RENDERING THE RENAISSANCE: A METHODOLOGY FOR RECREATING HISTORICAL FABRICS AND FASHIONS IN COMPUTER GRAPHICS

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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August 2015

Major Subject: Visualization

ABSTRACT

Fabric and costume is an integral part of film media and increasingly so in computer graphics. There exists a growing interest in the creation of period films. To stay true to historical accuracy, creating believable, accurate costumes with appropriate fabric is key. While films such as Pixar's *Brave* have made attempts at visual accuracy, there is little existing literature discussing a method of creating such costumes. This thesis aims to form a methodology and approach to historical costume using available technology, extant historical garments, period artist renderings and real world fabrics and sewing technique.

To approach this problem, a focus time period and location was selected for review and recreation. Due to the amount of visual data available, mid 16th century Florence proved a desirable candidate. Existing software packages Maya, Marvelous Designer, Mental Ray and Renderman were used for modeling, simulation and rendering respectively in order to execute the final product. The end goal was to render a model of a Florentine dress with identifiable fabrics using the designed methodology. An additional goal was to demonstrate a variety of fabric shaders to illustrate fabrics found during this period such as wool, linen, silk and velvet. The resulting renders represented visual accuracy to the sources used. Applications for this methodology can include film, games, historical documentation and education.

ACKNOWLEDGEMENTS

There are many wonderful people without which this thesis would not be possible. They deserve all the gratitude I can give and more. Firstly, I would like to thank my family. They have been nothing but supportive through the ups and downs of this journey and for that I feel extremely fortunate. You guys are my biggest fans even when I am my own worst enemy. Similarly, I would like to thank my two friends who are close enough to me to be sisters, Diana Sierra and Amber Bayles. I hope to someday be there for you in the same way you have been here for me.

I would also like to thank my thesis committee, Richard Davison, Ann McNamara and Stephen Caffey for all their knowledge and help with formulating my thesis and finding my focus. Additionally, I want to thank the staff at the Student Counseling Center for their fantastic support in helping me get back on my feet with this work.

Others that I am grateful to have along this journey: the local chapter of the Society for Creative Anachronism for sharing ideas and enthusiasm, Robin Foster for her enormous help with historical garment construction, Michelle Robinson, Christine Li, Sarah Spofford, and everyone else at the Department of Visualization. Lastly, I feel this acknowledgement section would be incomplete without showing appreciation for the artists who beautifully preserved the grandeur of history in their work. For all artists past, present and future: keep making beautiful work.

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1. INTRODUCTION

Since the advent of film as a storytelling medium, there has existed an interest in portraying historical events to capture audience's imaginations. From the earliest sword-and-sandal films to the rise of British period dramas in the 70s and even today's large-scale costumed epics, the portrayal of history on film has proven popular and profitable. [1]. In order to set the stage for these films, actors don historically inspired garb in order to ground the film in a particular setting in space and time. Costume designers meanwhile attempt to design garments based on historical documents and images to paint a believable picture of how people might have dressed during the time period being portrayed [2].

Over the last decade, the film industry's interest in period settings has migrated into the realm of computer animated films. High profile titles such as *Tangled* [3], *Brave* [4] (Figure 1), and *Frozen* [5] all feature historically inspired settings with elements of fantasy. In spite of high interest in these settings, there is a marked absence of a methodology for creating clothing in computer graphics directly inspired by historical source material. While these films feature historically inspired garments, a method of taking a historical garment from sources to a model within a digital environment is vague and unexplored.

Figure 1: Silk costume in *Brave*, [4].

This thesis aims to examine how historical costume can be recreated within the computer graphics environment. Due to the broad range of clothing styles across history, this thesis will primarily focus on gowns of the Renaissance era with particular attention to 16th century Florence. The end goal is to formulate a method that can not only assist an artist in creating historical garments but can also serve as a method that is accessible to computer graphics artists of any skill level using existing software packages. The purpose is to contribute to the computer graphic artist community at large with possible applications beyond the scope of film.

2. BACKGROUND

2. 1 Historical Costume in Media

A film or game is primarily intended as entertainment for the layman and not a moving museum to showcase costume history. However, the execution and accuracy of a costume are important. Cinematic history showcases numerous examples of glamourous costumes from films with a historical setting that are not necessarily historically accurate. If the goal is historical accuracy, a costume designer must have access to the knowledge base to design and execute costumes that fit the goal time period. The same is true for computer animated films. When costume design must be taken into account across multiple disciplines within a computer animated film's production pipeline, many hands must come to understand the design and construction of a costume.

When a costume works with the character beyond mere decoration, it contributes to the narrative success of a film at large. The opposite is also true: poor costuming quality can impede a film's ability to create a believable historical setting. A range of examples can be found among the many incarnations of Robin Hood and King Arthur stories. These films present a confusing amalgam of 'period' and 'fantasy' costume often pulling from a much later period in history than the legends originate. While the costumes do illustrate character nuance, the costumes place these films firmly in the realm of fantasy. One film in this genre, Ridley Scott's *Robin Hood* [6] features an approximation of what could be considered garb of the time period in 11^{th} century

Britain for the male characters. On the other hand, the garments chosen for Maid Marion are a smattering of different time periods and styles. Figure 2 shows actress Kate Blanchett wearing a few of the costumes created for the film and figure 3 is a period illustration of what women would have worn. Anachronistic costume may not take away from a viewer’s experience of a film, but dislodges the film from its intended setting.

Figure 2: Costumes for *Robin Hood* [6] featuring anachronistic qualities for 12th century England.

Figure 3: Illustration of 12th century clothing common in Europe from *Hortus Deliciarum* circa 1180 [7].

Games also contain narratives driven by historical subjects. Ubisoft's *Assassin's Creed* franchise pays extensive attention in grounding the stories in the time periods chosen for each leg of the saga using scenery, sounds and costume [8]. However, the designs of principal characters do take liberties. The main character of each game in the franchise incorporates a hood into their costumes, a feature that would otherwise be out of place (Figure 4). The hood is not only important to the narrative, but provides an iconic and recognizable feature to be exploited for marketing purposes.

Figure 4: The principal character with his iconic hooded costume in *Assassin's Creed: Brotherhood* [9].

2.2 Computational Power

Execution of costume in computer graphics is highly dependent on available technology and processing power. The computing systems must be able to handle dense polygonal meshes with high resolution of movement simulation and high quality textures and surfacing. Several examples of costumes in the computer animated films previously mentioned are successful in part because of the studio's computing resources. The studios responsible for these films have the advantage of a robust pipeline, proprietary software and render farms with which to compute and render frames.

Disney's *Tangled* and *Frozen* as well as Pixar's *Brave* feature hero characters wearing clothing requiring attention to detail and a need for visual accuracy to particular fabric types. Silk, for example, is a prominent fabric type in all three films. Not only is computational power needed for realistically rendering recognizable fabric types, but knowledge of the material itself and how it was used in historical context is important.

2.3 Context

The following pages provide the context and knowledge necessary for researching historical clothing. References for clothing came from historical sources such as extant garments and paintings as well as real, tangible fabric samples and photographs.

Art from the time period provided a wide source of reference for clothing styles as well as fabric choices. The clothing of interest to this thesis unfortunately had to stay within a certain class of people; those wealthy enough to afford not only these lavish fabrics but also a tailor and a painter to record it. These privileged few wanted to put themselves on parade with their portraits, choosing the finest clothing at their disposal for the painter to immortalize them in [10]. That is not to say artists were disinterested in more mundane sitters for their work. They did paint the common human as well. However, in order to find examples of silk from these time periods, look no further than the aristocratic portrait.

Parameters for choosing paintings to use as reference did not necessarily focus on famous works of the time period. Paintings were chosen based on visual accuracy and fabric type. While this didn’t remain exclusive to portraits, they stood as the main contender for the choices made. Several artists stood out for their attention to light behavior and the ability to create the illusion of woven fabrics with their brushstrokes. A sampling of these artists with notable works and features are as follows.

2.3.1 Giotto (1266 – 1337)

A Florentine architect and painter during the late Middle Ages, Giotto's work shows interest in the physical hang of the fabric on a subject. He stood as one of the first painters to break from the traditional geometric drapery style of the Byzantines and paint from life. While he captured organic and naturalistic drapery, he spent little time on the visual properties of the fabric, leaving much of the fabric with a generic woolen look. The draped figures in his paintings are reminiscent of the clothing in ancient Greek sculpture in spite of the newer complexity and tailored elements in European medieval clothing [11]. As such, the interest in Giotto's work is purely based on his 'freshly direct eye' on the physical behavior of fabric. Giotto's rendering of drapery can be seen in figure 5.

Figure 5: *Lamentation (The Mourning of Christ)* by Giotto , 1304-06 [12].

2.3.2 Jan van Eyck (1390 – 1441)

Following a growing interest in the depiction of objects from life, painters began to focus on how to capture the way light affected objects. Jan van Eyck came into his career during this time. Most notably known for painting *Portrait of Giovanni Arnolfini and his Wife* in 1434 (Figure 6), Jan van Eyck could do what few artists of his time could; create the illusion of fabric with brushstrokes alone. Artists explored alternative methods to achieve this, such as using gold leaf to depict cloth woven with gold thread or by physically adding the texture with raised areas of paint. Neither of these were as convincing as Jan van Eyck's technique [13]. Van Eyck was able to capture recognizable weave structures in fabric using a few well executed brushstrokes and allowed scholars to chart these historic weave patterns.

Figure 6: *Portrait of Giovanni Arnolfini and his Wife,* Jan Van Eyck, 1434 [14].

2.3.3 Hans Holbein the Younger (1497 – 1543)

Hans Holbein was a German artist who worked during the 16th century Northern Renaissance. Among his recognizable works are his series of portraits of King Henry VIII (Figure 7. Holbein was himself a detail oriented draftsman and studied the forms of his sitters on paper before going to paint and canvas [15]. He rendered costumes with meticulous detail, every wrinkle of every drape in place with realistic lighting. In the 1536, Holbein entered the service of King Henry VIII where he executed a series of portraits of the King and various members of his court and even designed clothing for the English monarch. [16]. Holbein's exquisitely detailed portraits mark him among the greatest draftsmen of all time.

Figure 7: *Portrait of Henry VIII.* 1540. Hans Holbein the Younger, 1540 [17].

2.3.4 Agnolo Bronzino (1503 – 1572)

Agnolo Bronzino was a Mannerist painter whose portraits are known for their icy, aloof stares and attention to visual accuracy in costume [18]. The Medici family of Florence particularly favored his work and made him their court painter in the 1540s after some time receiving patronage from Cosimo di Medici, the duke of Tuscany.

Figure 8: *Eleonora of Toledo with her son Giovanni de Medici.* Agnolo Bronzino, 1545 [19].

Among his most recognizable paintings is of the Cosimo’s wife, Eleonora in *Portrait of Eleonora of Toledo and Son Giovanni* painted in 1545 (Figure 8). The meticulously painted garments in Bronzino’s portraits become a character of their own, far upstaging the subject wearing them. Many of Bronzino’s works still reside in Florence to be viewed and admired today.

2.3.5 Lorenzo Lotto (1480 – 1557)

Selected mainly for his skill with portraiture, Lorenzo Lotto recorded the fashion of Venice over the course of his career. Lotto’s portraits featured convincing likenesses and tended to follow his own independent style [20]. Of particular interest to this thesis is his 1533 painting *Venetian Woman in the Guise of Lucretia* which showcases silk, velvet and Venetian dress construction including decorative sleeve slashes (Figure 9).

Figure 9: *Venetian Woman in the Guise of Lucretia.* Lotto, Lorenzo, 1533 [21].

Lotto took inspiration from many influences from Bellini to Raphael and often painted religious subjects. Many of his portraits were commissioned later in his life during his tenure in Venice. As such, the clothing featured in his works is solidly early 16th century Venetian.

2.3.6 Caravaggio (1571 – 1610)

Several artists who fell outside the period of interest are worth a mention for the detail of the fabrics or context of the work. Of these, Milanese painter Caravaggio's theatrical paintings moved the subject's clothing beyond portraiture and made them part of the character instead of an overshadowing element to showcase the wealth of the portrait subject. Caravaggio's subjects are a performance in themselves and appear lively as though part of a theatrical play. The use of costume to convey character makes

Figure 10: *The Fortune Teller*. Caravaggio, 1594 [23].

Caravaggio an important reference for historical costume in action. He shows his mastery of character and action with the subtle gestures in *The Fortune Teller* (figure 10) a painting of a scene presumably from his own imagining [22]. The fabric on the young man's doublet continues this subtlety, catching the light just enough to demonstrate its specular reflection.

2.3.7 Jean-Auguste-Dominique Ingres (1780 – 1867)

Another master of rendering fabric, Ingres was a principal member of the French Neoclassical school. Aside from portraits, Ingres was primarily a history painter following the tradition of classical works and artists such as Raphael [Shelton]. Among his numerous portraits, several striking examples of his ability to render fabrics stand apart: *Princess Albert de Broglie* (Figure 11) and *Portrait of the Countess of Tournon* [25]. In *Princess,* Ingres captures de Broglie's beauty and wealth. The material quality of her dress beckons the viewer to reach out and touch the smooth silk.

Figure 11: *Princess Albert de Broglie.* Jean-Auguste Ingres, 1853, Metropolitan Museum of Art, New York City [26].

2.3.8 Paul Delarouche (1797 – 1856)

Select works of Paul Delarouche are of interest for historical costume research as they contain anachronistic elements. Delarouche was a 19th century French painter who illustrated emotional episodes of history in his works, especially scenes of martyrdom. His history paintings captured awe and acclaim in Paris and were a rival to his contemporaries Ingres and Delacroix [27]. Delarouche's most famous painting, *The*

Figure 12: *The Execution of Lady Jane Grey*. Paul Delarouche, 1833 [28].

Execution of Lady Jane Grey (Figure 12), is of particular interest to this thesis. The painting depicts the final moments of ‘The Nine Day Queen’ Jane Grey before being executed as a traitor to the crown of England. Delarouche created the painting nearly three centuries after Lady Jane Grey’s execution. He clothed his subjects in an approximation of the garb of 16th century England or what is known as the ‘Tudor’ style. Delarouche’s attention to costume, detail and drama demonstrates the role of the artist in creating a contemporary view of history.

This handful of examples are by far not the only artists creating visually accurate fabrics. An independent researcher could possibly delve further, but for the sake of this thesis these artists serve to make the necessary point.

2.4 Examining Extant Textiles

Another way to gain an understanding of historical garments is to examine extant pieces. Depending on the period in question, the garment one wishes to study may only offer an idea of how a garment was constructed and what materials were used to create it. Unfortunately, fabric is comprised of organic material. As such, time and exposure to the elements deteriorate the material. However, there are remaining artifacts from these time periods that are now protected and studied. Many of these extant textiles were possessions of the wealthy, the very same who commissioned portraits in some cases. Others were church vestments worn by clergy that featured lavish embroidery with threads of gold [29]. These were typically cared for by the Church and as such have withstood the test of time.

Some extant textiles were exhumed from gravesites [13]. Again, the prior owners of these also had the funds with which to fund a gravesite capable of preserving the fibers. A relevant example is a gown belonging to Eleonora of Toledo found within a Medici tomb helped identify her remains [30]. The gown is visibly decayed, but the construction of the garment is clearly expressed when the fabric is laid out (Figure 13).

Finds such as these are critical to understanding what people wore, how these garments were constructed and what material they were made from [29].

Figure 13: Restoration of *Funeral gown belonging to Eleonora of Toledo,* 1562. Galleria del Costume, Florence, Italy [31].

2.5 Fabric Manufacturing

In order to gain an understanding of how fabric behaves physically and visually, it is helpful to have basic knowledge of the manufacturing process [32]. Fabric properties derive heavily from their base materials and the methods of weaving used to create the fabric [33]. For this thesis, several fiber types will be examined. The criteria for choosing fiber was determined by availability in the time period. Therefore, no synthetic fibers are included here. The upcoming sections require some prior knowledge of fabric terminology. Please refer to the Appendix for a helpful fabric vocabulary.

2.5.1 Linen

Linen is a material derived from fibers of the flax plant (*Linum usitatissimum*). Linen has been and remains an extremely prolific material used in clothing and cloth-based household items. It is cool to the touch and absorbent making it ideal for helping one stay cool in warm weather [34]. To manufacture, the flax plant is harvested and the seeds are removed. Fibers are extracted and sorted for quality. The stages of refinement are illustrated in figure 14. These fibers are then spun together to produce yarn which is woven into fabric. Linen fabric holds a natural luster, but doesn't have as much specular reflection as silk.

Linen use in history begins in antiquity where archaeological finds have unearthed linen wrappings dating back to ancient Egypt. In the Middle Ages and Renaissance, linen was widely used as an apparel fabric available to anyone. Depending on a person's wealth, the linen varied in fiber quality, weave quality, and dye color. Richer colors indicate the wearer's excess in wealth [35]. Linen is generally found with a simple weave pattern: an interlocking pattern with weft threads running over and under the warp threads (Figure 15). Linen may also be woven with other fibers in Jacquard weaves to create simple geometric patterns.

Figure 14: Stages of flax refinement before being spun and woven into linen.

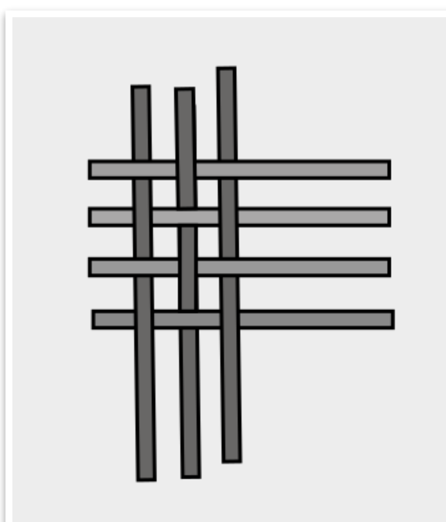

Figure 15: Example of a simple linen weave. [36].

2.5.2 Wool

Wool is a fabric made from animal hair fibers, most notably from sheep but may also come from goats, llamas or angora rabbits [37]. For the purposes of this thesis, the focus will be on fiber collected from sheep. Wool fabric is durable and can work as an insulator from the elements. Once the fibers are sheared from the animal it is sorted for quality. Afterward, the hair must be cleaned and scoured to rid it of dirt and other impurities. Before being spun into yarn, the wool goes through the process of carding where the wool is put through fine combs to detangle, straighten, and mix the hairs together [38]. There exists a wide variety of ways in which wool can be woven. The fabric can be thick with a fuzzy texture like felt or lightweight and smooth as with flannel and gabardine. Visually, wool carries soft highlights and shadows between weave threads and lint.

2.5.3 Silk

Silk is an often lustrous fabric created from woven fibers of silk secreted by the larvae of the domesticated silk moth (*Bombyx Mori*). The cultivation and rearing of silk mother caterpillars is known as sericulture. After hatching, the caterpillars consume mulberry leaves until they mature. They will then spin themselves a cocoon. The cocoons are harvested and boiled to soften the binding agent, sericin, killing the pupae in the process. From there, the harvested cocoons are unraveled and their fibers wound onto reels. Because the silk fibers are so fine, silk yarns are typically several fibers twisted together. The method with which the spun yarns are woven contribute to the visual qualities of the finished fabric [39].

Silk fabric types vary widely in visual quality. Satin is smooth with wide areas of specular highlights while crepe is rough and elastic. Velvet is comprised of a pile made with silk threads created by the warp threads drawn up over rods to make loops. Once weaving is complete, the rods are removed and the tops of the loops are cut to form the pile [40]. Sometimes, the pile is voided, leaving the under weaving empty or filling it with a different type of fiber such as gold threads to create the mixed fabrics seen in paintings of the Renaissance [40].

2.6 Deriving Patterns

Another item to consider in this process is garment construction. In order to achieve desired drape and silhouette of a piece of clothing the way the cut pieces of fabric come together on the body must be accounted for. If one is an experienced tailor, examining a garment and how it is worn provides the tailor with an idea of how to reverse engineer it to create a pattern. For amateurs and experts alike, it is usually more convenient to obtain a pattern.

There exist historical sources that describe clothing patterns complete with the tailor's notes. One of these belonged to a 16th century Spanish tailor, Juan Alcega. His 1589 pattern book was copied and translated in the 1970s and includes illustrations on how to arrange pattern pieces on fabric for the most economical use of materials [41]. Figure 16 shows a sample of Alcega's pattern work. Historical records such as these may require language translation not only for the written words but for the syntax and shorthand a tailor may have used to convey measurements and instructions for assembly.

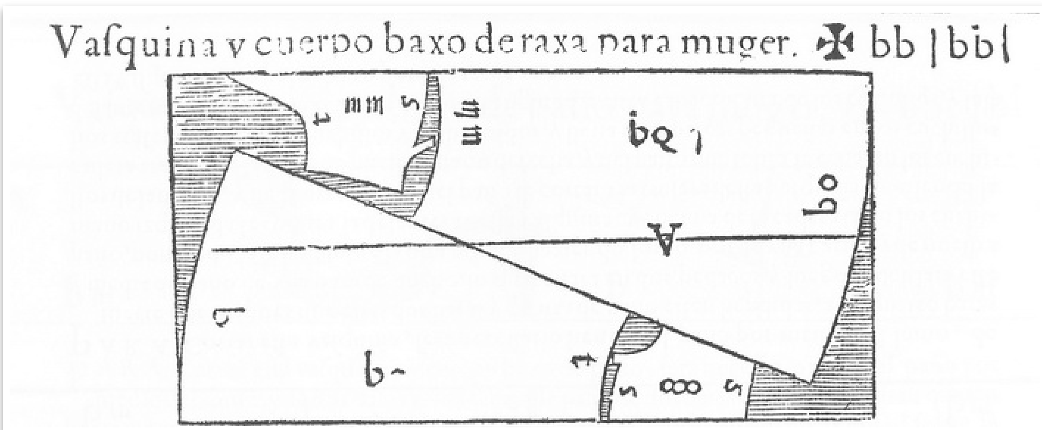

Figure 16: Image from Juan Alcega's 16th century pattern book [42].

Scholars like Janet Arnold (1932 – 1998) studied historical printed or written material, paintings, and extant garments to derive patterns closely approximating the garment as it would appear in its historical context. Her patterns are published in *Patterns of Fashion: The Cut and Construction of Clothes for Men and Women* [43]. The work of Arnold and her contemporaries proves useful in restorations and reference in costume design, re-enactors and hobbyists. Modern sewing pattern design companies do have 'historical' costume patterns available in their catalogs but they are designed in ways that are not true to historical fashion. They include zippers and overcomplicate clothing construction that can be achieved with simple geometric shapes. While these are perfect for Halloween, Renaissance festivals or other occasions inviting fantasy, they fall short of the goal of achieving historical accuracy [44].

3. LITERATURE REVIEW

This thesis topic covers a wide swath of disciplines. Because of this, covering previous literature requires examining historical documentation, computer graphics rendering techniques, and modeling clothing from patterns in a computer environment. Historical documentation in this case focuses on the use of clothing in paintings and how it holds up to real historical examples from extant garments. In the previous chapter, much of the historical background was laid out in a way such that the historical documentation may be easily grasped.

3. 1 Historical Documentation

In Anne Hollander's book, *Fabric of Vision: Dress and Drapery in Painting* [45], the history of the development of painting true to life fabric is discussed. Some of her discussions are outlined in the previous chapter under the summary of Giotto's work. Hollander begins with discussing the movement away from 'the ancient way of rendering truthful looking draped bodies' in the early Middle Ages to the 'abstracted and ritualized' style seen in Christian artwork, most notably the Byzantines. An examination of these works today reveals "a predominantly linear rendering of folds, as well as the form of full-length bodies. The garments are part of pictorial legend, not life" [45].

The stirrings of the ideals of the Renaissance and the rediscovery of Classical sculpture helped drive the movement towards naturalistic renderings of clothing as the artist saw it. Giotto demonstrated his grasp on realistic drape in the 14th century on the characters populating his paintings and frescoes. While his understanding of the physical flow of fabric was excellent, he did not detail the fabric enough to identify the fabric type. Hollander describes it as a 'matte finish.' As the technique and artistic medium progressed, a catalog of historical fashion began to emerge. A progression toward closely fitted garments comes to an apex in the 15th century with controlled folds and fine fabrics. Nevertheless, "In every kind of European image at this period, it's evident that all painters were offering cloth in its true character, even in legendary costumes" [45].

Lisa Monnas further discusses the development of naturalism in the newfound flourishing of art in her book *Merchants, Princes and Painters: Silk Fabrics in Italian and Northern Paintings* [13]. The book discusses the economic factors behind the use of the fabric, its availability to the noble class, and the painters who recorded these luxuries in paint. Pioneers of painting techniques in the Renaissance experimented with many methods to achieve the desired realism of rendered fabrics. An early Renaissance artist, Gentile da Fabriano used actual gold leaf to portray cloth of gold, a fabric with spun golden threads woven in. Others used physical texture with the paint to create the look of real fabric. The most effective technique rose with artists like Jan van Eyck who created illusions in oil paint as opposed to adding physical texture. Van Eyck's minute yet fluid brushstrokes demonstrate his precision in creating his works. His technical accuracy documents the arrival of specific patterns and even allows historians to identify weave

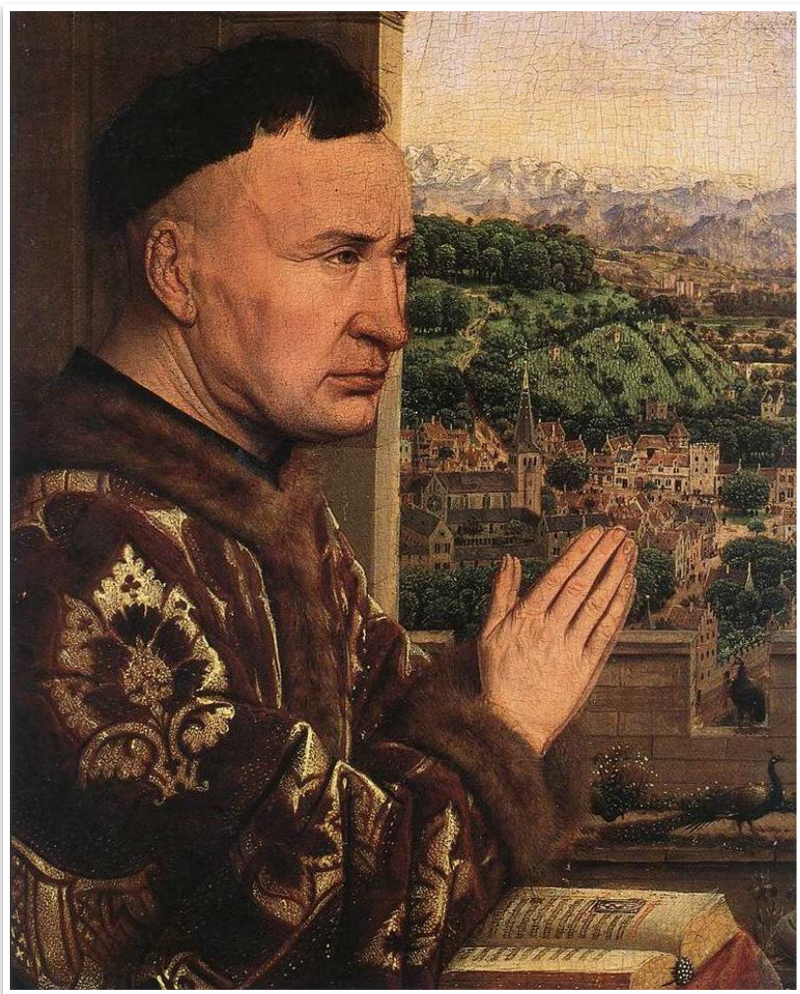

Figure 17: *Madonna Of Chancellor Rolin (closeup*). Jan Van Eyck, 1435 [46].

structures in velvet pile [13]. Figure 17 shows an example of Jan Van Eyck's detailed velvet pile renderings.

Artists like Jan Van Eyck became so skilled at creating these illusions that they were able to render realistic fabrics without the need of a model. They “had a vocabulary of stock motifs...prepared to repeat or rework” [13]. Some of his motifs are recycled across multiple paintings. Monnas writes:

“We can compare, for example, two different motifs made out of brocaded velvet worn by an Angel playing the organ in the Ghent altarpiece and by the Archangel Gabriel in the Annunciation in a church. The two garments, apparently made from the same fabric, are quite different in their tailoring, so we are not simply seeing two renderings of a real garment used as a studio prop” [13].

This implies the fabric seen in portraiture from the Renaissance may or may not be based on a real specimen. Unfortunately, few real specimens survive and the ones that did do not necessarily reflect painted depiction. Clothing exhumed from the graves of historical figures often creates further mystery into the accuracy of the fabric seen in their corresponding portraits. This may be due in part to the circumstances behind the painting. In some cases “the artist seems to have had a direct access to the clothing, but not the sitter” [13] or vice versa. A key example of discrepancy between the sitter and the clothing is the 1545 portrait of *Eleonora of Toledo and her Son Giovanni* painted by Agnolo Brozino [19].

This particular portrait inspires awe and curiosity in much of the literature surrounding the depiction of fabric in its historical context. Joe A. Thomas published an in depth analysis of how the dress in the portrait compares to the funerary gown exhumed from Eleonora’s tomb with his paper *Fabric and Dress in Bronzino’s Portrait* *of Eleanor of Toledo and Son Giovanni* [30]. Thomas' paper discusses the social implications of creating and owning such a gown to place it in context for a viewer unfamiliar with the economics and social graces of mid 16^{th} century Florence. Based on the collective painted images of Eleanora's wardrobe, Thomas asserts that the velvet and brocade gown so stunningly depicted in Bronzino's painting held special value to Eleonora due to its frequency in her portraits [30]. He goes on to make approximate identifications of the gown's fabric, describing it as a brocaded damask created using a technique called space weaving "in which additional threads, often of valuable materials such as gold and silver, are brought into the fabric on small shuttles and used only in the areas where a pattern is desired. These threads are looped up above the surface of the fabric to create the raised pattern we see" [30]. The combination of materials creates variation in the specular properties between different threads and different areas of the weave. For the wearer, this amalgam demonstrates their wealth. For the painter, a beautiful way of keeping the audiences' eye.

Examining the historical context, painted evidence, extant textiles, and samples of modern fabrics constitutes part of the bigger picture of recreating historical clothing in a computer environment. A computer graphics artist needs technical knowledge of modeling and rendering technique in order to apply the historical and visual information of a particular garment to this environment. Simulating and rendering convincing fabric has been a subject of active research in the computer graphics community since the early 1990s. As such, there exists a large body of work proposing a variety of approaches to solving this problem. Sources to be discussed paint the interest in rendering fabric with broad strokes with special attention to work specifically interested in exploring historical fabrics.

3.2 Rendering Techniques

Much of the literature on rendering fabric is focuses on acquiring light and reflectance data in order to formulate mathematical models expressing the relationships between light and reflectance so that the data can be applied to rendering. Authors Wallace Yuen and Burkhard Wunsche of the University of Auckland wrote an extensive evaluation on some of these techniques. In their paper, *An Evaluation on Woven Cloth Rendering Techniques* [47], they explain how different fiber types produce different shading results. Fiber materials include animal hair and secretions, plant fibers, and synthetically made fibers. The paper explains the effect of different yarns on the visual properties of the end woven material and compares methods in rendering the visual properties for their effectiveness.

The authors start by examining example-based models of cloth rendering techniques. One of the methods reviewed proposed collecting reflectance information from the materials using light sensor equipment. One such device, the gonioreflectometer, measures reflectance properties of a material at different viewpoints to obtain the Bidirectional Reflectance Distribution Function (BRDF) for the material [47]. Another model the authors discuss is the Bidirectional Texture Function (BTF) which is able to capture self-shadowing, occlusion, and inner-reflection of a material. For BTF, the data are stored as texture maps and are called at render time to reference illumination, camera position, and texture coordinates. Unfortunately, because of all the parameters used in BTF, the model requires a high memory cost and a laborious acquisition process [47]. This problem arises in many of the example-based models proposed. Luckily, some BRDF measurements are available on public databases but they do not entirely focus on data for fabrics.

Procedural-based methods also propose a variety of approaches to fabric rendering. These are largely based on analysis of fabric structures, but do not require as much memory. Some researchers are more interested in visual accuracy, while others attempt to optimize render times. Yuen and Wunsche examine an approach proposed by Ashikhmin, et al. in 2000 [48]. Ashikihmin, et al. developed a microfacet-based anisotropic model that could be applied to any material. This model was tested on several different materials including satin and velvet. When applied to fabric, Ashikihmin took the weave pattern into consideration. However the model does not hold up when applied to more complex weaves. Yuen and Wunsche evaluate several other approaches meant to mathematically model yarn and weave structures. Adabala, N., et al. analyzes yarn structure and reflectance properties therof [49]. Yuen and Wunsche weigh these methods against each other and recommend different methods for different rending needs. The paper in which these authors publish their own method, *An Applied Approach for Real-Time Level-of-Detail Woven Fabric Rendering,* they propose an algorithm to adjust geometry and texture details with a mipmapping approach to maintain a consistent representation of the fabric [50].

In the 2013 paper, *A Practical Microcylinder Appearance Model for Cloth Rendering*, authors Sadeghi, et al. collect data on fabrics in a similar approach and also examine how different weave patterns affect the way the fabric behaves in light. This is especially important as many silks are made of the same material but use different manufacturing processes to create different effects [33]. Sadeghi, et al. describe their proposal as "a practical shading model for cloth that can simulate both anisotropic highlights as well as the complex color shifts seen in cloth made of different colored threads…model is based on extensive Bidirectional Reflectance Distribution Function (BRDF) measurements of several cloth samples" [33].

Like Yuen and Wunsche, the authors discuss fiber content and type in how it affects light behavior but go further in analyzing the contribution of individual threads to the finished look. They consider fabric a mesh of woven cylinders orthogonal to each other and refer to them as microcylinders [33]. From here, the authors create a shading model taking all parts into consideration. In Figure 18 the complete result is illustrated.

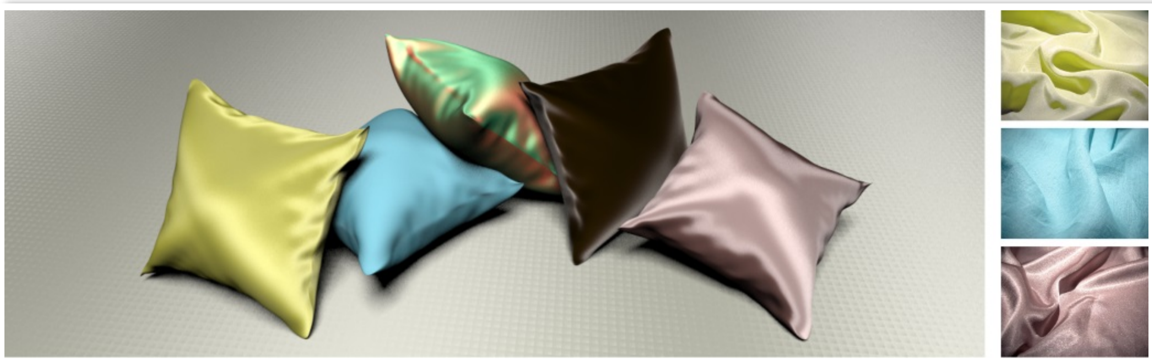

Figure 18: Resulting renders from *A Practical Microcylinder Appearance Model For Cloth Rendering* [33].

So far, the papers being reviewed concern themselves with rendering techniques applied to realistic recreation of modern fabrics as opposed to recreating historical elements. *Acquisition, Modeling and Rendering of Bidirectional Texture Function of Ancient Japanese Noh Costume Fabrics* published by Yuki Takeda and Hiromi T. Tanaka at Ritsumeikan University, Japan in 2007 examines historical costumes from extant works and attempts to recreate them based on collected light data. The historical costumes in question originate from a form of musical theatre in Japan, Noh, which arose as a theatrical art in the 14^{th} century and features elaborate silk costumes and masks to convey emotion. The plays revolve around Japanese folklore, literature and mythology and Noh costumes reflect the fantastical nature of the stories. Noh costumes "are precious cultural heritage and are made of specially woven silk fabrics" [51].

Takeda and Tanaka's paper proposes an image based method for acquiring, modeling and rendering BTF of silk woven fabrics and aims to create a precise BTF for

Figure 19: Sample render of Noh costume silk
from Takeda and Tanaka's paper [51].

Noh stage performance costume fabrics. As part of the research, Takeda and Tanaka described a mathematical model for ray interaction with warp and weft threads and the fabric normal. They scanned an example piece of Noh costume and scanned it with an Optical Gyro Measuring Machine to get multiple viewpoint data acquisition in similar fashion to the previously mentioned gonioreflectometer. While the researchers had difficulty acquiring data on the more three dimensional details of the fabric and its embroidery, they were able to use the results from the OGM to render a realistic image by combining these with texture maps. From this combination, the authors produce a convincing render of Noh costume silk [51] (Figure 19).

3.3 Making Models from Patterns

The third area of research to take into consideration is the physical simulation of clothing as it should be draped on a model. A garment's construction and material determine the physical interaction of the garment with the wearer. Deriving patterns for historical garments based on historical documentation serves as a good starting place for reconstruction. The problem arises when attempting to translate two dimensional drawings of pattern pieces to a three dimensional finished garment that exhibits correct drape and silhouette. Solutions vary from the use of commercial computer assisted drawing (CAD) software designed for the purpose of aiding clothing designers to more analytical methods of translating patterns into three dimensional objects.

The joint project by University of Berkley and University of Columbia conducted by Berthouzoz, et al. , *Parsing Sewing Patterns into 3D Garments,* attempts to create garment models using an algorithm that analyzes patterns, predicts how pieces are assembled, and generates a model of fabric draped on a mannequin. Patterns are provided in PDF format as purchased from fashion design websites like burdastyle.de and voguepatterns.com (Figure 20). The authors' algorithm accounts for different styling elements found on patterns such as darts, pleats, hemlines, and foldlines. Sewing patterns are seen as a list of operations dictating how a piece of fabric is cut and assembled to the garment as a whole [52]. The algorithm predicts the garment assembly by extracting panels and design elements from the pattern using their parser. It then identifies edges of the panels that are 'stitched edges', which are edges to be attached to another panel. Based on the parsed information, the algorithm predicts the most likely course of assembly for the garment. This information is fed to a simulator to drape the clothes on a mannequin.

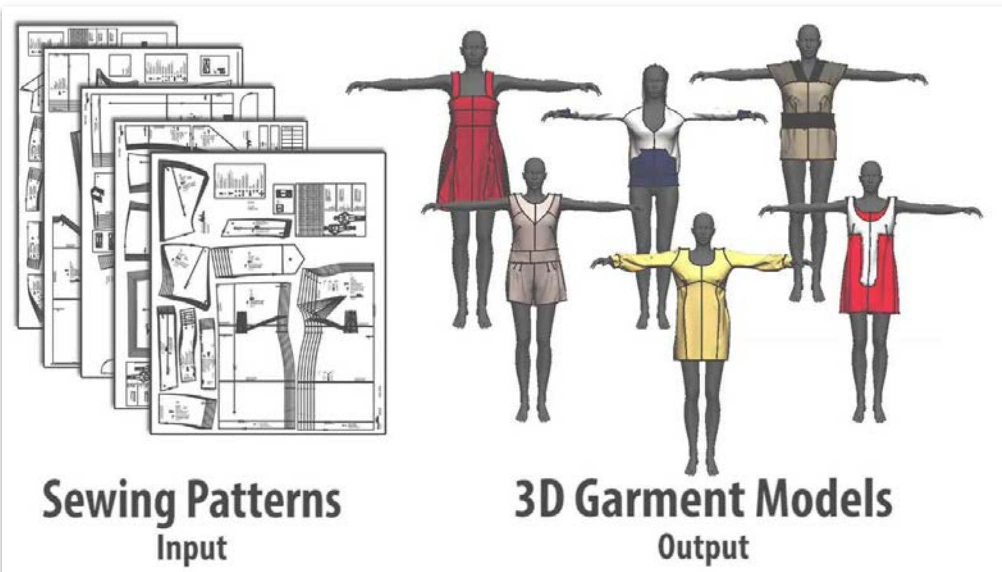

Figure 20: Input patterns and output models of the project created by Berthouzoz, et al. [52].

For the purpose of fashion design, the Berkley project is extremely useful to massively generate models and see patterns fully realized as garments at a glance. It may also be used for modeling for animation on a large scale. To narrow the scope of this thesis project, there is little need for massive model generation or sophisticated algorithms to achieve the desired end result. Available commercial software for fashion designers is a more accessible option. The end product of this thesis uses CLO's Marvelous Designer [53] to model the historical dresses, but there is value in evaluating different clothing CAD products available on the market.

CAD systems designed to aid the fashion designer perform several key processes: two dimensional pattern design, pattern prepositioning, a virtual sewing process, cloth drape simulation and the ability to modify the design [54]. Many of these systems include default mannequin models out of the box to act as the rigid body for fabric geometry to interact with during simulation. To design clothing for a different model, a designer can simply import their own geometry. From here, the designer is then able to take on the role of a digital tailor, defining two dimensional panels in a 'panel window' and performing editing operations to achieve the desired shape [55] A designer can add curves and vertices to a panel and perform duplication and mirror operations for multiples of panels that require symmetry. Seam lines can be defined to tell the CAD software which panels attach to each other as a tailor would to sew fabric pieces together. Once there are working panel diagrams in the panel window, the designer can begin working in 3D. Figure 21 shows a screenshot of Marvelous Designer's patterning and modeling interface.

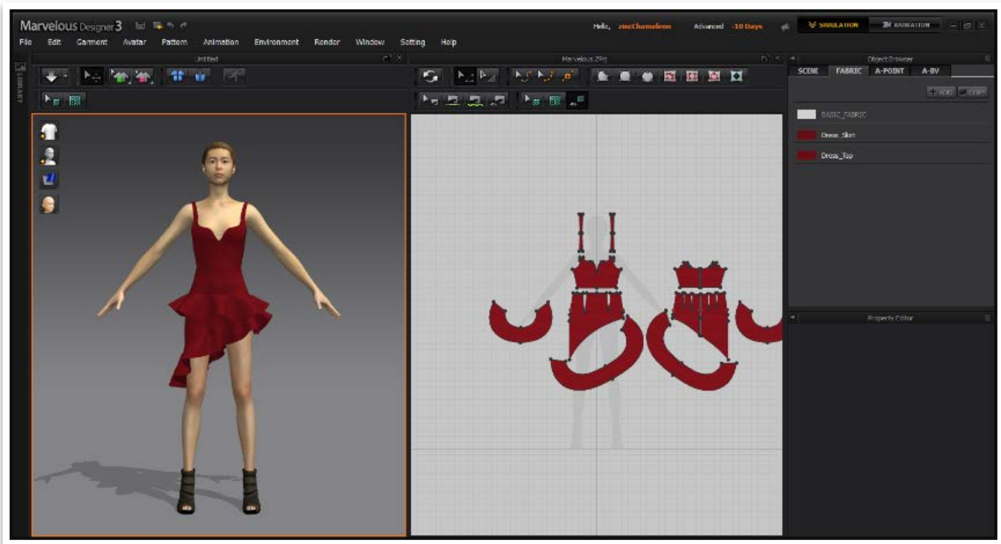

Figure 21: CLO's Marvelous Designer's user interface.

For the Marvelous Designer interface, panels can be arranged with 'Arrangement Points', markers surrounding a mannequin model to signify places the software will snap garment panels for better placement during simulation. Once the panels are arranged in the 3D space as desired, the user can test the structure, drape, and fit of the garment pattern on the model. This process is often referred to as 'virtual try-on' in the way it resembles the process a tailor might use to adjust fit on a real world mannequin or clothing model [54]. From here, the user may choose to reset the simulation to make adjustments to the pattern or adjust the simulation properties.

As fashion is a large, international industry, there are myriad clothing CAD software products available to the designer. They share many similarities and all attempt to recreate the experience of working with real world fabric using the aforementioned interface design choices. Some, such as Browzwear's Vstitcher [56], are optimized for designing and prototyping garments before they are produced to be worn by real people as opposed to only appearing within a simulated environment. The process between each software remains similar, a mode for designing a pattern and a mode for modeling and simulating with operations for making alterations as a real world tailor would.

4. METHODS OF CONSTRUCTION AND RECREATION

4.1 Workflow

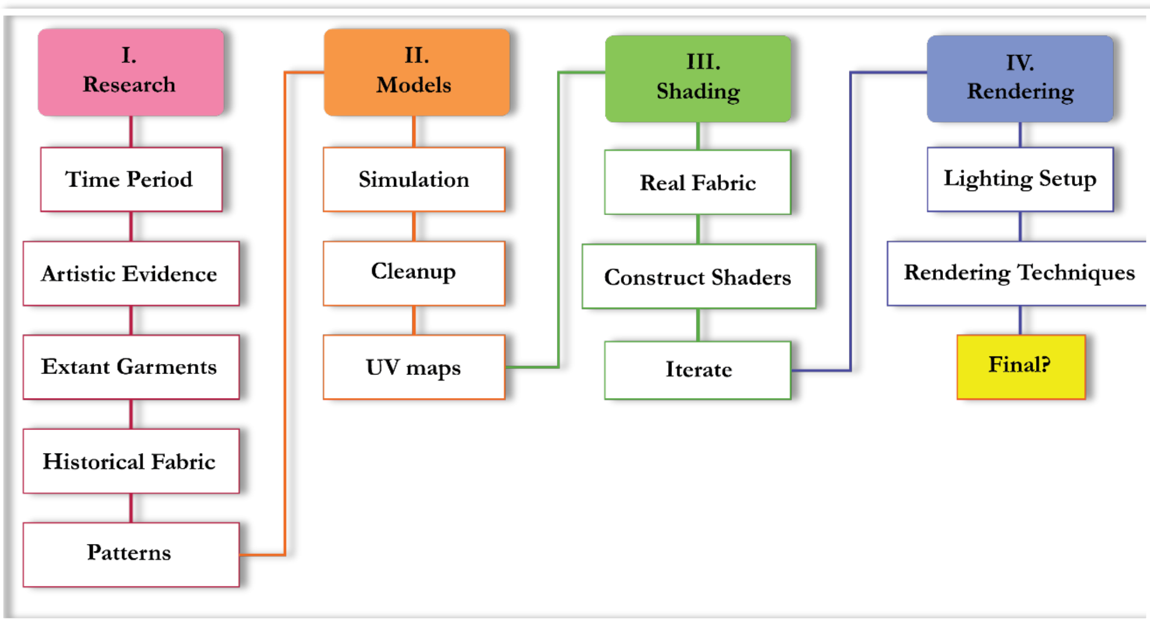

Figure 22: An overview of the proposed workflow.

Creating a cohesive methodology for bringing together the disciplines involved in the task of digitally recreating historical clothing may seem daunting. In reality, a digital garment is no different from creating other 3D models. The main difference is mostly to do with the groundwork an artist must do to execute their model. However, there are other challenges to take into consideration that are mostly to do with software and hardware limitations. The following is a proposed methodology for researching, designing, and executing a recreation of historical clothing in a computer environment.

The first item to consider is the garment's origins. The 'where' for historical clothing is just as important as the 'when', especially if the garment is intended to integrate into an historical setting. Anachronism may be welcome in fantastical settings, but can be disruptive if a setting is established as 'historical.' Additionally, once a time period is chosen, an artist may consider who might have worn this particular garment and why. However, if the goal is to merely create a model of a dress for documentation, accuracy to social class is negligible but if the dress is being created with a specific character in mind, the character's status in society will need to be considered when choosing what he or she will wear. Differing social classes tended to have different materials available to them [57]. A peasant is unlikely to have the need or the means to acquire a silk and whale boned bodice. It may look appealing, but it isn't a scenario accurate to reality.

Once a garment's place in space and time is established, visual research can begin. The first step is to narrow the search to primary source material from the time period in question. If possible, find artwork that depicts fabric naturalistically, an easier task if the time period is taking place at a time when the art depict naturalism such as the Renaissance. Thanks to the attention to detail and precision of artists like Jan Van Eyck, Agnolo Bronzino and others, identifying fabrics depicted in their work helps the digital artist choose the correct material for simulating and rendering fabric. There may be instances where the source material is not as helpful. The middle ages can provide rudimentary images of clothed figures, but will appear flat and caricaturized with very little visual information to reveal the clothing's material (Figure 23). However, archaeological evidence and documentation may fill in any gaps in this matter. Even if adequate visual source material is available from the chosen time period, researching

Figure 23: Illustrations of aristocratic clothing from *Tres Riches Heures du duc de Berry*. Limbourg Brothers, 1412-1416 [58].

commonly used materials, fabric weaves and dyes during this time zeroes in on the expectations of the end result.

4.2 Exemplary Garments

Every period of fashion has an exemplary garment that serves to bring together common and popular clothing aesthetics from the period. For instance, describing a gown as 'Tudor' invokes a particular style in early 16^{th} century English fashion. An exemplary Tudor gown is structured with a bodice and a hoop skirt (farthingale) to create the distinctive silhouette associated with this style. These gowns have similar necklines and sleeve shapes as well. Likewise, men's fashion follows particular guidelines for style and silhouette.

Determining what constitutes as an exemplary garment from the chosen time period requires some superficial internet searching. Historians and historical re-enactors provide quick answers to identifying the garments and breaking them down into anatomical detail. If possible, find an extant specimen of the chosen period's exemplary garment. The 16^{th} century Italian gown known as the 'Pisa' gown served as an excellent specimen for the end product of this thesis. Not only can it be considered an exemplary garment from 16^{th} century Florentine style, it has been restored in excellent condition

Figure 24: *The Pisa Gown*, mid 16th century, Florentine [59].

with trim and other details (Figure 24). The dress has also been well documented and deconstructed which will serve to aid in the digital recreation.

4.3 Deriving Patterns

With the target garment identified and studied, the next step in garment recreation is deriving a sewing pattern to use in the modeling process. The Background chapter addressed several sources for finding patterns for historical garments which will prove valuable moving forward. For those unfamiliar with garment construction and sewing, there is a learning curve in understanding terminology. Luckily, the same resources used in determining exemplary garments also can lead to finding a pattern with instructions for sewing and assembly. If the artist is a seamstress already, reverse engineering a piece of clothing based on prior knowledge is possible.

In some cases, an exemplary garment may already be displayed as a layout of dismantled pattern pieces. The most relevant example for this thesis is the funerary gown of Eleonora of Toledo. The gown is famously displayed with the major components of the bodice and skirt laid out to illustrate the shape and construction of the garment. Finds of this nature aid scholars of historical clothing and prove equally useful for the purpose of deriving a working pattern. Scholar Janet Arnold left behind an approximation of this particular gown with assembly instructions in her book *Patterns of Fashion Volume 3* [60]. Members of historical reenactment and recreation organizations such as the Society For Creative Anachronism collect their own documentation and make them available via their own web domains or Pinterest accounts. Members who maintain a web presence are available for consulting on forums or email and are usually happy to share expertise and sewing experience.

Patterns may also be purchased commercially. This route comes with its own problems for applying these to a digital model. Major fashion companies offer historically inspired costume patterns. However, as mentioned in the Background chapter, these are adapted to modern needs and are not necessarily accurate in many cases. Format also becomes an issue as commercial patterns may only come sized for use on real world fabric. Patterns do come with instruction booklets with illustrations of the pattern pieces contained within. If a .PDF is available for reference during pattern drafting within CAD software, a purchased pattern from reputable sources is ideal but is somewhat of a rarity.

4.4 Modeling

The modeling portion of this process depends heavily on the chosen software for the task. Pros and cons must be weighed before proceeding. Popular 3D packages like Maya [61] include modeling and simulation but are cumbersome to work with in this instance. Software like those discussed in the modeling software section of the literature review chapter are designed to handle the modeling situation at hand. In some cases, it may be to the artist's advantage to use multiple software packages for different aspects of the model. Marvelous Designer offers a streamlined platform for simulating drawn sewing patterns, but the artist is at the mercy of the simulator outside of the software's pinning capabilities.

A balanced approach begins in Marvelous Designer and moves to sculpting software like Mudbox [62] and then to Maya for UV mapping and rendering. Before a clothing model can be executed in Marvelous Designer, the artist must determine a human model to be used as a digital mannequin if the defaults are considered unsuitable. The underlying model is used for collisions to create the desired silhouette for the clothing so the mannequin must be modeled accordingly. Pattern shapes may also need to be adjusted to fit the mannequin, a task Marvelous Designer can easily accomplish with the editing tools available. Depending on the garment's fabric, the simulation settings will also need adjusting for desired creasing, elasticity and stiffness.

Once the garment model is completed to satisfaction within Marvelous Designer, the geometry can be exported to another modeling suite for further finessing. If there are adjustments needed in a sculpting software like Mudbox or ZBrush [63], export the geometry as a whole since Marvelous Designer treats each fabric panel as a separated piece of geometry even when 'sewn' together. If this is not an option due to computer speed or garment complexity, exporting to a 3D package to merge vertices between fabric panels of the same garment piece and creating a complete piece of geometry is necessary before it can be sculpted. Otherwise, sculpting operations will separate the panels leaving a hole which is not desirable.

4.5 UV Maps

Marvelous Designer conveniently creates UV maps for each clothing panel. If the artist is not so fortunate and is starting from scratch, the process of UV mapping resembles a process of disassembly similar to ripping out seams in real clothing and should follow the clothing pattern in reverse. The operations involved with laying out UVs is heavily software dependent and will require knowledge on the part of the artist to execute this step accordingly. For Maya, users will work within the UV Texture Editor to translate maps of the individual fabric panels into a desired position on the UV map.

When laying out the UV maps, it helps to do so in a way that would make sense if the map pieces were being laid out and cut from a piece of fabric. In this way, a texture with a visual pattern will continue in the same direction. Not paying attention to the direction of the ‘fabric’ can have undesirable results when rendered. As with real clothing, the threads of the ‘fabric’ need to be running the same direction on the pattern pieces or it will appear crooked and above all distracting to the viewer. In real sewing, this thread direction is referred to as fabric grain. Figure 25 demonstrates how pattern piece orientation and fabric grain creates undesired results. Pattern pieces on real world patterns will indicate which direction a pattern piece should go with an arrow. Pattern layout diagrams also indicate the orientation the pattern piece should go on the fabric to avoid the undesired crooked effect. The orientation of the fabric piece should be perpendicular to the weft threads. When laid out correctly, the threads should all be running in the same direction across seam lines.

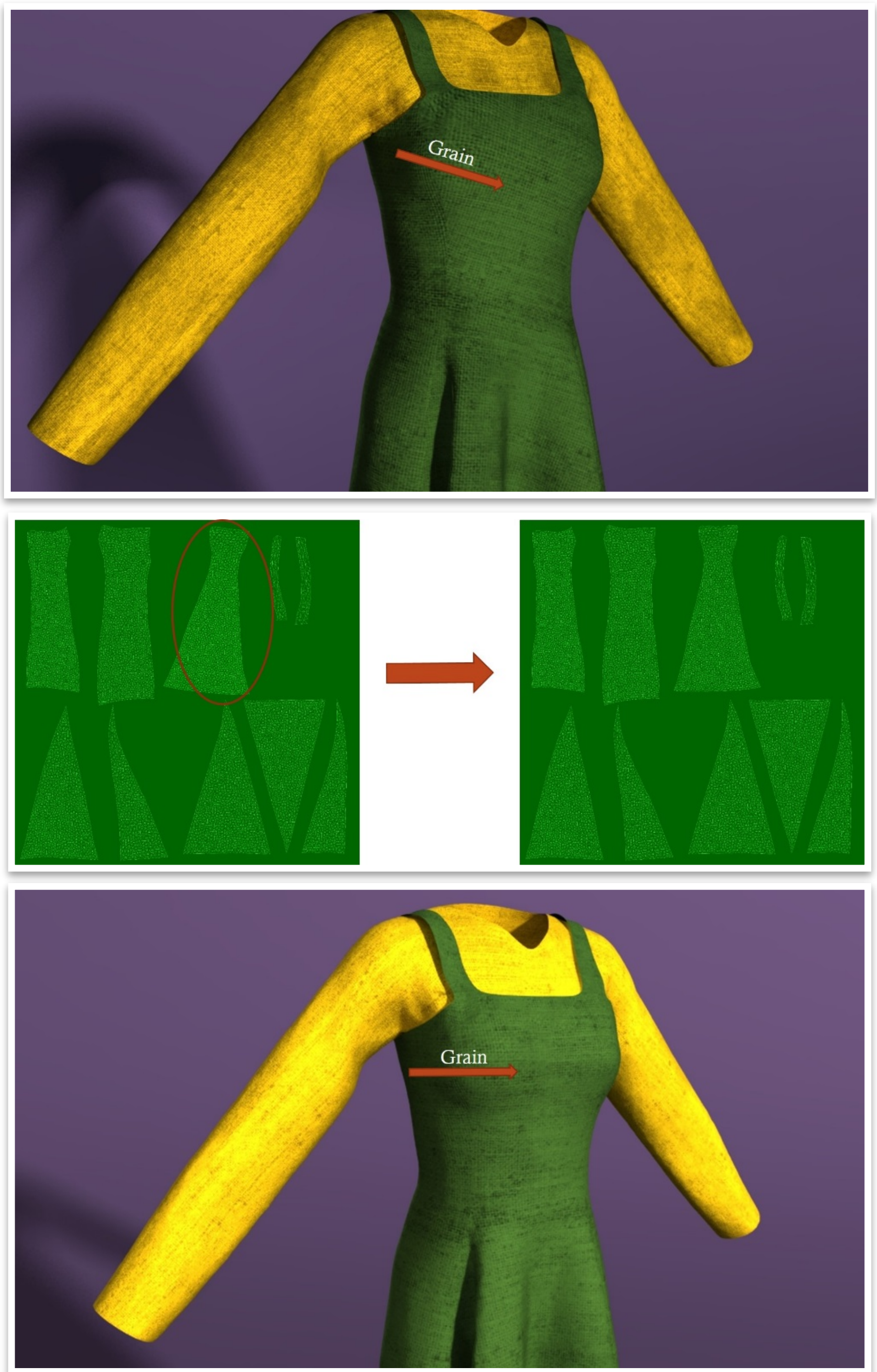

Figure 25: When pattern pieces are not laid out correctly, fabric grain creates a crooked appearance. Ideally, threads should maintain consistent direction across seam lines.

4.6 Rendering and Shading

With the UVs set up and arranged to satisfaction, the artist can now proceed to surfacing. A return to the paintings and extant garments may be needed to identify fabric types and how they interact with light in its environment. To supplement these studies, a collection of photos of the fabric in different light qualities and light positions will prove helpful in determining the qualities in the shaders. Obtaining sample swatches of real fabric for observation on the spot or for fabricating lighting conditions for reference can also be a valuable asset.

Shader construction can be executed with code or node based software and plugins. For example, Maya's Hypershade or Renderman's SLIM [64]. As long as the renderer supports the needed shading components, preference is at the artist's discretion. Much of the previous work in fabric rendering is procedurally based with algorithms designed to deal with the heavy calculations involved with rendering realistically. For the purpose of keeping these methods accessible to artists with a weaker computer science background, fully procedural shaders will only be mentioned as an option. Texture maps for this thesis are image based using maps edited with Adobe Photoshop [65] and adjusted within attributes in shader nodes to fine tune the look. A typical shader node network will contain the base shader with connections to different maps serving different functions. The input maps include diffuse, specular, bump and/or displacement and alpha masks and may include multiple layers depending on the details required for the target garment. Figure 26 is a screenshot of the shader network used to create a linen look within Hypershade. A garment's details need to be assessed to determine if layers are needed and if so, how many. For the Pisa gown, two layers are required with a bottom layer to hold the velvet shader information and another for the embroidered trim as it is a different material than the dress. In this way, details like trim, applique or other garment notions can be controlled separately within a shader.

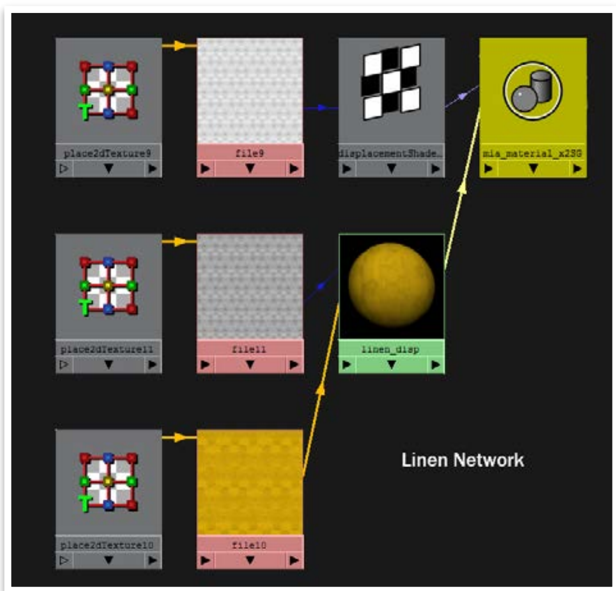

Figure 26: The linen shader network including nodes for displacement, specular and diffuse.

Before the final product, a process of shader testing and iteration occurs. Shaders can be developed for each fabric type and tested on a separate, simpler piece of geometry such as a sphere or a simple draped nCloth fabric ‘swatch’. To keep the lighting consistent between models, referencing in a lighting setup file containing all lights and a surface upon which to cast shadows into the model file is useful. For this thesis, each render used a standard lighting setup consisting of a 3 point light configuration with key, fill, and rim lights, and a slightly curving surface to cast shadows on. Shadows should be soft enough to show the model's volume and not distract from it.

Setting up renders depends again on the software chosen by the artist. In general, available renderers include some kind of raytracing and indirect illumination. Use of these options depends on available computing power and available time to render. In order to achieve desired realism, it is recommended to utilize indirect illumination. Both Mental Ray [66] and Renderman offer methods to add image based indirect illumination, but again, the more rendering algorithms utilized, the more computationally expensive the render. Perhaps the most time consuming step is iterating through options and settings until a satisfactory image is achieved.

5. RESULTS

5.1 Initial Challenges

Implementing this methodology presented several initial challenges. While the method is designed to be applied to many time periods and settings, a focus needed to be chosen for implementing the method. Progression through the early research stages unearthed an inspiring painting, *Eleonora of Toledo and Her Son Giovanni* by Agnolo Bronzino. Further research revealed the painting's popularity with historical recreation groups and costume researchers alike. The gown depicted in this painting can be considered exemplary of early to mid 16th century Florentine clothing. Eleonora's gown and its contemporary, the Pisa gown, provided enough visual research to proceed with 16th century Florence as the focal setting to implement the proposed methodology.

Exploring and choosing a suitable software for the tasks needed posed another challenge. Maya has the capability to create geometry and simulate drape, but did not have the specific tools to visualize how a garment might come together. The interface proved unwieldy and counter-intuitive for the needed tasks. Marvelous Designer's interface by contrast allowed for a better workflow in modeling and simulating. Additionally, Marvelous Designer offers software support and a community of creators sharing their experience with tutorials and other learning materials via its online forum (http://www.marvelousdesigner.com/community/forum). This software was not without a learning curve and did require experimentation to achieve the desired results. Marvelous Designer's simulator included options for manipulating the physical qualities of the fabric the user is working with. To create the Florentine dress model, using these options was required to achieve the stiffness of the bodice and skirt. Even so, the silhouette of the gown did not form as desired and required more hand-on manipulation using Marvelous Designer's pinning operations to freeze vertices on the panels in a position. Problems such as these are beyond the scope of real world sewing and the techniques used to solve them are not as intuitive.

Another software specific obstacle occurred in the shader authoring stage. The most readily available render and shader software was Mental Ray's Maya plugin. For the most part, it functions as expected within Maya's Hypershade except for layered textures. This function is not straightforward to use and required a roundabout solution using Maya's Surface Shader as a 'translator' to feed inputs from the Mental Ray shader networks into a larger, layered network. This will be further explained later in this chapter.

5.2 Collecting Visual Research

This step in implementing the proposed methodology had its own pitfalls. Sources had to not only be reliable but also include proper references to verify authenticity of information. Books provided high quality images for study, but tended to focus on more famous works and would prove inefficient for more obscure artists of the era in question. Using the internet introduced further traps as sources often omitted references or the image resolution quality was frequently poor, and color variation was extensive. Search engines such as Google provide tools to refine searches for higher quality images and content. Probing the different academic disciplines involved with this project also yielded helpful papers and resources.

Books and the internet are the most obvious sources for knowledge concerning history but they do have limits. For real world sewing advice, one on one interaction with people who sew is invaluable, especially those whose main interest is in recreating historical clothing. Surprisingly, historical reenactors, recreators and hobbyists collected sources via Pinterest boards. These proved to be a springboard for finding paintings and historical clothing patterns as well as tips for finding modern equivalents of period fabrics. Obtaining samples of these fabrics for hands on study could also be achieved through retailers providing services to the historical reenactment community. The most reliable way of obtaining fabric samples was through online retailers for non-synthetic specimens of linen, wool, and silk. Samples for this thesis were purchased via Dharma Trading co. Once a real sample library was collected, a rudimentary method of capturing the way they interacted with light was created with a lazy susan as a 'turntable' and

Figure 27: Images of silk velvet and satin turntables.

draping surface. These samples were filmed for reference during the shading process (Figure 27).

5.3 Generating Models

Before modeling the clothing can begin, the user must decide on the mannequin model to be used as the rigid body for collisions during simulation. Marvelous Designer provides several default ‘Avatar’ models for this purpose but some garments call for a specific silhouette. For loose fitting clothing, the default models work as expected. However, for clothing that forces the body into an unnatural shape like the cylindrical torsos and controlled look of 16th century Florentine garments [Hollander 2002], the default models hinder more than help. A female mannequin model was created for a fuller physique more like those depicted in Renaissance paintings. This was a personal aesthetic choice for the final product as the default models would have served the project adequately. The simulator handled loose fitting clothing on this mannequin model as expected but with the larger figure, the issue of creating the form modifying clothing was exaggerated. Solving this issue was a matter of reshaping the mannequin model to match the desired final silhouette of the target garment. Figure 28 illustrates the original mannequin model and the reshaped version.

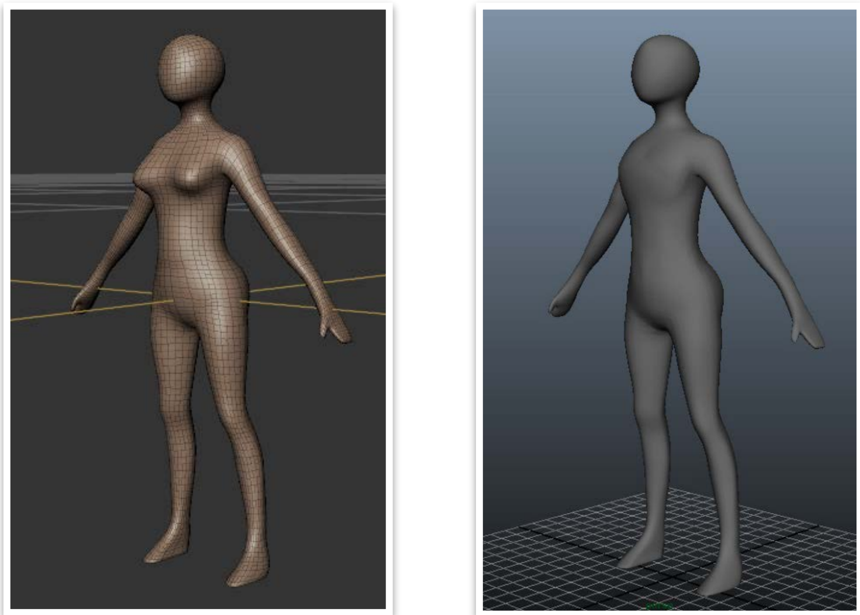

Figure 28: Mannequin model sculpt in Mudbox and model in Maya after reshaping.

Using a custom mannequin model in Marvelous Designer requires some initial setup. First, the model needs to be in the Wavefront .obj file format for Marvelous Designer to read. Plugins for exporting this format are available to load within Maya's plugin manager and other computer graphics packages. Marvelous Designer also needs files for positions of Arrangement Points and Bounding Volumes. Arrangement Points are above the surface of the mannequin model that aid in placing the 3D fabric panels and Bounding Volumes are cylindrical volumes placed around the limbs oriented along the axis a fabric panel will wrap and drape. These are useful tools for placing fabric panels and making it easier for the software to simulate and collide with the mannequin model. The placement of Arrangement Points and Bounding Volumes are shown in

Figure 29. To create files for the placement of these points and volumes to correspond to the shape of a custom mannequin model, the new model must be imported to adjust the positions of the Arrangement Points and Bounding Volumes. The adjusted positions need to be saved as their own file to keep the position data to import into Marvelous Designer whenever the corresponding mannequin model is used.

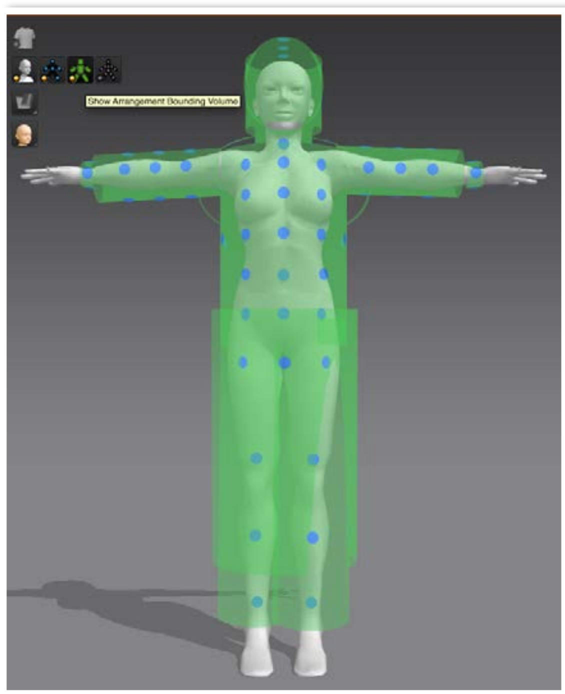

Figure 29: Arrangement Points and Bounding Volumes on an imported model.

Marvelous Designer’s learning curve required trial and error as well as the online support of the Marvelous Designer community. While the mechanics mimic real world sewing in the way it visualizes draping and ‘sewing’ together seams, there are still some ways in which the software is counter-intuitive. For instance, MD’s simulator may not behave as desired. Luckily, in later versions of the software, simulation is interactive, allowing the user to move panels during simulation into a desired position. Another issue

Figure 30: Skirt panels interacting with chemise model in undesirable ways.

is using MD's layering system to create different layers of clothing. This problem arises as a consequence of having an ensemble with a loose fitting under layer with a form fitting top layer. Collisions between the two fabrics look disastrous to an unsuspecting user. This particular issue comes into play with the 16th century gowns (Figure 30), but similar fitting layers behave as expected.

Simulations can be further controlled with MD's 'pinning' operations that freeze vertices on the fabric panel geometry. This can be used to hold straps in place or hold areas where the dress should billow outward so they do not cling against the mannequin. A major advantage to using CAD software like Marvelous Designer is that it automatically generates UV maps for each panel in the clothing file. The problem comes when importing into other 3D packages. Each panel is recognized as separate geometry so vertices must be merged before sculpting the geometry to refine the shape. For this project, panels were merged together as a single piece of geometry while retaining the UV maps. The UV maps were then rearranged to mimic the cutting layout on real world fabric. Further exploration may be necessary in order to discern a more effective method of achieving this result.

5.4 Base Fabric Shaders

The construction of shaders for different fabric types underwent a process of testing and implementation. A tester model was created by simulating a large square of nCloth in Maya and draping it over a sphere resting on a platform. This mimics the scene setup for filming turnarounds of real silk swatches for earlier visual research. Using this model, shaders for multiple fabrics could be tested in a neutral environment with the simple 3-point light setup. Shaders constructed here may be exported and used on other

Figure 31: Base fabric shaders applied to simple nCloth geometry.

geometry. In this way, a rudimentary ‘out of the box’ shader library was compiled.

These base shaders provided a platform from which to springboard into the more specialized looks of some garments with multiple fabric types and other details. Base shaders were developed for linen, wool, silk satin, silk dupioni, and silk velvet (Figure 31) all of which came in handy when being implemented in larger shader networks on garment models.

Some fabrics required more creative techniques to achieve the desired look. Maya's fur simulator was used to imitate the felt-lint fibers seen in wool fabrics. The consistency of the fur was similar to the fuzz on a tennis ball in order to achieve the effect from further away. On the full garment it only adds a subtle difference between renders, but on the shader testers, the difference is clear (Figure 32). Another fabric that needed more attention was silk dupioni. Silk dupioni has fibers of varying thickness on

Figure 32: Wool with Maya fur added.

the weft threads causing a random appearance of bumps, or slubs. This creates visual interest in the fabric and variation on how the fabric reacts to light.

5.5 The Clothing

The following section details the garments that were chosen to implement the proposed methodology. The clothing was selected based on the time period of focus as well as familiarity with the patterns.

5.5.1 Norse Apron Dress

This ensemble served as a means to test the software and techniques for viability and was chosen for its simplicity. The Norse Apron dress or Hangerock was worn by Norse women during the Viking age [67] and is a popular pattern among historical reenactors. The structure of the dress consists of simple polygonal geometry making pattern drafting and assembly a straightforward process.

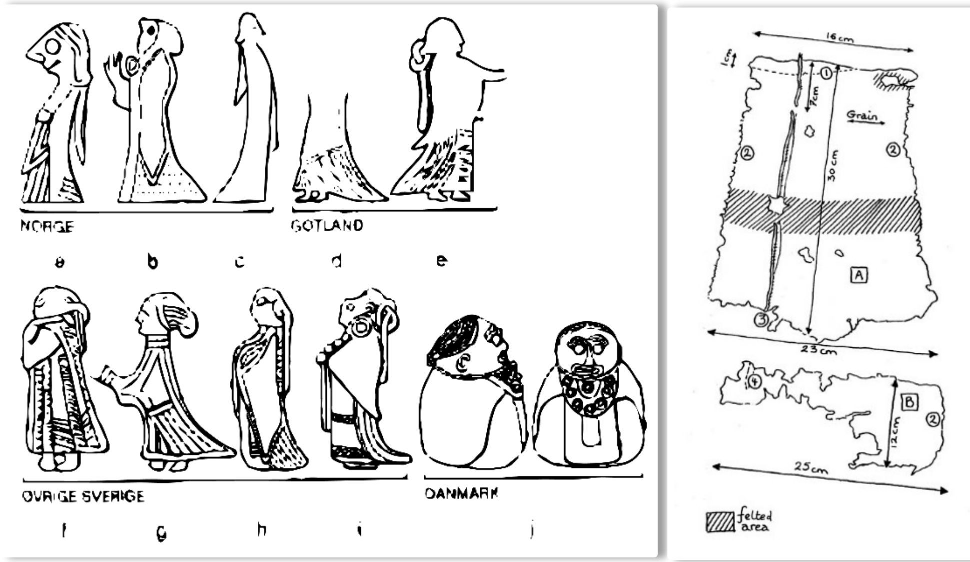

Figure 33: Illustrations of Norse garb from archeological evidence. The left images are Norse depictions of clothing. The right is an illustration of a fabric remnant found in Haithabu in modern day Germany [67].

To place this garment in its historical context: The Viking age occurred in the period between 793 and 1066 CE [68] and as such, very little clothing has survived the test of time [Short]. What is known is pieced together from archeological evidence (Figure 33) found in old settlements, artwork and historical accounts. Norse settlements can be found all over Nordic countries, the British Isles, France, Russia and evidence of their presence can be found as far away as Turkey and Greenland. Based on the evidence, they wore wool and linen but silk may also have been used for embellishment like trim [69].

Using this pattern provided an excellent introduction to using the mechanics of Marvelous Designer and working out the details in the proposed methodology. Figures 34 and 35 show screenshots of the Marvelous Designer pattern, all seams met at straight lines with the geometric panel shapes. The garment consisted of a long, t-shaped undertunic that flared gently from the underarms to ankles with a cylindrical that apron flared from the waist on top. The simulator had no trouble calculating collisions between both layers. The shading process utilized shaders developed during the process of

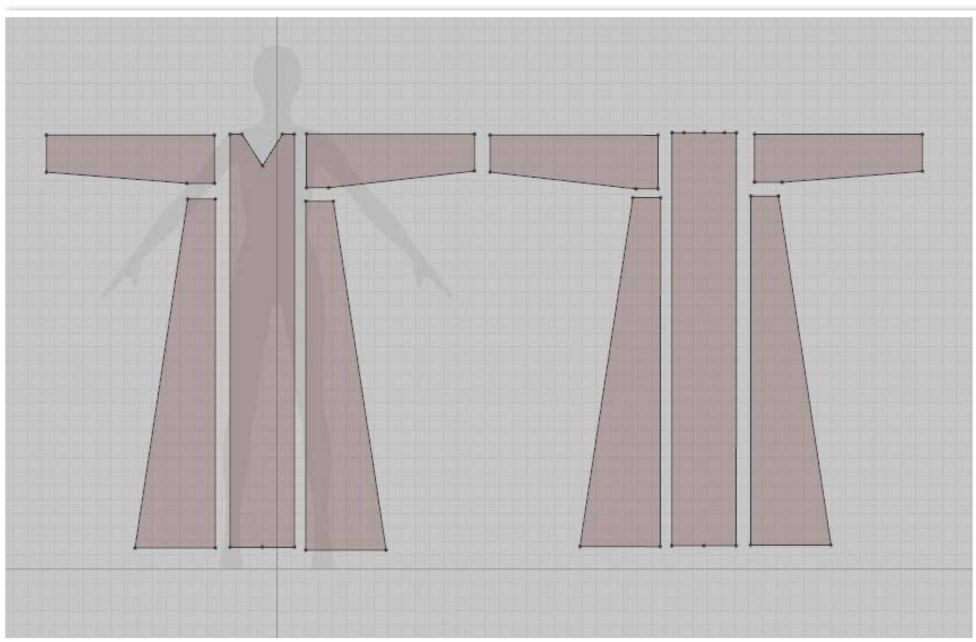

Figure 34: Pattern for Norse undertunic as it appears in Marvelous Designer.

creating basic fabric shaders and required very little adjustment to the full sized garment.

Figures 36 and 37 show resulting models and renders.

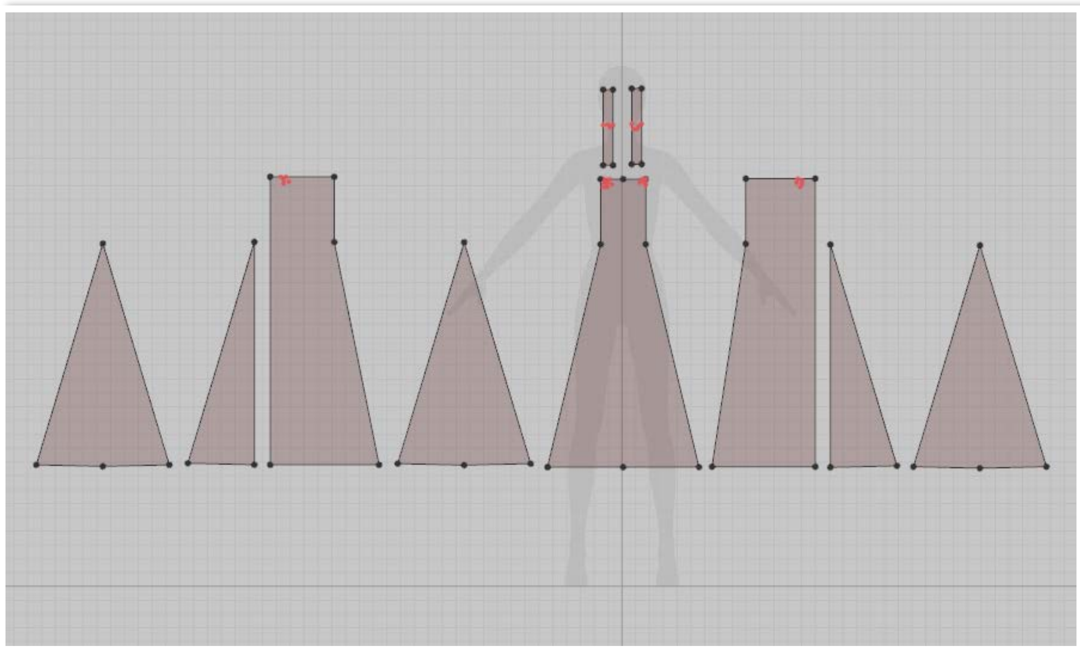

Figure 35: Pattern for Norse apron (Hangerock) as it appears in Marvelous Designer.

Figure 36: Completed model as rendered with Maya and Mental Ray

Figure 37: Completed render

5.5.2 Renaissance Italian Chemise

The chemise pattern is similarly simplistic but comes closer to the focus time period. A chemise or ‘camicia’ in Italian is a long, billowing shirt gathered at the

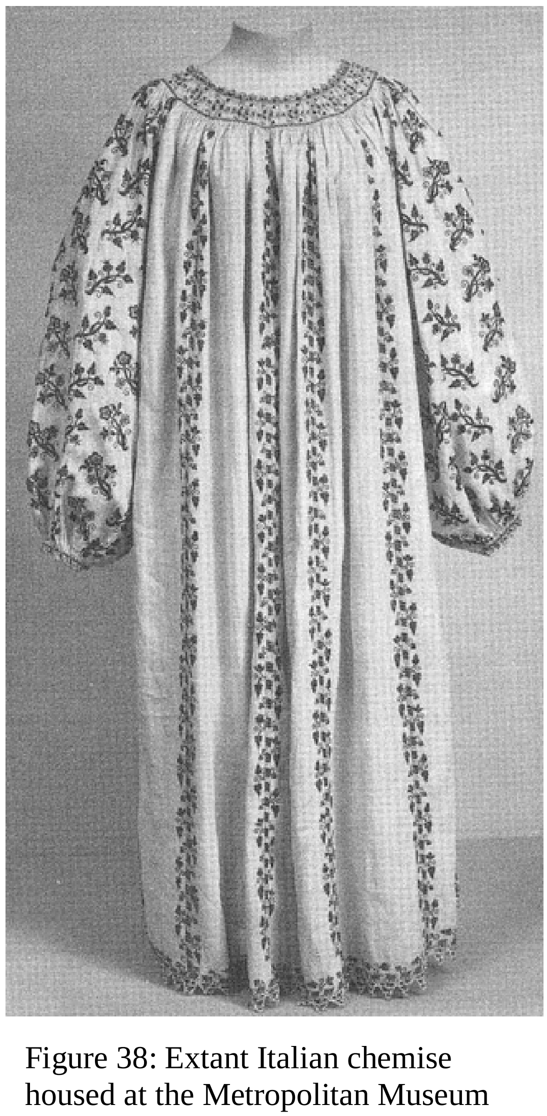

Figure 38: Extant Italian chemise housed at the Metropolitan Museum of Art, New York City [70].

neckline and cuffs with a round or rectangular neckline and was largely worn as an undergarment [71]. The chemise modeled for this project is inspired by an extant piece housed at the Metropolitan Museum of Art in New York (Figure 38) that originates in 16th century Venice. Similar garments can be found throughout Europe and may be referred to as ‘shifts’ or ‘smocks’. Chemises are generally made of lightweight linen and sometimes featured embroidery or trim embellishments [71]. A common type of embroidery, blackwork, can be found encircling the neckline and sleeves and may also

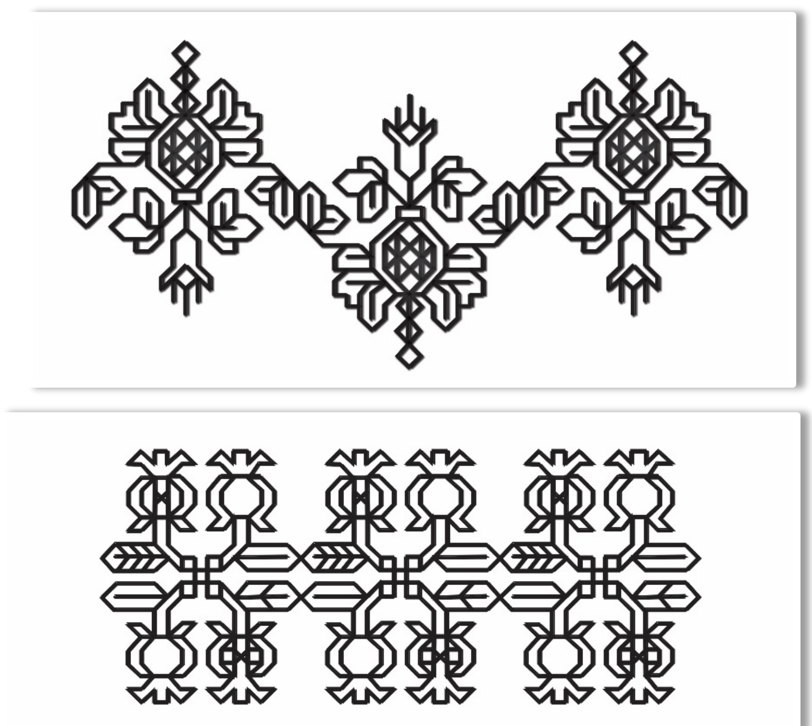

Figure 39: Blackwork embroidery designs by Paula Marmor based on period designs [72].

pattern the body panels. The simple geometric sewing pattern can be examined in the Met specimen and has been reconstructed from Janet Arnold's *Patterns of Fashion vol 4* [73] and web resources such as Anabella Wake's *The Realms of Venus* [74].

Initially, this chemise was intended to serve as the lower layer of the Italian gowns created later in this thesis. However, when paired with the tighter fitting over layers, Marvelous Designer's simulator calculated too many collisions between the two layers, resulting in a mangled mess as shown in Figure 30. This failure turned into an opportunity to test methods of layering shaders in Maya's Hypershade by adding blackwork embroidery details. The blackwork designs shown in Figures 39 are designed by Paula Marmor are based on period designs and features a pomegranate motif, a design frequently found in Renaissance textiles [40]. Figures 40 through 44 illustrate the resulting patterns, model, shader network, and renders.

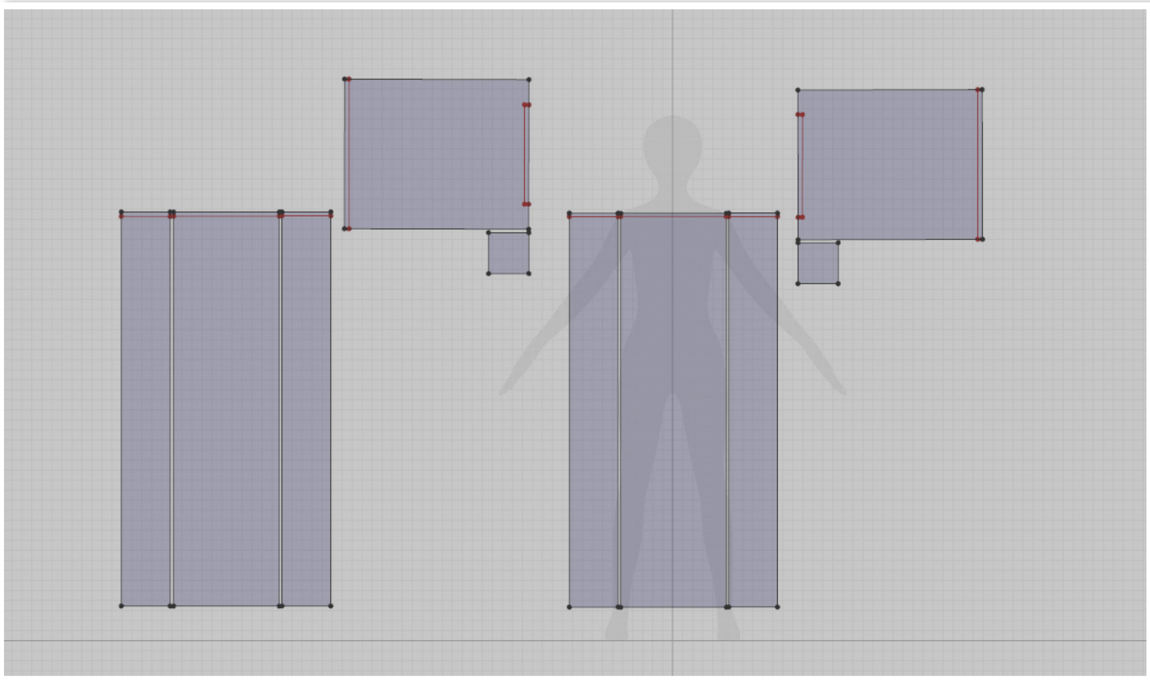

Figure 40: Chemise pattern as seen in Marvelous Designer.

Figure 41: Chemise model as rendered in Maya and Mental Ray.

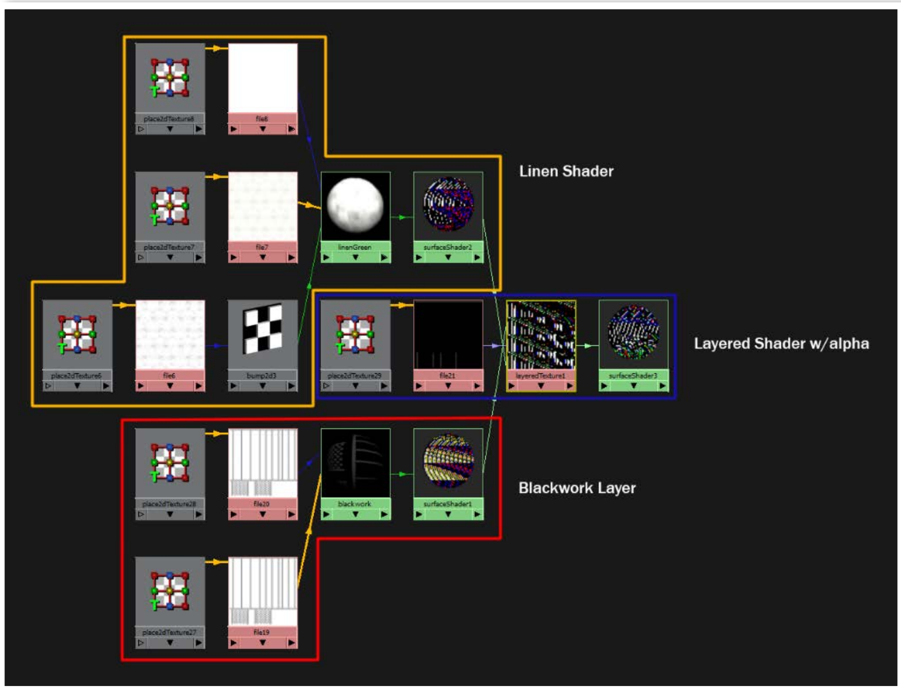

Figure 42: Hypershade shader network with linen and blackwork layers and layered shader.

Figure 43: Closeup of chemise with blackwork.

Figure 44: Full length chemise render.

5.5.3 Pisa Gown

The Pisa gown is an extant specimen of an 'exemplary' garment featuring the design and structure corresponding to Florentine styles of the 16th century. This particular dress is thought to have been originally created around 1560 and may have been worn as a court dress for Italian nobility. The dress is made from silk velvet with a decorative embroidered trim and consists of several parts: the bodice, skirt and detachable sleeves. The sleeves are slashed lengthwise, a style choice seen in other gowns and paintings of the time [75]. Currently, it is housed at the Museo di Palazzo Reale in Pisa.

In recreating this gown, more research into the pattern was required. A helpful piece in understanding the fabric layout was the strikingly similar garment: the funerary gown of Eleonora of Toledo. Patterns used for modeling this gown were based on several sources including Janet Arnold's analysis and Karen Carlisle's interpretation [76]. The main challenge was coaxing Marvelous Designer's simulator into creating the

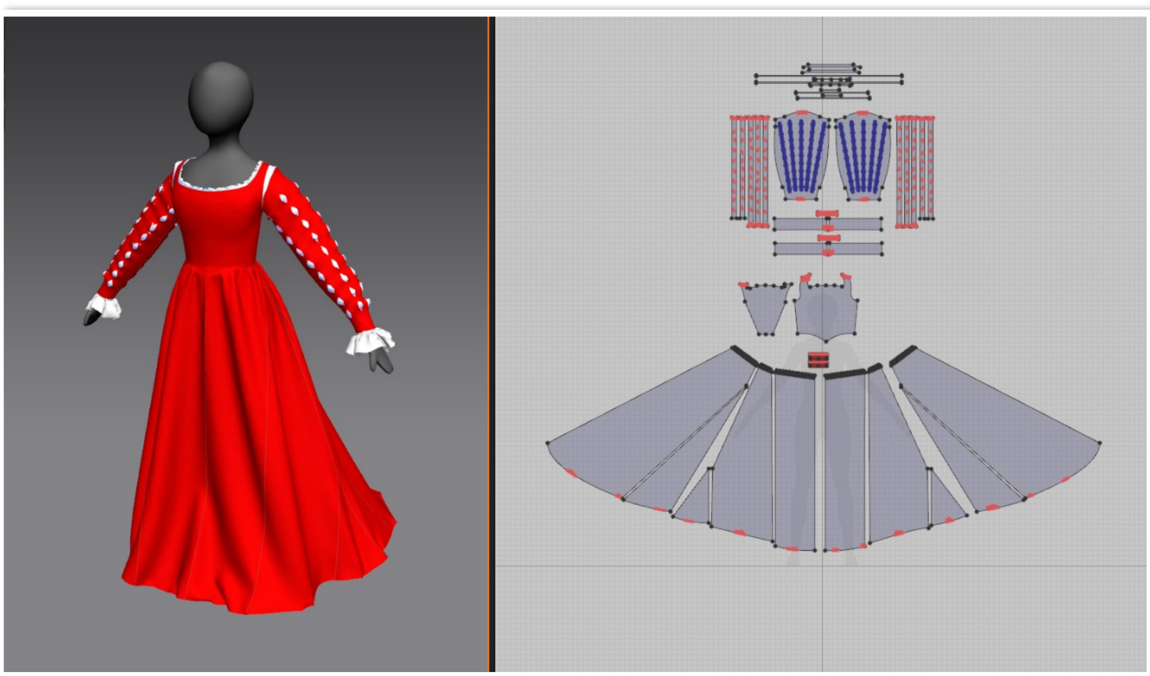

Figure 45: Model and pattern as seen in Marvelous Designer.

silhouette of the gown and to include the chemise. A workaround had to be devised as a compromise with the simulator to achieve this. Small strips were included at the neckline and sleeves to simulate the chemise's presence. To create the slashes in the sleeves, cuts were made as 'darts' in Marvelous Designer. When simulated, the slits opened up to reveal the dress' interior. Again, strips of fabric were pinned in place to simulate the chemise under layer. The resulting model and pattern are shown in Figure 45.

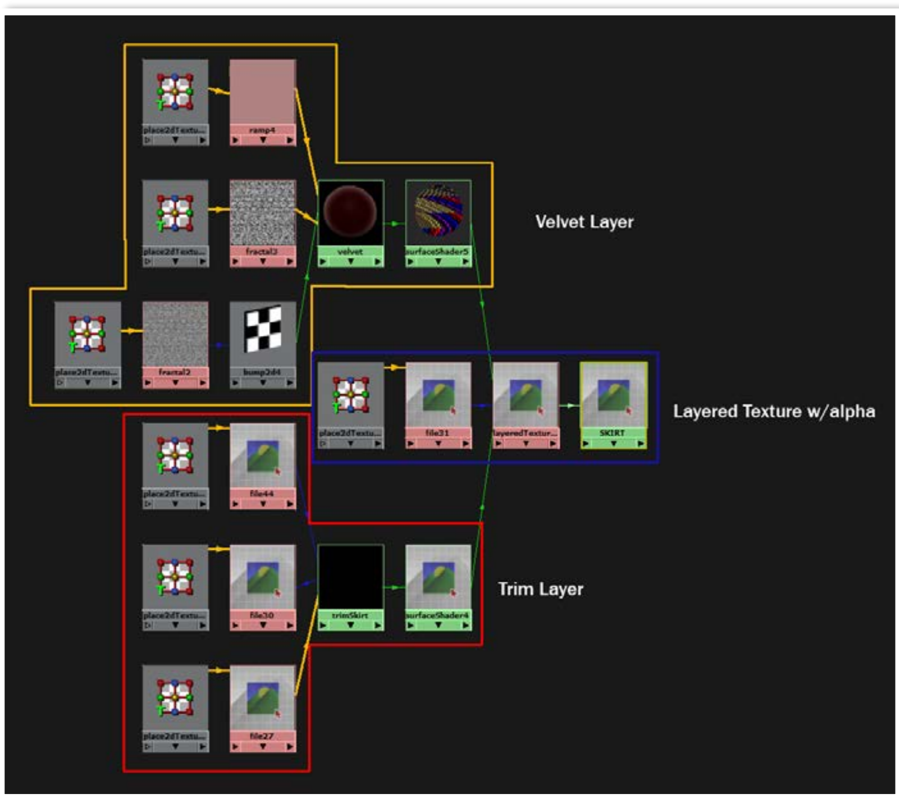

Figure 46: Pisa dress shader network.

The shading process implemented the use of layered texture nodes in Maya's Hypershade to include the trim layer as a different material (Figure 46). The trim design had to be recreated in Adobe Illustrator [77] (Figure 47) and copied over to its own image map in Photoshop and added as its own layer in Hypershade. Final renders are shown in Figures 48 and 49.

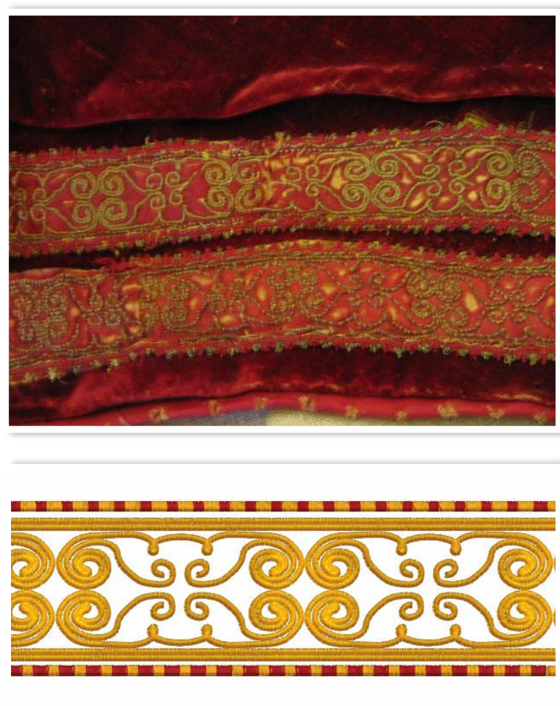

Figure 47: Embroidery on the Pisa dress and the recreated design.

Figure 48: Rendered dress model.

Figure 49: Final render of Pisa gown.

5.5.4 Eleonora of Toledo Gown

The Eleornora of Toledo gown was used as a final capstone to test the limits of this methodology and also serves as a culmination of the trials and errors of earlier models. Based on painted evidence, this dress originates in 1545, the year Agnolo Bronzino painted Eleonora’s famous portrait. The real dress was never discovered, however, there are textiles in existence that are similar to those depicted in the painting

(Figure 50). The dress' construction is consistent with other Florentine garments including the Pisa gown. Because of this, the same model was used in completing the recreation of this dress.

Figure 50: Agnolo Bronzino's portrait of Eleonora compared with similar fabric from the time period.

Previous scholars have worked to identify the materials displayed in Bronzino's work. The fabric can be described as a brocaded damask made of silk and silk velvet pile [Thomas 1994]. The design is a pomegranate motif with an arabesque pattern. Under the main gown, Eleonora wears a chemise with blackwork designs embroidered on the cuffs and neck.

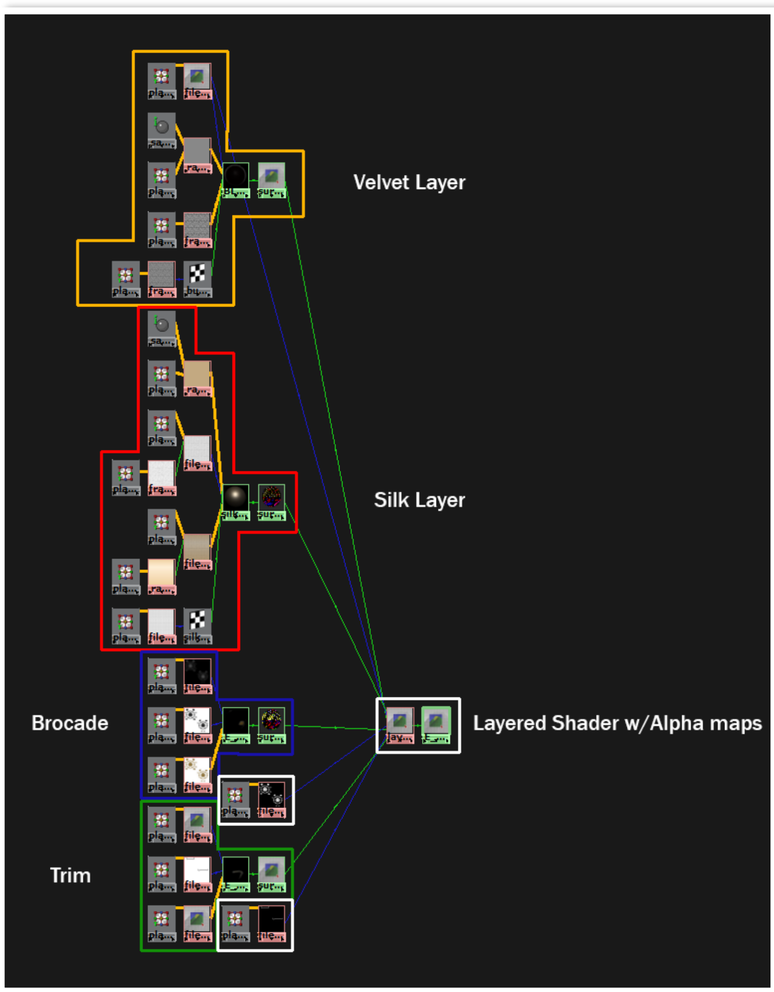

Figure 51: Eleonora of Toledo dress shader network.

The level of detail needed to achieve a recreation of the Eleonora gown puts the layered shader to the test. Up until this point, the render times had been consistent, taking about 2-3 minutes of time on a quad-core processor at HD resolution. A single frame of this gown took two hours, a huge time and computing expense. In each frame,

Figure 52: Recreated pomegranate motif as places on bodice image map.

four layers of the gown and the linen on the sleeves needed to be calculated and rendered. The layers of the gown included silk, velvet, trim, and the metallic parts of the pomegranate motif. This creates an extensive shader network (Figure 51). Velvet and pomegranate designs were recreated using the same technique as the Pisa gown (Figure 52). The end result is unmistakably Eleonora of Toledo's gown as shown in Figure 53.

Figure 53: Final render of Eleonora of Toledo's gown.

6. ANALYSIS

Results of implementing the methodology met expectations in some areas but fell short in others. The process of researching clothing in historical settings, finding the corresponding clothing patterns and using them to execute a model was largely successful in spite of the simulation problems. Renders however did not live up to the realism intended. The final images lack the depiction of visible wear on the clothing, running into the classic computer graphics issue of creating images that are ‘too perfect.’ Part of this issue is due in part to the images being based on Renaissance portraiture, a medium that was intended to exude the wealth and power of the subjects.

An issue in need of further consideration is the lighting setup created to render each scene. There existed a need for consistency for the sake of demonstrating the models as turntables. Part of the trouble of creating believability is the difference in lighting between the paintings and the renders. The artists were attempting to capture reality on their canvases to preserve the likenesses with all the beauty and dignity of the subject for the ages. Renders also did not create enough of a surface breakup with the displacement maps as expected. This problem was especially apparent in the velvet material. Light catches on the loops of velvet pile creating its distinctive look. The pile in the shaders did not appear dense enough for believable velvet.

Other areas to consider improving on in this methodology are the software and hardware limitations. Working on a single machine with a quad-core processor was not enough to handle some of the more expensive rendering demands. Renders also needed to be optimized for faster renders, something that if implemented would lose some of the desired quality. A custom renderer may have alleviated this, however in order to maintain accessibility to an amateur computer graphics artist such as the growing population of students in this arena, programming a custom renderer would not have been viable. Another solution would be investing in a remote rendering service or a render farm. If an artist or student already has access to a farm, render times and computing expense may be alleviated. The software used for creating models, Marvelous Designer, was also not without its limitations. Higher resolutions of polygons took more processing power and sometimes the calculations required in the simulator would crash the software. Further time working with the software may reveal possible solutions to some of the problems faced in this project.

With these issues in mind, improvement on this methodology will hinge on addressing solutions. Shaders can include maps to add visible wear on the garments so they lose their immaculate looks and gain a touch of reality. Alternative lighting setups can also be explored to further add character to the renders and bring to mind the lighting Renaissance artists already envisioned through their paintings. Exploring alternative software options with which to apply this methodology and test its viability outside the software used for this project would also be valuable in weeding out flaws in the method and creating a more software agnostic variation. Procedural methods such as those reviewed in the Literature Review chapter need to be explored so as not to solely rely on image maps. Most of all, more time was needed to iterate between renders to allow ironing out of visual problems. Solving the expense of rendering computations or utilizing a farm may allow more time for an artist to work with the shaders and lights and have more control over the rendered outcomes.

7. CONCLUSIONS

After evaluating the results against the expectations, the methodology can be considered a success with some exceptions. In order to full meet and exceed expectations, several problems need to be addressed for future exploration. Firstly, there is a need to take computing power of the artist implementing this methodology into account. To aid on this front, the method should include more efficient rendering techniques as well as continue to be accessible to artists and animators of varied skill levels. Monetary needs must also be considered in acquiring reference material or investing in better equipment, software or access to render farms either remote or local.

Due to the broad range of disciplines involved in this methodology, there are many situations in which it can be applied. The more obvious examples are film media and games where there is vested interest in creating believable costumes. Using the proposed methodology in this application may provide a launching point before customizing a design to suit the narrative or create audience appeal. Applications in education and historical documentation can add dimension to the subject and engage knowledge seekers in a novel way. These applications could manifest as interactive history lessons including a study of the lifestyles of people in the time period being studied. Historical garment models can serve as a digital museum allowing users to observe how a garment would have been worn. Having the patterns stored in Marvelous Designer or a similar software's files can also benefit students of theatrical costume and historical reenactors as easily accessible database.

To fine tune the details of the proposed methodology, more garments and time periods can be explored in the future with specific attention in the area of male fashion as many interesting and iconic styles were in use throughout history. While the range of disciplines and time periods available for study was much too broad for the scope of this thesis, the process of collecting research, studying and executing historical garments can be applied to any period of history. The hope is that much of history's greatest fashions live on through the hands of artists and historians for the future to admire and enjoy.

REFERENCES

[1] M. Landy, *The Historical Film: History and Memory in Media,* New Brunswick, NJ: Rutgers University Press, 2000.

[2] L Taylor. *The Study of Dress History*, Manchester, UK: Manchester University Press, 2002.

[3] N. Greno and B. Howard, *Tangled*, Burbank, CA: Disney Animation Studios, 2010.

[4] M. Andrews and B. Chapman, *Brave*, Emeryville, CA: Pixar Animation Studios, 2012.

[5] C. Buck and J. Lee, *Frozen*, Burbank, CA: Disney Animation Studios, 2013 .

[6] R. Scott, *Robin Hood*, Universal City, CA: Universal Pictures, 2010.

[7] H. v. Landsberg, *Hortus Deliciarum*, circa 1180. Illuminated manuscript.

[8] G. Dogramacilar, "Play and History: Authenticity and experience in virtual reconstructions and video gaming", Masters Thesis, University of Cincinnati, Cincinnati, OH, 2010.

[9] *Assassin's Creed*: *Brotherhood*, 2010, Ubisoft Entertainment.

[10] R.D. Masters, "The Portraiture of Women During the Italian Renaissance", Honors Thesis, University of Southern Mississippi, Hattiesburg, MS, 2013.

[11] A. Hollander, *Seeing Through Clothes,* Oakland, CA: University of California, 1993.

[12] Giotto, *Lamentation (The Mourning of Christ)*, circa 1304-06. Fresco. 200 cm x 185 cm. Cappella degli Scrovegni, Padua, Veneto, Italy.

[13] L. Monnas, *Merchants, Princes and Painters: Silk Fabrics in Italian and Northern Paintings, 1300-1550*, New Haven, CT: Yale University Press, 2008.

[14] J. v. Eyck. *Arnolfini Portrait*, 1434. Oil on oak panel. 82.2 cm × 60 cm. National Gallery, London.

[15] L. Hager, *Hans Holbein: Tricks of the Trade*. [Online]. Available: http://venetianred.net/2010/03/06/hans-holbein-tricks-of-the-trade/ [Accessed: Jun. 2015].

[16] C.S. Harbison, *Hans Holbein the Younger*. [Online]. Available: http://www.britannica.com/EBchecked/topic/269121/Hans-Holbein-the-Younger [Accessed: Jun. 2015].

[17] H. Hobein, *Portrait of Henry VIII*, 1540. Oil on panel. 88.5 cm x 74.5 cm. National Museum of Rome.

[18] Virtual Uffizi Gallery, *Agnolo Bronzino.* [Online]. Available: http://www.virtualuffizi.com/agnolo-bronzino.html [Accessed: Jun. 2015].

[19] A. Bronzino, *Eleonor of Toledo with her son Giovanni de Medici*, 1545. Oil on panel. 115 cm x 96 cm. Uffizi Gallery, Florence, Italy.

[20] E. Kren and D. Marx, *Lotto, Lorenzo*. [Online]. Available: http://www.wga.hu/frames-e.html?/bio/l/lotto/biograph.html [Accessed: Jun. 2015].

[21] L. Lotto, *Venetian Woman in the Guise of Lucretia*, 1533. Oil on panel. 95 cm x 110 cm. National Gallery, London.

[22] Kimbell Art Museum, *The Gypsy Fortune Teller*. [Online]. Available: http://caravaggio.kimbellart.org/exhibit/cardsharps-fortunetellers [Accessed: Jun. 2015].

[23] Caravaggio, *The Fortune Teller*, 1594. Oil on canvas. 115 cm × 150 cm. Musei Capitolini, Rome.

[24] A.C. Shelton, *J.-A.-D. Ingres.* [Online]. Available: http://www.britannica.com/EBchecked/topic/288120/J-A-D-Ingres [Accessed: Jun. 2015].

[25] J.A.D. Ingres, *Portrait of the Countess of Tourmon*, 1812. Oil on canvas. 92.4 x 73.2 cm. Philadelphia Museum of Art, Philadelphia, PA.

[26] J.A.D. Ingres, *Princess Albert de Broglie*, 1853. Oil on canvas. 121.3 cm x 90.8 cm, Metropolitan Museum of Art, New York City.

[27] The National Gallery, *Painting History: Delaroche and Lady Jane Grey*. [Online]. Available: http://www.nationalgallery.org.uk/whats-on/exhibitions/delaroche-lady-jane-grey [Accessed: Jun. 2015].

[28] P. Delarouche, *The Execution of Lady Jane Grey*, 1833. Oil on canvas. 246 cm × 297 cm. National Gallery, London.

[29] M. Gleba, C. Munkholt, and M. Nosch, *Dressing the Past*, Oxford, UK: Oxbow Books, 2008.

[30] J.A. Thomas, “Fabric and Dress in Bronzino's Portrait of Eleanor of Toledo and Son Giovanni” in *Zeitschrift fur Kunstgeschichte,* 1994, pp. 262-267.

[31] Anonymous, *Funeral Dress of Eleonora di Toledo*, 1562. Silk brocade. Galleria del Costume, Florence, Italy.

[32] R. Glazier, *Historic Textile Fabrics: A Short History of the Tradition and Development of Pattern in Woven & Printed Stuffs,* New York City, NY: C. Scribner's Sons, 1923.

[33] I. Sadeghi, O. Bisker, J. De Deken, H.W. Jensen, “A practical microcylinder appearance model for cloth rendering” in *ACM Transactions on Graphics* 2013, pp. 1-12.

[34] N.E.V. Bryk, *Linen*. [Online]. Available: http://www.madehow.com/Volume-4/Linen.html [Accessed: Jun. 2015].

[35] M. Snell, *Medieval Clothing and Fabrics*. [Online]. Available: http://historymedren.about.com/od/clothingandfabric/a/medieval-clothing.htm [Accessed: Jun 2015].

[36] K.D. Schroeder, *Plain Weave*, 2013. Digital. Wikimedia Commons.

[37] W.S. Pretzer and D. Pepper, *Wool.* [Online]. Available: http://www.madehow.com/Volume-1/Wool.html [Accessed: Jun. 2015].

[38] N. Powell and N. Yilmaz, “The Technology of Terry Towel Production” in *Journal of Textile and Apparel, Technology and Management* 2005.

[39] Textere, *Silk Making and Silk Production*. [Online]. Available: https://texeresilk.com/article/silk_making_how_to_make_silk [Accessed: Jun. 2015].

[40] M. Watt, *Renaissance Velvet Textiles*. [Online]. Available: http://www.metmuseum.org/toah/hd/velv/hd_velv.htm [Accessed: Jun. 2015].

[41] M. Mcnealy, *Deciphering Juan de Alcega's Tailor's Pattern book of 1589*. [Online]. Available:http://www.curiousfrau.com/resources/research/76-deciphering-juan-de-alcegas-tailors-pattern-book-of-1589 [Accessed: Jun. 2015].

[42] J. Alcega, *Tailor's Pattern Book, 1589: Facsimile*, Bedfordshire, UK: Ruth Bean Publishers, 1999.

[43] J. Arnold, *Patterns of Fashion: The Cut and Construction of Clothes for Men and Women.* London, UK: Macmillan,1985.

[44] D. Duperault, *Commercial Costume Patterns.* [Online]. Available: http://www.reddawn.net/costume/costpat.htm [Accessed: Jun. 2015].

[45] A. Hollander, *Fabric of Vision: Dress and Drapery in Painting*, New Haven, CT: Yale University Press, 2002.

[46] J.v. Eyck, *Madonna of Chancellor Rolin*, 1435. Oil on panel. 66cm x 62cm. Louvre, Paris.

[47] W. Yuen and B. Wunsche, "An Evaluation on Woven Cloth Rendering Techniques" in *Pro. Of the 26th International Image and Vision Computing New Zealand Conference*, 2011, pp. 7-12.

[48] M. Ashimikmin, S. Premoze, P. Shirley, "A Microfacet Based BRDF Generator" in *Siggraph '00 Pro. Of the 27th annual conference on Computer graphics and interactive techniques*, 2000, pp. 65-74.

[49] N. Adabala, N. Magnenat-Thalman, G. Fei, "Real-time Rendering Of Woven Clothes" in *Proc. Of the ACM symposium on Virtual reality software and technology*, 2013, pp. 41-47.

[50] W. Yuen, B. Wunsche and N. Holmberg, "An Applied Approach for Real-Time Level-of-Detail Woven Fabric Rendering" in *Journal of WSCG*, 2012, pp.117-126.

[51] Y. Takeda and H.T. Tanaka, "Acquisition, Modeling and Rendering of Bidirectional Texture Function of Ancient Japanese Noh Costume Fabric" in *The 8th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST*, 2007.

[52] F, Berthouzoz, A. Garg, D.M. Kaufman, E. Grinspun, and M. Agrawala, "Parsing Sewing Patterns into 3D Garments" in *SIGGRAPH 2013*, 2013, pp 1-12.

[53] *Marvelous Designer 4*, 2014, CLO Virtual Fashion Inc.

[54] T. Spahiu, E. Shehi and E. Piperi, "Advanced CAD/CAM systems for garment design and simulation" in *6th International Conference of Textile*, 2014.

[55] H. Werner, N.M. Thalmann and D. Thalmann, "User Interface For Fashion Design" in *CSI International Conference on Computer Graphics*, 1993, pp. 24-26.

[56] *Vstitcher*, 2014, Browzwear. Singapore.

[57] P. L. Hanson, *Renaissance Clothing and Sumptuary Laws*. [Online]. Available: http://www-personal.umd.umich.edu/~cfinlay/sumptuary.html [Accessed: Jun. 2015].

[58] Limbourg Brothers, *Tres Riches Heures du duc de Berry*, 1412-1416. Illumination on vellum. Conde Museum, Paris.

[59] Anonymous, *The Pisa Gown*, mid 16^{th} century. Silk velvet. Laboratorio Centro Restauri Tesseli, Pisa, Italy.

[60] J. Arnold, *Patterns of Fashion 3: The Cut and Construction of Clothes for Men and Women C. 1560-1620*, Woodstock, IL, Dramatic Publishing Co, 1985.

[61] *Maya 2015*, 2015, Autodesk Inc. San Rafael, CA.

[62] *Mudbox 2015*, 2015, Autodesk Inc. San Rafael, CA.

[63] *Zbrush*, 2015, Pixologic Inc. Las Angeles, CA.

[64] *Renderman 19*, 2014, Pixar. Emeryville, CA.

[65] *Photoshop CC 2014*, 2014, Adobe Systems. San Jose, CA.

[66] *Mental Ray 3.12*, 2014, Mental Images. Berlin, Germany.

[67] P. Beatson, and C. Ferguson, *Reconstructing a Viking Hanging Dress from Haithabu*. [Online]. Available: http://members.ozemail.com.au/~chrisandpeter/hangerock/hangerock.htm [Accessed: Jun. 2015].

[68] A. Forte, R. Oram and F. Pedersen, *Viking Empires*, Cambridge, UK: Cambridge University Press, 2008.

[69] W.R. Short, *Clothing in the Viking Age.* [Online]. Available: http://www.hurstwic.org/history/articles/daily_living/text/clothing.htm [Accessed: Jun. 2015].

[70] Anonymous, *Extant Italian Chemise,* mid-16th century. Linen. Metropolitan Museum of Art, New York City, NY.

[71] K.J. Carlisle, *What Lies Beneath: Florence*. [Online]. Available: http://katerina.purplefiles.net/DOCO/What%20Lies%20Beneath.pdf [Accessed: Jun. 2015].

[72] K. M. Marmor, *Blackwork Embroidery Archives.* [Online]. Available: http://www.blackworkarchives.com/ [Accessed: Jun. 2015].

[73] J. Arnold, J. Tiramani and S. Levey, *Patterns of Fashion 4: The Cut and Construction of Linen Shirts, Smocks, Neckwear, Headwear and Accessories for Men and Women,* Los Angeles, CA: Quite Specific Media Group, Los Angeles, 2008.

[74] A. Wake, *How To Sew A Venetian Camicia.* [Online]. Available: http://realmofvenus.renaissanceitaly.net/library/camiciahowto.htm [Accessed: Jun. 2015].

[75] R. Landini and B. Niccoli, *Moda a Firenze, 1540-1580: lo stile di Eleonora di Toledo e la sua influenza*, Oakville, CN: David Brown Book Company, 2005.

[76] K.J. Carlisle, *A Possible Pattern for a 16th century Florentine Sottana*. [Online]. Available:

http://www.sca.org.au/collegium/notes/Possible%20Pattern%20for%20Florentine%20Sottana.pdf [Accessed: Jun. 2015].

[77] *Illustrator CC 2014*, 2014, Adobe Systems.

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