Armor Influences on Designing a Character Costume with 3D Modeling and Printing Methods

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ARMOR INFLUENCES ON DESIGNING A CHARACTER COSTUME WITH 3D MODELING AND PRINTING METHODS

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Fine Arts
Digital Production Arts

by
Genevieve Marie Watkins
May 2019

Accepted by:
Dr. Eric Patterson, Committee Chair
Insun Kwon, M.F.A.
Anthony Penna, M.F.A.
Abstract

This thesis documents the process of researching, creating, and constructing body armor for a live-action film character, from artists’ concepts to 3D modeling methods to physical construction. Additionally, I will review the early and futuristic histories of armor designs, and their influences on the creation, composition, and construction of costume forms. Such review should reinforce the notion that it is important to understand the past for its influence on the future, and that a historical understanding of armor is vital to warrior costume design across multiple platforms.

The idea of a warrior is essential to the development and design of this project. I created an armored costume that is designed for a character focused on survival in an advanced world that has forgotten how to coexist and collaborate. This serves as an example of a potential world we may one day have to face. This character exists in a world of chaos and strife and needs to learn how to unite those of different skills and background. My aim in this project is to create a character with armor that feels familiar and plausible with the potential to exist.

In developing my thesis, I used the 3D computer graphics application, Autodesk Maya 2017; the 3D digital sculpting tool, ZBrush 2018; the retopology tool, TopoGun 2; and the image-editing software, Adobe Photoshop. I used several artist resources for my conceptual art, and real-life imaging body scans from MR-3D to create photogrammetry models and assets for proper body fit. Renders were achieved with the 3D rendering application, Arnold, while 3D printing assets were constructed using various technologies and materials in the Clemson Makerspace facility.

Through research and practical applications, I acquired new 3D skills while enhancing current ones, investigated resources relevant to the field, and gained additional design and manufacturing experience. I also gained an appreciation for the historical significance and design trajectory of armor in both traditional and futuristic settings. Furthermore, documenting the various aspects of the thesis emphasized efficient production skills, identified creative challenges as they appeared,
and prompted adaptive methods to achieve stated goals.
Acknowledgments

I would like to express my sincerest thanks to my committee members, Dr. Eric Patterson, Professor Insun Kwon, and Professor Tony Penna. Their patience and understanding is to be commended. Dr. Patterson has been immensely supportive of my attempts to do something new, Professor Insun Kwon has always been able to push me in a direction to create my strongest work, and Professor Tony Penna has kept me grounded in reality and focused on functionality.

I would like to thank all my fellow DPA students who spend their time in the studio with me. I find that working around these amazing artists and technicians has energized and motivated me. It means a lot to be able to turn around and ask for an opinion, or engage in a conversation. Being accountable to my peers guaranteed that this project would be possible.

One of my main sources of encouragement and affection came from my dog. He has been my rock and constant support throughout the many challenges encountered both inside and outside of the DPA program. My dog lights up my life.

I would also like to express a very special thank you to Tami Grabowski, the talented seamstress who was extremely influential and helpful during the creation of the bodysuit for my armor pieces. She combined several patterns to assemble the final design I was hoping to create. Without her time, effort, and skills, I would have been without a custom-made bodysuit to attach my design to.

I am also particularly thankful to the amazing student interns at the Clemson Makerspace who made this entire adventure possible. I want to give a warm appreciation to Colby, Pranav, Jensen, David, James, Heather, and Jiawei. I have spent many weeks with these individuals while printing this design, and their encouragement and excitement really made the process a delight.

I would also like to thank Jeff Grawbowski who helped me select the proper finishing supplies, and showed me that I could make something high quality with the skills I already possessed. His
encouragement and assistance sanding my 3D printed pieces has been greatly appreciated and noted. His knowledge and understanding of how to paint and finish my armor pieces has been invaluable to the execution of the final result.

I want to personally thank my fellow Digital Production Arts candidates and graduates who all started at Clemson University seven years ago and have worked our way together through two degrees. I want to thank Chris Cornejo, Thomas Rapp, Christian Sharpe, Philip Hatfield, Thaddaeus Wassynger, and Evan Hicklin. Going through this program with this amazing group of people has enabled me to become the artist I am today.

And finally, I wish to convey all my thanks and appreciation to my parents and sister. They have been my anchor throughout the stress and excitement of this project. They have been my sounding board. Their willingness to make themselves available to confer and discuss ideas has been wonderful.
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Chapter 1

Artist Statement

As a Computer Scientist and Digital Artist, my strengths lie in digital sculpting and organic character modeling. It is particularly exciting for me to see a fully fleshed-out character rendered on a computer, but I wanted my thesis to take it a step further. I wanted to physically hold my digital design in my hands, to feel the weight and tangibility of the work itself. As an artist accustomed to rendering designs held *inside* the computer, I wanted my design to be held *outside* the computer. I could have easily made something for someone else, but I wanted a level of ownership over my design and model. With that, a true sense of reality and accomplishment would be achieved.

I wanted my thesis to also demonstrate the artistic range and creative potential 3D printing has to offer. My new work explores how 3D modeling has applications in film beyond visual effects and post-production: it can also be used as a physical product during the filming process in its practical use for costuming. With the ever-growing presence of 3D printing in mass media, digital design, and modeling, the method has both artistic and practical applications. This means that not only do these products exist behind a television or film screen, they can exist on a body itself.

Knowing I wanted to incorporate 3D printing into my thesis, I set out to create something permanent and designed for myself. As stated earlier, much of my experience is in sculpting organic forms with digital tools, yet I wanted to push myself in a new direction. This time I chose to not model a character’s body (typically one of the most exciting things for me to do), but instead focus on designing and constructing armor that would encase my own body. My thesis would be a body armor costume for a live-action film character made from various 3D modeling tools and software applications, with a physical prototype manufactured by 3D printers and extruded materials. The
real stretch here was the scope and size of the thesis project, its products, and the manufacturing and time constraints. I was fortunate enough that my university funds a Makerspace that ultimately made the project possible.

Additionally, I wanted the armor to not only look good but be functional and, most importantly, wearable. Of particular inspiration during the design and creation process were three main bodies of work: *Star Wars*, *Star Trek*, and *Fallout*. The crisp clean edges and armor patterns from the *Star Wars* film series helped guide design decisions in regards to armor shape language and silhouette, and the contours of the costumes from Star Trek Discovery helped inform certain decisions behind the bodysuit development and construction. Furthermore, the rustic found-quality of the armor from Fallout 4 influenced the world and function of my design.
Chapter 2

Background

This chapter will discuss the main topics essential to understanding the context and parameters of my thesis: the description of the design and creation of a character’s armor costume through the use of 3D modeling methods alongside 3D printing devices and materials. But first, it is important to understand the background and history behind armor, 3D printing, and science fiction, and the interplay between them when designing and creating defensive protection.

Although I am developing armor in a science fiction context, it is imperative that one understand the beginnings and advancement of armor, since both influence design and construction decisions. Additionally, they provide a visual record of the technical and societal emphases of a particular moment in time. “Throughout time the best armor and weapons have represented the highest artistic and technical capabilities of the society and period in which they were made, forming a unique aspect of both art history and material culture” [10].

2.1 Historical Applications of Armor

In this section, I will describe certain time periods, regions, function, and development of armor. As stated previously, it is important to understand the past to appreciate its relevance when designing something in the present, yet it is equally important to consider cultural and technical elements that impact the construction, physical features, and modifications of armor. Richard Holmes observes that historically, “Armor has striven to do more than safeguard its wearers. It is often intended to impress or terrify as well as advertise its wearer’s wealth or status” [11].
Defensive warfare in its earliest forms relied heavily on warriors, and the most basic of hand-held shields were eventually supplemented with protective body coverings. Animal skins and padded fabrics preceded metal, yet even with the addition of animal and machinery for battle support, armored soldiers remained the dominant system of defense on multiple continents throughout history. “Gradually, from the 16th century, armor was reduced to save weight—and expense—for foot soldiers. For the cavalry, however, back and breastplates (or cuirasses) survived into the 19th century, and in ceremonial form even later” [11].

2.1.1 Ancient Greece

There were two types of armies typically described in the Ancient Grecian city-states between the 7th and 4th century BCE. One of these consisted of a highly regimented and skilled Spartan soldier trained from youth, the other being the part-time citizen soldier know as a hoplite [11]. The Greek city-states employed these troops of heavily armed hoplites in close phalanx formations, an advancing body of soldiers eight men deep in tight ranks that moved in unison and designed to terrify enemies as it traveled forward into battle.

For the hoplites, only the citizens who could afford armor would have a full set. A full set of armor would be the combination of a cuirass, greaves, and a helmet. These types of armor were designed to cover areas that the citizen soldiers could not easily protect with their shield or deflect with hand-held weapons. A cuirass is a chest and a backplate connected and secured by a series of hooks and straps. An example of a bronze cuirass from the 4th century B.C. can be seen in Figure 2.1 on view at The Met Fifth Avenue in Gallery 155. Custom-made armor plates would only be made for a senior officer, and then shaped to fit their particular muscle shapes. Regular foot soldiers would have simple cuirasses made from bronze or stiffened leather. The greaves would protect the shin and knee area[11].
And lastly, a hoplite would have a helmet. Looking at surviving battlefield relics, helmets evolved over the centuries with material and regional differences, and could take on different forms to increase function at the expense of protection. “The Assyrians and Persians had helmets of leather and iron, and the Greeks brought helmet making to a pinnacle of craftsmanship with their bronze helmets, some of which covered the entire head, with only a narrow opening in front for vision and breathing” [12].

Usually a helmet was designed to protect key areas: the back of the head, brow-line, neck, and cheeks. Its basic function was to protect the head, face, and sometimes the neck from projectiles and the cutting blows of swords, spears, arrows, and other weapons. Most helmets during this time limited the wearer’s hearing and vision. Over time, some helmets were designed with hearing and visibility preferred to a lack of protection, and the helmet remains the most universal form of protective headgear.
2.1.2 Japanese Armor

The Tokugawa Period, also known as the Edo Period, extended from 1603 to 1867 and is considered the final timeline for traditional Japan. Founded by the Shogun Tokugawa Ieyasu, there was relative prosperity and political stability throughout the country. This period of time could be best described as comparatively peaceful in contrast to the constant warring of feudal lords from earlier times. Provincial conflicts featured competing clans engaged in unbroken battles for contested territories, and these nonstop wars set the stage for a constant need for soldiers to be armed and ready for attack. Each man from the shogunate military dictatorship, regardless of social class, could be a samurai; having and maintaining a warrior’s armor would be ingrained into every citizen, because every man was a potential soldier [1].

Figure 2.2: Japanese Armor: Gusoku from the 16th and 18th centuries [3]
Regarding warrior armor, note the breakdown of the armor pieces a samurai warrior would wear, a Tosei-gusoko, in Table 2.1. Not only does it describe the order in which a samurai was dressed and armed, it provides a brief layman’s description of each part in question. Not reflected in the table is the corresponding drawing of a wearer putting on the article described in each of the twenty steps. The highlighted sections in the table identify specific armor pieces designed to protect a particular area.

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Table 2.1: Tosei-gusoko—in order of armoring from the manuscript Koku-Buki-Zuji, 1775 [1]

These armor pieces were created in a variety of ways, many of which were fabric sewn with splints and mail sewn together, or with small plates laced in between cloth. These construction methods were also applied to shin guards and in sleeves for forearm protection, even as far as shoulder and thigh protection, although these had more variance with the inclusion of plates of hide.
Interestingly, the amount of armor and the locations where it was placed are the same locations I am aiming to protect in my thesis design. The samurai were heavily armored warriors prepared at all times for battle, either as an individual or in the collective, and I am trying to portray that same urgency for the wearer of my armor. I, too, am protecting these same key areas with armor: foot armor, shin/calf armor, hip armor, thigh armor, forearm armor, chest armor (cuirass), shoulder armor, and throat armor. The only difference is I am forgoing a helmet design, and there are more gaps between the armor plates than its samurai predecessor.

2.1.3 European Armor

European protective clothing was designed to prevent injury from a variety of weaponry and subsequently took on a variety of forms. As on other continents, early armor was constructed from animal skins, treated fabrics, interlocking metal rings, or rigid plates made from puncture-resistant materials. The political upheaval and ongoing battles between England and France in the fourteenth century, however, demonstrated that warriors could be easily felled by well-placed penetrative weapons and prompted an increase in combining multiple wearable armors for advanced protection, another theme present in my thesis design.

In terms of the technical development of European armor, the fourteenth century is often referred to as the “age of experimentation.” Mail armor was being reinforced with a range of additional defenses of varying shapes and construction for different parts of the body, ultimately leading to the development of the complete suit of plate armor in the following century. An equal variety is witnessed in the use of materials, such as quilted fabrics, hardened leather (cuir bouilli), and metal plates [13].

These various armors provided different degrees of protection depending on the type of warfare encountered, and were often most protective when used in combination with each other. The European Renaissance was also notable for the influence of civilian clothing styles on the construction of armor, and armor began to reflect cultural and regional tastes in its forms and decorations. “One of the first markedly noticeable instances of fashion in armor appears to be the use of small shoulder shields (ailettes), which were directly attached to the shoulders or upper arms as protection and/or a heraldic device”[14].

Around 1420, the development of full plate armor—a defense enclosing almost the entire body with a system of steel plates articulated by rivets and leather straps—was
complete...Since the larger surfaces afforded by plate armor now allowed for an entire harness and its elements to be more individually shaped and decorated than armor of previous periods, such characteristics gave rise to distinctive styles and fashions of certain nationalities [14].

Figure 2.3: European Armor: Elements of a Light-Cavalry Armor, ca. 1505–10 [4]

The use of plate armor with larger surfaces now offered designers a broader canvas for both construction and decoration. The armor-making regions encompassing Germany and Italy were best known for producing quality armor, and they eventually introduced their stylized forms to neighboring countries where the regional differences were notable. These differences continue to maintain their hold on armor costume design, as trace elements of them appear in the Star Wars film series, as well as virtual reality and gaming environments.

In general, the German style favored a slender, symmetrical outline of the body. An
emphasis on elegance and the vertical was achieved by richly decorating the surfaces of
the plates with ridges and grooves, often in direct imitation of the folds in contemporary
costume, while the plate’s edges were decoratively cut with openwork, or embellished with
applied or gilt brass borders reminiscent of Gothic tracery. By contrast, fifteenth-century
Italian armor usually is asymmetrical (the left side, as the first point of an enemy’s attack,
being protected by larger plates that sometimes carried additional reinforces), somewhat
rounder and heavier in appearance, and—if decorated at all—features less obtrusive
decoration [15].

2.2 Modern Military to Science Fiction

Robert A. Heinlein’s 1959 science fiction classic, Starship Troopers, introduces combat sol-
diers wearing the author’s early vision of weaponized exoskeletons. Heinlein’s idea was more literary
construct than technical specifications, but it served as a blueprint for future science fiction litera-
ture, films, 3D design, and military applications. Body armor has evolved from its first appearance
on the earliest battlefields to armor that now integrates advanced technology into its various ele-
ments. That rudimentary science fiction vision of a weaponized exoskeleton has expanded its reach
to the development of modern military protective gear.

The computer-generated suit featured in the Marvel Studios Iron Man film translated Hein-
lein’s vision into a heavily muscled suit of armor that doubled as a jet fighter and missile launcher.
This reimagined suit also mirrors the United States Special Operations Command’s (SOCOM)
weaponized TALOS combat uniform, first announced in May 2013. The uniform was even dubbed
the “Iron Man” suit, as it was “designed to enhance the survivability of personnel in the line of fire,
and to enhance their physical capabilities” [16]. It meant to protect the most at-risk combatants
during a tactical assault.

The TALOS, or Tactical Assault Light Operator Suit, appeared to be the true intersection
of modern military methods and science fiction as it traveled from concept to prototype. It was
to be bulletproof, weaponized, and provide strength and protection with an augmented exoskele-
ton, weapon sensors, tactical improvements, weight bearing systems, life support monitors, and
 telecommunications arrangements. After years of development, SOCOM recently announced that
the technology remains out of reach for its troops, as the current design is unsuitable for close com-
bat. Powering the suit was one of the biggest obstacles, as the load-bearing requirements outstripped
current technology. Certain individual components—notably the protective gear, exoskeleton units,
enhanced vision and communication systems—remain in development, but they will never come together in a single assembly.

2.3 3D Printing

At its most basic definition, 3D printing is a technique that maps out the shape of a 3D mesh object, layer by layer, to create a physical representation of the desired object. Early equipment, methods, and materials were developed during the 1980’s, in parallel forms and on multiple continents, with initial attempts at securing copyrights for the new technology receiving mixed results.

Not a lot of people know this, but a Japanese lawyer called Dr. Hideo Kodama, was the first person to file a patent for Rapid Prototyping (RP) technology. Unfortunately for him, the authorities denied his application. Why? Because Kodama missed the one-year deadline and so failed to file the full patent requirements on time. This was back in May, 1980. As Dr. Kodama was a patent lawyer, his blunder was both embarrassing and disastrous [17].

In 1984, Charles Hull of 3D Systems Corporation obtained the first patent for 3D Printing for a stereolithography apparatus (SLA) [17] that forecast the current file, digital slicing, and infill methods of today’s 3D technology.

2.3.1 3D Printing Methods

3D printing can be reduced to three categories differentiated by the beginning state of the material to be printed. These classifications are divided into liquid-based, powder-based, and solid-based systems. Stereolithography (SLA) is a liquid-based system; Selective Laser Sintering (SLS) is a powder-based system; Fused deposition modeling (FDM) is a solid-based system [18]. In order to print a 3D model using additive manufacturing processes, a program will divide a 3D object into layers which will extrude or activate an outline of the layer with the provided material then fill in each layer according to a defined fill density. Each of these systems has a corresponding slicing algorithm that defines how the system will create a physical 3D model. There are many ways in which this can be addressed or optimized, and there are many programs and software that calculate the interpolation behind a graphical user interface.
A Stereolithography Apparatus (SLA) uses a laser beam or light source focused on the surface of a photosensitive liquid resin. “The key to stereolithography is a kind of acrylic-based material known as photopolymer. Hit a vat of liquid photopolymer with a UV laser beam, and the light-exposed portion will instantly turn into solid piece of plastic, molded into the shape of your 3D-model design” [19]. Each layer is formed through the process of activating a section with a ultraviolet light inducing polymerization [20]. The solidified mass is removed and reinserted repeatedly into the liquid to start each new layer. This allows fresh resin to be set into a freshly made section. As new 3D printed layers start to solidify, the object increases in height and is pulled out of the liquid range. The in-progress print is attached to the underside of a plate that gets raised and lowered into a vat of resin. As a result of this process, only a small section of the recently formed layers is inserted into the resin suspending the rest of the 3D printed form.

“3D Systems (Charles Hull’s company) created the world’s first stereolithographic apparatus (SLA) machine...That same year, startup DTM produced the world’s first selective laser sintering (SLS) machine—which shoots a laser at a powder instead of a liquid” [19]. The term “sintering” refers to a process of melting and fusing materials through the direct or selective use of a high-power laser heat source. Selective Laser Sintering (SLS) processes use a laser beam that heats a powdered base material until it forms a solid mass [21]. Excess powder can then be sifted away to leave just the solidified object.

A Fused Deposition Modeling (FDM) system heats a solid strand of filament and feeds it through a heated nozzle to create a string of solid material to outline and fill the layers of a 3D object. For a FDM machine, the essence of a slicing program is that it will divide a 3D object into layers which will extrude an outline of the layer first then fill each layer according to the defined “fill density.” When the filament is heated and quickly cooled on contact, it can create a solid mass which can be used to form layers on top of one another [22].

2.3.2 Materials

There are a variety of materials that can be used for 3D Printing. They typically fall under these categories: polymers, metals, ceramics, or any combination of the three previous descriptors.

For my production purposes, I had access to the university-funded Makerspace 3D printers that used thermosetting polymers. This designation refers to the fact that plastic is heated to form the 3D shape and cooled to set. This means that the plastic cannot be reshaped once cooled or
I used PLA for my thesis project, a material that is biodegradable, does not produce harmful fumes during printing, and has a high print speed and resolution. However, it is brittle, not flexible, and has low heat resistance [18]. The low heat resistance has both benefits and drawbacks. The material can be modified with a heated tool, which proved beneficial for me during construction when I used one to make holes and larger indents for fitting. However, low heat resistance means that using a power sander for modifications runs the risk of melting the material from friction. In addition, 3D printed parts should not be left in a hot car or a non-temperature controlled environment, since excessive heat may melt or warp the materials, an undesirable result.

Here are the list of materials that Simplify3D describes on their “Ultimate 3D Printing Materials Guide” [23].

- **ABS**
  - Pro: low cost; good impact, wear, and heat resistance; less stringing and smoother finish
  - Con: heavy warping; produces odor while printing; parts tend to shrink

- **Flexible**
  - Pro: flexible and soft; excellent vibration dampening; long shelf life; good impact resistance
  - Con: difficult to print; poor bridging characteristics; possibility of blobs and stringing

- **PLA**
  - Pro: low cost; stiff and good strength; good dimensional accuracy; good shelf life
  - Con: low heat resistance; can ooze and may need cooling fans; filament can get brittle and break; not suitable for outdoors (sunlight exposure)

- **PETG**
  - Pro: glossy and smooth surface finish; adheres well to the bed with negligible warping mostly odorless while printing
  - Con: poor bridging characteristics; can produce thin hairs on the surface from stringing
Chapter 3

Related Work

This chapter will discuss certain work related to my thesis design, in particular, that of costume designers in film and television. It is important to consider these professionals for their creative strength, design influence, and cultural contributions to the overall look of an onscreen story. Additionally, they are meticulous researchers whose knowledge and designs embody the notion that by examining the past, one can identify applications for the present.

3.1 Power of Costumes in Film and Television

John Mollo, the award-winning Star Wars costume designer, says the key to a good costume design is, “That the costumes should be real clothes, and that if they were noticed too much they would distract the attention of the audience” [24]. If subtlety was John Mollo’s intent with his original Star Wars designs, “His costumes injected the space fantasy with an authenticity that capture the imagination of a generation of cinemagoers. They remain some of the most recognisable, and loved, film costumes ever made” [25]. They are also a testament to the power and influence of costume designers.

3.1.1 Costume Designers in Film and Television

Costume designers are charged with translating a director’s vision into physical forms, and their work often remains the most recognizable and revered elements of a production. In their role, they are responsible for designing all apparel and accessories for a film or television show including
primary and secondary actors, as well as on-screen extras. Working from production art and their own drawings, costumers typically blend vintage and contemporary attire with original designs and cutting-edge technology to produce materials that best express the onscreen characters.

As in any film or television production team, costume designers operate with a large supporting cast. Their team might include an assistant designer, costume illustrator, costume supervisor, costumer, and skilled assistants responsible for construction, fittings, and alterations. This group also benefits from detailed research into story, characters, and settings. Mindful of how differing cameras and lighting schemes can potentially alter the look of costumes, designers additionally collaborate with cinematographers. Costume designers can easily be considered traditional artists, as they are constantly aware of how shapes, forms, colors, and texture are regarded in the “picture frame” of film and television.

Although these on-screen garments could be considered by some as everyday wardrobe they are, in fact, transformative costumes. They establish not only physical identity but a cultural one as well. Much like military insignia provides clue to the rank of the wearer, costumes and accessories can identify social standing, occupation, and ethnic origins. When paired with actors, they transform a narrative story into a visual one, communicating a character’s history and personality in the process. As Deborah Nadoolman Landis once observed, “The Costume Designer gives the clothes to the actor, the actor gives the character to the director, and the director tells the story” [26].

3.1.1.1 Let’s Talk About Star Wars

Although George Lucas had a distinct on-screen vision of what he wanted to see for his first film, he never realized it would become so much larger than life, yet it did. It all started in 1975 when George Lucas brought his ideas for the film, colloquially known as The Star Wars, to two important individuals [24]. It was these two individuals who brought both the tone and look of George Lucas’ Star Wars to life: Concept Artist, Ralph McQuarrie, and Costume Designer, John Mollo.

Prior to his Star Wars assignment, John Mollo had worked on three films in the capacity of historical advisor. This first Star Wars not only served as Mollo’s debut as costume designer, but the first professional opportunity to combine his passion for military uniforms with cinema. Working with a bare-bones budget and a schedule of 14 weeks preparation, it was still a natural fit.

It fell to Mollo to translate McQuarrie’s concept art into costumes that would meet the
director’s approval. George Lucas told Mollo that he wanted two distinct looks for “the two opposing factions in the film, the ‘Rebels’ and the ‘Imperialists.’ The former should be very casual and American, with a ‘Western’ look. The latter, on the other hand, very military and efficient, with a German flavor” [24]. Laela French, Director of Archives for the Lucas Museum of Narrative Art, believes that it’s this mixture of old and new, the familiar and the profoundly strange, that has made Star Wars a movie that’s endured [27].

Figure 3.1: Star Wars: John Mollo’s sketch for a Stormtrooper[5]

It also did not matter to George Lucas that Star Wars would be Mollo’s first science fiction film assignment. According to the fellow costume designer, Nilo Rodis-Jamero, “It didn’t matter to George if a designer had not done storyboards, not done spaceships, not done movies” [24]. In
fact, Rodis-Jamero was a designer for automobiles and military vehicles with no prior film experience before joining the pre-production team on *The Empire Strikes Back*. As costume designer for *Return of the Jedi*, Rodis-Jamero was tasked with the continuation of designs from which a distinct look and following had already been established.

### 3.1.1.2 Let’s Talk About *Star Trek*

Science fiction stories have appeared on film and television screens since both mediums were invented. Although the original science fiction television series, *Star Trek* had a brief on-screen run, it has continued to prosper in both film and television forms. *Star Trek*’s multiple offspring have not only extended the original vision of creator Gene Roddenberry, but the costuming of its crew and fellow interplanetary species.

Costumes had to be designed to suit the diverse imaginary aliens encountered throughout the starship’s many explorations. Garments and accessories had to suit the various alien body forms Roddenberry envisioned, as well as the contrasting physical features among them. Actors were expected to don these futuristic wardrobes and use the transformative power of both costume and movement to embody the physical stature, gait, and cultures of disparate interplanetary races. Many actors also wore varying degrees of prosthetics for additional authenticity; as a result, many costumes were designed to conceal multiple prosthetic devices, or accentuate distinctive features, to maintain another level of believability.

Robert Blackman, the costume designer for *Star Trek: Enterprise*, had a unique challenge when approaching the design for his crew uniforms. This particular show was set 100 years after the present time, but 100 years before *Star Trek: The Original Series* and its distinctive 1960’s imagining of the future. Blackman approached the design and visual aesthetic in a logical way: rather than trying to work backwards from the original concept, he decided to work forward by designing uniforms inspired by current NASA suits, as can be seen in Figure 3.2. The design outcome was a militaristic costume with a flight suit appearance, rather than the form-fitting versions of earlier seasons. Reinforcing the notion that the best costumes are those most familiar in form, Blackman decided against using invisible zippers, but instead intentionally placed them everywhere, even affixed to “fake pockets.” Blackman wanted to make it look like these clothes were actually worn, and that an individual could easily get in and out of them, an unclear design concept in costume iterations that appeared later in the *Star Trek* timeline [28].
3.2 Science Fiction Armor

Science fiction costumes can be the most challenging for designers, since an extremely futuristic wardrobe can be unbelievable in the eyes of the viewer. For some costumers, the answer is a nod to the past by constructing futuristic forms with simple, retro lines. The result is a believable costume made so by the authenticity derived from its familiar form, with the best appearing both functional and lived-in. For example, many full-body suits of armor in science fiction stories imitate the protective leather and armor suits used by motorcyclists. They ranged from the simple base layer of Darth Vader’s caped costume in Star Wars, to the elaborate ones worn by the title characters in Ant-Man and the Wasp.

Additionally, the Iron Man II suit uses traditional warrior forms in its removable armor breastplates and leg greaves, as well as the plates for hips, biceps, shoulders, and head. Fiberglass resin was used in their construction, with a specialized metal finish made to mimic more traditional stainless steel. This method of merging modern materials to traditional forms is a constant theme in
science fiction armor. The classic lines of the leather armor for Tessa Thompson’s Valkyrie character in *Thor: Ragnarok* evoke that of ancient Greece and Rome—the customized protective arm plates and cape reinforce the concept—while Thor’s reappearance in *Avengers: Infinity War* shows him shorn of both long hair and traditional gladiator gear, now replaced with a short haircut and new, modernized armor plates in menacing black.

### 3.2.1 Armor in Film

In the 2018 film, *Black Panther*, costume designer Ruth E. Carter mines multiple locations and cultures to create the iconic wardrobes and armor for the inhabitants of Marvel Comics’ mythical country of Wakanda. Her garments not only clothed individual warriors, but established a larger visual pattern when the lone warrior became part of a moving, collective battalion. “Sometimes the costume needs to subside and be a part of the whole entire scene, not just on the wearer. It’s not fashion. It’s more of a character,” says Carter [29].

*Black Panther* is notable for the dominance of its visually arresting clothing, making it the most “fashionable” of recent superhero films and earning Carter an Academy Award for Best Costume Design. A meticulous researcher, Carter’s work exemplifies the theory that by examining the past one can discern practical applications for present use, as well as predict future styles and physical forms. “I looked at all kinds of armor, from indigenous African tribal armor to Japanese armor,” Carter says. “One of the most important things for me was to make sure their armor pieces look handcrafted, something from African tribes. Handcrafted elements looks a lot stronger and more personal” [30].

Carter examined Japanese armor and quickly embraced one revealing aspect of the armored traditions of samurais: that each warrior’s protective clothing is crafted for that one particular combatant. The hand-tooled elements of Carter’s inspirations are meant to embody the physical, personal, and spiritual attributes of the individual warrior, and the same is true of my armor design. Additionally, my construction is a thoughtful blend of form and function, much like Carter’s.

“There were elements that were there for function, like the two way stretch of the leotard, and elements that were there for the culture, like the pattern work that evokes the sacred geometry of the line work that you see across the continent, and I infused all of that together,” she says [30].
3.2.2 Body Suit Design Styles

Undergarments reveal body contours and silhouettes, and the costume designer must keep in mind that specific constructions can alter a character’s movements and personal comfort. Even the earliest full-body armor systems featured a layering scheme of cumbersome protective elements, starting with undergarments. Base layers would typically consist of a variety of materials and might include silk, linen, cloth, wool, leather, and metal.

It proved essential that I consider how these early elements were attached when designing my thesis, and just how individualized my armor pieces should be. Although these layering components were important to the effectiveness of protective gear, what went underneath them was equally important. The design style I wanted to emulate in my creation was that of Star Trek: Discovery’s Environmental Suit, as seen in Figure 3.3.

![Figure 3.3: Star Trek: Discovery Environmental Suit](image)

Bodysuits evolved from these early forms, and they are no longer necessarily hidden from view. For a costume designer, bodysuits can serve dual purposes: as a base layer and a physical expression of character. Texture is especially important, and has been an integral part of recent on-screen superhero stories, taking on unique forms and assembly through advanced technologies in materials production. For Man of Steel (2013), designer Michael Wilkinson envisioned the title character’s costume as an outer layer worn over a muscle suit [26]. “Over the top of this we stretched
a thin mesh over-suit that is printed with a dimensional chainmail texture. We wanted to evoke a ‘man of steel’...We wanted our Superman to glow on screen, to create a texture that the camera loves, and make him stand apart from the human race” [26]. In parallel fashion, the material I selected for my thesis bodysuit possesses similar textural features.

### 3.3 Use of 3D Printing Technology in Film and Television

The mask that encased the head of Anthony Daniels, the actor who brought the Star Wars character C-3PO to life, was so cumbersome that Daniels implored the film’s costumers to design a more comfortable one for the next installments. Early masks were made from fiberglass and molded plastic, which proved impractical while filming outdoor scenes in harsh climates, and the methods for obtaining body measurements were not as accurate as today’s. It would take another decade for the early development of 3D Print Technology to address Daniels’ request, but once the technology was perfected, it would grip the field of costume design.

An extraordinary example of the latest use of 3D printing technology in film is the crown constructed for Queen Ramonda, matriarch of the mythical kingdom Wakanda and surrogate mother to T’Challa, in the film Black Panther. To construct the film’s Afrofuturistic world and its inhabitants, costume designer, Ruth E. Carter, sent her staff across Africa to locate indigenous designs and products for inspiration. Carter was particularly intrigued with a traditional Zulu headdress worn by married women, an object that ultimately laid the design foundation for Queen Ramonda’s crown. West’s collaboration with 3D designer, Julia Koerner, resulted in a much enlarged and lace-like interpretation printed with 3D wearable plastics, including a fitted bolero jacket with standup collar and shoulder pieces. Koerner describes the technology her firm used as,

...laser sintering, a powder-based 3D printing technology that enables the highest level of freedom of design as not supports are needed. The costume props were made from PA 12, a polyamide material that provided us with a high level of accuracy, flexibility, and strength. The material is also well suited for skin contact, making it ideal for fashion and costume designs [31].

As for the use of 3D printing technology in television, the much-praised television series, Westworld, is an especially notable example. Produced by HBO and loosely based on Michael Crichton’s early films, Westworld and Futureworld, the setting is a Wild West, role-playing theme park populated with robotic hosts built and programmed to interact with visitors in supposedly
predictable scenarios. All a viewer has to watch is the opening credits to understand that not only is 3D printing technology present in *Westworld*, it is literally interwoven into its characters. The technical aspects on display are very realistic.

Production designers, Nathan Crowley and Zack Grobler, wanted to blend robots with realism in a setting more today than in the future, a concept that contributes to the show’s disquieting feel. “The glass-walled rooms and everything in them had to seem cutting edge, but the designers couldn’t go *too* far with it — this was a show steeped in science, not magic. They were, in effect, vaguely futuristic factories, with 3D printers working like they do today” [32]. There have always been elements of science in science fiction, and *Westworld* seems a true alliance of both.

The show feels unnervingly real, partly because much of the technology displayed in the show is already with us. The extrusion of plastic materials displayed in the credits is central to current 3D printing technology, and the human form being lowered into a vat of liquid plastic is reminiscent of the original method of 3D printing, stereolithography. The robotic 3D printers seem to be all-in-one systems printing multiple materials simultaneously, a technology that is not quite reality but likely a short time in the future.

Even though *Westworld* is a blend of actual and simulated technology, medical applications for 3D printing have existed since the early 2000s. Since then, 3D printers produced enough models that have successfully replaced organic parts to make the 3D printed robots of *Westworld* entirely plausible. There are even biologically based extrusion printers under development that print skin tissue, so the notion that *Westworld*’s role-playing inhabitants have an artificial skin over their 3D printed bones and muscles is also believable.
Chapter 4

Design

This chapter discusses the start of my development process. Without reference art or design direction, 3D modeling proves difficult and tends to lack cohesion. Starting out with a clear direction and design is essential, as it sets the tone and course of the entire project. The project design centers around the creation of body armor for a science-fiction themed character.

4.1 Character Development

This character exists in a world where technology is advanced but the earth and environment is suffering. This advancement serves as a contrast to the decaying world. From this duality, I wanted to showcase a character that has to fight to survive in a forgotten world. The ability to quickly snap on and take off armor plates was a unique and important factor to the character design. She needed to be able to remove pieces if speed needed to be increased and snap on the pieces when hard-surface protection is essential.

This character has to be ready for a battle or skirmish at a moment’s notice. She has to be able to defend herself. She does not necessarily have a person she can depend on; therefore, she depends heavily on her armor. She is a warrior and has to fight to survive.

I wanted to create a character that could potentially exist. Although she is set in a futuristic world of increased technology, my aim was to design a character with familiar designs and armor structures. When designing a science fiction world, there are no limitations or design directives like those in historical fiction. However, it is important that the science fiction world and characters feel
like an extension or plausible deviation.

4.2 Context and Setting for Character

Part of my design reference was inspired from rustic worn-down, forgotten spaces. I envisioned my design to exist in a space where there is less social structure and more chaos. Places would be abandoned and left to crumble back into the earth. I imagined my character to be focused on survival in a futuristic world built upon nature’s reclaim of earth from human influence. I was inspired by the ways man-made structures can succumb to the formidable power of time.

The photo I took of a house in my village (see Figure 4.1) really captures a specific moment in time, slowly decaying. This crumbling house is barely maintaining its shape, yet you can still see clothes hanging up, forgotten. This is a bleak reminder of the fragile balance humans are traveling in. The future will arrive, but it might arrive at a cost.

![Figure 4.1: Setting the Stage: A Forgotten Home](image)

Figure 4.1: Setting the Stage: A Forgotten Home
I also drew inspiration from an urban photo shoot inside an abandoned school by the photographer, Martin Quinn, of my sister Juliana Watkins. I feel that the destructive elements and forgotten objects help emulate the setting and mood for the type of character I am creating. In addition to gaining an insight for setting, I also did a draw-over of her poses, then added in base shapes of the armor to gauge how the pieces would potentially fit together on a human form. You can see this in Figure 4.2. This character was designed to fit into a futuristic earth. She is a boots-on-the-ground type of character, who is not afraid to get dirty or engage in a firefight.

![Figure 4.2: Draw-Over Photo with Armor Design](image)

4.3 Reference Images

As much of my academic experience is in digital sculpting and modeling organic forms, creating an original design for my thesis project was proving difficult for me. As a compromise, I employed a technique called “photobashing,” a method for merging multiple photographic or digital assets into a singular piece. I was fortunate to find two fantastic character designs for inspiration, from two separate artists on ArtStation, and selected elements from each character to merge into
one cohesive design that best suited my needs.

These two artists are Puz Lee and Jang Wook (Azure) Kim and are both from Shenzhen, China. As you will see in the Figure 4.3, Puz Lee’s work inspired much of the lower body armor I created, while the inspiration and design style for my armor’s upper body portion was inspired by the artwork from Jang Wook (Azure) Kim, as seen in Figure 4.4.
Figure 4.3: Concept Art by Puz Lee [8]
Figure 4.4: Concept Art by Jang Wook (Azure) Kim [9]
4.4 Concept Art

As discussed above, I used concept art from two different artists to help inform and create the finalized design for my body armor. Using a “photobashing” technique, I combined assets from concept art by Puz Lee (see Figure 4.3) and Jang Wook Kim (see Figure 4.4) and merged them to create one cohesive design. I was particularly drawn to the leg and forearm armor from Puz Lee’s design and felt that the upper body armor from Jang Wook Kim’s design would work well with those pieces for a finalized full-body form. I then merged those elements into one fully-fleshed concept art for my thesis.

I used the pose, character, and upper-body armor plates from Jang Wook Kim’s design and placed it in a new Adobe Photoshop document. Next, I lasso selected the armor plates for the legs, hips, and forearms from Puz Lee’s concept art and placed them into this working Photoshop document. I rotated, arranged, scaled, and warped these armor pieces until they fit onto the pose from Jang Wook Kim’s design.

Afterwards, I did a series of color correcting and modifications so that the two sets of armor pieces looked like one cohesive design. I then conducted various touch-ups and painting to clean up the edges, until I had a balanced concept for my armor.

One of the challenges I had to consider was that the base character and pose from the original designs had unrealistic proportions. As a 3D design, it looked great, but I had to wonder if it would look as clean placed on my own body, as the legs in the concept art are extraordinarily long and hips very narrow. My next challenge would be to take this original concept art and create a turn around design sheet using my own physical proportions. You will see the result of this in Figure 5.3.
4.5 Armor Design Decisions

The above armor concept (see Figure 4.5) may appear to have one major design flaw: the exposed stomach. However, the lack of armor plating there is intentional. Although the stomach is a weak and easily targeted spot, it is the area where the most movement and flexibility occur. The stomach area of the human body has to be able to crunch, stretch, twist, tilt, or any combination or the aforementioned. Therefore, having any kind of hard surface plate in this area restricts mobility, therefore reducing speed and function, which is undesirable.

Another area that lacks hard surface armor protection is the head. Similarly to the reason stated before, I choose not to create a helmet because it would limit mobility and potentially restrict hearing and/or vision. Alternatively, I was considering making a mask for the jawline. However, the reasons against that are twofold. Firstly, I wanted the wearer to be understood while speaking. Secondly, the jawline is in close proximity to the chest plate, so I wanted to avoid unnecessarily bumping the two pieces together.

Additionally, two other smaller areas that are uncovered are the upper arm area and the back of the thighs. The upper arms are uncovered, but the forearms and shoulders are protected, so that potentially minimizes the risk of harm. Naturally the back of the knee is uncovered, because that is where a bend occurs. The back of the thigh is uncovered primarily for ease and comfort while crouching and sitting.

Mobility is extremely important for this character, and has been a design consideration throughout. She cannot be weighed down by too much armor, so the ability to quickly remove or add pieces to her suit is extremely important. This is achieved by a series of magnets and connections placed throughout the body of the suit for nearly immediate attachment.

An important design decision was not only placement and look of the armor pieces, it was also choice in material and color palette. I wanted to create contrast between the armor plates and the bodysuit underneath. I knew I wanted to create grey/silver toned armor plates, so I felt that a black or dark toned bodysuit underneath would create the desired contrast.
Chapter 5

Implementation: Modeling

In this chapter I discuss several techniques, procedures, and workflows that defined the creation of the assorted assets and parts that comprise my armor design. This process would define the remainder of this thesis. The implementation process required much thought and attention to detail in order to turn 2D concept art into a series of 3D objects, which would then be produced in a physical form. I could not create pieces without thinking about their functionality, how they would move, or how they would be attached to a person. The modeling for this project was primarily done using Maya 2017, with small assets and base models utilizing other programs.

5.1 3D Body Scan

The whole modeling process depended on one particular design element: I needed to make sure that I would design pieces that would actually fit my person. To accomplish this, I traveled to Atlanta to receive a 3D scan of my own body. The final scan would help create models and assets that would properly fit my body shape. I went to a group known as Mixed 3D, or MR-3D, to obtain a full-body scan with their equipment. They have a booth with over 100 cameras that capture an object or person in a variety of pre-calculated angles at a single instance.

First off, trying to position myself in a symmetrical pose was a lot more difficult than originally imagined. In the end, my shoulders were at different heights, and my head was canted at an angle, as seen in Figure 5.1.
I received two scans of myself. I then chose one to modify in ZBrush 2018 in order to make the form more symmetrical. It was of particular importance when designing my armor that I work with a symmetrical base figure. I needed a center line and a symmetrical pose, so that I could easily visualize how the shape of my armor pieces would look.

Figure 5.1: 3D Body Scan: Before Symmetry

Figure 5.2: 3D Body Scan: After Symmetry
5.2 Reference Views

After creating the original photobashed concept art, I then had to create a turn-around reference sheet for modeling in Maya, as seen in Figure 5.3. Once I received my 3D scan, I took orthographic screen shots of my modified 3D scan in multiple orthographic views. I used these images as a base to design the armor from multiple viewpoints. This allowed me to consider how the different shapes would look within multiple angles. This method would serve as a guide to help inform the multiple shapes and angles of my modeling process.

![Reference Views](image)

Figure 5.3: Reference Views

5.3 Modeling in Maya 2017

The first thing I did when I created my Maya scene was to import my modified 3D body scan. I set my Maya scene so that the Working Units Setting uses centimeters as it’s base unit. I am
161 cm tall; however, I scaled my 3D representation to be approximately 158.5 cm tall. The reason I deducted a few centimeters from my actual height was to account for the slight difference in height that occurs when you position your legs shoulder-length apart. I verified these measurements using the distance tool between two locations (the floor and the crest of my forehead) in my Maya Scene.

The next task in approaching my Maya scene was to import my turn-around reference sheet (see Figure 5.3) as two individual Image Plane objects. I then moved away from the center origin in the corresponding axis so they would not be cutting through the 3D scan. I made certain to scale the image planes uniformly until they matched the scale and position of my 3D scan in my orthographic views (front and left). I was able to verify the positioning by going to the Shading tab in the viewport and selecting the X-Ray checkbox. This allows my meshes to have a translucent quality so I can build and shape objects within the scene, while still seeing the underlying structure and details from my image plane reference views.

![Maya: Setting the Scene](image)

While working in Maya, I used a specific layout for my panes that helped with my workflow. I had three panes side-by-side-by-side open. The center panel would be my perspective view, where I would change angles and view what I was working on within multiple angles. The left panel would
be an orthographic front view, and the right panel would be an orthographic left view. The front view and left view panels would have the x-ray modifier on in the shading section for those windows. This was particularly helpful when determining silhouettes and angles to create my models.

However, I soon came to realize that my turn-around sheet was not perfect in matching specific parts. Consequently, in certain places I had to make innovative decisions or imagine how a part would actually be formed. This is where I had to problem solve in a creative manner, if I hoped to design pieces that would both work and match the conceptual configuration.

5.4 Using One Part Multiple Places

After printing one of the knee plates, a peer at the Digital Production Arts Studio space tried to guess where it belongs; his first guess was that it was a shoulder plate (although he also said the same thing about the thigh plate). Nevertheless, his guess made me think that I should consider using some of my 3D objects in other ways. That thought made me examine additional applications for certain parts, or pieces of parts.

This led to a design consistency that linked my two concept art pieces together with a shared shape language, and I have applied this consistency in several different areas. I simply duplicated the knee shape and affixed it to the shoulder as a shoulder plate; no changes were necessary, as that whole part is able to serve in those two different places. I also used the base shape of the shin plate and re-scaled and formatted it to fit and strap onto one of my forearms. I liked the idea of reusing the design language and shape from the shin plate to my arm, as this allowed for more design interest by breaking up the stale symmetry of the character.
In Figure 5.5, you can see shared shapes and design styles between the side pouch and the armor on top of the hand. Similar design styles and shape languages appear in two separate plates on the backpack. The bottom u-shaped plate that serves as the base of the backpack is the same shape on the plate at the backpack’s top protecting the neck region. You will see these pieces more clearly in Figure 5.13.

### 5.4.1 3D Scan Base Shapes

Since I needed to design a custom armor plate to fit the top of a pair of boots, I decided it would be most effective to work from an object that captured the specific curves and shape of the boot. This required the use of an additional 3D scan. This time, however, I used a hand-held 3D scanner that the Clemson Makerspace offers.

I placed one of the boots on a piece of wood on top of a stool. I rotated the piece of wood while trying to capture multiple angles of my object. Because the shoe’s position did not remain stationary, the 3D scan came out very rough. As a result, the 3D mesh had a significant amount of “explosions” that required some post-processing to clean up the shape. In Figure 5.6, you can see the process of correcting the rough 3D scan by creating quads along the surface.
Once I had clean topology, I inserted the mesh into my Maya scene where I filled in some small gaps in the new mesh. These gaps were where the boot met the surface it was sitting on. I made these corrections in Maya by bridging the gaps, using the multi-cut tool, and the merge vertices option to create a solid mesh. I then selected the newly created faces that were at the base of the boot, scaling them in the y-axis so that they were flat on the bottom.

I measured the dimensions of the boot and applied those measurements to the object in my Maya scene. Once the boots were scaled and placed properly, I duplicated the object and scaled it in the negative x direction across the origin. I also modified my base mesh for 3D scan so that the feet were hidden. This would allow the boots to be new feet in the scene.

Now that the boots were properly placed in the scene, I then created a boot plate by duplicating the boot, selecting some faces on the surface of the boot where the plate would be, detaching those faces through the Edit Mesh tab, then separating them into a new object in the Mesh menu. I then deleted the excess object and selected the object I separated. Afterwards, I used the extrude function and its Local Translate Z attribute to form the shape of plate. Other details were created using a series of adding-in edge loops and extruding faces. This process allowed the
plate to keep the same silhouette as the base boot shape. You can see this in Figures 5.7 and 5.12.

5.4.2 Designing Connections

I had to be extremely mindful of the design effectiveness for the connections that would be strapped onto my person. The three primary areas are: the forearm plates, the belt, and the chest/backpack connection.

Paying particular attention to the belt, I had to design the armor plates along the hip to work with a belt system. This also meant that the parts would need to be worn together and sit comfortably. I decided against using the rounded details along the hip line, as they were not able to be properly secured and would additionally restrict movement. Figure 5.8 highlights a base belt shape while showcasing how the armor plates would be attached to the belt.
5.4.3 Creating Rounded Detail From a Flat Surface

Several of the armor plates I created required panel lines and edge details to create the distinctly futuristic design. Most of these designs were created to follow the flow and shape of the designed part. However, there were some instances where I needed to create additional topology to create a circular detail.

I found that when trying to add or remove a circular form from a mesh, the faces in the mesh would detach and ruin the original 3D object. To combat this, I would create a new cylindrical shape and place it onto the object in approximately the right size and orientation in relation to the original mesh.

I would match some of the angles and vertex points to allow for a simpler mesh transition. I then used a series of multi-cut operations to draw the circular details on the armor plate to build out the shape of a circular detail. You can see an example of this typical process in Figure 5.9, along with the description of all the steps involved.
1. Placing Proxy Geometry to determine overall shape.
2. Using Multi-cut Tool to cut around the Proxy Geometry.
3. Hiding the Proxy Geometry to Modify the Edge Flow beneath.
4. Removing Unnecessary Edges.
5. Using Multi-cut tool to find the center point by connecting two set of opposing vertices.
6. Connecting outside edges to the find the center vertex.
7. Using Multi-cut tool while holding the “shift” key to connect a ring exactly half-way through the edge ring.
8. Result.
9. Result with “smooth mode” selected.
10. Adding additional edge loops to reinforce shape.

Figure 5.9: Modeling Workflow: Creating Circular Details From a Flat surface
11. Extruding out selected edge loops.
12. Extruding in inner faces.
13. Extruding in innermost edge loop.
14. Smooth Mode Result showing Topology.
15. Smooth Mode.

5.5 The Result

I cannot conclude a modeling chapter without first showing what my models look like from multiple angles. Figure 5.10 shows the full armor designed around my 3D scan front a side, front, three-quarter, and back views. Comparing this image to the original design in Figure 5.3, you can easily see where some design elements have changed.

![Figure 5.10: Turnaround: Renders](Image)

The areas of noticeable changes between the original design and the final models occur in several areas. As previously discussed, the first is the shoulder plate. This piece demonstrates how it matches the knee plate design. Another area of distinct design modification is in the side
pouches. I ultimately drew inspiration from the armor plate on the top of the hand to create a somewhat functional object, although I had trouble working out how to attach the original design while maintaining its functionality.

![Figure 5.11: Renders: Torso](image)

The legs for the most part, kept most of the same design styles as my concept art. However, one change was in the back portion of the calf plates. I decided on a smooth, curved-like shape for that section, rather than a hard-angle with booster-like vents out the back. I feel that having a smooth curve would not catch on other objects and, in theory, be more comfortable to move in.
Another area is the backpack armor. This section required a lot of thought and effort. This area was not as well-conceived in my original reference sheet, so I had to take several artistic liberties to create the backpack system.
Chapter 6

Implementation: 3D Printing

This chapter discusses decisions regarding the tools and equipment used to 3D print the objects designed and discussed in the previous chapter. Some of the equipment and system decisions were easy to make, because I was limited to the production methods that were accessible to me. As a result, I used the filament, 3D printers, and slicing software provided by my university-sponsored makerspace.

6.1 The Clemson Makerspace

This project could never have been attempted without the availability of the Clemson Makerspace and its supportive staff. The makerspace has been one of the greatest assets in the creation of this thesis, and Clemson’s facility is unique in the fact that it is completely student run and maintained. These talented undergraduate students are responsible for instructing other students, as well as faculty members, on how to use the 3D printing tools and materials. Additionally, they maintain the equipment and make certain that each individual is being safe and courteous in the space.

I spent seven weeks going into the makerspace to prep and print my files. During that time, I got to know many of the undergraduate student workers and benefited from their well-trained eyes and wise advice. They were an integral part of the development and progress of my thesis. Figure 6.1 shows the wall displaying all the PLA 3D printers, along with three models of FDM 3D printers. These include nine Lulzbot Mini machines, two Lulzbot Taz 6 machines, and six Type A Series 1
I chose to print my pieces using a combination of the available Lulzbot Mini machines and the Lulzbot Taz 6 machines. These machines used 2.85 mm PLA filament. The only noticeable difference between these two types is that build area. The print area for a Mini is 152 mm x 152 mm x 158 mm (6 in x 6 in x 6.2 in) [33], whereas the Taz has nearly double the print area of 280 mm x 280 mm x 250 mm (11.02 in x 11.02 in x 9.80 in) [34].

Although the makerspace does have several Type A machines, I choose not to use them, primarily because they did not have any available filament for those machines until more than halfway through my printing process. The machines also use a thinner PLA filament, and I wanted a consistency of thickness for all my printed arts. These machines also have a noticeably undesirable higher rate of failure.

Of the nine Lulzbot Mini machines, one of them was not functional and another needed occasional repair throughout the printing process. Additionally, for the first half of my thesis printing, one of the Lulzbot Taz machine remained out of order. Once the second Taz machine was fixed, I was ecstatic, but did not anticipate the surge of students also wanting to print on that machine. The
result was difficulty securing the machine, so I had to arrive at the makerspace at least an hour earlier to line up and be guaranteed a spot. It was general practice that each user would only queue in a print and occupy a single printer during each session; however, once all users had installed their own files, you could queue in more prints.

The makerspace was only open during specific hours each weekday, and time limitations presented a daily production challenge. Printing hours varied because they were determined by the availability of student staff, whose classes and other commitments determined their makerspace schedules. Because these hours varied so much, I am going to discuss my average week’s printing schedule.

I would arrive at the makerspace facility around 7:00 a.m. At 7:30 a.m., the building would automatically unlock so I could enter (if I timed it right, a kind staff member for the building would occasionally let me in early at 7:05 a.m.). A student worker would typically arrive at the makerspace around 7:55 a.m. to remove the pieces that had finished printing overnight; he or she would then unlock the door at 8:00 a.m. and let the users in for that day. I would queue up my prints and wait to make sure they adhered properly. Each time I queued in a part to print, I would log that print in the makerspace system. The makerspace would then close at 9:00 a.m., and I would return to my studio to continue my thesis work.

The makerspace would reopen at 1:00 or 1:30 p.m., and remain open for an hour. Again, I would arrive at the space an hour early, and would stay nearly the entire time. By this time, all the 3D printers would be occupied, and more scheduled to print overnight, but if I needed to check on a piece, the makerspace would be open for a longer session from 5:30 until 9:00 p.m. However, on Fridays the schedule was slightly different in that the makerspace was only open from 8:00 until 9:00 a.m., and 3:00 until 5:30 p.m. With that in mind, I would normally queue in my most time-consuming prints on Fridays. That way I was certain to not occupy a printer that could be turned over and put in use for another user.

6.2 Using Cura

The Clemson Makerspace provides four computers installed with software to prep and slice 3D models. The computer program the Clemson Makerspace uses is Cura, so all computers available at the makerspace are pre-programed with the proper settings for their corresponding printers. The
information in the table below, Table 6.1, contains the typical settings I used while printing at the Clemson Makerspace.

<table>
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</tr>
<tr>
<td>Flow (%)</td>
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Table 6.1: 3D Printing Settings

6.3 Stages of 3D Printing

The largest solid piece was the back plate for my armor. I had to place that object slightly angled across the Lulzbot Taz 6’s build plate. The entire print weighed in at 883 grams, with most of that weight in the supports, as the plate itself weighed only 393 grams. This is notable because Cura had estimated that the object would take 925 grams worth of filament. Cura also initially estimated that the piece would take 64 hours to print while, in reality, it took 75 hours. This is an extreme example of how print time and material estimates can be incorrect.
Figure 6.2: Backplate: 8 hours into the print

Figure 6.3: Backplate: 64 hours into the print
Figure 6.4: Backplate: Completed Print (Weighed in at 883 grams)

Figure 6.5: Backplate: weighing in without supports
6.4 PLA and its Properties

PLA filament has good dimensional accuracy, which is particularly important when I am designing parts to scale that need to fit together in a specific way. Once the filament sets, the parts are strong plus sturdy and great for my design, yet the pieces can break if enough force is exerted.

One of my main concerns is the low heat resistance for PLA. This means that a power sanding tool could melt the plastic and destroy the part itself. To combat this, I applied a protective liquid coating to all my pieces. This liquid coating is Smooth-On’s XTC-3D. It is a two-part liquid that, when combined, fills in the layer lines of a 3D print to create a resin layer between the plastic underneath and the surface. This allows the use of a power sanding tool without fear of melting the part underneath from friction. This additionally benefits the post-processing step, since it helps remove the layer lines typically associated with a 3D printed object.

6.5 Failure: It’s just a part of the process

It is impossible to discuss 3D printing without addressing failed prints. This section is an important visual narrative, as it necessary to view and understand just how traumatic (and interesting) a print fail might be, and what it might look like if a 3D printer runs without being stopped.
Figure 6.6: Print Fail Example: Extrusions spaghetti noodling out of control

Figure 6.7: Print Fail Example: Print Fell off its supports
Figure 6.8: Print Fail Example: Dragging brim off print bed

Figure 6.9: Print Fail Example: Clogged Tool Head
6.6  Evaluating the Data

The Clemson Makerspace is only open for a few hours and just two to three times during the weekdays. Between January 23rd through March 11th, I went to the Clemson Makerspace a total of 59 times. During those visits, I either queued in a new print, picked up a completed one, or restarted a failed print.

<p>| | |</p>
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Table 6.2: Clemson Makerspace Printing Data
Chapter 7

Implementation: Finishing

The project does not end at 3D printing, it merely marks the beginning of the finishing process. This chapter discusses the steps necessary to finish the 3D printed pieces, which includes using XTC, sanding, and painting all the PLA 3D printed pieces. The finishing process is important because it allows the refinement of 3D printed items into smooth professional-looking parts. Layer lines are characteristic of 3D printed objects, and polishing them removes those imperfections.

7.1 Limitations of PLA

One complicating aspect of using PLA filaments in 3D printed objects is its low threshold for heat. Its use, however, actually presents both positive and negative opportunities to the 3D designer. One positive feature is that you can melt away any excess PLA filaments where necessary, and with little effort. A negative feature is that you cannot use a power sander or dremel directly on the PLA material, because the heat generated by the tools will prove destructive. Either device will melt the plastic filaments, and can ultimately damage or destroy the finished piece. This complication makes sanding and finishing 3D objects printed with PLA materials a very long and arduous process.

7.2 Using XTC

To counter the problem of the low threshold for heat in PLA printed objects, I had to select a protective coating that would address this issue. As a result, I chose Smooth-On’s XTC-3D liquid
compounds. The product is a two-part liquid that, when combined and brushed on the object, fills in the layer lines of a 3D print to create a protective resin layer between the plastic underneath and surface. This secondary layer allows the treated 3D object to be sanded without risk of damage from heat generated by finishing tools. Another consideration is that it is important to wear long sleeves and disposable gloves when using XTC products. I also had to work in a well-ventilated area and be cautious of the fumes while working.

This two-part mixture takes only 10 minutes to set, so I needed to work in small increments only mixing less than an ounce of the mixtures at a time. Once applied, the surface of the 3D print will remain tacky for the next two to four hours. For better results, it is advisable to apply the second coat of XTC while the surface of the part is still tacky.

The curing process for XTC can be sped up by the use of a heat gun or slowed down when there is a lot of moisture in the air. During one cold and rainy day, the parts were still tacky 12 hours later. After that experience, I started to move my parts from the covered alcove entrance to inside my apartment, two to four hours after the last coat of XTC was applied.

7.3 Sanding

Since I printed my parts with PLA and sealed them with XTC, sanding is an essential part of the finishing process. The rough sanding of the parts was accomplished with the use of a Black & Decker Mouse Detail Sander with 220 grit sanding sheets. Rougher sanding sheets (100 and 80 grit) were not recommended, as they could rip the XTC right off the 3D printed part. This system was used to clean up and smooth the main surfaces and curvatures of my 3D printed parts. Figure 7.1 shows the selection of items I am using to sand and finish my armor pieces.
After rough sanding with the Mouse Detail Sander, additional sanding needed to be done by using the needle files and regular sand paper. I would use 100 grit or 80 grit only on areas where I needed to remove a large amount of XTC, such as areas where the XTC collected in drips. Diamond files were used to clean out the crevices and hard angles. This was particularly useful in areas where I had extruded a shape or detail into or out of the base shape in the original model.

7.4 Painting

There are two main stages of painting for 3D prints: the primer stage and the painting stage. For this project, the priming stage is particularly important since I want my armor pieces to look like they are manufactured. I used two types of primers, the primers shown in Figure 7.1. The first primer is a generic filler primer and the second is an automotive primer.

The way I approached priming my 3D parts was to apply two layers of filler primer while ensuring that the lines stay crisp through the occasional sanding with 220 grit sandpaper. Once this is complete, I applied a layer of automotive primer, waited an hour, then applied a second coat of automotive primer.

Using automotive primer produces a very good finish along with a smooth, easily cleaned paint surface. I would continue to polish the parts with 400 grit sanding supplies, and use a wet sanding technique to polish the pieces. This entailed using a small bucket of water and a damp 400
gilt sanding sponge to polish. When dry, the 3D part was ready for the first layer of paint.

I three different aerosol spray cans of paint. I used two tones of metallic paint and an orange paint for the details. I coated every single piece of armor with the lighter gray metallic paint before adding the secondary tones. The darker metallic tones were only applied in select areas, so I used masking tape and a plastic drop cloth cut to size. This created clean edges and solid paint.

![Image](image.png)

Figure 7.2: Finishing: Masked Area for Clean Paint Application

### 7.5 All the Pieces

The 3D printed pieces shown below are at varying levels of completion. Some are fresh off the printer, some have a layer of Smooth-On’s XTC-3D applied to them, and some have that application layer sanded down.

The objects with a shine on them are those that have the XTC-3D coating. The objects that have a gray, sand-like surface are the objects that had XTC-3D applied and then sanded down. The objects that have a matte finish, or do not have either of the other two qualities, have not yet been finished.
The pieces in Figure 7.4 have had XTC applied, then sanded, sprayed with filler primer, sanded again, sprayed with automotive primer, wet sanded, and then sprayed with the base metallic paint coat.
Chapter 8

Implementation: Bodysuit

This chapter will discuss my decisions for incorporating a bodysuit into my armor design; the form, function, and construction of the bodysuit will also be discussed. During the early research and design phase of my thesis, it became clear that a custom-made bodysuit was vital to the success of my project. Even the earliest full-body armor systems featured layering and attachment schemes. Base layers typically consisted of various materials including silk, linen, cloth, wool, leather, and metal; Samurai armor, for example, featured items made of fabric with reinforcing metal elements. How my armor’s protective elements would be attached and worn became an early design challenge, as I wanted the finished body armor to look good, be functional—and most important—wearable.

8.1 Design and Modification of Patterns

The design and shape of the bodysuit was heavily inspired by the same artwork by Jang Wook (Azure) Kim, seen in Figure 4.4, that influenced my concept drawings. I was particularly inspired by the material panels that connected the sides to the arms. In order to bring my idea for a bodysuit to life, I worked closely with the seamstress Tami Grabowski.

Just as costume designers help translate a director’s creative vision into physical forms, so did Tami. We collaborated frequently, often marking and noting seam lines that were particularly important to the design, and she was especially helpful in selecting several Simplicity jumpsuit patterns for the initial bodysuit. These patterns were eventually modified to fit my armor design and attachment needs. The original designs can be seen in Figure 8.1. I purchased this October 2018
pattern, and it served as the starting point for the entire design.

![Bodysuit: Pattern Reference Material](image)

Figure 8.1: Bodysuit: Pattern Reference Material

Once the bodysuit was selected, Tami took all necessary body measurements to begin construction of the bodysuit’s first prototype. Those measurements can be found in Figure 8.2. Design modifications and physical adjustments continued throughout the development process. Tami’s design sketches for her modified version of the initial bodysuit pattern can be found in Figure 8.3. We continued to meet numerous times throughout this six-month development process and, as a result, some of the bodysuit sections had to be altered several times.
Figure 8.2: Bodysuit: Measurement Page by Tami Grabowski

Figure 8.3: Bodysuit: Pattern Design by Tami Grabowski
8.2 Materials

The material for the first iteration of the bodysuit was very light and stretchy, but could easily tear. I found the texture of the original material very appealing, as it had a hexagonal-like pattern to it that felt futuristic. Although I ultimately decided against using that material in any large portion of the final bodysuit, I did take inspiration from a lunchbox found at a local thrift store, seen in Figure 8.4, for its use in detailing. The gray piping that edged the box seemed a good way to emphasize the bodysuit’s seam lines in the torso and arm areas.

![Figure 8.4: Bodysuit: Inspiration from a Lunchbox](image)

The materials I eventually selected for the main body, along with a swatch of the first fabric, can be seen in Figure 8.5. The gray material was the base material for the prototype bodysuit and the material for the piping in the second iteration.
Figure 8.5: Bodysuit: Materials

This black fabric has a very interesting specular quality to it. It can reflect the tone of any lighting applied to it, which can be seen in Figure 8.6. In this instance, you can see how sunlight passing through stained glass can be reflected by the fabric.

Figure 8.6: Bodysuit: Material interacting with different lighting

To contrast the highly reflective material selected for the bodysuit, I bought extra fabric in a matte black that would absorb all the light. This matte material was placed in the area above
the hips and down each arm, which would also serve as a slimming element and alter the silhouette. This experience with the color-refracting quality of the fabric brought home the reason why costume designers collaborate with cinematographers on film productions.

8.3 The Iterations

As stated previously, there were two iterations of the bodysuit. The first material selected, the gray fabric, hung loose on the body and would stretch too much. I liked the surfacing detail on it, but it was too tightly woven and not as accentuated as I would have liked. Additionally, I had been planning to paint my finished armor plates several tones of gray, so having a gray bodysuit as well would have been visually undesirable. In terms of color composition, contrast is important, and gray armor pieces situated on top of a gray bodysuit would be too monochromatic. With that in mind, I decided to go with a thicker black fabric for constructing the suit.

Figure 8.7: Bodysuit: Iterations

Figure 8.7 shows three photos of different stages of the bodysuit creation, the first two photos show here were captured by Tami Grabowski. The first iteration was primarily to determine
angles and shapes. These photos do not show where the armor attachments will be placed, as that will be discussed in the next chapter.

8.4 Design Functionality

Tami’s assistance was invaluable throughout the bodysuit planning process, since I was able to discuss the costume’s concept, design, and attachments scheme with her. The bodysuit development also required a careful consideration of practical applications, as the main purpose of the jumpsuit is to support the modular nature of the armor of my thesis. The bodysuit presented several challenges, as not only did we have to consider the functionality and practical applications of the form, but the composition and texture of the material itself. Plus, it was always meant to look good and at the same time be wearable. Additionally, certain constructions of an underlying form can alter the wearer’s movements and personal comfort. All these considerations came into play when designing the bodysuit. The most valuable protective armor pieces of earlier time periods were those that were individually crafted for each warrior, and that concept is reflected in my final bodysuit.
Chapter 9

Implementation: Assembly

Beyond my armor’s 3D design, models, and printing lies a critical element to the success of its creation: attachment of armor pieces to the bodysuit. This was a constant consideration throughout the development process. However, it was not until I had each specific part in hand, that could I truly understand the true value of well-thought design decisions. These applications were in several key locations, primarily where the armor’s strapping system has to connect, attach, or sit on a body part. These connections took the form of magnetic attachments from one part to another, magnetic attachments from one part to the bodysuit, strapping and belted parts attached to the body part on top, and attachments for hard-surface armor parts to a secondary object (i.e. the backpack).

9.1 Connections and the Use of Magnets

It is important that not only do the shapes and armor pieces look good, they must also be easily and securely attached to the underlying garment. With this in mind, I chose to use a magnetic method of attachment for many of my 3D printed armor plates. Dr. Patterson and Professor Insun Kwon both suggested that I use neodymium magnets, as opposed to ceramic ones. This was an excellent suggestion, since these magnets are extremely powerful and able to hold up large pieces. Mindful that the strength of a magnet correlates to its surface area, I chose magnets with a large surface area that would best suit my needs. I eventually employed both bar magnets and round magnets, as the combination allowed me the most range in terms of use and function.
9.1.1 Connections: Part to Part

The shin and calf armor plates were the hardest parts of my thesis to design. This was primarily the result of some limitations and considerations, in regards to printing, assembling, and wearing of certain pieces. I knew I could not print the shin/calf system as one solid piece. It simply would not fit on the print build space. In fact, I had to slightly decrease the size of the pieces in order to get them to even fit on a Taz build platform.

The connections for the lower leg required some intense designs. Thankfully, the concept art I had to work from had already worked out some of the logic. The hard angle in the middle between the front and back pieces actually prevent the parts from slipping and falling off. Those right angles allow the part to maintain its form without sliding. These two parts easily snap together when the magnets are connected as seen in Figure 9.1.

![Figure 9.1: Magnets: Shin and Calf Plates Connection](image)

I designed some inserts into the thickness of the 3D object during the modeling process. These indents were designed to the measurements of the neodymium magnets, as seen in Figure 9.2. I used epoxy to seal the magnets in place.
Figure 9.2: Magnets: Shin and Calf Plates Close-up

Figure 9.3: Magnets: Shin and Calf Plates Full View
In this example (see Figures 9.1, 9.2, 9.3), the gray part features a loop that the leg slides into. This loop allows the shin/calf system to stay attached to the leg, and also allows the purple part to slot in like a puzzle piece.

9.1.2 Connections: Part to Bodysuit

There are eight armor plates that use magnets to connect directly to the bodysuit, and two pieces that use magnets to connect to the boots. The eight pieces that connect to the bodysuit consist of two knee plates, two thigh plates, two hand plates, and two shoulder plates. There are also two hexagonal pieces that connect to the outer edges of the ankle of the boot with magnets. The breakdown of the magnet distribution is as follows: three magnets for each thigh plate; two magnets for each knee/shoulder plate; one magnet for each hexagon/hand plate. This totals to 18 individual magnet connections secured directly to the bodysuit.

I also had to consider where to place the magnets on the armor plate for best attachment. The locations were determined primarily by what function the part in question would have, and how that part would need to move. For example, the thigh plates do not have to move or rotate, just hold solid. For the thighs, I placed three magnets in the shape of a triangle pointed down. This allowed for the most secure attachment.

In contrast, the knees and shoulder plates needed to rotate at the pivot point, which was where the far edges were. These parts needed to rotate only on axis, so placing the magnets on the left and right corners gave the part the most function without restricting natural movement, as seen in Figure 9.1.2.
In Figure 9.1.2, you can see the attached hexagonal pocket sewn directly onto the bodysuit. The opening is the exact size and shape as the hexagonal printed piece that is attached to my boots. Furthermore, this shape is very convenient since it allows the magnet to move around relatively freely within the pocket, yet remain secure.
I worked closely with my seamstress, Tamira Grawbowski, to select the proper orientation and placement for these hexagonal pockets. Moreover, they would be sewn so that the uppermost side would be open to allow for easy installation of the magnets. I decided against having interior pockets, as I felt they would be much more difficult to maneuver if one of the magnets slid with its pair while detaching. To combat the possibility of having magnets loose inside my bodysuit, I decided to construct external pockets for easier control and access. This also makes it easy to adjust a magnet if it is in the wrong orientation.

9.2 Modifying Parts for Modular Assembly

One of the most complex parts is the centerpiece of the design: the chest plate. The armor piece is unique in how it has to sit on the body and connect with other pieces. The chest plate is a three part system that has to be assembled in a unique way. The three parts are split into a center plate that sits above the sternum and two mirrored wing plates that connect near the crook of the arm along the shoulder to arm-pit area.

My plan consisted of stringing the two chest wing plates through the straps of the backpack. One of the major design concerns I had was being able to actually wear the system. So having a solid chest plate in between two straps of a backpack would prove difficult to put on. Therefore, being able to easily snap in a chest plate like buckling a strap was the logical answer. I used a series of magnets along the seam between the plates to allow for a clean connection.

After printing out the first iteration of the chest plate, I decided that neodymium magnets would be stronger and more reliable compared to ceramic magnets I had initially designed for. As a result, I redesigned the chest plate pieces so that the magnet insets would fit a pair of neodymium magnets instead. You can see the difference between the second iteration (the purple part) and the first attempt in gray filament in Figure 9.6.

Additionally, I noticed that the hole at the top of the wing would show a fold in the backpack strap in an undesirable way, so I redesigned that part of the interior inset for the backpack straps. You can see the differences in Figure 9.7.
After attaching two sets of neodymium magnets, I was concerned about the natural flex the plates have. I realized that I needed to cut out another section inside the wings to attach a third,
slightly smaller, bar magnet. This would make for a more secure chest plate and connections at the angles of the chest plate. This secured the chest plate.

### 9.3 Belts and Strapping

Protective layers were frequently padded and laced with both simple and advanced systems of fasteners. The simple cuirass armor of Ancient Greece featured a chest plus back plate connected and secured by a series of hooks and straps, a design that has survived centuries to find its way to both contemporary body armor systems and my thesis.

For my armor pieces, I used a series of belts and strapping to attach and connect the pelvis armor pieces, forearm/bracer plates, and the chest and backpack plates. I was inspired by the western shoulder gun-holster design in the development of the strapping for the chest plate. The result can be seen in Figure 9.8 to which the photo credit goes to Philip Hatfield.

![Figure 9.8: Chest Plate: Execution of the Strap Connection](image)

The complicated area was the backpack. I had not completely worked out how all the pieces would be assembled in my 3D scene. I ended up having to melt the PLA to create holes in the models where the rounded rivet details were so I could lace the parts onto an interior backpack structure. One of my considerations I made was so that the chest plate could be worn without the
attachment of the bulky backpack piece. To attach the backpack, I used D-rings on the straps of the chest plate and clips at the key points of connection to attach the backpack system to the chest plate, as can be seen in Figure 9.9.

Figure 9.9: Backpack System: Modular Connection to the Chest Plate
Chapter 10

Conclusion

Through research and practical applications, I acquired advanced 3D skills while strengthening current ones, investigated new resources relevant to the field, and gained additional design and manufacturing experience. Furthermore, documenting multiple aspects of the thesis project allowed me to identify and address unexpected challenges as they appeared, practice adaptive methods to achieve stated goals, and adopt efficient production and finishing methods.

I also gained an appreciation for the historical significance and design trajectory of armor in both traditional and futuristic settings, and the power inherent in armor individually crafted for its wearer. The primary goal of my thesis was to push my 3D skills beyond their earlier range to create a physical armor specific to my own form; I also wanted my final pieces to serve as both a visual and narrative tale of its designer. Since I have met those goals, there is a strong sense of accomplishment and personal ownership in the project.

Throughout my 3D modeling studies and practice within Clemson University’s Digital Production Arts program, I was able to apply the many skills and techniques learned to my final thesis. Everything here began with modeling. It was the most time-consuming portion of this project, but it set the bar and standard for the project’s entire design and function. I modeled simple shapes with well-placed edge details and paneling to turn a simple silhouette into a complex form.

I began the 3D printing process while I was still refining shapes and parts of the body armor. Both areas were time consuming, but I was able to work on both aspects at the same time. This helped expedite the production process and allowed me to not wait until everything was completed; in the process, I was able to focus on one area of the armor and nearly finish it before starting
another section. During that time, I also discovered simple curves and recognizable shapes placed and attached in the correct way can make for an interesting and effective design tool.

Although it took nearly seven full weeks to print all my 3D designed pieces (even with all the failed prints and unsuccessful adhesions), I was still able to print a full set of armor. Additionally, I was able to have a customized bodysuit with attachment systems produced during that same time. The original production goal seemed imposing, yet I was ultimately able to accomplish it. Every single armor plate remains whole, as I did not have to split any into parts, and every single armor piece has a carefully considered function and connection. You can see the painted and assembled armor costume in Figures 10.1 and 10.2 which were photographed by Philip Hatfield.

I was able to create a cohesive and functional armored costume. If I were to make some modifications, I would re-print the thigh plates with a slightly lower fill-ratio. This would make the thigh plates lighter and the magnet connections would hold stronger. In addition, I would make the leg armor plates slightly smaller so that the legs could bend without jostling the neighboring plates. I would also modify the backpack plates to have modeled in holes where the rivets are, rather than having to melt the plastic after the parts were already printed. I was disappointed that the connection for the shoulder plates were where the chest plate sat. This needed some more thought and strategic placement. Overall, I am pleased with the modeled armor plates. I believe that the plates could use more weathering to make them appear more broken in.

Through the development and design of this character, I created an armored character. This character has a distinctly futuristic look with a familiar color palette and material quality. I created this heavy armor-clad warrior that belongs to a future where survival and battles have become commonplace.

Although this thesis took longer than anticipated, I am pleased I was able to provide each part of it the necessary time and attention to develop and produce a cohesive physical product. My original goal is now a reality.
Figure 10.1: The Armored Costume: A Front View - Photo by Philip Hatfield
Figure 10.2: The Armored Costume: A Back View - Photo by Philip Hatfield
Bibliography


