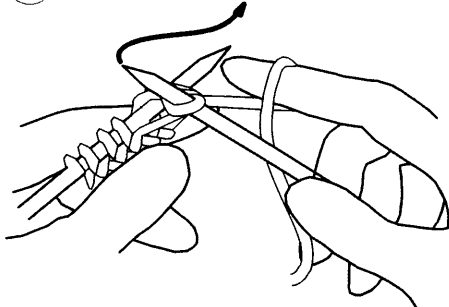
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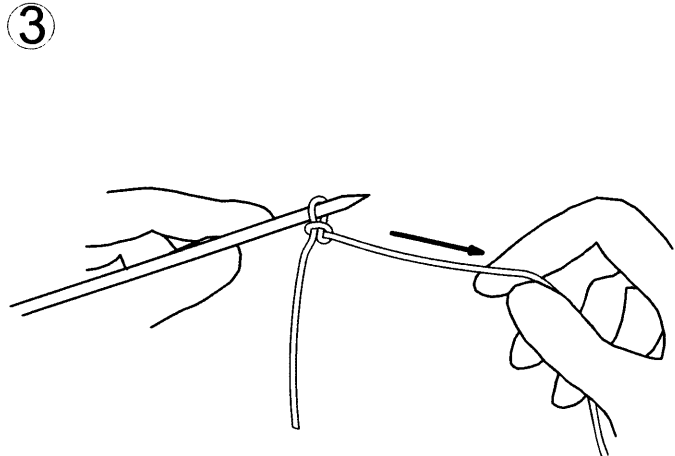
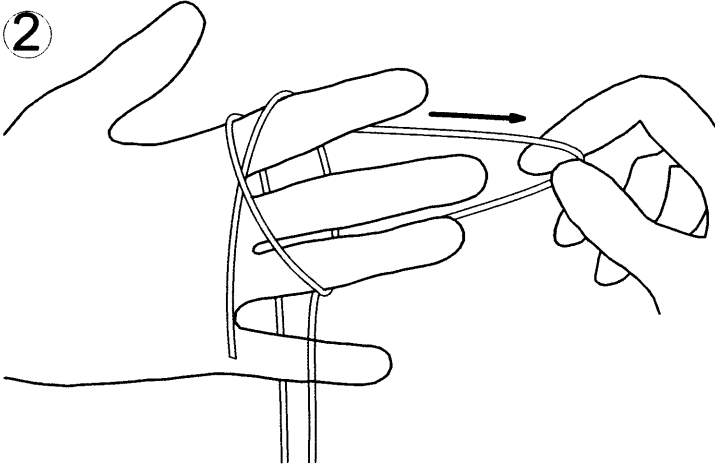
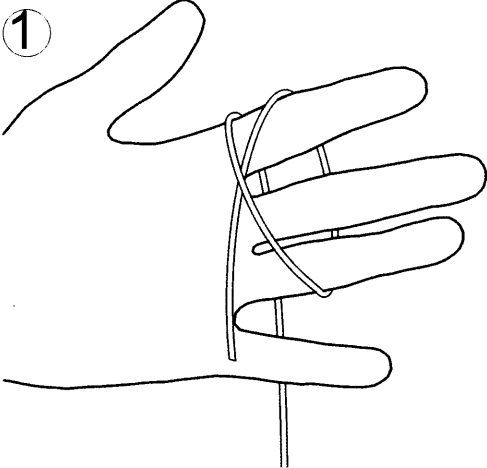


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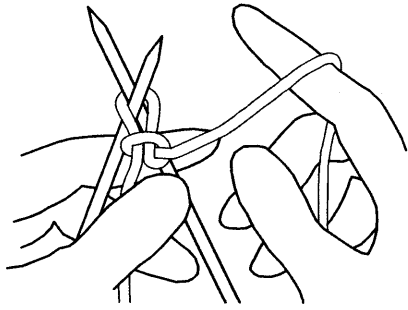
Beginning and Finishing Stitches

Slip Knot

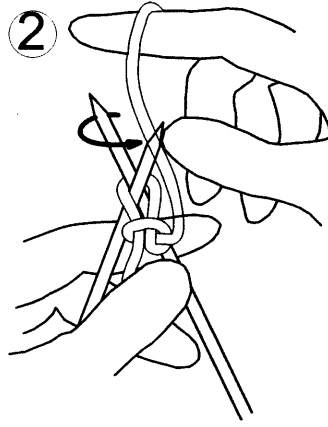


Cast On

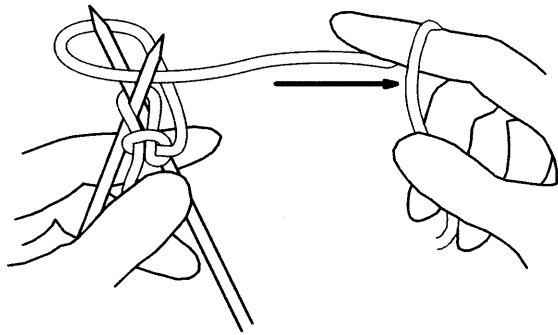
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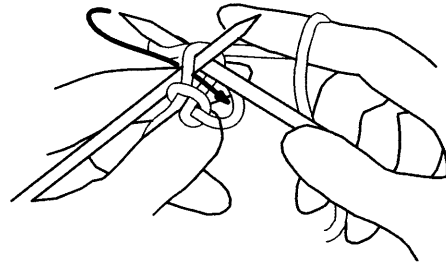
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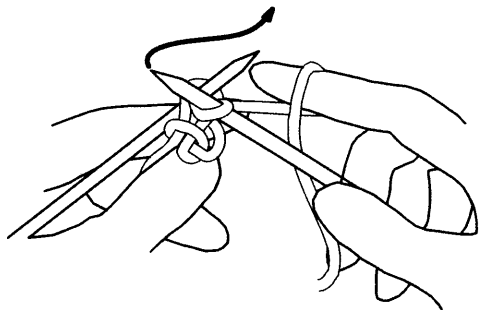
③



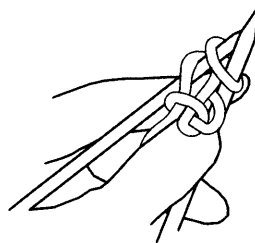
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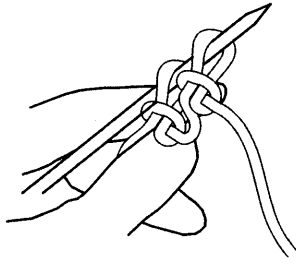


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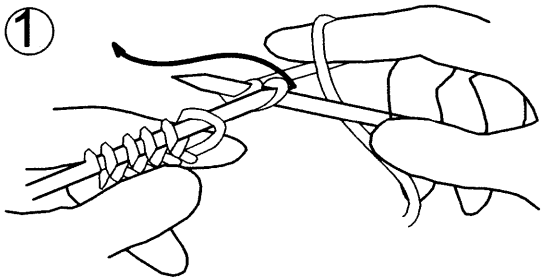
Cast On (continued)

7



Bind Off

1



Appendix B
Profiles of Project Respondents



Name: **Bradly**
Gender: Male
Age: Unknown
Location: Leechburg, PA
Experience: Unknown
How'd You Hear?: Facebook
Crafting Resources: Unknown

Personal Information:



Name: **Holly**
Gender: Female
Age: 56
Location: Raleigh, NC
Experience: 5 years Knitting
How'd You Hear?: Word of Mouth
Crafting Resources: Ravelry, KnittingHelp, KnitPicks, other

Personal Information:

Knitting since Christmas 2006 - I relearned as I tried to teach Caitlin [my daughter] because she'd joined a knitting club at school and had to make two scarves before Christmas break was over. I initially learned to knit as a girl from my mother. I've only been knitting in the winters.



Name: **Jacqui**
Gender: Female
Age: 52
Location: Erie, PA
Experience: 46 Years Knitting
How'd You Hear?: Word of Mouth
Crafting Resources: Unknown

Personal Information:

I have a passion for crafts of many kinds. I am retired due to a disability. I was a Braille transcriber. I have two sons, who are both married. And two beautiful grandsons. I have been married to my high school sweetheart for 33 years.



Name: **Jeanine**
Gender: Female
Age: 41
Location: Wentzville, MO
Experience: 5 Years Knitting
How'd You Hear?: Craftster
Crafting Resources: Knitty, Ravelry, Craftster, Etsy...

Personal Information:

Married for almost 20 years, I have a 22 year old daughter, 18 year old son. I am currently attending college for computer science. I am obsessed with knitting and my needle and yarn stash is proof of this.



Name: **Jen**
Gender: Female
Age: Unknown
Location: Erie, PA
Experience: Unknown
How'd You Hear?: Word of Mouth
Crafting Resources: Unknown

Personal Information:



Name: **Karen [Mossie]**
Gender: Female
Age: Unknown
Location: Unknown
Experience: Unknown
How'd You Hear?: Craftster
Crafting Resources: Unknown

Personal Information:



Name: **Katie [appleorchardghost]**
Gender: Female
Age: 18
Location: Unknown
Experience: Unknown
How'd You Hear?: Tumblr
Crafting Resources: Unknown

Personal Information:



Name: **Michelle**
Gender: Female
Age: 34
Location: Erie, PA
Experience: Unknown
How'd You Hear?: Instructables
Crafting Resources: Unknown

Personal Information:



Name: **Michelle**
Gender: Female
Age: 22
Location: Moorestown, NJ
Experience: 10 Years Knitting
How'd You Hear?: Word of Mouth
Crafting Resources: Knitty, Ravelry, Etsy, Knitting Patterns Central...

Personal Information:



Name: **Orli**
Gender: Female
Age: 27
Location: Philadelphia, PA
Experience: 6 Years Knitting
How'd You Hear?: Tumblr
Crafting Resources: Knitty, Ravelry, Knitting Help, other

Personal Information: When I'm not knitting, I work in the ICU of the veterinary hospital at the University of Pennsylvania as a veterinary technician. A lot of my knitting time is also TV-time or reading time (whether for pleasure or to learn more about some medical issue I saw at work). I have 4 cats who love the accoutrements of knitting--they like to steal my yarn, chew on my needles, and hide my stitch markers and other various odds and ends.



Name: **Pamela**
Gender: Female
Age: 36
Location: Bryan, TX
Experience: 8 Years Knitting
How'd You Hear?: Word of Mouth
Crafting Resources: Knitty, Etsy, Tumblr, Pinterest...

Personal Information: I'm a generally crafty girl who does all kinds of crafty things, knitting and crochet included. My sister taught me to knit 8 years ago, and I've been at it off and on ever since.



Name: **Rachel**
Gender: Female
Age: MIT Student
Location: Cambridge, MA
Experience: Unknown
How'd You Hear?: Tumblr
Crafting Resources: Unknown

Personal Information:



Name: **Sarah**
 Gender: Female
 Age: 28
 Location: Leechburg, PA
 Experience: 7 Years Knitting
 How'd You Hear?: Craftster
 Crafting Resources: Craftster [knitting moderator], Ravelry...

Personal Information: I'm a software developer as my profession. My hobbies include roller derby and traveling to see roadside attractions in addition to crafting. I do a lot of crafting...knitting, crocheting, making resin creations, stenciling...really anything to make what I desire!



Name: **themodestadventuresofflat13b**
 Gender: Unknown
 Age: Unknown
 Location: Unknown
 Experience: Unknown
 How'd You Hear?: Tumblr
 Crafting Resources: Unknown

Personal Information:



Name: **woolymatt**
 Gender: Unknown
 Age: 22
 Location: Davis, Ca
 Experience: Unknown
 How'd You Hear?: Tumblr
 Crafting Resources: Unknown

Personal Information:

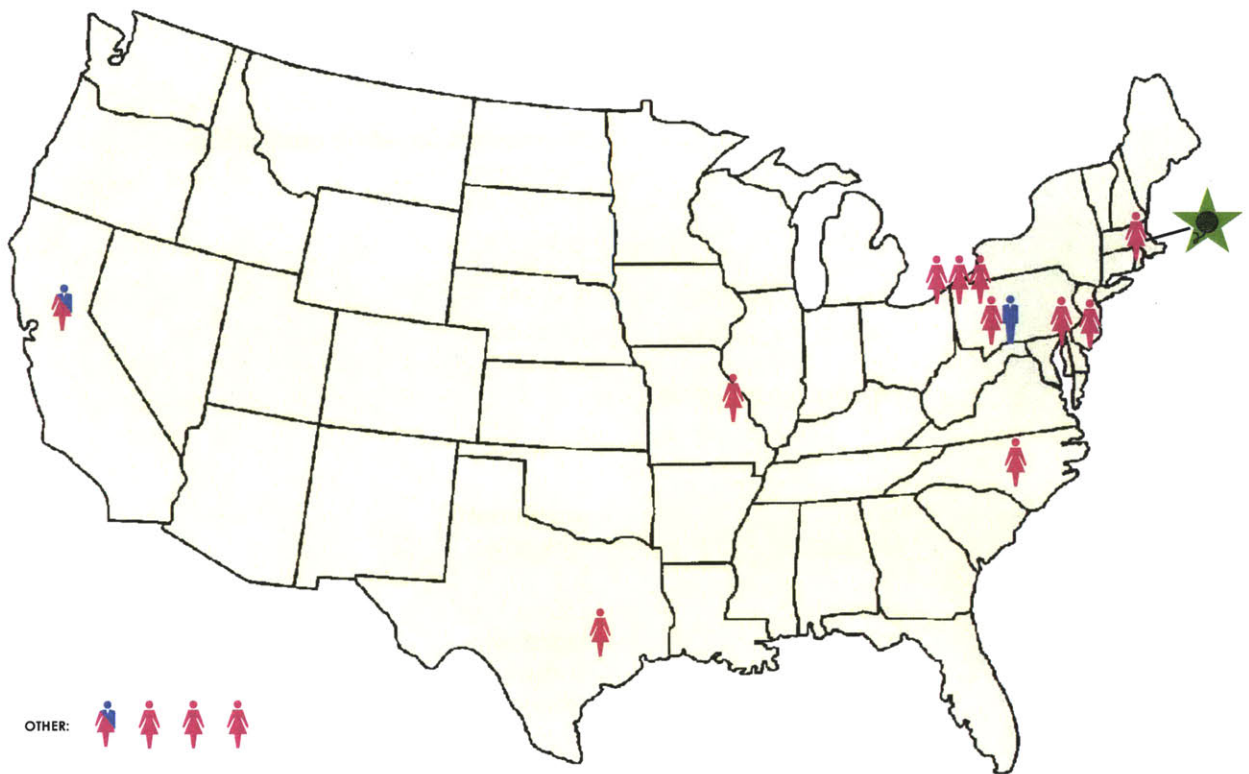


Figure A.1: Geographic Distribution

This map shows where the respondents to this project live. The other category, listed at the bottom of the map, refers to those who did not respond to the survey question about location.

Appendix C
A Brief Critical History of Needlecraft

The earliest evidence of knitting was discovered in an archaeological dig in Egypt, where a pair of blue and white cotton socks dating back to as early as 1300 B.C.E. was unearthed. As the fibers in early yarns were organic, and therefore subject to decay, it is possible that knitting predates even this time period, but no earlier evidence of its existence has been discovered. Needlecraft existed in the background of history until the Late Middle Ages, although some technical advancements were made during this period, such as the cultivation of new fibers and the development of new methods of spinning fiber into yarn.

Knitting again surfaces as a cultural force near the end of the Middle Ages. There are several Renaissance-era paintings depicting the Virgin Mary knitting or using knitting paraphernalia such as spool organizers. The depiction of the handicraft in religious painting is evidentiary of the importance of the craft in the minds of people at that time. Around the same time, the guild system began to emerge in Europe. Knitting became an economic market, and it was soon controlled by the guilds. As guilds were composed of highly skilled craftsmen, knitting in the Middle Ages was considered a masculine activity. This is the first time that the handicraft is tainted with a sexual bias.

Knitting is a labor-intensive pursuit, and even the guilds could not keep up with the demands for knit fabric from the public. Members of the lower classes began to take up the craft as a means of earning extra money. As the men were almost exclusively the bread-winners of the family at this time, much of their work was done outside of the home, leaving little time to knit. Thus, piecework was primarily left to the women. The power of the guilds slowly began to yield, and by 1700, the sexual-bias of the handicraft was inverted.

The invention of the first knitting machine, the stocking frame, in 1589 points to this reversal. Its inventor, Reverend William Lee of Cambridge claimed that he was tired of his wife spending all of her time working on piecework. Thus, to reclaim her time, he attempted to mechanize the process.

Slowly, hand-knit piecework was replaced with mechanized knitting, but it wasn't until the invention of the latchhook knitting machine in 1847 that knit piecework in Europe ceased to exist. Knitting evolved into more of a hobby, gaining popularity during the Victorian Age, and reenergizing the sexual bias that piecework had established. Knitting was seen as a very lady-like pursuit, and thus young girls were taught the craft. This renewal of the craft's popularity was accompanied by advent of continental style knitting. Continental knitting was far slower than traditional knitting, but it allowed the knitter to appear more feminine and therefore more alluring to the opposite sex.

Crochet developed as a new craft in the late 1700's. The first crochet pattern was published in a Dutch women's magazine in 1790. Crochet was initially seen as a simplified version of tatting, or lace making, a craft that emerged in the 1300s. The advent of crochet allowed those who were not members of the highest social echelon to create and use lace, a symbol of femininity. Crochet received a further boost to its popularity around 1800 when reports of the poor living conditions of tatting pieceworkers spread throughout Europe. It was revealed that their wages were so low that they often had to result to prostitution to supplement their wages. Women who did not wish to condone these activities took up crochet hooks and learned the craft themselves, rather than investing their money in the industry. Crochet remained relatively popular throughout Europe until the Potato Famine

struck Ireland in 1845. People began to purchase Irish lace as a means of feeding money into the Irish economy in support.

When the Great Depression hit in 1929, it triggered a resurgence in the popularity of needlecraft. Women could make and alter their own clothes and the clothes of their families rather than purchasing new ones, which was economically preferable. Crochet also grew in popularity during this time, but less so than knitting, as crochet uses more yarn to produce the same amount of fabric. The popularity of needlecraft continued throughout World Wars I and II, as a means of supporting the troops by conserving resources. Following the conclusion of the wars, however, both needlecrafts lost favor with the public.

It was not until the counter-cultural revolution of the 1960s and 1970s that knitting and crocheting experienced another renewal of popularity. Handicraft was seen as rebellion against consumerist culture, and people turned to making their own clothes. Crochet, as it was easier to learn than knitting, experienced more of a surge in popularity during this period than knitting did. The popularity of needlecraft was short-lived, however. With the rise of the feminist movement in the late 1970s, needlecraft was scorned as a symbol of the subjugation of women.

In the late 1990s, needlecraft saw another resurgence. This time, the movement was led by feminists and artists who saw the beauty in knitting and its power to bring together women and men of all generations. Some worked to remove the stigma of oppression from the handicraft while others worked to redefine it by calling into question some of its most basic concepts.

References & Image Credits

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Figure 0.0.1

- (a): <http://jezebel.com/olek/>
- (b): <http://www.lostateminor.com/2011/08/11/oleks-incredible-crocheted-art/>
- (c): <http://agataolek.com/home.html>
- (d): <http://agataolek.com/home.html>
- (e): <http://agataolek.com/home.html>

Figure 0.0.2

- (a): <http://www.neatorama.com/2009/01/13/crochet-coral-reef/>
- (b): http://blog.craftzine.com/archive/2006/12/hyperbolic_coral_reef_new_phot.html
- (c): <http://primesurrealestate.com/2010/11/hyperbolic-crocheted-coral-reef/>
- (d): http://blog.oregonlive.com/knitting/2008/06/crochet_your_part_in_a_coral_r.html
- (e): <http://www.purselipsquarejaw.org/labels/craft.php>

Figure 0.0.3

- (a): http://farm5.staticflickr.com/4132/4987462645_b8914d6560.jpg
- (b): <http://knittyblog.com/?p=282>
- (c): <http://knittyblog.com/?p=282>

Figure 0.0.4

- (a): <http://corkysaintclair.blogspot.com/2011/12/penguins.html>
- (b): <http://www.heywemadeit.com/2011/10/sweaters-for-penguins.html>
- (c): <http://penguinplacepost.wordpress.com/2011/09/15/2288/>