InterWoven: Integrating Traditional Basket Weaving Craft into Computer Aided Design

by

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B.Des, Indian Institute of Technology Guwahati, 2014

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Master of Science in Media Arts and Sciences

at the

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Abstract

The need and desire to create objects is built into human civilization throughout history. The immense diversity of cultures in the world has led to the development of tremendously diverse design and making traditions. Each of these reflects unique imagination threads in our collective thought process and carries immense value in the growth of it. These days, we are witnessing a rise in the digital maker movement, propelled by digital fabrication machines like 3D printers. These are democratizing manufacturing, however, a point to note is that all of the CAD (computer aided design) software tools to design objects for digital fabrication have been developed in an industrial context. This inherently means that these tools support operations like extrude, revolve etc., but not traditional operations like weaving techniques (plaiting, twining etc.) for example. Digital design language therefore lacks a representation of the diverse making traditions and as such these are not accessible to people to design with. This projects to a subsequent decline in usage of these traditional methods resulting in them slowly fading out. Instead, modern design tools should celebrate the diversity of making traditions and harness the strength of digital means combining it with traditional operations and aesthetics to create objects that were not possible with either of them individually. Through this thesis, I explore questions around how traditional making practices can be incorporated in CAD tools. How can one approach the design of such a tool and what is the variety of design possibilities this opens up, once the traditional and modern techniques inter-*weave*. I present *InterWoven*, a CAD tool that aids people in creating designs using traditional basket-weaving techniques.

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Chapter 1

Introduction

We live in a world of transformation where digital means of fabrication are rapidly replacing traditional manufacturing processes. The interesting aspect about this is that for the first time, this is not only happening at an industrial scale, but also at an individual level [1]. More and more people are using personal digital fabrication devices like 3D printers and the software design tools associated with them. These offer tremendous scopes for enabling people from around the world to design objects they want and then have them created. This rapid iterative cycle of designing, fabrication and testing is resulting in a lot of people experimenting with designs that suit their needs, instead of looking up catalogues to buy them off the shelf. This puts forth the interesting fact that CAD tools are no longer restricted to just their use in designing industrial objects, rather they have become tools for creative self-expression and are being used both by designers and non-designers to design custom objects for themselves.

The popularity of these new means of fabrication asserts the notion that, we, as humans, have an innate desire to make objects. It is a profound human impulse. Making acts as a primary means of expression, be it through making objects, music, dance or any other output medium. Given the rich diversity of cultures across the world, people have practiced diverse making traditions, resulting in an immense diversity of designs and

ways of making objects itself to emerge over thousands of years. Basketry for example, is one of the oldest artifact making practices, and has been practiced for centuries in different parts of the world, resulting in wide varieties of processes, operations, techniques and designs. Beadwork is another making practice that has existed for a long time and has resulted in the creation of beautiful objects in various places.

Thinking about these two modes of making, with digital fabrication on the one hand, and traditional making on the other, we find similarities and differences that provoke thoughts and questions on the design of modern tools. We realize that modern CAD tools have largely been developed in an industrial context. They, therefore, lack a means of incorporating traditional operations and techniques in the workflow of designing objects. Therefore, the digital design language lacks a representation of the diverse making traditions and these are therefor not accessible for people to design with. This projects to a subsequent decline in usage of these traditional methods, resulting in them slowly fading out.

CAD has transformed from an industrial tool to a personal tool, yet CAD tools are still primarily influenced by industrial practices, with little or no influence from diverse traditional making practices. I believe we are at a very interesting juncture, with digital making methods having spread to various makers around the world and people appreciating the computational power that it offers, to create design interventions that incorporate traditional operations as means of making, within these tools.

When design techniques of the past weave together with the strengths of the computational media, it opens up a new design language, with each building on the other to produce design possibilities not possible by either of them separately. *InterWoven* explores this through a CAD tool that enables designers and hobby makers to design using traditional operations. To anchor the tool around a specific traditional craft, we built the tool around basket-making practices. The process of building the tool itself, as discussed in later sections, presents an approach of thinking how traditional making practices can be incorporated in modern day CAD.

Such a tool raises questions around what it means to digitally implement traditional operations as algorithms that a designer can easily invoke in their workflow of designing objects, how this representation allows for thinking of designs that wouldn't have been thought without their ready availability, how such a tool can be an entry point for people to experience and understand traditional practices themselves and what the different design strategies are that may be adopted for different audiences of such a tool (digital makers as opposed to traditional craftsmen).

1.1 Contributions

In this thesis I present the design and implementation of the InterWoven CAD tool, which allows for integrating traditional basket weaving craft techniques into a modern day CAD paradigm. I discuss the broad framework of the tool, and how that can serve as a starting point for CAD tools of such nature. I present the design and software implementation details of the two parts of the tool, one which allows a person to create a basket from the ground up, using all the sequential steps needed to create a basket and the second part, which is more tightly integrated in current CAD workflow, allowing to apply different basket weaving operations to shapes designed using regular CAD software. I show the various design possibilities opened up by the tool to create design outputs that go beyond what either traditional weaving or CAD would have allowed for individually.

1.2 Road Map to the Thesis

In Chapter 2, I review the context in which CAD tools first came about and the how their early design intentions set in motion the advancements we saw in them over the years. This leads to looking at how CAD tools are being re-contextualized with a rapid rise of digital fabrication machines like 3D printers, causing the personal fabrication revolution [1]. With this rapid spread, the purpose of CAD tools has dramatically shifted from industry specific design outcomes to more creative expression and customized design of everyday objects. I then discuss how artists and non-artists alike are harnessing such tools to create custom designs and how researchers are responding to this shift by creating domain specific CAD tools to allow for easier design of specific objects. In Chapter 3, I discuss related works, which focus more on projects that have looked to address the lack

of traditional ways of making in the digital domain. In Chapter 4, I present the InterWoven tool, beginning with its framework and then discussing in detail the two parts of the tool, including the implementation details. In the next chapter, I present a preliminary qualitative user study. I conclude by discussing how the work serves as an initial embodiment in the research direction of how traditional making practices can influence and blend with digital design tools and practices. I also present future directions of work.

Chapter 2

Background and Motivation

"In any environment, both the degree of inventiveness and creativity, and the possibility of discovery are directly proportional to the number and kind of variables in it." - Simon Nicholsa [2].

2.1 A Brief History of CAD

As the designs of aircrafts and vehicles grew in complexity with advances in understanding of fluid dynamics, CAD tools emerged from a need to accurately draft these complex engineering designs for their successful production. Also, the volumes required of these objects kept increasing, especially with the demands of the Cold War era, thereby requiring research into how these drafting operations could be automated [3]. With the complexity of the designs, the accuracy needed in their drafting increased, thereby needing software tools, as opposed to human sketches, to match up with it. First-generation CAD software systems were typically 2D drafting applications developed by a manufacturer's internal IT group (often collaborating with university researchers) and primarily intended to automate repetitive drafting chores. Dr. Hanratty co-designed one such CAD system, named DAC (Design Automated by Computer) at General Motors Research Laboratories in the mid 1960s [4]. With a need to create complex shapes out of materials for the production of vehicles and aircrafts, these CAD tools were hooked up to

computer-numerical-controlled milling machines giving rise to the first CAD/CAM (computer-aided-manufacturing) workflows.

In essence, these have now grown to be the digital fabrication revolution we are experiencing these days. From 2D drafting, advances in research led to creation of tools that allowed for 3D design creations, with advances in curve and surface representations. The early research however, continued to be primarily driven by aircraft and vehicle manufacturers, like Boeing [4].

This brief history clearly highlights the influence of the industrial sector in the early design of CAD tools. CAD tools were inherently meant for the design of industrial objects and for machines that could carry out industrial operations. Their primary motive was to aid an engineer in the drafting process of these objects. As a result, CAD tools began to support operations that were derived from an industrial context and research in this direction continued to grow.

Even after these systems began to be developed independent of large manufacturing companies, and their use spread to design of objects beyond industrial parts, the initial design directions of CAD tools continued to be influential in the subsequent advances made. Therefore, the developments in various operations within CAD still continue to be derived from the industrial production context. Today, the physical design of almost all the objects around us relies heavily on 3D CAD tools. Modern day computational design tools, like SolidWorks [5], Rhinoceros [6], and AutoCAD [7] provide designers with the ability to model complex forms with great detail. These tools are operation-rich, enabling

experienced users to create 3D models to their exact detailed specifications. However, as noted, these operations are derived primarily from an industrial context. Therefore, these tools lack an inherent incorporation of operations that are central to the more traditional ways of making, like those present in basket making and beadwork, for example. This void of influence continues to result in a tremendous lack of representation of the diverse making traditions within modern day CAD, which are hence not accessible for people to design with.

2.2 CAD as a Tool for Craft in Today's World

> *"...in the Machine lies the only future of art and craft - as I believe, a glorious future; that the machine is, in fact, the metamorphosis of ancient art and craft; that we are at last face to face with the machine - the modern Sphinx-whose riddle the artist must solve if he would that art live...." - Frank Lloyd Wright [8]*

2.1.1 Artistic Expression Through CAD

CAD tools have moved beyond their sole use in industry and are being widely used today by both designers and non-designers to create everyday objects of personal interest. This has been largely aided by the growth of digital fabrication machines that allow for easily realizing free-form designs in the physical world. Every new tool for arts and crafts opens new pathways for creation, and the use of computers as art/design tools is no different. As Blaise Augera, head of Google Machine Intelligence points out (though in the context of deep dream artwork, but applicable in this scenario as well), "*Art has always existed in*

a complex, symbiotic and continually evolving relationship with the technological capabilities of a culture" [9]. Computational design tools are expanding the practice of artists by enlarging artistic repertoires and opening up design to new physical possibilities [10]. Various artists and designers are harnessing the crafting strength of this new medium, as is exemplified in the work of these two wonderful artists/ designers/ engineers who are pushing the boundaries of design by the use of CAD and digital fabrication for personal expression [11][12][13][14].

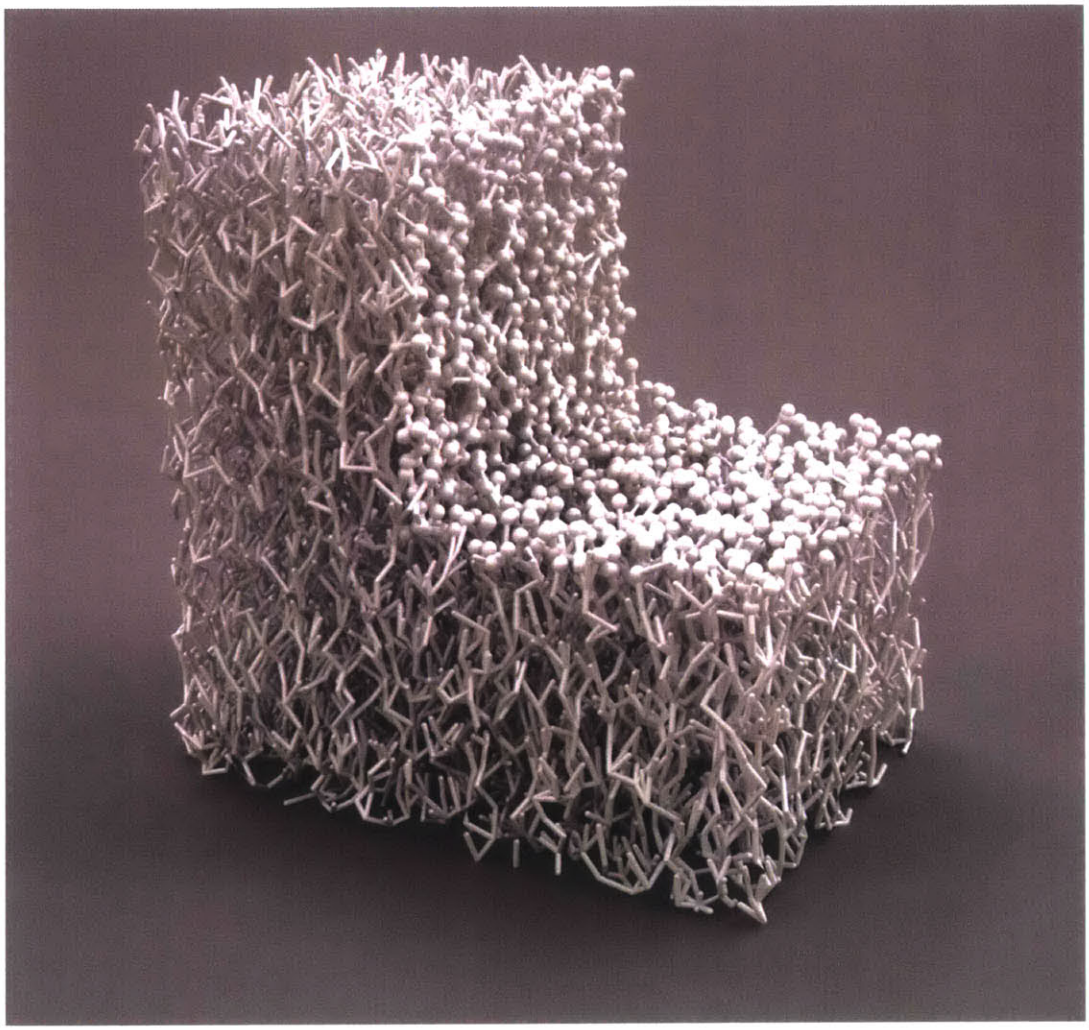

Figure 1. Bristle Shoes, Francis Bitonti

Francis Bitonti, a New York based designer, in his manifesto says that he makes designs for the information age. Given the advancements in fabrication, he assumes materials can be generated and modified as digital media. He goes on to say, "we don't design static things, we design systems and algorithms that shape materials." [11] In his work titled 'Bristle Chair' [12], Bitonti uses many tiny branches, which work together to form a rigid structural mass. The chair is developed algorithmically by reconstructing a cloud of

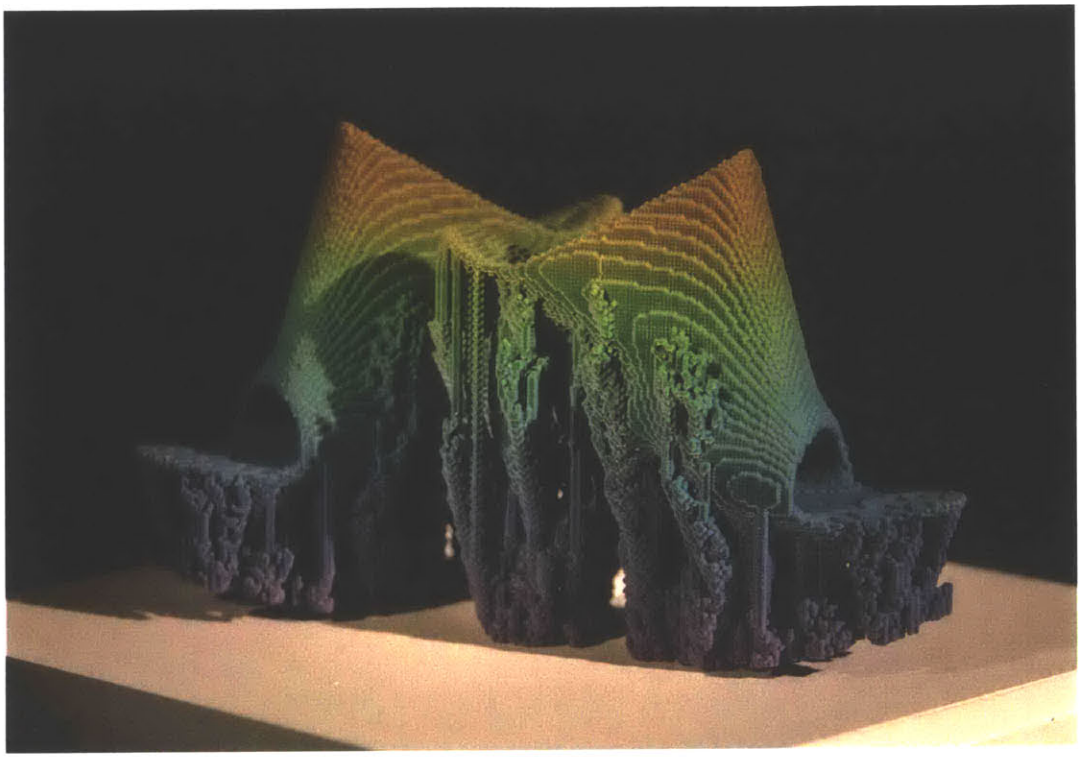

Figure 2. Molecule Shoes, Francis Bitonti

independent floating points (Fig 1). He also created the 'Molecule Shoes' (Fig 2), which were designed by custom written algorithms using Adobe design tools [13].

Neri Oxman also uses 3D design and printing as a means of creative expression. She takes inspiration from mythical stories and nature. Among a plethora of designs, she has created a dress called Anthozoa (Fig 3) in collaboration with the artist Iris Van Herpen [14]. Through this piece, Neri explored the use of multi-material printing (a form of printing I use in my explorations as well, to create basket inspired 3D printed outputs) to create hard and soft areas in the same dress, thereby beautifully merging functionality with aesthetics.

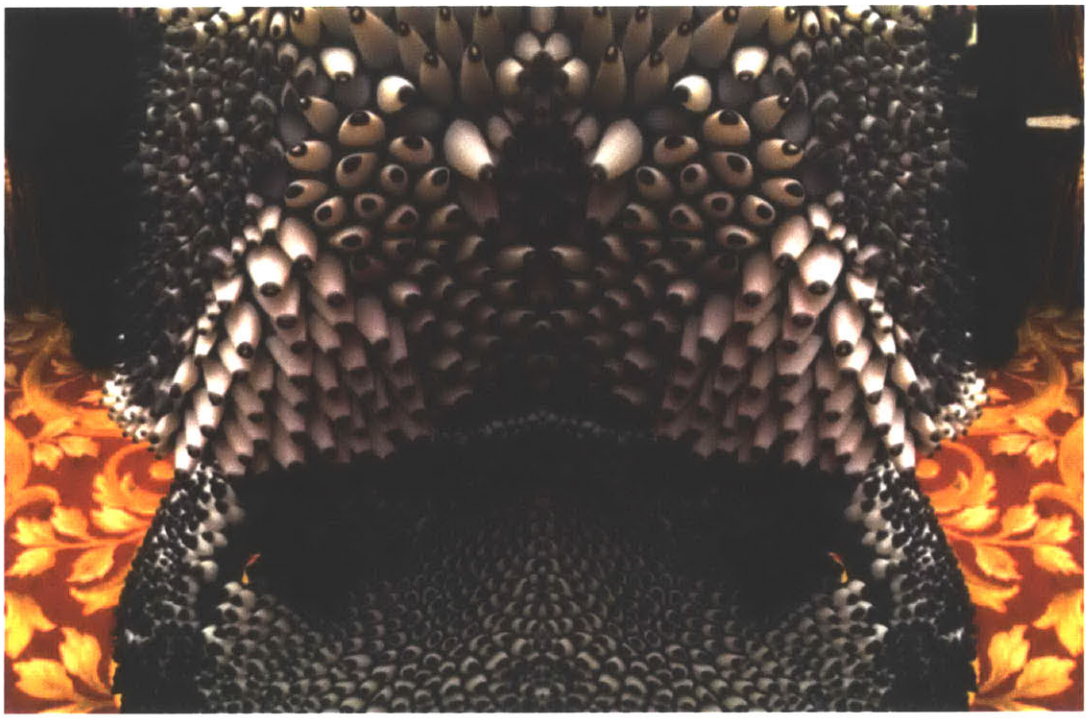

Figure 3. Anthozoa 3D printed dress, Neri Oxman and Iris Van Herpen

These works highlight the power of what the combination of algorithmic design and digital fabrication can result in. These works are a small representation of a large growing body of works, which are using CAD for artisitc expression. Computational design tools are increasingly becoming the 21st century's craft tools, as demonstrated through these examples. McCullough's wonderful book, 'Abstracting Craft: The Practiced Digital Hand' [15] examined digital design practices as a form of craft. Through the book he investigated the possibility of craft in the digital realm, observing that the emergence of computation as a medium, rather than just a set of tools, suggests a growing correspondence between digital work and traditional craft.

2.1.2 Domain Specific CAD Tools

"...the attuned craftsman asks, "What can this medium do?" as much as "What do I wish to do with this medium?"

"In theory you could draft with a paint system, if you set out to do so, but the raster data structure would hardly encourage the act; conversely, you could paint with a vector graphics system, but the experience would be clumsy at best. "

- Malcolm McCullough [15]

The workable capacities of something, be it a material or a tool, strongly influence the things that will be created out of it. Psychologists (and nowadays software experts) use the term 'affordances' to describe the workable capacities of a medium [15]. Just as in the physical world, it plays a crucial role in software design, especially when the software is meant for facilitating expression by its users. As McCollough points out, *"This reflects the truism that opportunities shape outlook: how we see the world depends on what we can do with it." [15]*

Within a CAD environment, these opportunities are the sets of operations that are provided in it. These are what the digital designer engages and experiments with, in order to move towards a design they like. The set of operations leads to thoughts and creations one would not have fathomed if those did not exist. Though Bret Victor situates his talk 'Inventing on Principle' from the importance of immediacy in output for the creative process, one of the key parallel takeaways from his talk is that of how the existence of certain operations leads to thoughts that one would not have thought of otherwise [16].

As Richard Hamming says, *"Just as there are odors that dogs can smell and we cannot, as well as sounds that dogs can hear and we cannot, so too there are wavelengths of light we cannot see and flavors we cannot taste. Why then, given our brains wired the way they are, does the remark, "Perhaps there are thoughts we cannot think," surprise you?" [17]* Jaron Lanier, in his book, 'You are not a gadget', [18] discusses how a tool affects and limits what you can make with it. In that sense, the operation set within CAD tools are critical as they directly translate to the creations that are enabled by it.

CAD is today increasingly used at an individual level, even by non-designers. Lawrence Lessig [19] argues that we have moved from a "read-only" culture to a "read/write" culture: instead of passively consuming information or products, users now actively participate in creating their own, personalized objects. CAD tools have transformed to powerful and popular tools for creative self-expression at an individual level, along with their continued use in the industry for designing mass-produced objects.

As more people get excited about designing their own objects, there has been growing research into creating CAD software tools that allow users (both trained designers and novice users) to easily create a large spectrum of designs. As observed, the design of the tool itself affords for creation of certain type of designs easily and not other kinds of designs. The primitive operations contained within the tool guide the designs that are commonly created by it. To create a highly custom shape that one has in mind, a designer has to combine different sequences of operations and commands, often in complex manners, thereby making it hard for designers (especially novice designers) to design

highly custom shapes from a raw set of primitive operations. Thus, if one set out to, one would be able to eventually design a traditional basket like woven object in CAD, however, the tools today do not afford such creations.

This inaccessibility of creating highly customized designs has led researchers to create domain-specific CAD tools. Takeo Igarashi's lab has carried out a range of projects related to creating domain specific CAD tools. SketchChair is one such example (Fig 4). It allows users to design their own chair by sketching with a computer stylus [20]. The design that is created can then be cut on a computer-numerical controlled (CNC) milling machine and assembled into a 3D furniture object. SketchChair includes a simulation tool that allows users to test the usability of their chairs before they cut them. Therefore, something as complicated as a chair design is made easy by building a custom design platform for it.

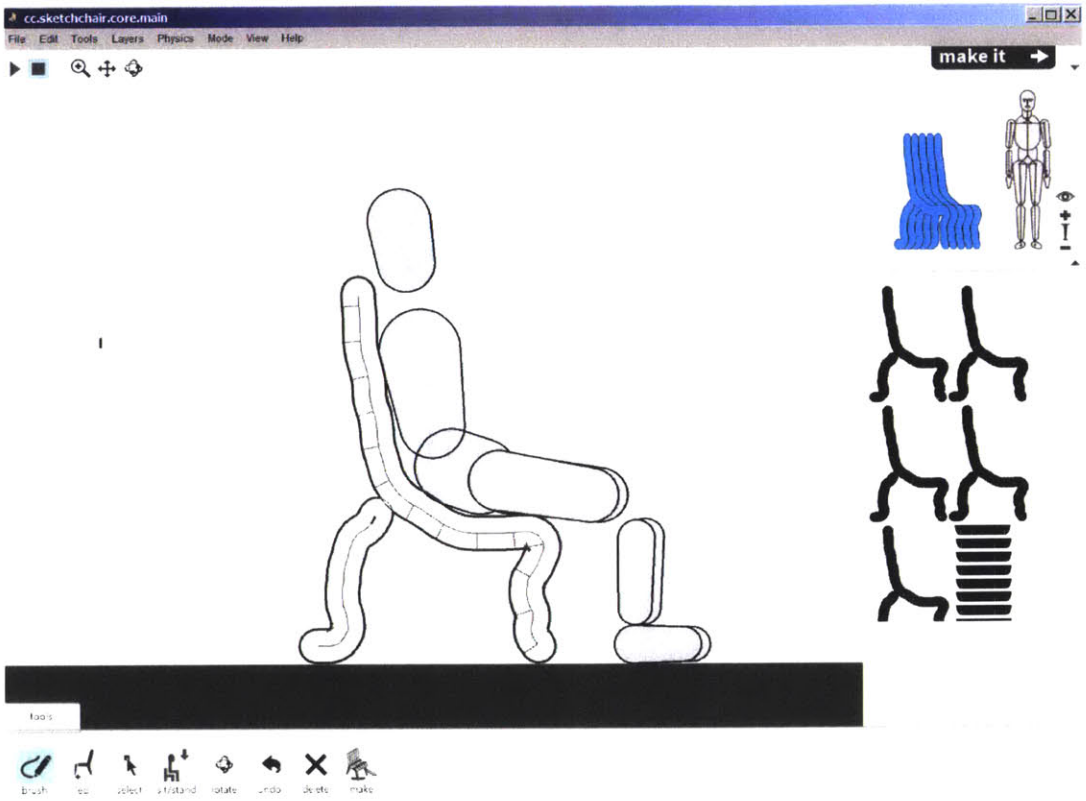

Figure 4. SketchChair- CAD Tool to easily design chairs

Igarashi et al. also created a very interesting tool called Beady to allow for easily creating 3D objects with beads (Fig 5) [21]. They created a software tool where one can design a 3D geometry or import foreign geometry directly and the system transforms it into a wire-structure, within which beads are inserted. After producing the simulation virtually, they also present users with a step-by-step construction guide to creating the artifact in the physical world.

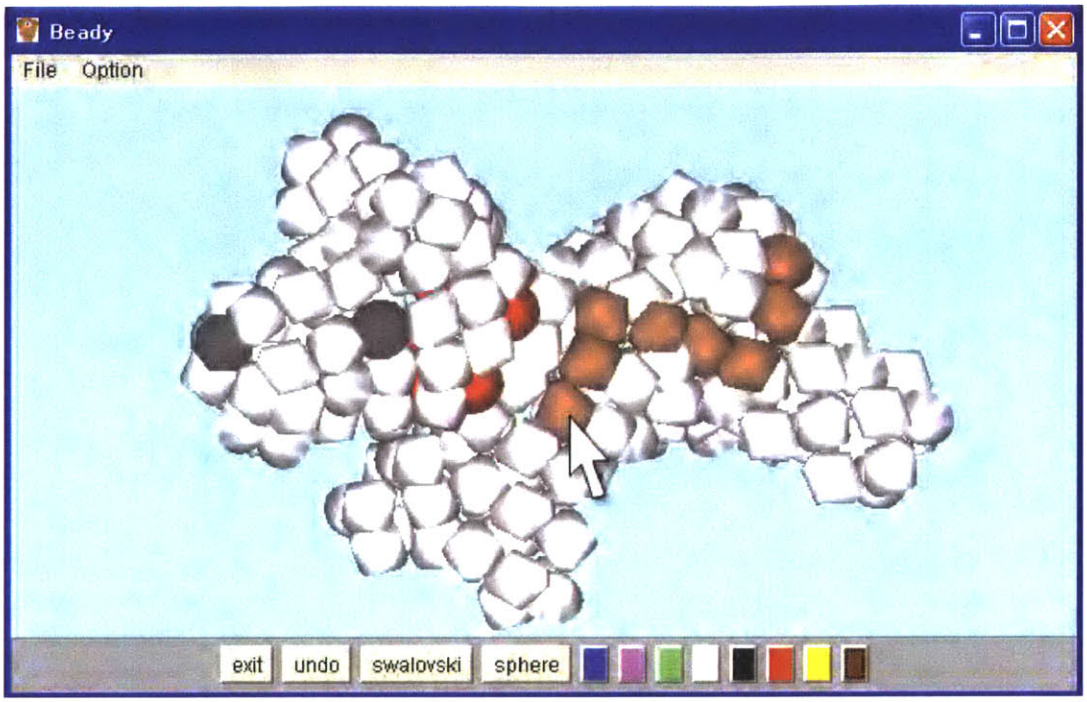

Figure 5. Beady - CAD tool to easily design and make 3D bead objects

Igarashi et al. also created Plushie (Fig 6) [22] that allows for novice designers to easily design custom plush toys.

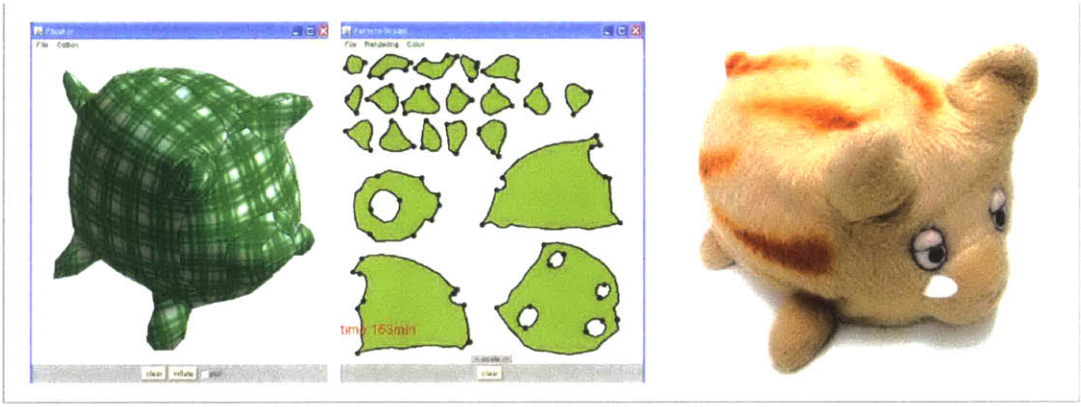

Figure 6. Plushy- CAD Tool to easily design plush toys

Jennifer Jacobs has done work that looks at writing computer programs as a means of creating craft. She terms her work as 'algorithmic craft' (Fig 7) [23]. In particular, she has written domain specific environments called DressCode and Codeable Objects, which act as manifestations to exemplify the broader concept of writing computer programs to create designs to build objects.

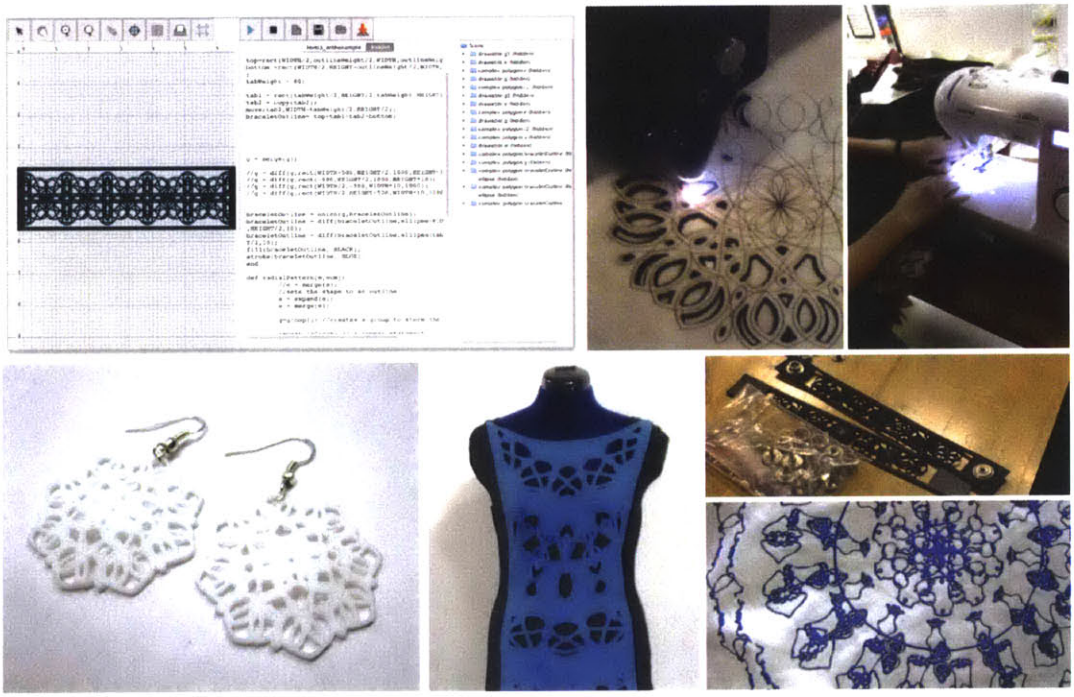

Figure 7. Algorithmic craft- showing the tool and its various outputs

In my own previous work, I have looked at how one can use a visual programing language to design 3D models that can be 3D printed. To this extent, I built an online platform called Fabcode (Fig 8), as a means of combining computational thinking with digital fabrication [24][25].

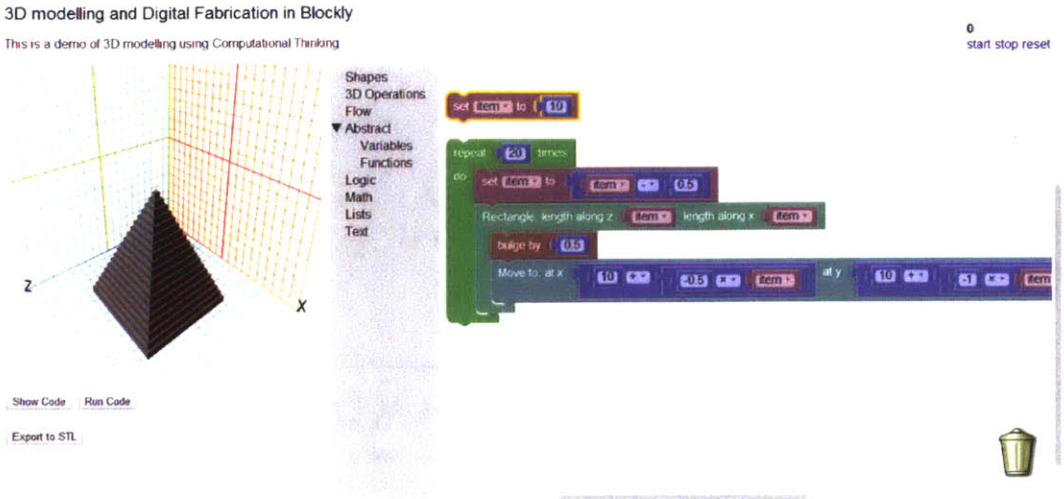

Figure 8. Fabcode- A visual programing platform for 3D modeling and printing

Mothersill et al. created EmotiveModeler, an emotive form design CAD tool (Fig 9) [56]. The tool helps people design emotive character within objects more easily. It does so by integrating knowledge about emotive perception of shapes into a CAD tool that uses descriptive adjectives as an input to aid designers in creating objects that can communicate emotive character.

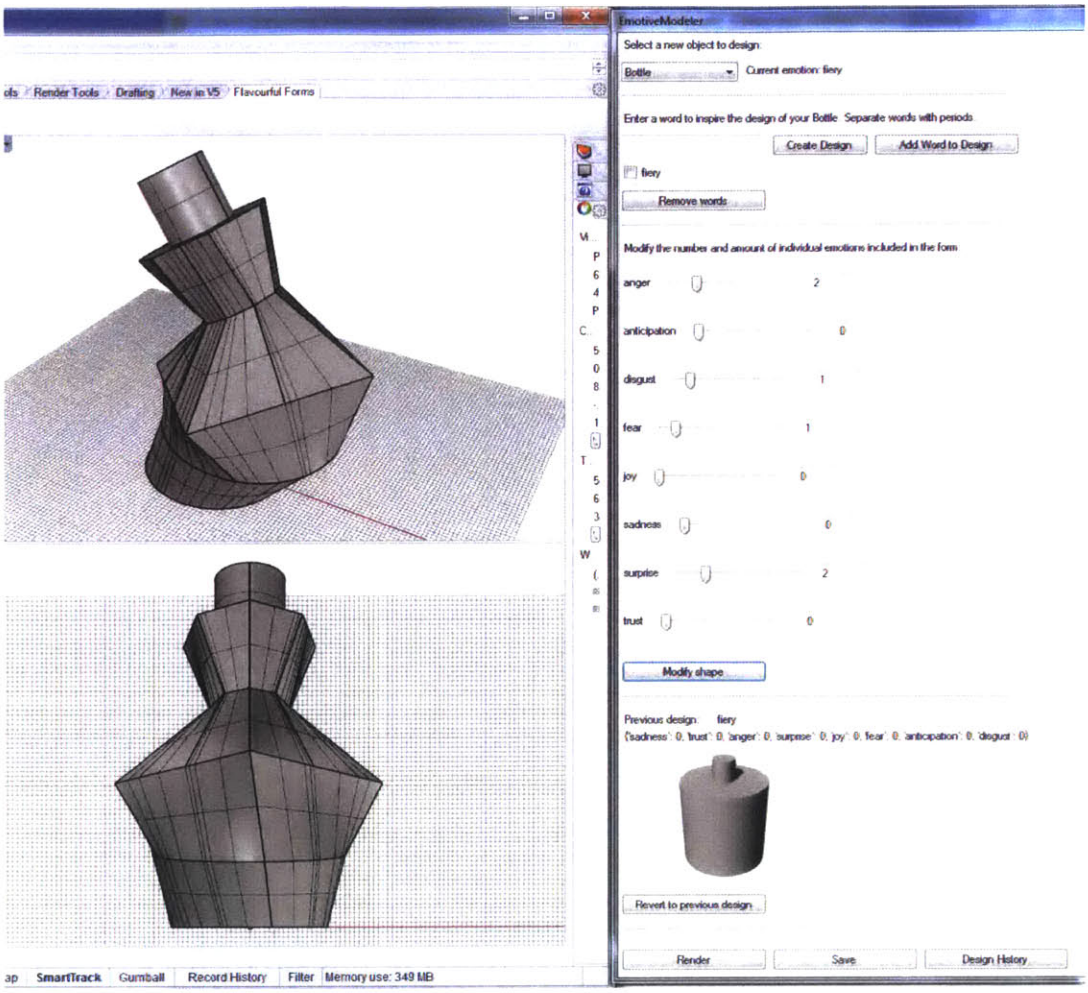

Figure 9. EmotiveModeler - an emotive form design CAD tool

Another interesting example of a series of custom tools that gives high-level parameters to users to design specific objects like jewelry, dresses and lamps is the Nervous System's design tools series [26]. Nervous System is a generative design studio that works at the intersection of science, art, and technology. They create their designs by writing algorithms inspired from nature and bring these out to users through a user-interface where they can tweak parameters to customize shapes of artifacts. These designs can then be physically produced using digital fabrication. Among other works,

they have created a series of dresses called 'Kinematics', where they turn a three-dimensional dress shape into a flexible structure using 3D printing by creating small interlocking modules (Fig 10) [27]. They also provide software tools for editing the shape of the dress to fit a person, and then have the user choose from a few different interlocking module designs to apply to the surface.

Figure 10. Nervous System Kinematics dress user interface

They also created Radiolaria (Fig 11) [28], a bio-inspired design app using which a person can design jewelry items.

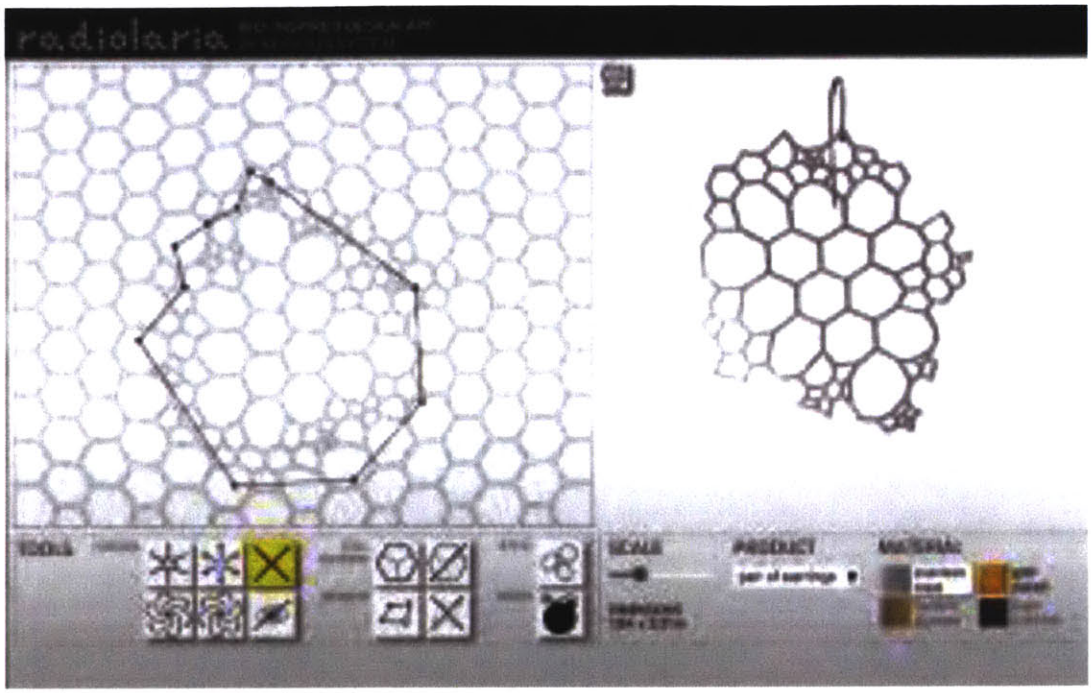

Figure 11. Nervous System user interface to design jewelry objects with algorithms inspired from nature

There has been a lot of work done in the domain of creating different kinds of CAD tools. All these share the core functionality of providing a means of designing and making objects. However, little research has been done in the area of creating CAD tools inspired by traditional making practices and techniques to provide for carrying out of traditional operations in digital design.

Chapter Three

Related Work

While in the previous section, I discussed various domain-specific implementations within CAD, which highlight how design of different kinds of objects requires a corresponding creation of a toolset within CAD, in this section I focus more on projects that have looked to address the lack of traditional ways of making in the digital domain.

In some sense, the situation today can be paralleled with that of how the early age of industrial revolution and the subsequent Arts and Crafts movement emerged. The Arts and Crafts movement emerged as one of the most powerful philosophical objections to the changes the industrial revolution was introducing to society. Scholars and practitioners like Morris, Voysey, and Stickley were in objection of the uniformity of aesthetics, functionality, and material composition of mass-produced objects [29][30]. Though the digital fabrication and emerging maker-movement [1] promise decentralized production and can thus be viewed as different from the practices of the industrial revolution, there are details to it that need to considered carefully. The tools for the digital maker-movement used for design and fabrication have been developed in a pre-dominantly industrial context. Therefore, even though the design and fabrication happens in a decentralized manner, the very fact that the tools used are developed in an industrial context results in a design language that does not afford for designing with traditional making methods (like basket making weaving operations). Therefore, even though digital

fabrication tools offer decentralized opportunities of design and fabrication, the design primitives of these tools are such that they lead to lack of designs made with traditional operations, especially in the case of hobby makers, who are not skilled enough to use the general purpose tool to create highly specialized personal designs.

Some researchers have looked at how traditional craft practices can influence digital design tools. Jacobs et al [31] performed workshops with craftsmen at the Kalahari Desert in Namibia (Fig 12) to compare their practices with those of digital making and see how the former could inform the design of the latter. Working together with the local people, they merged digital tools with ostrich eggshell jewelry craft. As one of their findings, they suggest the development of *domain-specific CAD tools* that enable designers to reconfigure virtual and physical modular parts through a small number of operations that are derived from the topology of the parts themselves. While this approach does serve to transfer traditional craft to the digital domain to a large extent, in some sense it also takes away from the strengths of the computer as a craft tool. It also brings up the question of the audience of such a tool. Such tools could definitely play a major role in enabling non-digital cultures to take up digital design, as they would be presented with similarities to their traditional knowledge of making things. The more digitally attuned designers might find a need to blend these domain-specific operations with other operations they are familiar with to exploit complete expression capabilities of these new operations themselves, especially with digital fabrication allowing very complicated shapes to be realized in the physical world. Jacobs et al also suggest that the domain specificity of such a tool could serve as an alternative to current tools that require

designers to work from an expansive set of operations to generate custom forms. This is in line with the ideologies of various domain specific tools presented in the previous section.

In the tool that I have built (presented in subsequent sections), I experiment with providing domain specific operations of basket weaving within a larger CAD environment and show how that results in unique outputs that would have been difficult to create with either independently. I also present a part of the tool where the design approach is different. In that part, the operations and effects are a result of the topology and physical properties of the basket making material and sequential nature of the basket making process itself. This results in greater understanding and learning of the actual process, and produces outputs more in line with shapes produced in traditional making. However, these too can be modified with regular CAD operations.

Figure 12. Jennifer Jacobs conducting a 'Hybrid Craft' workshop with craftsmen from Kalahari desert

Amit Zoran has carried out various projects with the aim of combining hand craft with digital precision. His projects primarily focus on how one can take a hybrid approach to physically producing an artifact, with parts of it created through machine driven processes and parts of it made by hand (rather than it being completely digitally manufactured). Among his works, Hybrid Basketry [10] (Fig 13) is closely linked to my work. Through this work, Zoran looked at how 3D printing techniques could be merged with practices of hand weaving for basket making. He created different baskets, within which most baskets had a 3D printed structure into which he hand-wove organic strands. This hybrid approach to designing objects serves an interesting perspective on how traditional crafts can merge with digital manufacturing. In contrast, in my work, I focus primarily on how traditional techniques can be part of digital design tools themselves and

what design possibilities they open up for novice to expert designers.

Figure 13. Hybrid Basketry from Amit Zoran. The white structure is 3D printed and the reed is hand woven into it

Ron Eglash has done a tremendous body of work on creating culturally situated design tools [32], where he studies mathematical patterns in designs of different cultures to create online design tools (Fig 14). His work is situated mainly in a learning context, where, through explorations of underlying math of cultural patterns, people can gain both a mathematical and cultural understanding. His work also highlights how looking at various traditional making practices can offer new perspectives, in this case, in the field of Mathematics education.

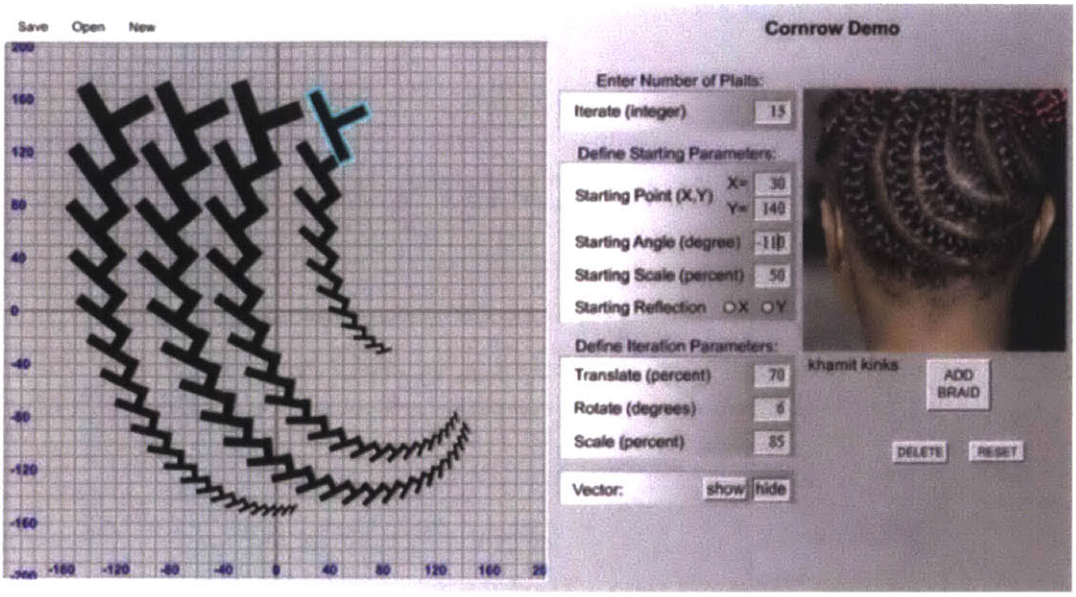

Figure 14. One of the examples of Culturally Situated Design Tools created by Ron Eglash. This one allows for generating hair-braid using mathematical understanding

Leah Buechley created a series of works which [33][34], through which she studied how traditional electronics could be combined with various crafts like carving (Fig 15), sewing, painting and drawing. One of the interesting aspects that emerged from her studies was how the introduction of new materials like wood, textiles and paper resulted in the growth of the diversity of artifacts, by expanding the "material landscape of technology." She also went onto discuss how such an inclusion of various craft practices led to a diversification of people participating in carrying out electronics related projects as well (Fig 16) [35].

Figure 15. Crafting Technology: Creating circuits by carving out connectors

Figure 16. Crafting Technology: Engaging diverse participants in various ways of crafting electronics.

Chapter Four

InterWoven

> *"Baskets speak a universal language. For the historian, they are a signature of time and place. For the collector, they are an art form of wonderful variety and beauty. And for the maker, baskets offer the chance to work in a range of styles, sizes, colors and techniques almost without limit." - Billie Ruth Sudduth [36]*

In this section I present my approach to designing the InterWoven tool and present its broad framework. I also include a discussion on the primary intended audience of the tool. I then go on to describe the tool and how a personal study and understanding of different basket making techniques helped me in its making. I provide implementation details and describe the various design possibilities the tool opens up.

4.1 Basket Making

Basket making is one of the oldest and widest spread crafts in the history of human civilization. Some of the oldest known baskets have been carbon-dated back to 10,000-12,000 years [37]. Though ancient, basketry is a flexible craft that was independently developed by many cultures across the world. It appears in all kinds of forms, designs, and sizes. Raw material for making baskets vary from bamboo and cane [38] to pine and leaves [39], and today even metal and plastic wires. Over years, baskets have found various uses. Their common usage has been for storage of food and vegetables, but there

have been various other purposes they have been used for as well. They were used as fashionable items in the Victorian era in the form of wicker furniture, whereas during the World Wars, thousands of baskets were used for transporting messenger pigeons. Many basket-making practices also borrow from different crafts, for example, to make wooden handles and bases, to make marble decorative pieces on baskets etc. Several contemporary makers have worked on creating beautiful basketry examples, combining different craft techniques, as illustrated by Billie Ruth Sudduth's in her book- 'Baskets: A Book for Makers and Collectors' [36].

Craftsman and artist, Stephen Kostyshyn has created a series of works that combine pottery and basket making (Fig 17). His baskets are made with a combination of three materials- clay, fiber (reed) and wood. For his baskets, he begins by creating a vase using traditional wheel-throwing and hand building techniques. Once that is done, he positions and glues reed, dowel, or ash spokes in place. This stabilizes the form for weaving. The final process is the weaving using natural and dyed reed [40]. Kosthyshyn says, "Breaking from the clay-only vessel and exploring the endless possibilities afforded by basketry as an art form has allowed me to explore shapes and textures that were unattainable to me in the past," highlighting the design power of basketry as a craft and how it offers readiness in being adapted to different making practices.

Figure 17. Stephen Kostyshyn's artifact which combines pottery with basket weaving practices [38].

Gerri Johnson McMillin is another artist who experiments with the basket making process, in both materials and practice (Fig 18). She uses Albacore pectoral fins (fish bones) and monofilament (fishing line) to create her vessel forms. She carries out her own fishing trips to collect the Albacore, whose pectoral (side) fins she transforms into "beautiful magical pieces of art." She calls them her "jewels of the sea, my vessels of remembrance."[41]

Figure18. San Miguel (2002). A basket made by Gerri McMillin using fishbone, monofilament and shells

These qualities of the basket-making tradition- its flexibility with new materials, its ever growing variety of uses, use of variety of techniques for creating it and most importantly its presence as a traditional making practice across the world make it an ideal practice to

incorporate into CAD tools. (As an interesting side point- the terms "technology" and "textile" are both derived from the Latin texere, meaning to weave, connect, and/or construct [42]. It seems all the more fitting then, to weave traditional basket weaving in modern day digital design practices).

Figure 19. A collection of baskets created from the technique of twining [43]

4.2 Approach and Design of the Tool

InterWoven is a CAD tool that provides ways of designing with traditional weaving (and coiling) and pattern design operations used in traditional basket making practices. The tool allows for creating such designs in two broad ways (Fig 20):

1) A user designs from the ground up an artifact using basket-weaving techniques directly. Here, the operations and effects are a result of the topology and physical properties of the basket making material and the sequential nature of the basket

making process itself. This method results in greater understanding of the traditional process and produces outputs more in line with shapes produced from traditional basket making.

2) A user designs the shape of an object and then transforms that into an object that is made of the different basket weaving techniques they choose. Users can combine different weaving techniques within one artifact, design patterns for the same and also vary density of weaves across the structure. This is more as a means of providing different weaving operations and options within the workflow of modern day CAD.

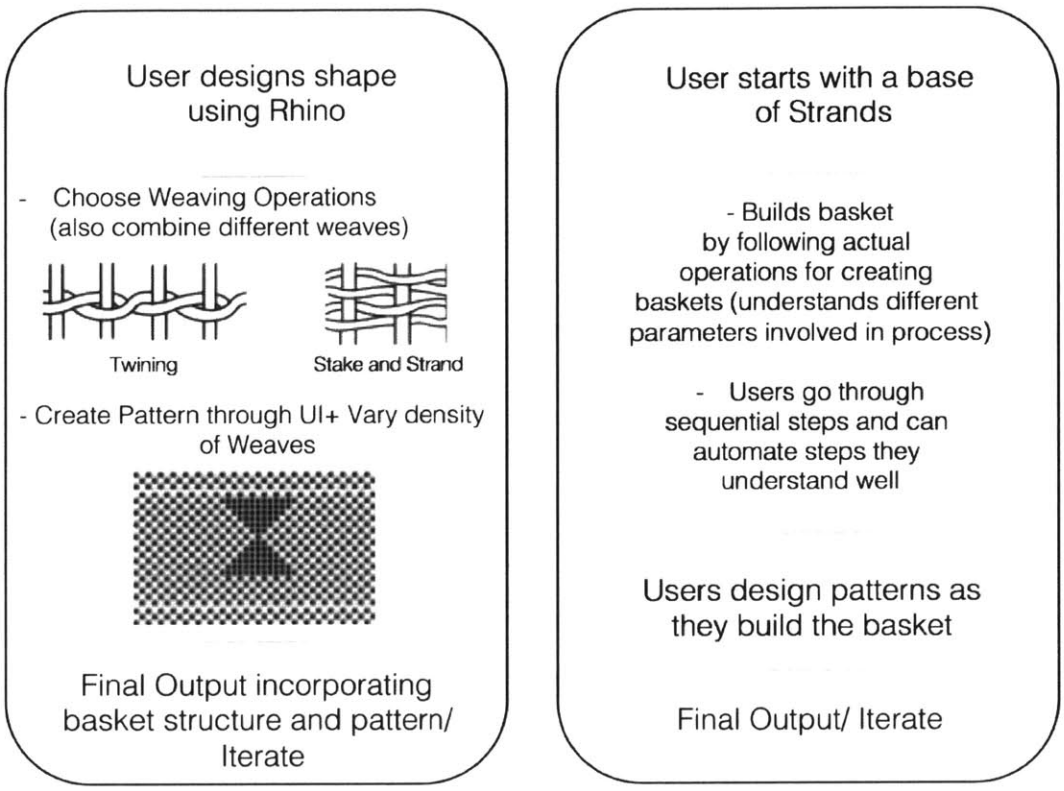

Figure 20. The basic CAD tool framework, discussing the 2 approaches that the tool supports to create objects with traditional operations of basket making. 1) User designs shape of object using Rhino and transforms that to a woven structure 2) they create the entire shape from ground up using basket-making methods.

An important part of this approach is to situate InterWoven within the context of a regular, larger CAD tool. This is primarily to ensure that the user can experiment with the wide range of design capabilities that open up through a combination of traditional weaving operations that InterWoven provides and regular CAD operations available within the larger CAD tool. Even with the first part of the tool, which essentially

simulates the creation of a basket in a stand-alone manner, I feel a lot of interesting opportunities arise when such a tool can be combined with the powers of computational design at large. For example, one can cut out a pattern from the surface, form a free-form surface shape (as vertical strands of the basket) or add a decorative element, and so on. I explore some of these possibilities by creating designs shown in Fig 21. This is also especially important when the tool is situated in the context of being used by digital designers, who rely on the larger set of operations provided by regular CAD to modify designs and be expressive to the fullest.

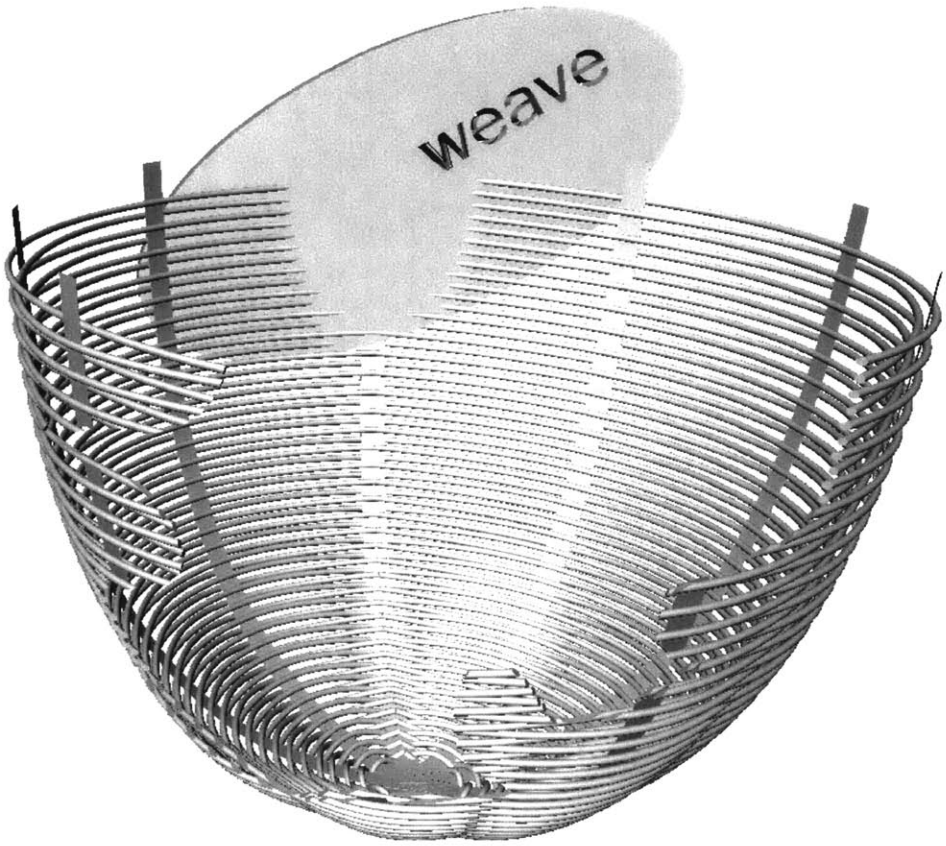

Figure 21. Adding design expressivity using CAD functions to cut out a free form shape and add a decorative text element to a basket made from ground up using the InterWoven software tool

4.2.1 The Primary Audience of InterWoven

The two major categories of makers that exist today are those who use digital design tools in their process of making (at least to some extent) and those who don't. The primary audience of the InterWoven tool is the former set of people. The tool looks at how traditional operations can be incorporated and provided to people who use digital design tools to create objects. Given the lack of representation of traditional operations and techniques in digital tools, InterWoven looks at what the access to such operations can result in, especially in their combination with the strengths of the computation media. An approach to designing a tool for the latter might mean a much more domain specific, to some extent, constrained tool, so as to ensure they feel familiar in the design territory. The first part of InterWoven (designing a basket from ground up) could perhaps serve as an initial implementation of such a tool. Though I do not try it out with the latter set of audience in the scope of this thesis, and hence its viability in terms of design for such an audience remains a speculation.

4.3 Part 1: Crafting a Basket from Ground Up

4.3.1 Understanding Basket Weaving Craft Through Self Practice

I carried out a personal project of making a simple stake and strand basket using round and flat reed. Stake and strand baskets consist of two sets of interlaced elements (flat and round reed in my case). One set is stable (the flat reed), while the other is moved in and out of the stakes (round reed) [44]. To prepare myself and make myself familiar with the process of making the basket, I watched various Youtube videos on making baskets. I also visited various basket-selling shops in the region and correlated the crafting steps with the baskets I saw at the shops. Unlike traditional craftsmen who collect their own material from the wild, I ordered different thickness of round reed and flat reed from Amazon to get started on my experiments with basket making. While that is the nature of the society we live in today, I guess there is no right or wrong about it. However, I do feel that digital tools could benefit by including information on the processes of how such raw materials are obtained, through an extension of the tool itself, if a person were to desire a more thorough understanding. Once I had the materials and a general feel for how the basket is going to be made, I set forth on the task.

I began by laying out the base of the basket (these form the stakes) and held them together with a board-pin (Fig 22b). One needs to make sure that the number of vertical stakes around which the strands are woven are odd in number, so that the strands form a closed loop. As the number of vertical stakes is double the number of stakes laid out, I split one of the stakes into half using a pair of scissors. For the initial 2-3 strands, I used a long piece of yarn, as the gap between the stakes is less in the beginning and yarn serves

as flexible material for these small gaps. I then began to weave with the round reeds. The reeds (both round and flat) constantly require to be dipped in water, to give them flexibility (the red bucket on the table in Fig 22 contains water). I initially ended up snapping one of the round reeds, in an attempt to get them to go under and over the flat reeds. During the early stages of basket making (from about 3rd to 10th strand) is when the shape of the basket is determined. Shape here essentially refers to the roundness/ oval-ness of the basket. The shaping is done by applying pressure on the stakes as one passes a strand under it (Fig 22d). The greater the pressure applied, the more the stake curls up, thus, if one wants a highly curved basket- one applies greater pressure with each pass of the strand. One of the important points while doing this is to also provide equal pressure to each stake, else it leads to a slightly crooked basket, as happened with my basket making attempt (Fig 22g). To create a pattern (motif) on the basket, instead of passing the strand under and over the stake, one passes the strand continuously over it, thus letting it stand out and become a visual pattern. This can only be done after a certain number of strands have already been woven, else the structural integrity of the basket will suffer. The entire basket, while being made, constantly needs to be dipped in water to allow for shaping of the basket. The color of the reed becomes darker when dipped in water, which serves as an indicator whether it needs more water or not. Once a shape has been set, and one gets a hang of passing the strand under and over the stake, the process becomes a little repetitive, unless one wants to create a pattern. There is almost a rhythm to this repetitive nature of weaving, which is enjoyable, but can also get a little tiring, especially for larger baskets.

Figure 22. Learning by creating a stake and strand basket manually. a) Laying out the materials required. b) Beginning by laying out the stakes and dividing one of them into half to form odd number stakes. c) Forming the basket by weaving the strand around the stake. d) Notice how the thumb is used to apply pressure to the stake and bend it up to give shape to the basket. e-f) Finishing the basket. g) The finished basket.

4.3.2 The CAD Tool for Ground-up Basket Making

I translated this stake and strand basket weaving process into a virtual basket-weaving tool (Fig 23). This tool runs within the Rhino CAD platform [6]. Using this tool, a person can create a custom basket. The tool provides them a means to carry out the sequential basket making steps, while giving them options to make various design decisions on the way and automate steps if needed. Using this tool, a person begins by laying out a single starting stake, and then chooses how many stakes they want to work with. They do this by entering a numerical value on the command line of Rhino. The command line serves as the interface for this part of the tool, giving the user various options to choose from as they carry out the sequence of operations to build the basket. The person can choose an odd number of stakes, to ensure that the alternating strands form a closed loop around the stakes. This results in all the stakes being laid out equally spaced from each other in a circle. The person then begins the weaving process. Based on the thickness of each stake and number of the stakes, the tool determines where to begin the first strand. The distance of the first strand is equivalent to the distance of the intersecting point of 2 adjacent stakes from the center (origin). This is to prevent the strand from weaving into a solid stake. As the strand goes around the stake, it bends up the stake under which it goes, as is done by applying hand pressure while weaving a physical basket. The amount of pressure to be applied is a choice the user makes through a numerical input - the higher the value - the greater the pressure - the more the bend. This simulates the physical properties of sufficiently wet reed. By performing a few iterations, the user understands the effect of the pressure strength on the bend and henceforth the overall structure. Each iteration of carrying out the weave presents the user with the option of choosing which stakes they

want to weave over (in order to allow for pattern generation). They can either select the particular stakes by clicking on them, or choose to go for the regular alternating weave. With either option, they can choose the pressure value or go for the default pressure value. This also results in the user understanding over a few iterations of making baskets, that it is better to begin pattern generation after the shape of the basket has been determined through initial regular weaving iterations, else the shape of the basket is likely to be lopsided (because not all the stakes would bend evenly) (Fig 23f). After eight initial weaves, the stakes stop getting curled up. The length of the stake determines the angle to which it will curl up with a given pressure value (with the angle being inversely proportional to the length). The user can also choose to *automate* the process for a certain iterations of weaves, which repeats the last weave the number of times the user chooses to repeat them. The user can carry out various other design experiments through the regular toolset offered by the Rhino CAD environment. Such experiments would have been tricky to execute in the context of a physical weaving process. The designs thus created can either be 3D printed or serve as a starting point for someone to use basket making material to realize them in the physical world, by following the steps from the virtual basket they made.

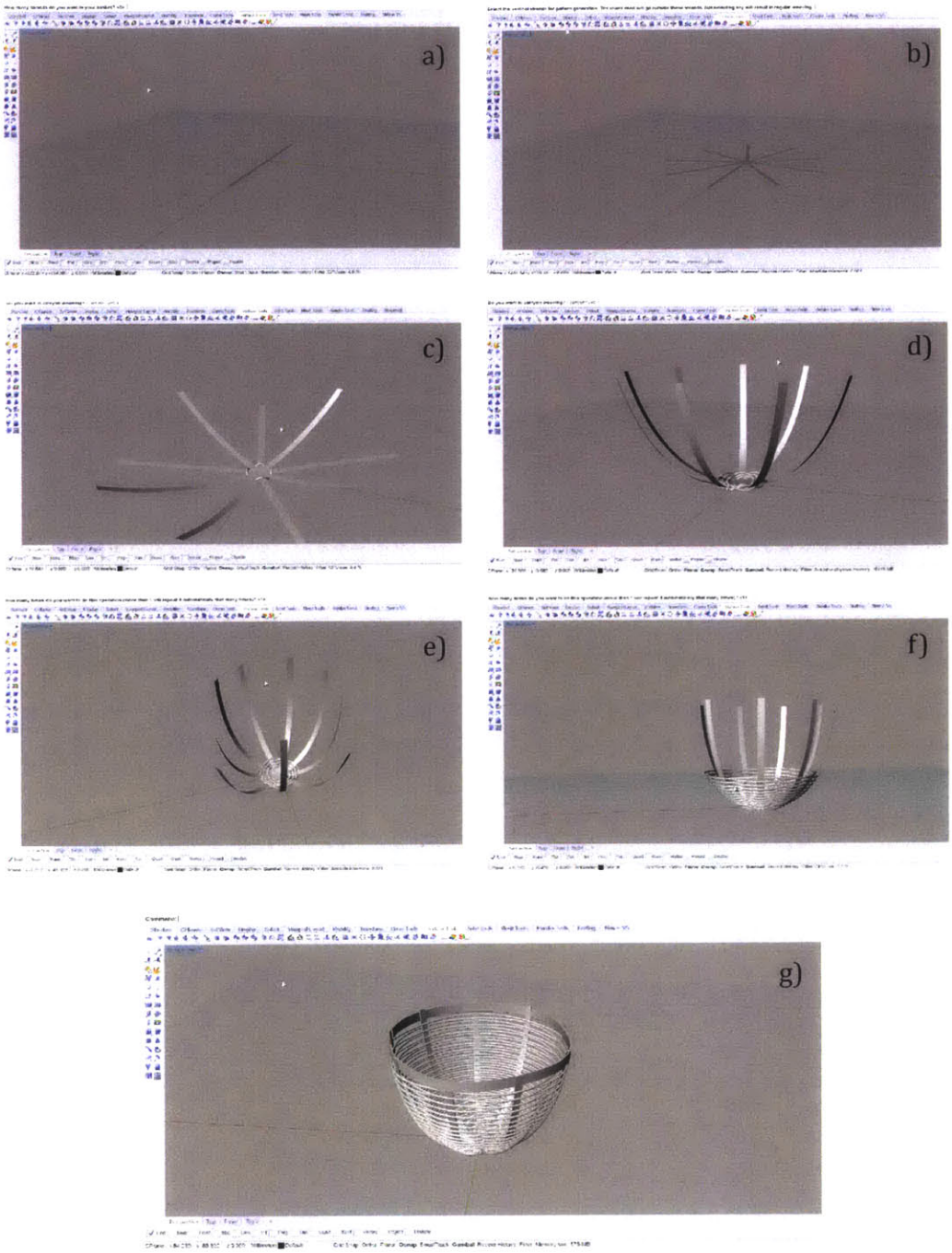

Figure 23. Steps of the Software tool for making a basket from ground up. a) A user begins by laying out a single stake. b) They then choose how many stakes they want in their basket. c) The user then follows steps in creating the basket. The user determines the pressure applied to the stakes at each iteration, causing alternate stakes to bend accordingly. d-e) After a few iterations (8-10), the basket forms its shape. f) The user can also automate the weaving and create patterns as they build up the basket. e) The basket is created as a result of the steps and the various parameters chosen by the user along the way.

4.3.2.1 Software Implementation

This tool (and the next one) is built within the Rhino CAD modeling platform. The implementation for both is written in Python with the use of Rhino Python library. We also use Grasshopper functions but port everything to Python (with the use of some of the GhPython Library components), instead of calling Grasshopper scripts separately. Grasshopper is a visual programing plugin to Rhino, which helps, in parametric modeling. This implementation approach holds for the next part of the tool as well.

The main step in creating this basket tool is to create the strands that go under and over the stakes in each iteration. To do this, we create each stake as a separate surface object within Rhino. For each surface, we divide it into a number of horizontal parts and two vertical parts. The number is based on length of the surface. We keep the diameter of the round reed fixed at 2mm. Therefore the number of horizontal divisions is equal to the length of the strand (in mm) divided by 2. We find the vector normal to the surface at each point of this division. We then re-arrange the points of each vertical stake into horizontal lists and offset alternate points of each list above and below the surface [Fig x0]. Interpolating between these points results in the strand. Based on which stake the strand goes under (which could be alternating or based on the pattern the user chose) and the pressure value chosen by user, we curl up the stake accordingly.

4.3.3 Reflections

The digital tool allows for an environment to explore the subtle intricacies of basket making, like how and when to generate a pattern, the effect of pressure on the shape of the basket, the role the number and thickness of stakes play in the process and so on. The digital manifestation bypasses some of the requirements of constant watering of reeds, doing away with any breakage possibilities, allows for automating the weave operations, provides for the ability to apply equal pressure easily as determined by a number, thus providing a comfortable environment to explore. Along with that, it provides strengths of the computational media to be expressive in varieties of ways in one's designs, weaving the traditional with the modern.

4.4 Tool Part 2: Incorporating Traditional Weaving in the Workflow of Current CAD

The second part of the tool looks at how different weaving techniques can be provided as operations within the CAD environment such that they can be more directly integrated within the workflow of a designer using CAD. It allows for creating more free-form structures.

4.4.1 Nantucket Lightship Baskets

The design of this part of the tool is similar in nature to how Nantucket Lightship Baskets are made [46]. I visited a Nantucket basket making studio called Gray Mist [47](Fig 24) to learn more about this craft. This place offers Nantucket basket making classes and runs a shop to sell the baskets produced in house.

Figure 24. Understanding Nantucket basket making at the Graymist basket making studio

Lightship basket making is an intriguing practice, which began in the early nineteenth century on the lightships of the Nantucket Island. These baskets have a standardized making process, with all the baskets made with an odd number of staves (vertical strands, similar to the odd number of stakes we had in the previous section), a solid wooden base, and a nailed and lashed rim. All the baskets are woven over a mold. A person takes a mold (made of solid wood), which determines the shape of the basket they want to make. To this mold they attach a base, which has a split in it to house the vertical staves.

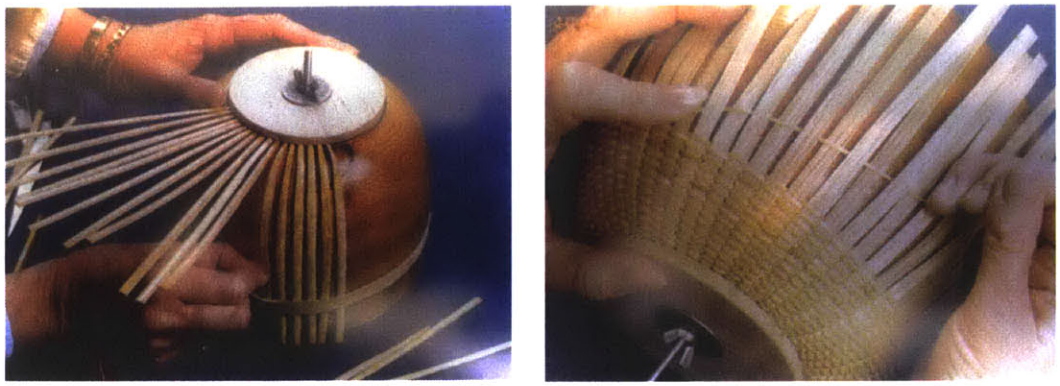

Figure 25. The Nantucket Lightship baskets are made by staves stuck into a base and weaving the strand around them. The staves are given shape using a mold [49]

The vertical staves are stuck to the base with glue. Once the staves are fixed, they are held close to the mold using a rubber band or something similar (till the initial weaves give it stability). The horizontal strands are then woven through the vertical staves, forming the basket around the mold (Fig 25). At the top, a rim is added in a similar manner as how the base was added. A wooden handle is generally added to the basket. Each basket mold has a corresponding handle made for it (Fig 26). The fact that each of these baskets has a wooden mold over which they are woven was very interesting to me. Figure 27 shows the various kinds of molds available in the studio. The lady at the studio who I most interacted with (Melissa Chao) told me that many more molds were stored in the go-down! This was interesting because to make a particular shaped basket, one had to essentially make the mold, and then the basket would flow from it. It also meant in a way that instead of being entirely grown up from nothing, this basket had been grown *around* a pre-determined shape. The use of molds also gave rise to interesting challenges in the physical basket making process.

Figure 26. Various handles for the baskets. Each mold has a corresponding handle made for it (at Graymist studio)

For baskets that are smaller at the top than at the base, the molds are held together with bolts, and when one is done weaving, the mold comes out in a few pieces, usually three or four. The other challenge is the maintenance of the molds to prevent environmental factors from damaging its shape. Another interesting aspect, suggesting the design strength of the mold is that over time, mold shapes get standardized. As an example, modern day standardized molds exist for wine bottle baskets. An interesting point to note is that molds also act as one of the primary areas for experimentation, with basket makers/ designers trying out different shaped molds to give different shapes to their baskets. The intricacy of the shapes is of course limited, given constraints of working in

the physical world. Melissa pointed out that creating sharp edged baskets (Fig 28) was considerably harder than rounded baskets for example.

Figure 27. The various molds for making baskets (at Graymist studio)

I studied about Nantucket Lightship basket making practice more online [46, 48] and through the wonderful book, 'Lightship Baskets of Nantucket' by Martha R. Lawrence [49].

Figure 28. Different shaped baskets, with my 3D printed basket among them (at Graymist studio)

4.4.2 Second Part of the InterWoven Tool

A user begins by creating a surface, which serves as the basic shape to be transformed to a woven structure. This resonates with how Nantucket Lightship baskets are constructed. Once the user creates the surface, the user begins to transform it to a woven structure through the GUI of the tool (Fig 29). The different features offered by the tool help experiment with different combinations of designs to create the final output. These features include: choosing different weaving techniques and ability to weave different weaves into a single structure (choosing how much of each weave one wants), pattern (motif) generation that is woven into the structure and also capability to vary density of weaves across the structure.

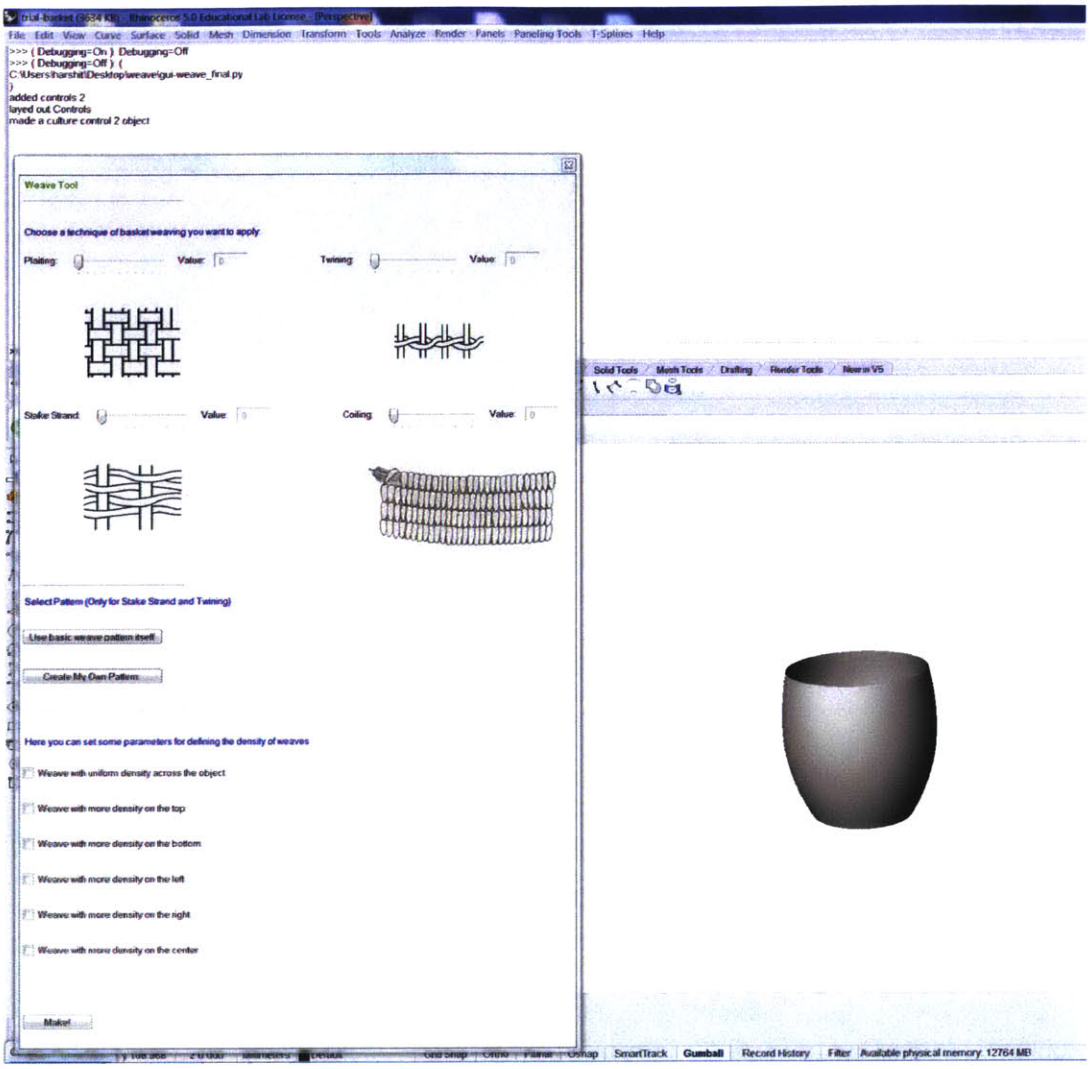

Figure 29. The InterWoven tool GUI

4.4.2.1 Weaving Techniques

The user chooses among different weaving techniques they want to apply to a surface. There are four weaving techniques currently supported by the tool. These include plaiting, twining, stake and strand and coiling (Fig 30, 31). Here are the descriptions of the 4 techniques [44]:

- *Plaiting* involves passing strips of material over and under each other at a fixed angle. It produces a checked pattern.

- *Twining* consists of passing horizontal elements (weft) around stationary vertical elements (warp). Specifically, it is a technique in which two wefts cross over each other between warps.

- *Stake and strand* consists of two sets of interlaced elements; one set is stable, while the other is moved in and out of the stakes.

- *Coiling* involves wrapping helically a moving vertical element on a stationary horizontal element (the foundation or the core). The foundation itself moves helically upward, forming the structure of the basket. The techniques used for coiling a basket are usually identified with sewing, rather than with weaving.

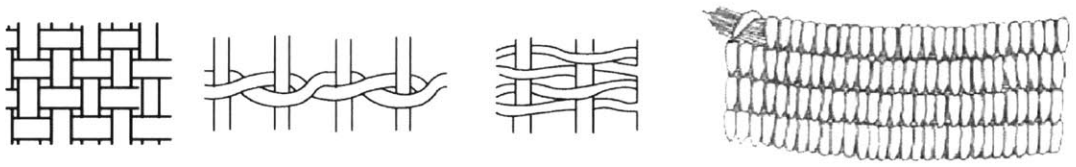

Figure 30. Different basket making techniques. (L to R) Plaiting, Twining, Stake and Strand, Coiling [44]

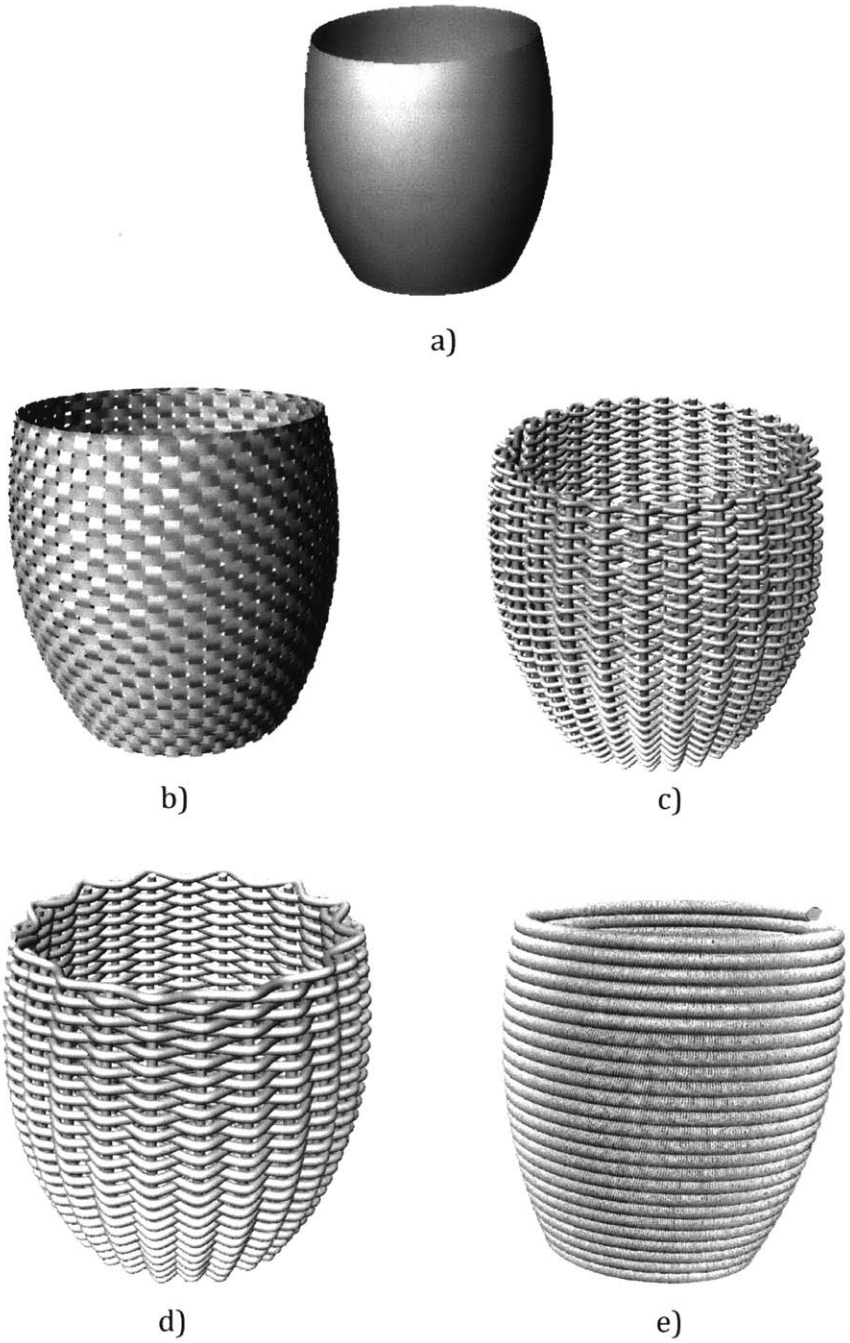

Figure 31. The different weaving techniques of b) plaiting, c) twining, d) stake and strand and e) coiling applied to a base structure (a)) using the InterWoven tool.

4.4.2.2 The Weave of Weaves

Another interesting feature that arises from the algorithmic embodiment of weaving techniques is the ability to *weave different weaving techniques together*, within a single artifact (Fig 32, 33). These are also available as options to the user, such that they can select how much of the structure they want woven in what weaving technique, combining coiling with twining for example, to give rise to interesting structures. Such features exhibit how the combination of traditional techniques with computational media can expand the scope of artifacts created beyond what would be created with either, on their own. Such artifacts would be difficult to make, if not impossible through traditional means of manufacturing, yet remain highly inspired by it.

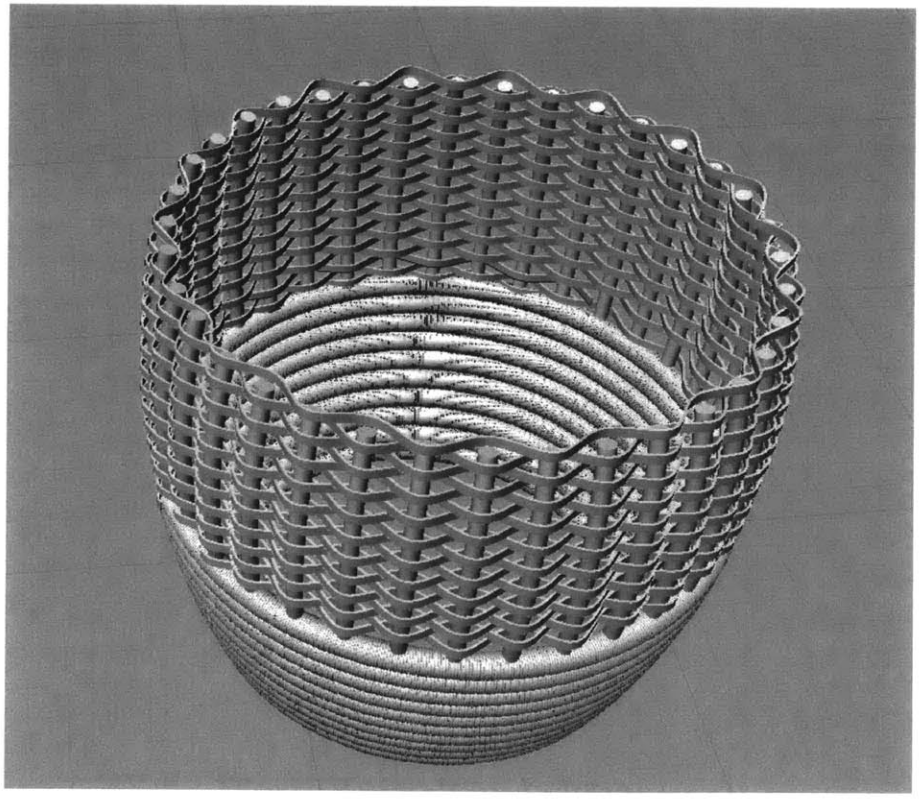

Figure 32. Artifact that combines coiling and stake and strand within a single structure

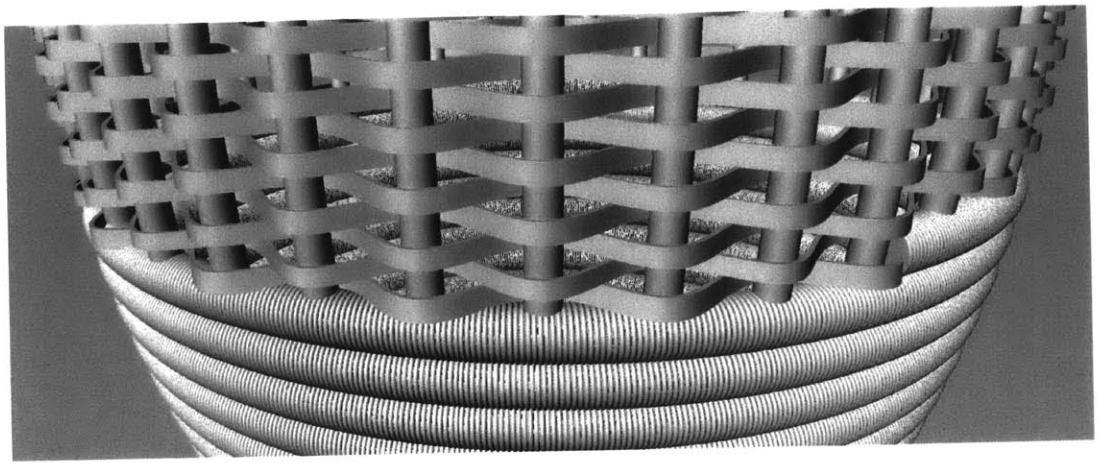

Figure 33. A closer look at the weaving together of weaves.

4.4.2.3 Pattern Generation

After choosing the kind(s) of weaves, the user then chooses the number of vertical and horizontal strands (warps and wefts) they want in their structure (for coiling, this translates to the number of horizontal strands (foundation) and coil density around it). Based on the number of strands, a pattern generation UI is presented to the user (Fig 34). The top and bottom three layers are kept reserved for regular alternate weaving. This is to ensure the structural stability of the artifact, because the alternating structure results in holding the horizontal and vertical strands together. Therefore, say that the number of horizontal strands the user chooses is 25 and the vertical strands is 40, then the user is presented with a (19 * 40) 2 dimensional matrix to create the pattern (Fig x with diamond pattern). Thus, the rounded structure is laid out flat for creation of the patterns. The user can choose to use the default alternate weaving pattern if they so desire (plaiting and coiling support default patterns only).

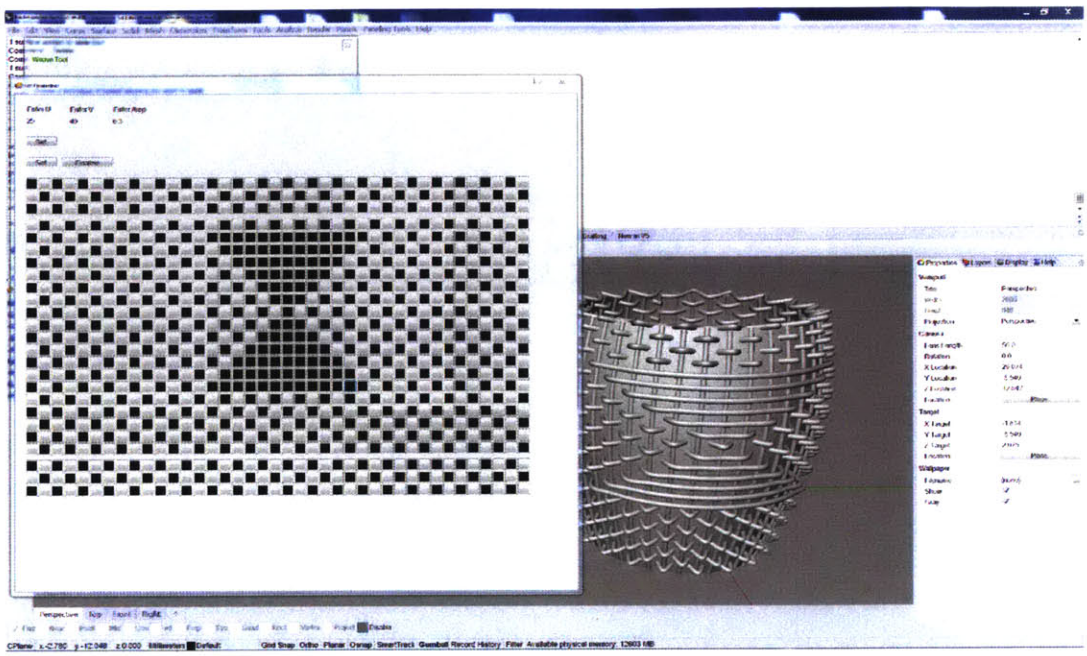

Figure 34. InterWoven pattern generation GUI

4.4.2.4 Density of Weave

The user can also specify some higher-level parameters like the density of weave across the model (Fig 35). They can choose from various options available, allowing for varying the density of the weaves across the model. Given that all these models can be realized in the physical world by 3D printing using material with varying flexibility, a combination of changing weave density and flexibility can result in interesting outputs, both from an aesthetic and functional point of view.

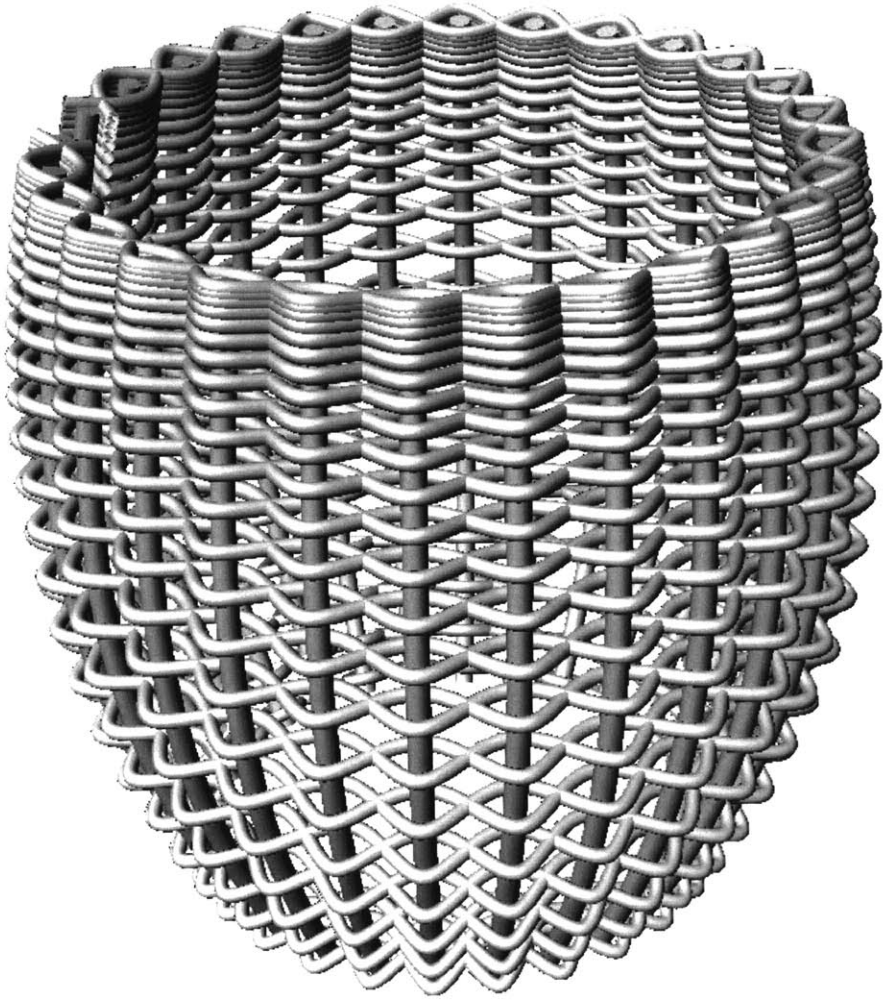

Figure 35. Artifact showing a varying density of weave, more dense at the top

Fig 36 and 37 show some more example objects created using the tool.

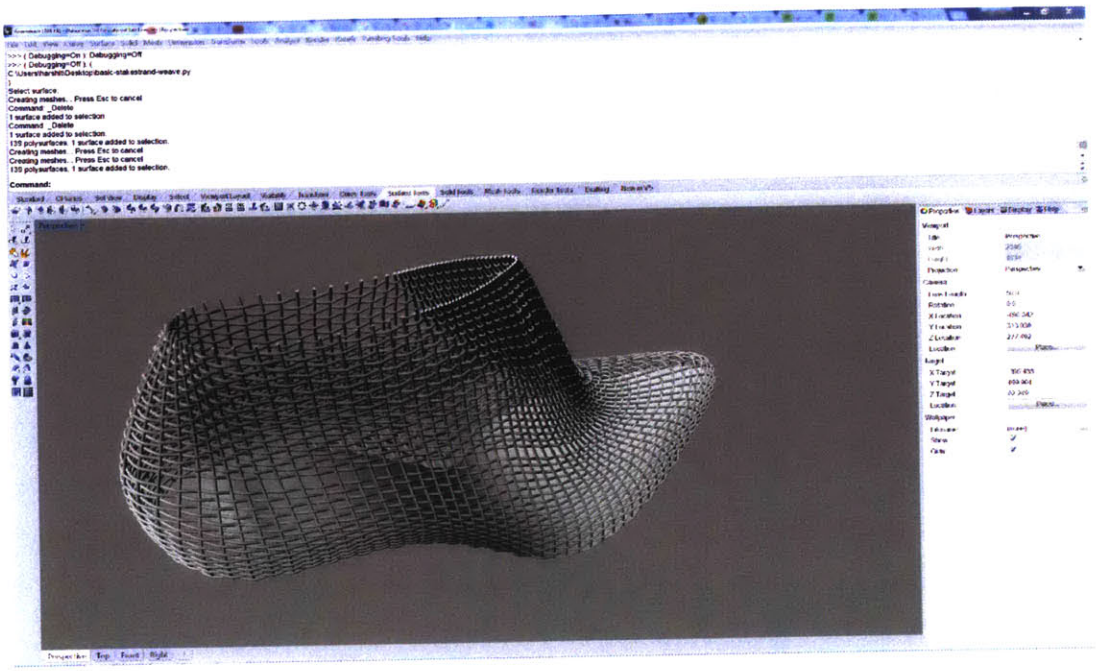

Figure 36. A shoe model I downloaded from GrabCAD [50] with a stake strand weave technique applied to it

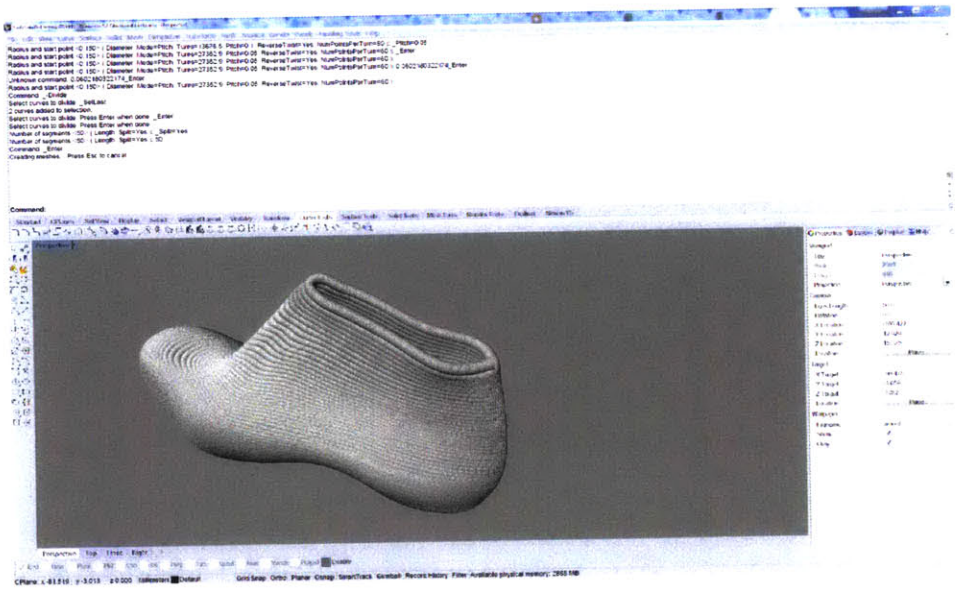

Figure 37. The same model with coiling technique

4.4.3 Software Implementation

As mentioned in the implementation details of the previous part, the software tool is built on top of the Rhino CAD platform.

The first algorithmic step in implementing the weave operations is to split the input surface into a number of horizontal and vertical divisions as decided by the user (these translate to number of horizontal and vertical strands in the basket ultimately). By default, these divisions are spaced out according to the degree of curvature of the surface at a given point (the smaller the curvature, the farther the divisions). When a user chooses to vary the density of the weave, the spacing of these divisions is affected accordingly. For denser weaving areas, the divisions are spaced closer together. To achieve this, once we have an input surface, we have a corresponding UV domain (UV domain can be roughly thought of as dimensions of the surface in the horizontal and vertical direction). We re-parameterize this into a UV domain of 0 to 1 in both directions for simplicity. This UV domain is then split into the number of horizontal and vertical divisions as decided by the user. For uniform weaving, this becomes the final division of the surface. However, to achieve non uniform density, we create two separate lists of values from 0 to 1 with the same number of divisions as required in each direction, but now split this list unequally, keeping more numbers towards, say 0, if greater weave density is required towards the bottom of the structure. The surface is then split according to these lists instead.

Once the surface has been divided, we locate a point at the center of each of these divisions on the surface. The manipulation of these points and subsequent interpolation between them gives the various weaving techniques. For the stake and strand, twining and plaiting, the scripts are similar. They involve splitting the points into horizontal lists and offsetting the points in each list alternatingly towards and away from the surface in the direction of the normal vector at that point. The offset amount can also be determined by the user through the GUI. For coiling, the horizontal lists are all interpolated, in a way so as to create a helical structure. These serve as foundations, around which another helix is wound, forming the vertical element. The interpolations result in Rhino curve objects. These curves are converted to a printable volume structure using either a *'Pipe'* function or an *'extrudeCrv'* function present within Rhino Python.

A GUI front-end enables the user to feed in various parameters to affect the output structure. The GUI is implemented using a combination of Windows Forms [51] written in IronPython and the Meier UI utility (a python library for creating GUIs) [52].

4.4.4 3D Printing Process

I printed objects created from the InterWoven tool using the Stratasys Direct Manufacturing service [53]. All the objects are printed using the Polyjet printing technology, in an Objet Connex machine [54]. This process allows for a linear combination of 2 materials, thereby allowing for creating 'woven' 3D structures (Fig 39, 40). One can choose from different materials, including a flexible polymer (which I use as the horizontal strands in the printed outputs). The durometer (flexibility) value of the

material can be varied to print tire like rigid outputs to very flexible outputs. I printed the vertical strands with a rigid white polymer. The output of InterWoven gives separate meshes for the woven part and the vertical strands (or the foundation and wounded helix in coiling), which allows for directly sending them to the printer, with the choice of material of each separate mesh.

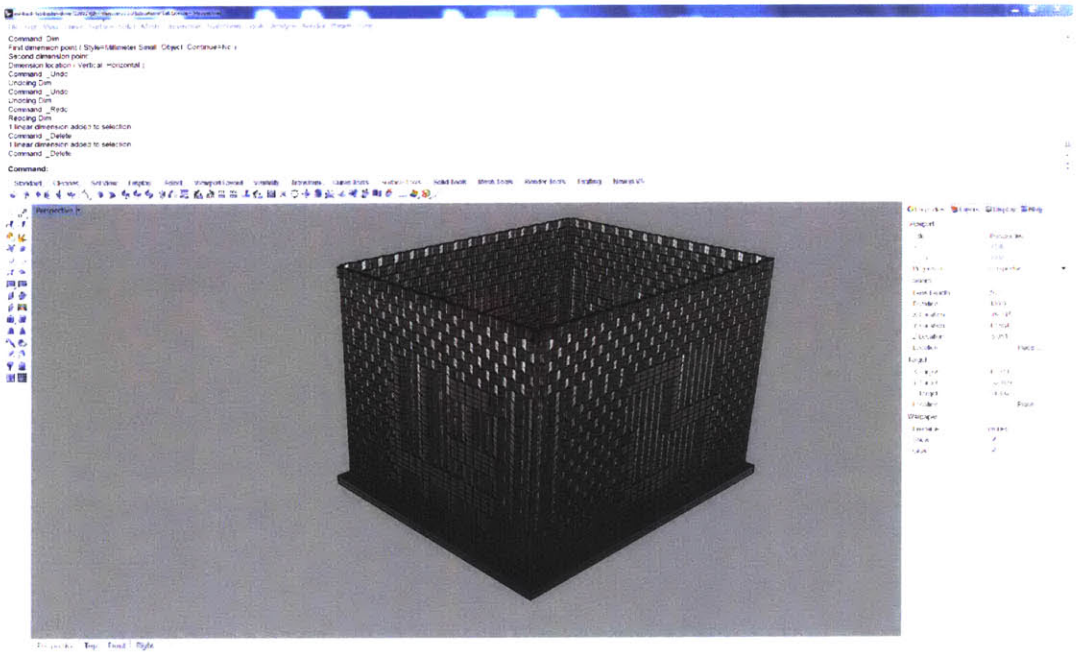

Figure 38. A cuboid basket created from the tool with the MIT Media Lab and Fluid Interfaces research group logos

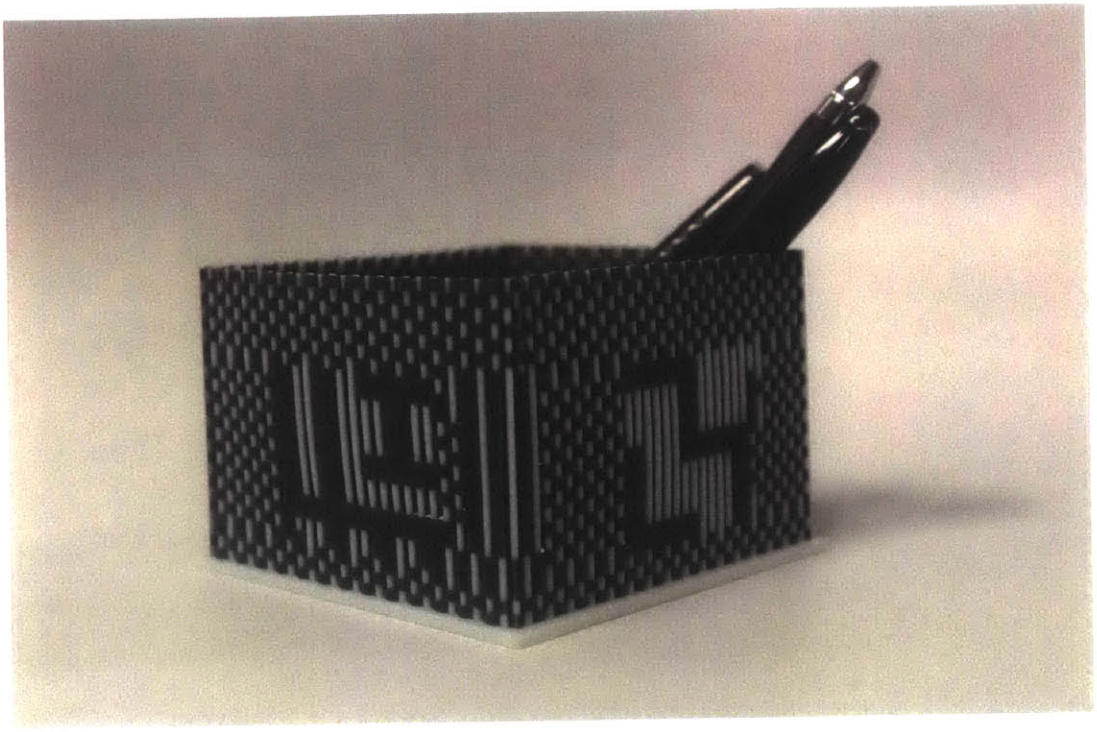

Figure 39. The basket 3D printed using Polyjet multi-material printing technique

Figure 40. A shoe model 3D printed

Chapter 5

User Study

I conducted a preliminary qualitative user study of the two parts of the tool with 4 participants (mean age- 26.75, 1 female user). All of them had used at least one CAD software tool in the past. Three of them had used the Rhino platform earlier at least once. None of them had used CAD extensively for carrying out their research or for any other purposes. None of them had ever made a basket before, but all of them knew what baskets were.

The main purpose of the study was to get an overall sense of the effectiveness of the tool in helping people design with traditional basket making operations and the general usability of the software tools. The study was aimed to understand how each of the different features of the tool were dealt with by the participants, which feature they used to what extent and why, how much understanding of the basket making process they derived from using the tool, what the designs were that they created (how much they experimented with the standard design in the first part) and any general comments they had.

The participants were briefly introduced to the two parts of the tool and given an open-ended design exercise to design whatever they desired. They were free to also download shapes off the Internet or use some shapes I already had. During the task, the participants

were encouraged to speak out loud any comments they had about the tool. They were all briefly interviewed after the task was over.

5.1) Reflections

All the participants enjoyed using both the parts of the tool and were happy with the designs they created. All of them felt that the tool helped expand the aesthetic space of what current CAD tools allowed them to do easily, and found the idea of incorporating traditional operations *'that served both aesthetically and functionally'* interesting. All the participants agreed that the first part of the tool helped them get some understanding of the basket making process. One of the participants even said they wanted to make a basket in the physical world and test their skills, stating, *"I had always imagined the basket making process to be much more complicated and almost un-doable by me. Making a basket using software now makes me want to make one in reality to see how it comes along!"* All the participants felt that creating a pattern in this basket was difficult. One participant pointed out, *"It needs a lot of planning and patience to make a pattern as we have to do it step by step"*.

For the second part of the tool, one of the users downloaded a model from GrabCAD (Fig 41) [53] and used that as an input surface (Fig x), while the rest just preferred to play around with the shapes I had made in advance. One of the interesting aspects was that only 1 participant used the density varying option in their final design. One participant commented, *"Unless it is a functional requirement, I will use standard weave as that gives a more regular look"*. All the participants played around with the pattern generation

feature and found it significantly more usable than in the first part of the tool, with one of them creating a pattern of their name initial, one of them of their research group logo and one a face. They found this part of the tool *fun.* One participant expressed that it takes *"some thinking to work at individual blocks"* to create the pattern. One participant expressed disappointment, as they wanted to create a camel but got *"bored"* while trying to do so. Two of the participants also wanted greater instantaneous back and forth between the surface and weaving. They wanted to modify the initial surface after creating the weave and have the weave update according to the new surface automatically (currently not a feature of the tool).

Figure 41. A user downloaded a GrabCAD model [55] to create their design

5.1.1) Possible Additions to Tool

Based on the results from the user study, I think some of the initial improvements that can be made to the tool are as follows:

- Add a means to 'paint over' the pattern generation matrix to create a pattern, instead of having to individually select the pixels.

- Create a means to add simple icons or images directly to generate a pattern.

- Have a means to edit a surface and have the weave adapt to it automatically.

- Perhaps the user can be guided towards generating a pattern for the first part of the tool. Maybe the user creates a pattern initially, and the software guides them through the basket making process, as to how to create the pattern, giving them step-by-step instructions in doing so.

Chapter 6

Conclusion and Future Work

In this thesis I have presented the design and implementation of the InterWoven CAD tool, which allows for integrating traditional basket weaving craft techniques into a modern day CAD paradigm. I hope this thesis serves as an initial embodiment in a research direction that I feel has a lot of potential for impact, that of seeing how traditional making practices can influence and blend with digital design tools and practices.

In the introduction and motivation sections, I showed how current day CAD tools derive operations and workflows from industrial processes. CAD was initially designed and popularized for its accurate and quick drafting capabilities, and has evolved in complexity in similar directions since. However, people have been designing and making objects for a long-long time, yet this traditional form of making finds no influence in digital design tools, reflecting in the lack of their usage in today's world. With a rampant rise in personal fabrication, use of digital design tools has gone way beyond just producing objects for industrial manufacturing. This offers a great opportunity to think of how traditional making practices can become part of CAD, as their purpose is not restricted to producing industrial objects anymore.

In fact, the observation that CAD is increasingly a tool for personal expression and artifact creation has been considered by many researchers. This has led to the creation of several easy to use CAD tools with limited operation sets, to ease a novice user into creating designs. Researchers are also increasingly active in producing 'domain-specific' CAD tools. These tools optimize the workflow for creating specific types of objects, like chairs or dresses or other specific objects. While these make it easy and efficient to design such specific objects, they are restrictive in nature, with limited operations and shape creation possibilities and do not allow for utilizing the full potential of CAD, thereby limiting expressivity and room for experimentation. However, these research directions in CAD have not addressed how traditional making processes could inform and be part of CAD. This serves as a motivation and starting point for the research presented in this thesis.

This thesis discussed the design and implementation of the Interwoven tool. I presented the two parts of the tool, one which allows a person to create a basket from the ground up, using all the sequential steps needed to create a basket and a second, which is more tightly integrated in current CAD workflow, allowing to apply different basket weaving operations to shapes designed using regular CAD software. I then showed the various design possibilities opened up by the tool to create design outputs that go beyond what either traditional weaving or CAD would have allowed for individually. All the outputs from the tool can be 3D printed. A few of the 3D printed artifacts created by the tool were also presented. A preliminary user study was conducted. Some interesting points emerged from the study and will influence further iterations of the tool.

6.1 Future Work

Through the design and implementation of the InterWoven tool, I provide an initial *framework* for how traditional making practices can be incorporated in modern day CAD tools, looking at a two pronged approach in doing so. As immediate future work, I plan to work on some of the directions brought out through the user study. I hope to continue using the tool to produce more and more design outputs, with greater varieties of different weaves, and plan to conduct workshops with experienced designers to see how they use the tool and what kinds of designs they produce. I also plan to add another part to the tool, similar to the first part of the current tool, for creating coiled baskets from ground up. There are interesting stitching techniques involved in some of the special coiled baskets (like an eight stitch),that would be very interesting to support in a virtual basket-making tool. Another direction I want to explore is to weave conductive threads into the outputs to create electronically responsive artifacts.

Basket weaving techniques and operations are one of the first forms of artifact making to have existed and thereby served as great starting points for this investigation. Among the vast, rich varieties of making traditions that exist within basketry, I picked a few to present my approach and framework in creating craft-inspired CAD tools. Beyond basketry, other tremendously rich and beautiful making traditions have existed for centuries, such as beadwork. I hope that InterWoven can serve as a starting point for investigating more such practices among researchers. I hope to adapt the framework and learning from this thesis in building tools for other such traditional practices myself. Beadwork for example has many intricate stitching patterns that give rise to different

shapes and patterns. Can one create operations analogous to weaving operations for those? Will a similar approach to that of incorporating beadwork within the workflow of CAD (by transforming the underlying structure to a structure of beads stitched together) work? What amount of abstraction can one do in beadwork to allow for automatic operations as opposed to a step-by-step approach? How can one create a step-by-step beadwork simulator similar to the one InterWoven presents for basket making, to understand beadwork in greater detail? Would that follow a similar approach or would a different interaction workflow be needed? Also, once more traditional practices get embodied in digital tools, it opens up a large design space for creating *chimeric objects*, by combining different traditional and modern operations into a single artifact. Imagine a vase that starts off as a basket being woven and merges into a beadwork form, something difficult to realize through traditional practices, yet highly inspired by it. All these are very interesting questions that I hope to investigate in future work.

Another broad area of research for future iterations of the tool can be around the audience of the tool. The current implementation of InterWoven is meant essentially to empower designers who already use digital tools to some extent in their workflow, to enable them to incorporate traditional basket making operations. It also provides a means for people to learn basket making from the ground up. However, a tool meant for traditional craftsmen to design their baskets would potentially be different. Would it require a stricter adherence to the constraints of physical basket making, as the craftsmen are familiar with that? Do they even need such a tool in all its completeness, or only the part of it that is sufficient for them? Perhaps they will never actually simulate a basket or design a beaded

necklace in CAD before they make them, so there will be some other design goals that are necessary for them to want to use CAD tools at all. Maybe all they need is to design decorative ornamentation for their baskets or specially shaped beads. In the case of Nantucket baskets, maybe a mold making CAD process could be extremely beneficial. Molds, rims and bases could even be 3D printed, easing the process of creating intricate shaped molds. Rims and bases could be automatically generated, once a designer has designed the mold, and handles could be semi-automatically generated. Building a tool for the traditional craftsman would require thorough studies with them to observe much more closely their workflows for creating artifacts thereby identifying optimal designs of such tools.

I believe a lot of work can be done in this area and hope that this thesis serves as a good starting point for such research.

Chapter 7

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