COMPARING PHYSICAL TO VIRTUAL: FIT AND APPEARANCE OF MULTI-LAYERED CULTURAL GARMENT

by

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ABSTRACT

The purpose of the study was to expand the use of virtual technology to include multi-layered non-western cultural garments and to demonstrate comparisons of these complex garments, physically and virtually. In addition to this, 3D simulation of non-western garments would be beneficial for the emerging market in China. The procedure of this study included five parts: material selection, avatar customization, physical multi-layered garment construction, virtual multi-layered garment construction, and evaluation of the physical and virtual garment appearance and fit by the online survey. The researcher adapted the traditional product design process, including virtual multi-layered garment construction. As well, the researcher developed an evaluation survey to better understand the success of hybrid garment design process. This study found that multi-layered cultural garments could be relatively effectively simulated in virtual software, such as EFI Optitex. First, this study suggested that the virtual simulation technology could be used for loose fit multi-layered cultural garment. Second, the presented software could be used for garments with different kinds of fabrics and different design silhouette. Third, number of fabric layers did not significantly affect either appearance or fit similarity between virtual and physical garments. Based on these results, it can be concluded that virtual presentation has great potential as a tool to evaluate the appearance of a garment in a relatively simple and quick way.

Chapter 1

INTRODUCTION

The traditional model of apparel product development requires multiple sample revisions. At an industry level, 3D virtual prototyping is being adopted as an innovative model of product development, promoting better communication of design throughout the supply chain. This innovation lessens impact by saving valuable time and reduce physical sample waste (Song & Ashdown, 2015). Most of the academic studies existed now are limited to the virtualization of single-layered garments. The fact that consumers of clothing commonly dress in layered assortments or looks offers an interesting opportunity to expand on previous research. This study builds on prior research by investigating the simulation of multiple layered garments. In this exploration, the researcher posits that 3D virtual prototyping has the potential as a tool to evaluate the appearance and fit of multi-layered garments, specifically Chinese cultural garments as non-western apparel is aligned and more representative of a global market.

1.1 Purpose and Research Question

This study was designed to analyze the similarity of appearance and fit between physically constructed multi-layered cultural garments and those that are virtually constructed. The purpose of the study was to expand the use of virtual technology to include multi-layered non-western cultural garments and to demonstrate comparisons of these complex garments, physically and virtually. In addition to this, 3D simulation of non-western garments would be beneficial for the emerging market in China. Hypotheses for the study were as follows:

H1: Fabric type significantly affects the appearance similarity in multi-layered cultural garments

H2: Design silhouette significantly affects the appearance similarity in multi-layered cultural garments

H3: Fabric type significantly affects the fit similarity in multi-layered cultural garments

H4: Design type significantly affects the fit similarity in multi-layered cultural garments

H5: Number of fabric layers does not significantly affect the appearance similarity between virtual and physical garments.

H6: Number of fabric layers does not significantly affect the fit similarity between virtual and physical garments.

1.2 3D Virtual Prototyping Technology

Virtual prototyping is a technology which combines two-dimensional (2D) and three-dimensional (3D) computer-aided design (CAD) assisting designers in visualizing their design, through simulation of 2D pattern pieces "stitched" on to virtual mannequins (Goldstein et al., 2009). In 2001, the virtual prototyping technology first appeared on the fashion market (Goldstein et al., 2009). Currently, virtual prototyping software is readily available for use in the fashion industry; common platforms include EFI Optitex, Lectra, TUKA3D application, and CLO (PI Apparel, 2018).

Fabric mechanical characteristics can help garment simulation systems build up realistic virtual garments with realistic fit and appearance (Ancutiene et al., 2014). In this study, the researcher used EFI Optitex, which is one of the world leading providers of the virtual prototyping platform (EFI Optitex, 2018). By adding characteristics of stretch, shear, friction, bending, thickness, and weight, into a customizable fabric library, EFI Optitex can create a more accurate garment simulation.

Virtual prototyping technologies are useful for the development of the garment industry because of the potential to create more efficient supply chains by reducing time, sample waste, and other impacts. Power (2013) provides one example of this potential by stating that virtual prototyping could create realistic draping behavior of fabrics, based on physical properties; the product can be viewed, assessed, modified and re-fitted without any actual cutting of fabric. One Nike report shows that cutting down the pre-consumer waste would be more effective than managing downstream waste in the supply chain (Nike, 2013). Using virtual garment samples instead of physical constructed ones, can significantly reduce the time and waste of the sample making stage.

During the sample making stage, apparel prototypes are shipped back to the studios in the United States to be rejected, edited, and sent back to factories, with comments for improvement. Then, the factories improve the apparel sample and ship it back to the United States (Cobb et al., 2017). This cycle would continue if the sample is not approved or close to approval, which increases lots of sample waste in the design process (Cobb et al., 2017). Thus, virtual prototyping technology can help the apparel industry eliminate the need to create multiple physical apparel samples, which is one of the pre-consumer wastes. Also, apparel suppliers are claiming several benefits of using 3D systems. The benefits include better communication of design throughout the supply chain, saving valuable time and reduction in product development, and helping designers reduce a product's carbon footprint (Sayem, 2017).

However, some studies comment on the lack of practical application and adoption of these technologies within the fashion industry, due to reasons including setup costs, user expertise, technology limitations, and inaccurate fabric simulation (Power, 2013). Also, studies related to 3D virtual garments are still in their early stages, the field of virtual prototyping lacks fine-tuned visual data regarding fit and appearance. One major complaint from potential 3D garment simulation users is that virtual components do not look realistic; they do not transcend the technical aspects of composition and lack tactility. Even with these limitations, it is essential to reduce the time in the developmental stage of apparel in a rapid response environment. In the research field, 3D simulation is now being used to generate single-layered garments (Sabina et al., 2014; Kim, Yin, & Song, 2014; Uh, 2016).

1.3 Cultural Garments Industry in China

Compared to single-layered garments, multi-layered garments are more common in daily life. Specifically, multi-layered cultural garments such as Qipao and Hanfu are becoming more popular in Chinese fashion markets, with the rising of the "Hanfu movement" (Ji, 2016). As one of the largest fashion markets, China has a long glorious history, with magnificent cultural traditions. The Chinese government and consumers played critical roles in the promotion of cultural garments among the Chinese market.

In the beginning of the 21st century, China was able to interact more confidently with the West. Under this historic opportunity, the Chinese government decided to host the Asia-Pacific Economic Cooperation (APEC) Summit and introduced a cultural garment, which showed the traditional Chinese flavor and modern ideas to the world (Liu & Xing, 2017). The young, highly educated generation in China who were born after 1978, are comfortable and willing to accept Chinese culture and cultural brands (Heine & Gutsatz, 2015). The Chinese style and cultural heritage attracted designers from all over the world to create Chinese-inspired designs, in order to engage this expanding market (Liu & Xing, 2017).

Nowadays, the Chinese apparel industry is moving from capital-driven to innovation-driven. Many famous brands, such as Shanghai Tang, Shang Xia and Shiatzy Chen, have embraced Chinese culture through referencing traditional craftsmanship, and drawing on traditional Chinese aesthetics and design (Heine & Gutsatz, 2015). These brands promote these aspects in their marketing and communication strategies (Schroeder, Borgerson, & Wu, 2015). As an emerging market, the Chinese cultural garment market has some characteristics of a developed market. Over the past 10 years, Shanghai Tang, Shang Xia and Shiatzy Chen have had rising annual revenue due to the rapid development of the cultural garment market (Heine & Gutsatz, 2015).

As the standard labor cost slowly grows in China, some garment factories start to move to other developing countries with lower costs (Ruan & Zhang, 2014). The garment supply chains in China become more complex and inefficient than before. In the case of Chinese Cultural Apparel Companies, designers create drafts in the studio often located in China. The physical prototyping process is finished in factories, usually offshore, in Bangladesh, Turkey, or other counties of manufacturing. Apparel prototypes are shipped back to the studios in China to be rejected, edited, and sent back to factories, with comments for improvement (Cobb et al., 2017). This design process of garments will repeat until the design can be accepted by designers, which makes the supply chain inefficient and increases the sample waste. It is useful to carry out mass production of Chinese cultural garments, which can be put into the Chinese fashion market, to appeal to their increase in consumers. Making the supply chain more efficient will help cultural garment companies to meet this demand.

1.4 Method

Cultural garments, Qipao (tight fit) and Hanfu (loose fit), were constructed and produced in order to investigate the appearance and fit of virtual and physical garments based on existing patterns. The research method used for this study was an online survey. In general, online surveys are an effective way to collect what people think with no research intervention. In this case, the researcher can get useful information about how people think about the appearance and fit of virtual and physical garments. The researcher compared virtual and physical garments by distributing an online survey sent to students in the fashion department.

The research procedure involved measuring the physical parameters of the fabric, customizing an Optitex EFI Fabric Library, developing 2D and 3D patterns via EFI Optitex pattern drafting software, creating physical and virtual garments, and conducting an on-campus survey. Samples for this study include a loose fitting multi-layered garment (Hanfu) and a tight fit multi-layered garment (Qipao). Prototypes were developed in various fabrics. The researcher took into account the physical fabric mechanical properties, and the fabric objective measuring data such as weight, thickness, stretch, shear, bend, and friction through the Kawabata evaluation system of fabric (KES-F) and other instruments. Simulation technologies were researched and EFI Optitex technology was utilized to virtually simulate the garments.

1.5 Justification

While the similarity of appearance and fit between physical single-layered garments and virtual ones has been investigated, no study has been found on evaluating the appearance and fit of multi-layered garments. With the continuation of the supply chain globalization, it is more important than ever to find the way to make design processes more well-organized. The virtual simulation software might be a business opportunity for an emerging market, the cultural garments will not be forgotten by consumers. Also, this has the potential to negatively affect the environment because it could cause unwanted sample waste. It is important to evaluate how virtual prototyping technologies can help designers and pattern makers to make good choices on the appearance and fit of multi-layered cultural garments.

By carrying out 3D simulation of multi-layered cultural garments, it may be beneficial to simplify the design process of cultural garments and have a positive influence on overall development of the emerging market in China.

1.6 Operational definitions

1.6.1 3D prototyping term (Optitex Terms, 2018)

- 2D pattern piece

"A 2D pattern is created in the working area then plotted onto paper or sent to a cutter to cut out of fabric and sew into a garment. User can virtually stitch the 2D pattern into a 3D garment in the model window".

- Layer

  “Defining each piece using layers enables simulation of multi-layered products”.

- Seam

  “A line where two pieces of fabric are sewn together in a garment”.

- Shader

  “A texture applied to pieces stitch or drill hole”.

1.6.2 Similarity term

- Appearance

  ‘The garment structure appearance includes many aspects such as pilling, wrinkling, and puckering, and so forth’ (Hu & Xin, 2005).

- Fit

  ‘Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer’ (Chambers & Moulton, 1969).

- Drape

  ‘The manner in which a fabric falls when hung or placed on a form, frame or manikin. Draping will readily show if a material is to be used in a form-concealing or a form-revealing garment’ (Fan, Yu, & Hunter, 2004).

- Multi-layered garments

  ‘A way of dressing using many garments that are worn on top of each other’ (revolvy.com, 2018).

- Tight fit clothing:

‘Tight fit clothing fit very closely to the body’ (Dictionary.cambridge.org, 2018).

1.6.3 Cultural garments term

- Qipao

“The Qipao is a Chinese dress for women. The style is also called cheongsam in Cantonese. The defining features of the dress are a fitted silhouette, a high collar, and side skirt slits” (Wilson, 2018).

- Xiejin

“Xiejin is a front flap overlapping to the right, which fastens along the collarbone, under the arm and down the right side” (Wilson, 2018).

- Hanfu

“Chinese hanfu robes are full-length wrapped garments with bell-shaped sleeved extending over the hand. Hanfu means dress of the Han people” (Eicher et al., 2014).

Chapter 2

LITERATURE REVIEW

2.1 Overview of 3D Simulation in the Fashion Industry

In the apparel industry, 3D technologies, including 3D virtual prototyping, 3D body scanning, and 3D try-on, are becoming commonly used by brands and designers. These 3D technologies are used in product design and manufacture stage, consumers' body measurement, and "try-on" processes. The 3D body scanning technology has already been used to measure thousands of volunteers of all ages in different countries, at the end of the 1990s (Faust & Carrier, 2011). 3D virtual try-on technologies can help consumers virtually wear the garments, with their body measurements.

Without the physical try-on process, the consumer can evaluate clothes' physical characteristics, such as silhouette, fabric, color, and embellishments, and clothing fit (Istook, 2008). Nordstrom, Macy, and Lands End have used some 3D technologies in their marketing strategies (Cordier, Seo, & Magnenat-Thanlmann, 2003). Web applications developed by those brands have supported some basic functions such as "viewing apparel items in 2D or 3D, combining different items, and mixing and matching colors and textures (and sometimes using a mannequin adjusted to the shopper's proportions)" (Cordier et al., 2003, p. 38).

Virtual prototyping technologies are currently widely used in the development of many materials, processes, and products in engineering industries such as automotive and interior design. By integrating 3D virtual prototyping technologies into manufacturing process, brands can effectively lessen negative impact generated during the manufacture of physical prototypes. Specifically, the 3D virtual prototyping technologies can cut down the time spent obtaining the raw materials and construct samples. It has a potential that the virtual prototyping technologies can be applied to apparel and footwear industries.

Since the 1980s, some methods for clothing prototyping have been presented by different companies (Fontana, Rizzi, & Cugini, 2005). Virtual prototyping is an emerging technology, which "creates product prototypes using computer-generated virtual reality and the manufacturer's engineering data" (Bux, 2014). Compared to the physical prototyping, 2D pattern modification can be simultaneously reflected on the simulation of the 3D garments during the virtual prototyping process (Huang, Mok, & Au, 2010). Virtual prototyping is a 2D-to-3D approach. During the virtual prototyping process, designers sketch the 2D patterns, and later assemble the virtual garment through virtual stitching (sewing) processes to produce a virtual sample (Huang, Mok, Kwok, & Au, 2012). Therefore, the virtual prototyping technologies allow designers to validate their product design.

Virtual prototyping can be a useful tool for evaluating the visual quality of garment product. Under Armour, Theory and Roberto Cavalli, as the world's leading brands and retailers, are using 3D technologies to a create better product (EFI Optitex, 2018). Also, Lectra's 3D virtual prototyping solution has built an advantage for Zannier, a French fashion brand, solving the major issue—master fit (Lectra, 2017). However, one study shows that the virtual prototyping technologies cannot be the prerequisites for the clothing development (Huang et al., 2012).

2.2 Overview of 3D Simulation in Academic Studies

There are some exploratory studies for 3D virtual design technologies that were investigated. Baytar and Ashdown (2015) explored the using of 3D virtual design technologies and try on technologies. With these technologies, the design process could have a sustainability impact on the creative stage, and consumers can also be involved in the design process as a co-designer (Baytar & Ashdown, 2015). 3D simulation technologies have been used not only for manufacturing but also for e-commerce. Also, Kim and Forsythe (2009) found that the 3D virtual prototyping can encourage consumers to visit retail websites. Park, Kim, and Sohn (2011) explored the effectiveness of 3D virtual prototyping technology for enhancing spatial visualization skills in apparel design education. They found that 3D simulation technology has positive potential as a useful instructional tool for improving students' visualization skills in apparel design (Park et al., 2011).

Sabina et al. (2014) completed the basic patterns for women dress in 3D virtual space, based on the correspondence between the product and actual body. They calculated the mean and range of stature, conformation, proportions, and specific indicators. Then, they made a comparison between those indicators with some basic morphological types (Sabina et al., 2014). One study tested the effectiveness of 3D virtual garment prototyping with a reconstructed body scan model (Stjepanovic, Rudolf, & Jevsnil, 2011). Ancutiene and Sinkeviciute (2011) proved that the 3D virtual simulation system could fit different on the human body, based on measuring distance ease and strain. Tao and Bruniaux (2012) realized that using 3D virtual garment prototyping, designers can directly image the virtual clothing on a mannequin morph types with the consideration of the ease allowance between the body shape and the garment.

Power (2013) pointed out that 3D virtual simulation can offer more opportunities in the garment industry. Studies have shown that virtual prototyping is faster (Hamon, Green, Dunlap, Camburn, Crawford, & Jensen, 2014), and performs equal to physical prototyping (Wojtczuk & Bonnardel, 2010). For instance, 3D virtual simulation can speed up the apparel-making process, from raw material to consumer products and can help the apparel design process with accurate mapping of comfort and support (Power, 2013). Also, a few researchers explored the feedback of 3D virtual simulation technologies from consumers. Shim and Lee (2011) found that compared with the 2D image, the 3D virtual model can reduce the perceived risk of four apparel attributes: silhouette, color, texture, and fit. One study investigated the response from users about the fidelity and accuracy of 3D garment simulation technology when consumers were in a virtual online shopping scenario (Kim & LaBat, 2013).

Both designers and consumers not only want to see the real fit of garments on a wearer but also want to compare it with its virtual fitting. Several researchers have analyzed and verified the virtual fit information for garments. Naglic, Petrak, & Stjepanovic (2016) made the virtual fit of a female diving suit, which was created by using the 3D flattening method, in static and dynamic body postures. Rudolf et al. (2016) examined the important parameters regarding the similarity between real and virtual garments. They pointed out it is essential that fabric drapes need to be the same as real fabrics. Lim (2009) compared virtual simulations of women's wear produced in two different systems, namely OptiTex and Vstitcher, utilizing identical material properties and found that visual appearance of simulated garments differed in two systems.

2.2.1 3D Simulation of Garment Appearance and Fit

The fitting of the real garment is based on four principles: design, fabrication, appearance, and comfort (Ancutiene et al., 2014). It is unclear to how effective 3D simulation systems are regarding allowing development personnel to make good decisions about fit (Porterfield & Lamar, 2016). Sayem (2017) found that a limited number of investigations on the accuracy and applicability of virtual prototyping and fit analysis tools have been reported so far.

To enable virtual garment simulation to occur two factors are paramount: the accurate representation of the human form and the realistic cloth simulation (Power et al., 2011). Also, Luible and Magnenat-Thalmann (2007) explained that the true representation of a virtual garment is dependent on precise computational models and exact input of fabric parameters.

Clothing fit studies have been evaluated referring to either expert judge opinions or wearer's responses. Recently, one study proposed an automatic virtual garment transfer system for human models of various shapes and poses, focusing on the realistic fitting result while preserving the original garment size (Lee, Ma, & Choi, 2013). During the garment simulation process, the quality of virtual garments can be described by aesthetic appearances, such as its drape and fit quality (Ancutiene et al., 2014). Kim and LaBat (2013) investigated the fidelity and accuracy of 3D garment simulation technology used in the online market. They used rating scales for the number of critical fit locations were often used to measure both wear and expert evaluations of garment fit. One study (Rudolf et al., 2016) tested the influence of parameters on the accuracy of virtual garments' drape quality to achieve better realistic appearances of virtual garments. Kim et al. (2014) analyzed the similarity of fit and appearance between real and virtual torso length sloper.

Nowadays, some 3D virtual simulation software can test garment fit and appearance, such as 3D Runaway Design by Optitex. Gerber Technology, Lectra, and Optitex have 3D virtual clothing simulation system for garment fit evaluation. However, it is still a challenge for 3D virtual simulation technologies to simulate fit and appearance (such as drape) of a particular garment. Ancutiene et al. (2013) evaluated the fit of the virtual garment based on local tensile strains at 11 points in the warp, weft, and bias directions with the help of Modaris 3D Fit (Lectra) software. They found that the mechanical characteristics would affect the quality of garment appearance. Kim and LaBat (2013) analyzed the fit quality at 13 critical areas using a seven-point scale. Their result shows that the pants length and the waistband position have higher similarity compared to other locations.

Baytor and Ashdown (2015) collected data by participant observation, analysis of image journaling and documentation, and semi-structured in-depth interviews to evaluate the fit of the virtual garment. In Kim et al's study (2014) thirty experts assessed the similarity of fit and appearance between virtual and real clothing. They judged by observing garment images classified by the front, back, and side views.

Rudolf et al. (2016) compared the orthogonal projections of the real and virtual fabric drapes using Cusic Drape Testing, which used to test the fabric drape coefficients and parameters. They also compared the appearance and dimensions of the real and virtual garments (Rudolf et al., 2016). Kentare, Lamar, Pandurangan, and Eischen (2008) found that since fabric drape behavior is highly variable, the 3D virtual simulation should provide no single drape configuration to improve the simulation between virtual and real garments. Sabina et al. (2014) observed and analyzed the correspondence between the body and garment, to improve the simulation technique with tensions map specific.

Kim and LaBat (2013) used Ferwerda's Functional Realism Framework, which provides standard criteria to examine garment realism. Uh (2011) measured the similarity between real and virtual garments according to a change in the length and princess line, in a silhouette of a one-piece dress.

Rudolf et al. (2016) found that when accurate virtual 3D human body models were used for the simulating process, the garment drape simulations would provide more accurate garments. Also, one study (Kim & LaBat, 2013) showed that the overall appearance of the virtual and real pants is similar, and the length and the waistband position of the pants were accurate. According to a study by Ancutiene and Sinkeviciute (2011), the 3D virtual simulation software could be used for tight-fitted garments.

However, fabric wrinkles of virtual pants were not represented similarly; the relationships between overall garment and body shape were not accurate (Kim & LaBat, 2013). Also, Buyukasian et al. (2015) compared the similarity between real and virtual skirts, and the result shows that the real skirt on a live body was noticeably different than the virtual skirt. Although virtual skirts seem more fitted in the hip area, the hemline is more draped in the real skirt (Buyukasian et al., 2015).

Several studies have been undertaken to show that mechanical characteristics of fabrics affect strain distribution and the similarity between virtual and real garment appearance (Ancutiene et al., 2014). However, Rudolf et al. (2016) used the default simulation parameters Hybrid IMEX and Soft Bending, which is a solver setting, received an inaccurate drape simulation. Also, the results indicated that in the virtual platform, the presenting of real fabrics' physical and seam properties still have fundamental problems (Rudolf et al., 2016).

2.2.2 3D Simulation of Garment Textile Characteristics

Nowadays, apparel and textile (A&T) industries rapidly change to virtual simulation, which can both present the 3D virtual view of garments and simulate mechanical behavior of materials (Ancutiene & Sinkeviciute, 2011). Several technical tools for virtual fit analysis, such as tension, pressure, stretch, and ease mapping tools, are available within 3D CAD systems. Those tools offer both subjective and objective evaluation of fit in a combination with a visual check of the simulated fit on the computer screen (Lim & Istook, 2011). Textile materials are usually defined regarding aesthetics, mechanical and physical properties. The current provision for objective testing is dominated by two test methods FAST (Fabric Assurance by Simple Testing) and KES-f (Kawabata evaluation system). However, KES-f is in the main limited to scientific research, and FAST is still not fully adopted across the industry sector (Power, 2013).

Theoretical studies about fabric and fibers started about 60 years ago, mainly funded by the textile industry, from Peirce's precursor work in 1949 up to De Jong and Postle's model (1977) in the 1970s. Previous studies have shown that fabrics' mechanical (tensile, bending, and shear) and physical properties (weight, thickness, yarn density, and count) influence the 3D simulation results. One study shows that it is important for the 3D virtual garment simulation programs to express the appearance of virtual garments, by accurately reflecting the properties of real fabrics (Rudolf et al., 2016; Buyukaslan et al., 2015). In the apparel industry, "Modaris 3D Fit" (Lectra) can investigate the influence of materials' mechanical properties upon virtual garment fit

(Ancutiene & Sinkeviciute, 2011); this software uses mechanical properties data tested by KES-f. KES-f system provided precise predictions of fabric handle and was credited to provide the answer to the relationship between the functional properties of textiles and fabric handle (Power, 2013). Although the KES-f system is very sophisticated, it requires significant expertise to use and analyze the results.

Some companies, such as Optitex, already have their fabric testing center to get fabrics' mechanical and physical properties for drape simulation. However, there is a challenge for the 3D virtual simulation programs that the models for fabric drape simulation have a limited ability to produce accurate virtual representations of particular fabrics (Kenkare et al., 2008). The fabric measurement methods and derivation of fabric parameters need to be improved (Luible & Magnenat-Thalmann, 2008). Power et al. (2011) introduced methods of obtaining fabric mechanical and physical properties, such as FAST and KES-F. Moreover, Power (2013) compared and interpreted the difference for six knitted fabrics.

However, there has been no systematic investigation on the validity of 3D clothing simulation for fit analysis, especially taking into the diversity of fabric properties (Wu et al., 2011). Specifically, Sayem and Bednall (2017) investigated the correlation between the change in virtual drape parameters (tension, stretch, and pressure) and the change in fitting ease of blouse. They found this correlation can lead to a development of 3D virtual garment simulation technology. Rudolf et al. (2016) found that soft bending on the virtual fabrics' drape simulations is essential, and without soft bending, the drape simulations of the garments would be inaccurate.

After testing tensile, bending, shear, and surface by KES-f, Ancutiene and Sinkeviciute (2013) explored the influence of those mechanical properties upon virtual garment fit. There are mainly two standard measurement systems: FAST and KES-f for 3D virtual garment simulation technologies used by the researchers. Luible and Magnenat-Thalmann (2007) used both FAST and KES-f to test six different textiles. They found those systems provided satisfactory information for the evaluation of linear bending characteristics, and non-linear tensile and shear can derive from the KES-f stress-strain curves (Luible & Magnenat-Thalmann, 2007).

2.2.3 3D Simulation of Multi-layered Garments

A second fabric layer can be added, to make a garment more durable for function or aesthetical reasons. Compare to the single-layered virtual garment, the research of multi-layered garments simulation is still a difficult issue. One study shows that clothing aspects, such as seams, interlinings and fabric fusing are important influencing factors for the multi-layered garments simulation (Luible & Magnenat-Thalmann, 2007).

The 3D virtual prototyping technologies existing now are using a Physically Based Simulation method to construct the multi-layered garments, layer by layer in the simulation. However, preparing a character dressed in multiple layers of garments can be very time-consuming and tedious (Hu, Komura, Holden, & Zhong, 2017). In multi-layer virtual garment development, the under-layer fabric sometimes may appear across the upper-layer fabric, which results in a technical problem, penetration. Hu, Wang, and Zhou (2015) explained that at the beginning of the virtual dressing with the existing garments, the effect of penetration always appears. Lazunin and Savchenko (2017) found similar problems in their research that the 3D virtual prototyping technologies existing now do not work in situations where several layers' interlock: for example, a shoelace in a shoe.

Hu, Wang, and Zhou (2015) designed a simple system based on physical simulation models. Also, they developed an efficient solution using computing algorithm to identify penetration points to resolve the penetration problem that appears among multi-layered garments. Hu, Komura, Holden, and Zhong (2017) presented a novel scanning-based solution for modeling and animating characters wearing multiple layers of clothes. Lazunin and Savchenko (2015) proposed a non-iterative approach to the visually plausible rendering of multi-layered clothes. Specifically, they developed a visualization technique to complement existing physically based methods (Lazunin & Savchenko, 2015). However, these studies did not verify the virtual fit, appearance, and fabrication characteristics of virtually simulated multi-layered garments.

2.2.4 3D Simulation of Cultural Garments

In the early 1990s, China was first recognized as one of the main economic powers around the world. Also, Hong Kong and Taiwan were stated economic miracles in the 1980s. Those changes facilitated cultural confidence and national pride in China. Chinese economic market promotion and diverse aesthetic needs offer a good marketing position for Chinese Cultural garments (Niu, Xiu, Cui, & Lu, 2016). Although most of the cultural clothes in China are no longer worn as an everyday garment, these styles have gained new consumers types, renewed global recognition and powerful symbolic meanings (Chew, 2007). The cultural garments' style has been marginalized in recent history; the re-emergence has been swift and broad in scale in the last few years (Chew, 2017).

Hanfu is an important part of the dress culture of China, "design as the main external visual symbols of clothing, is the direct reflection of the social history, folk culture, is the important carrier of Chinese civilization" (Wei, 2014). In the 2008 Beijing Olympics, the ceremonial dress looks elegant and charming. It is quite clear that the style has some Hanfu elements, such as the collars and patterns (Hu, 2014). In 2014, when Chinese First Lady Liyuan Peng's first visited the Netherlands, the garment she wore is from the Hanfu named as "upper Ru, lower skirt" (Hu, 2014). She got the world's attention, at the same time, Hanfu became popular with more and more people over the world (Hu, 2014). Similar to other cultural garments, the Qipao had completely faded out in China during the Cultural Revolution. Chew (2007) found that the culture producer and celebrities play a meaningful role in the Qipao's re-emergence. Brands have repackaged the meanings of the Qipao, and cater to a variety of clients (Chew, 2007). The beginning of Qipao re-emergence is on an even broader scale (Beijing Summer Olympics 2008), after the film *in the Mood for Love* was released, (Chew, 2007).

There are few studies have been done to adopt 3D virtual garment simulation in the design process of Hanfu and Qipao. One study has described the method for design and implementation the virtual prototyping process for Qipao (Jiang, Guo, & Hu, 2014). Also, Ji (2016) prototyped and verified 13 different kinds of Hanfu, and he built up the database of Hanfu classification for customer choice.

Chapter 3

METHOD

3.1 Research Question

This study was designed to analyze the similarity of appearance and fit between physically constructed multi-layered cultural garments and those that are virtually constructed. The purpose of the study was to expand the use of virtual technology to include non-western cultural garments and to demonstrate comparisons of complex garments, physically and virtually. In addition to this, 3D simulation of non-western garments would be beneficial for the emerging market in China. Hypothesis for the study were as follows:

H1: Fabric type significantly affects the appearance similarity in multi-layered cultural garments

H2: Design silhouette significantly affects the appearance similarity in multi-layered cultural garments

H3: Fabric type significantly affects the fit similarity in multi-layered cultural garments

H4: Design type significantly affects the fit similarity in multi-layered cultural garments

H5: Number of fabric layers does not significantly affect the appearance similarity between virtual and physical garments.

H6: Number of fabric layers does not significantly affect the fit similarity between virtual and physical garments.

3.2 Variables

This study used a two-level factorial experiment in a complete 3x2 experimental design with two independent variables, fabric type and design, as shown in Figure 1. The independent variable fabric type has three levels: cotton, silk, and hemp. Another independent variable design status has two levels: Qipao (tight fit) and Hanfu (loose fit). The researcher assumed that two dependent variables, the overall similarity between virtual and physical garments, and the similarity between virtual and physical garments of critical areas would respond to the independent variables.

Fabric type

Design

Levels	Cotton	Silk	Hemp
Tight fit	Tight fit * Cotton	Tight fit * Silk	Tight fit * Hemp
Loose fit	Loose fit * Cotton	Loose fit * Silk	Loose fit * Hemp

Figure 1 3x2 experimental design model.

3.3 Procedure

The procedure of this study included five parts: material selection, avatar customization, physical multi-layered garment construction, virtual multi-layered garment construction, and evaluation of the physical and virtual garment appearance and fit by the online survey. The method for this study was inspired by the traditional product development process (Shaeffer, 2012). The operations within the process of product development include fabric selection, pattern making, sample making, and appearance and fit evaluation. However, the traditional appearance and fit evaluation are sophisticated; the sample garments need to be modified several times until the product is accepted by the designer (Shaeffer, 2012).

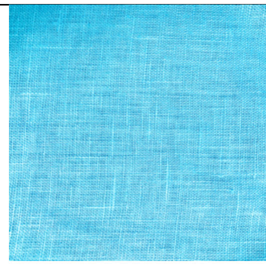
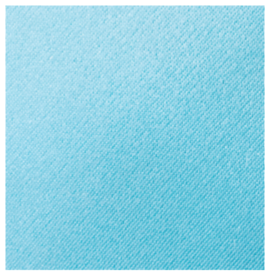
The researcher adapted the traditional product design process, including virtual multi-layered garment construction. As well, the researcher developed an evaluation survey to better understand the success of hybrid garment design process. The customized multi-layered cultural garments developed by researcher supported an investigation into whether the use of virtual technology can be expanded to non-western multi-layered garments and frames the potential to evaluate the appearance and fit by virtual garments, instead of assessing physical sample garments.

The quantitative approach was selected for the online survey because it can sharpen the focus on, provide additional explanations of the observed relationship, and offer an enduring yardstick for measuring change (Madey, 1982). Institutional Review Board (IRB) was acquired by University of Delaware IRB (HUMANS) on IRBNet before progressing with the study.

3.4 Material selection and fabric properties testing

In Asia, the traditional fabrics are constructed out of natural fibers. Therefore, this researcher chose three natural fabrics (cotton, hemp, and silk) to construct multi-layered cultural garments. The cotton fabric was obtained from China, and the hemp and silk fabrics were obtained from the USA. The detailed fabrics description measured by the researcher as shown in Table 1.

Table 1 The description for each fabric measured by the researcher.

Fabric	Picture	Weight (g/m^2)	Thickness (mm)	Fabric width
Hemp summer cloth		185.833	0.465	53''
Silk habotai		77.667	0.183	45"
Cotton		121.583	0.296	/

Prior research has determined that fabric properties affect garment appearance and fit (Fan, Yu, & Hunter, 2004). In this study, Kawabata Measurement System (KES-F), Portable gauge (SDL.Atlas Inc., Rock Hill, SC, Model: J100), and a digital scale were used to test mechanical properties of selected fabrics in warp and weft directions. The fabric objective measurements were tested in the textile labs at the University of Delaware and Donghua University. For these tests, the researcher prepared three 20cm x 20cm square samples. The standard conditions for the test were 21°C and 65% relative humidity.

The weight, thickness, and other mechanical properties of fabric were measured in interval level. These properties were measured three times and the mean values were calculated. The weight was measured by a digital scale and the unit of measurement was g/ cm^2. The thickness was measured by a portable gauge (SDL Atlas Inc., Rock Hill, SC, Model: J100) and the unit of measurement was mm. Other fabric properties such as the tensile, shear, bending, and surface properties were measured by KES-F system.

3.5 Virtual avatar customization and Pattern development

The researcher customized a virtual mannequin offered by EFI Optitex. The standard dress form, size 8 misses, was used in this study, as shown in Figure 2. The investigator took the measurements of the size 8 misses dress form of the ASTM D 5585-95 standard in the University of Delaware.

Figure 2 The size 8 misses standard dress form used for this research.

The EFI Optitex software offered the dress form measurement standard, as shown in Figure 2. To gain accurate measurement, the researcher measured the physical dress form three times. The measurements were input into the EFI Optitex software, as shown in Figure 3, to finish the virtual avatar customization.

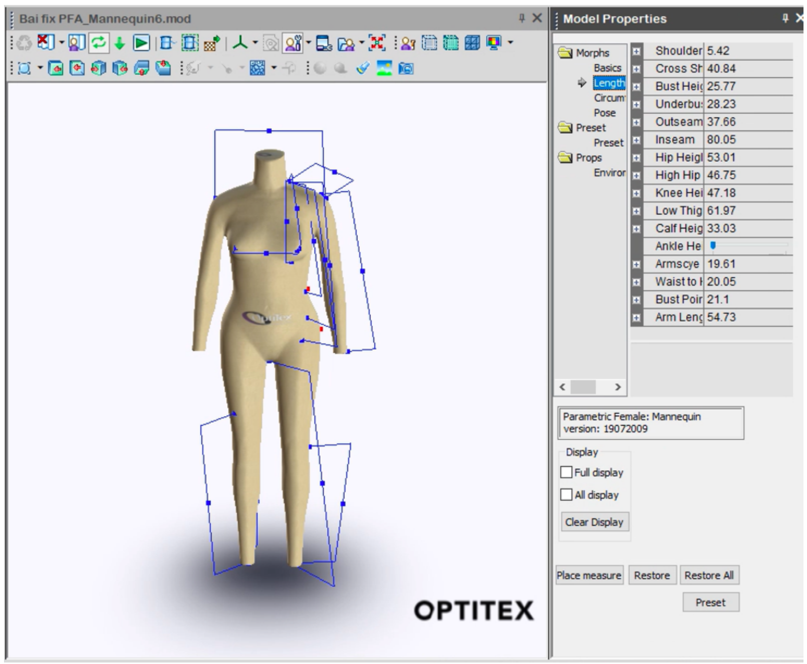


Figure 3 Optitex virtual avatar customization system.

Two Chinese cultural garments, Qipao (tight fit) and Hanfu (loose fit), were selected for this study. The researcher found the US size 8 Qipao pattern from a patternmaking book (New Look, 2018) and designed a no waste Hanfu pattern. Those 2D paper patterns were digitized into the EFI Optitex software using GTCO 3036 Roll-UP III Digitizer with 16-Button Cursor Model RD3-3036.

3.6 Physical multi-layered garment construction

The steps for making garments include “taking measurements, preparing the pattern, cutting, basting, fitting, sewing, ironing or pressing and finishing” (Di & Di, 1979). The researcher constructed and produced cultural garments, Qipao and Hanfu based on the patterns created before. Before constructing the garments precisely, two muslin prototypes, Qipao and Hanfu in full size were created to confirm the accuracy of the patterns. Physical garments were cut, assembled, sewn, and ironed in three different fabrics (cotton, silk, and hemp) by the researcher. With the process of dyeing fully garments (Followed the instructions offered by iDye (2018), the garments were dyed blue. Therefore, all of the garments would be in same color. However, dying and washing garments may lead to shrinkage. The dyeing steps were shown in Figure 4 (idye, 2018):

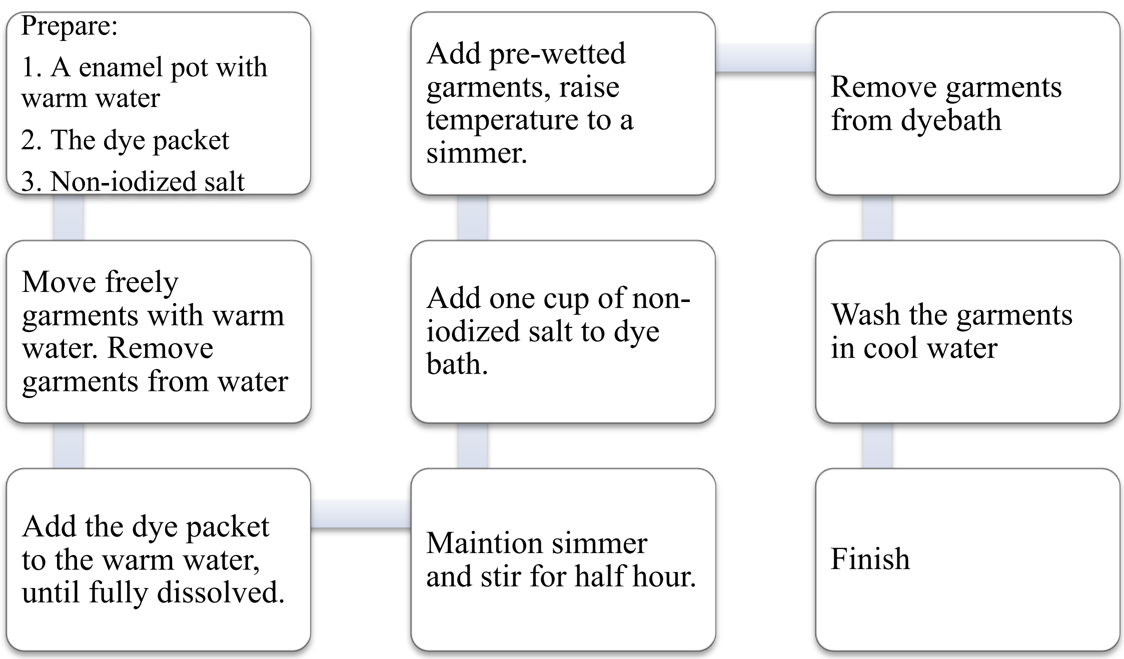


Figure 4 The dying instructions (idye, 2018).

Overall, this study developed six multi-layered cultural garments. Garments were out on the size 8 misses dress form. To prepare for the appearance and fit evaluation survey, the researcher documented the garment photographically (digital camera) took the garment from front, side, and back views of physical garments.

3.7 Virtual multi-layered garment construction

The simulation process for virtual multi-layered garment construction includes: customizing an EFI Optitex Fabric Library, developing 2D and 3D patterns via EFI Optitex pattern drafting software, and creating virtual garments. The selected Qipao and Hanfu patterns were digitized into the software as shown in Figure 5. Stitches and seamlines were defined on the 2D pattern pieces. Virtual garment was stitched. The researcher draped and simulated garments, documenting simulated virtual garment visually in a variety of orientations. To record the virtual garment construction processes, the researcher took screenshots during this study

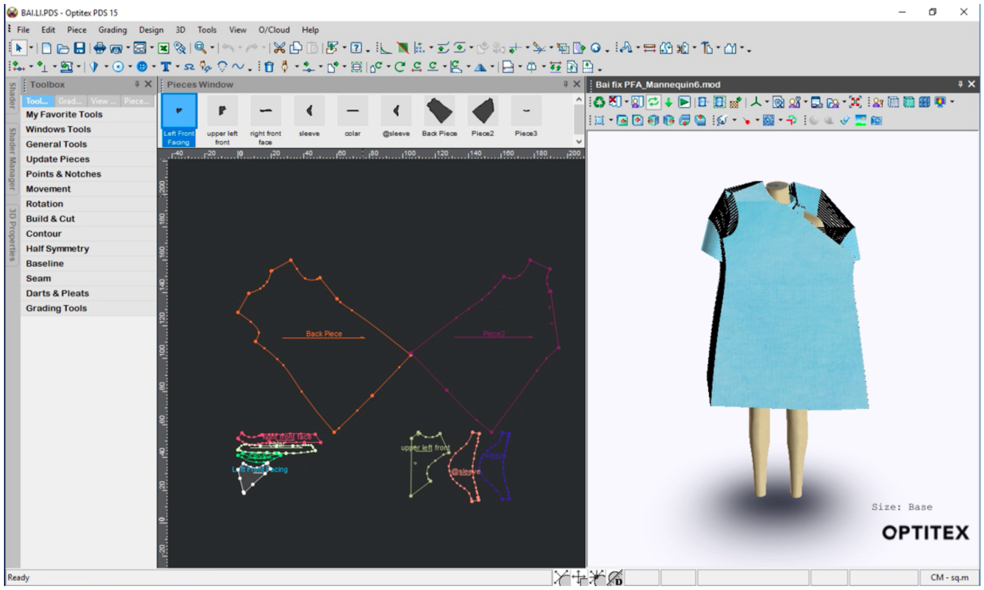


Figure 5 EFI Optitex garment simulation system.

The Fabric Editor developed by EFI Optitex can import and convert KES-F data into Optitex fabric parameters, as shown in Figure 6. With the Fabric Editor, the researcher converted the fabric properties measured by KES-F into the EFI Optitex system. Fabric images shot by the camera with well-defined appearance and texture characteristics were input to the EFI Optitex Fabric Library. Captured fabric images were used to construct the surface image (texture map) of the multi-layered cultural garments. To prepare for the appearance and fit evaluation survey, the researcher made screenshots from the front, side, and back views.

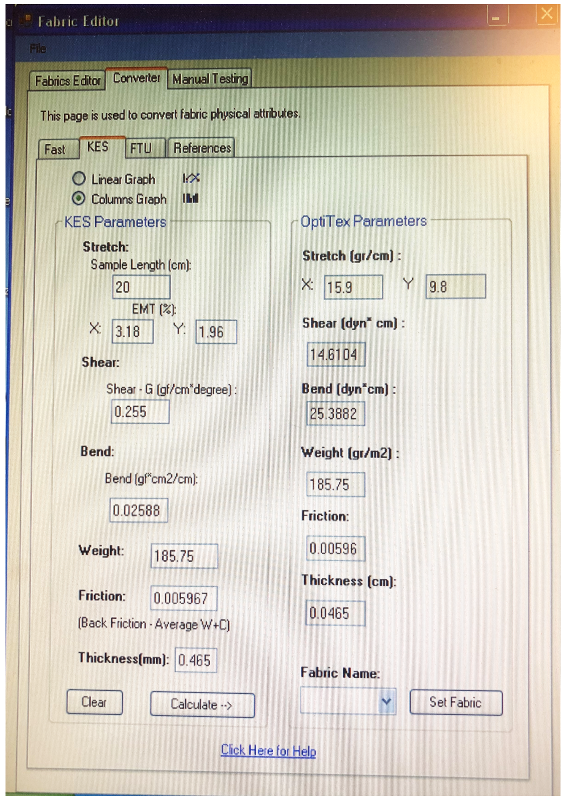


Figure 6 The Fabric Editor developed by EFI Optitex.

3.8 Survey

In order to compare virtual and physical garments, the researcher conducted an online survey sent to students in the fashion department at the University of Delaware. The survey protocol was approved by University of Delaware Institutional Review Board (IRB) (HUMANS). The researcher contacted four professors who teach large classes (more than 30 students). With the professors' assistance, the researcher sent the online survey link to the students while they were in class. The survey, as part of the coursework, was expected to take 15 minutes of the class time. The garments' evaluation questionnaire asked participants about the appearance and fit of critical areas and overall appearance and fit.

The study was conducted using a quantitative method. The researcher developed a survey to explore the possibility that participants could evaluate the similarity between virtual and physical garments. Specifically, the participant needed to evaluate the multi-layered cultural garments from the front, back, and side images as shown above (Figure 7):

Figure 7 The example of the front, back, and side images.

The survey included two sections. In the first section, the participants were asked to compare the overall physical garments (based on the images of the dress form in garments) to the overall virtual garments (based on the screenshots 3D virtual image). The participants can evaluate the similarity on the 7-point Likert-type scales, which range from 1 (poor similarity) to 7 (excellent similarity), as shown in Figure 8.

	1	2	3	4	5	6	7
Appearance	○	○	○	○	○	○	○
Fit	○	○	○	○	○	○	○

Figure 8 The screenshot of questionnaire (1).

After the participants completed the first section, the researcher asked them to evaluate the similarity of 2 to 3 critical areas like sleeve, xiejin and collar using the 7-point Likert-type scales, as shown in Figure 9.

	Appearance							Fit						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Collar	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Xiejin	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Figure 9 The screenshot of questionnaire (2)

Chapter 4

RESULTS AND DISCUSSION

This chapter includes the results of this research, detailing similarities and differences between virtual and physical prototypes of multi-layered cultural garments. The fabric mechanical property report, physical apparel product prototypes, virtual apparel prototypes, and quantitative analysis report are presented.

4.1 Research Question

H1: Fabric type significantly affects the appearance similarity in multi-layered cultural garments

H2: Design silhouette significantly affects the appearance similarity in multi-layered cultural garments

H3: Fabric type significantly affects the fit similarity in multi-layered cultural garments

H4: Design type significantly affects the fit similarity in multi-layered cultural garments

H5: Number of fabric layers does not significantly affect the appearance similarity between virtual and physical garments.

H6: Number of fabric layers does not significantly affect the fit similarity between virtual and physical garments.

4.2 Fabric Selection

4.2.1 Fabric properties testing

The physical garments prototypes were constructed out of selected materials including cotton, hemp, and silk. The unit and meaning for the mechanical properties measured by KES-F index, which was used in this study, are shown in Table 2. The fabric properties were measured in interval levels. These properties were measured three times the mean values, and standard deviation were calculated as shown in Table 2, and the results from fabric testing proprieties indicated that the objective measuring results for cotton fabric are shown in Table 3.

Table 2 The 4 KES-F indices tested in this study (Kawabata, 1980).

KES-F index	Unit	Meaning of index
EMT (warp)	%	Extension at 500 gf/cm on the warp direction
EMT (weft)	%	Extension at 500 gf/cm on the weft direction
lgB (warp)	cN*cm/cm	Bending rigidity on the warp direction
lgB (weft)	cN*cm/cm	Bending rigidity on the weft direction
lgG	cN/(cm*deg)	Shear rigidity
MIU	-	Surface friction coefficient

Table 3 Objective Measuring Results Tested by KES-F for Each Fabric (test for 3 time).

Code	Tensile resistance EMT (%)		Bending resistance B(cN)		Shearing resistance G (cN/(cm*deg))	Friction MIU
	Warp	Weft	Warp	Weft		
Cotton	0.95 (0.00)	3.53 (0.26)	0.10 (0.02)	0.05 (0.00)	3.15 (0.12)	0.13 (0.00)
Hemp	1.01 (0.05)	2.33 (0.16)	-0.25 (0.29)	0.35 (0.05)	0.68 (0.30)	0.10 (0.00)
Silk	1.96 (0.07)	3.18 (0.16)	0.05 (0.00)	0.03 (0.00)	0.26 (0.01)	0.12 (0.00)

M: means, S.D.: standard deviation in parenthesis

4.2.2 Fabric properties conversion

EFI Optitex uses weight, stretch, shear, friction, bending, and thickness for garment simulation. In this study, the fabric properties were tested by the KES-F system. However, the standard for KES-F parameters and Optitex parameters are different, so a data conversion process was necessary to enter the data into the simulation software. The meaning of the KES-F index and EFI Optitex index are listed in Table 4. The Optitex index can be derived from KES-F parameters, using the fabric editor of EFI Optitex PDS 10 (Sayem, 2016). However, the fabric conversion tool is not available in the newest version of EFI Optitex. All KES-F data were converted into the EFI Optitex, as presented in Table 5.

Table 4 The meaning of the KES-F and EFI Optitex properties (EFI Optitex, 2018).

KES-F Index	Means	EFI Optitex Index	Means	Affection
EMT	Extension at 500 gf/cm on the warp and weft direction	Stretch	The resistance of the cloth to stretching forces on the warp and weft direction.	Elasticity of the fabric
G	Shear rigidity	Shear	The resistance of the cloth to shearing forces.	The diagonal direction of the cloth
MIU	Surface friction coefficient	Friction	The resistance of the cloth to its motion on the body's surface	The way the cloth slides on the body
B	Bending rigidity on the warp and weft direction	Bending	The resistance of the cloth to bending forces affects the rigidity of the fabric	The rigidity of the fabric

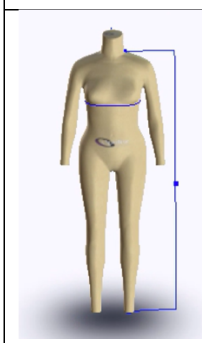
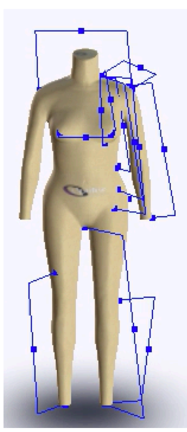
Table 5 Fabric properties conversion result.

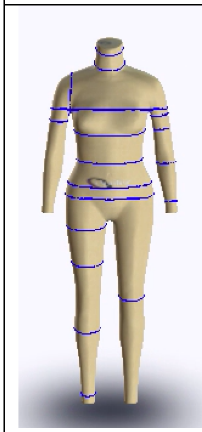
KES-F data	Fabric type			Converted data for fabric library	Fabric type		
Parameters (Unit)	Cotton	Hemp	Silk	Parameters (Unit)	Cotton	Hemp	Silk
EMT (%) at warp	0.95	1.01	1.96	Stretch (gr/cm) at warp	4.75	5.033	9.8
EMT (%) at weft	3.53	2.33	3.18	Stretch (gr/cm) at weft	17.625	11.633	15.9
Bending resistance B (cN) at warp	0.10	-0.25	0.05	Bending (dyn*cm) at warp	96.825	-242.11	53.563
Bending resistance B (cN) at weft	0.052	0.35	0.03	Bending (dyn*cm) at weft	51.453	340.145	25.388
Shearing resistance G (cN/(cm*deg))	3.15	0.68	0.26	Shear (dyn)	180.481	39.152	14.610
Friction MIU	0.13	0.10	0.12	Friction	0.132	0.1	0.118
Thickness (mm)	0.296	0.465	0.183	Thickness (mm)	0.296	0.465	0.183
Weight (g/m^2)	121.583	185.833	77.667	Weight (g/m^2)	121.583	185.833	77.667

4.3 Virtual avatar customization

A virtual dress form model provided by the EFI Optitex mannequin library was selected to reproduce the virtual avatar of American standard size 8 misses. In the EFI Optitex program, there are four morphing categories, including basics, lengths, circumferences, and pose, under the model properties. Some criteria can input numerical values, others offer sliding bars. Specifically, some measurements are interrelated, so when one datum is changed, the other automatically changes with it, according to the system software default settings (Sayem, 2016). For example, the biceps and upper biceps are interrelated (Sayem, 2016). This means that the data entered in the software is not always synonymous with the data that was measured by the researcher. After measuring the physical dress form three times, the researcher gained the measurements as in Table 6. The customized virtual dress form is shown in Figure 10.

Table 6 Effective dress form (mannequin) measurement.

	Morphs	SL		Effective dress form measurement in Optitex
 	Basics	1	Size (underbust)	79.92
		2	Height	142
		3	Cervical Height	145
	Lengths	4	Shoulder Slope	5.42
		5	Cross Shoulders	40.82
		6	Bust Height	25.77
		7	Underbust height	28.23
		8	Outseam	37.66
		9	Inseam	80.05
		10	Hip Height	53.01
		11	High Hip Height	46.75
		12	Knee Height	47.18
		13	Low Thigh Height	61.97
		14	Calf Height	33.03
		15	Armscye Depth	19.61
		16	Waist to Hip	20.05
		17	Bust Point to Bust Point	21.1
		18	Arm Length	54.73
	Circum ference	19	Underbust	80
		20	Waist	71.11
		21	Hips	96
		22	Bust	26.53
		23	Overbust	109.16
		24	High hips	92.29
		25	Thigh	54.07
		26	Knee	34.18
		27	Low Thigh	42.76
		28	Calf	33.82
		29	Ankle	19.87
		30	Armscye	46.27
		31	Biceps	25.97
		32	Upper Biceps	27

	Morphs	SL		Effective dress form measurement in Optitex
		33	Elbow	24.49
		34	Wrist	16.38
		35	Base Neck	38.04
		36	Neck	32.36

Front view	Side view	Back view

Figure 10 The customized virtual dress form

4.4 Physical multi-layered garment construction

Classical-style Qipao and Hanfu were selected as physical garment silhouettes. Physical Qipao and Hanfu garments were constructed for size 8 misses, using full-scale printouts of the pattern from the patternmaking book (New Look, 2018) (Qipao) and from the digital pattern (Hanfu). The images of physical garments were documented on the same size 8 misses dress form. In this study, the Qipao was a short-length style, with a low collar, short sleeves, Xiejin, and no split. The collar has two layers, the Xiejin part has four layers, and the rest of the Qipao has one layer, as in Figure 11. The Hanfu has two layers: an inner dress and an overcoat. In addition, it has two design elements: collar and sleeve. The physical prototypes of the Qipao and Hanfu, which were produced from three fabrics, are represented in Figure 11 and Figure 12.

Cotton		
Front	Side	Back
		
Hemp		
		
Silk		
		

Figure 11 The physical prototypes of the Qipao.

Cotton		
Front	Side	Back
		
Hemp		
		
Silk		
		

Figure 12 The physical prototypes of the Hanfu.

4.5 Virtual multi-layered garment construction

The 2D patterns were either created or digitized into the EFI Optitex, as shown in Figure 12. The Hanfu pattern was customized in the software by the researcher, and the Qipao was digitized from a paper pattern found in a book (New Look, 2018).

Within the 3D window, patterns were simulated on the virtual dress form. As presented in Figure 13 and Figure 14, the researcher first defined the stitches and seamlines on the 2D pattern.

To create virtual multi-layered garments successfully, the researcher arranged the pieces in layers under the 3D properties dialog (Optitex, 2018). Layer 1 is the lowest and closest to the body (Optitex, 2018). In the process, the effect of penetration appears on the multi-layered garments. Following the suggestions of the EFI Optitex team, the researcher solved the penetration problem by modifying the resolution. The 3D garment is represented by a mesh made of triangles. Specifically, smaller triangle (high resolution) means more accuracy in representing the virtual garments, such as complex curved lines, folds, and wrinkle (Optitex Term, 2018). After setting a higher resolution, the penetration problem was solved. On the EFI Optitex platform, the virtual multi-layered cultural garments were constructed, which are presented in Figure 15 and Figure 16.

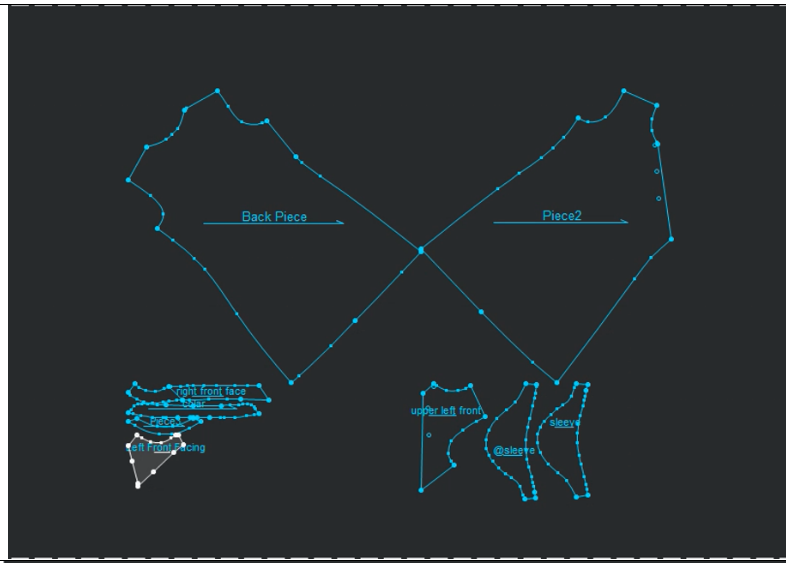
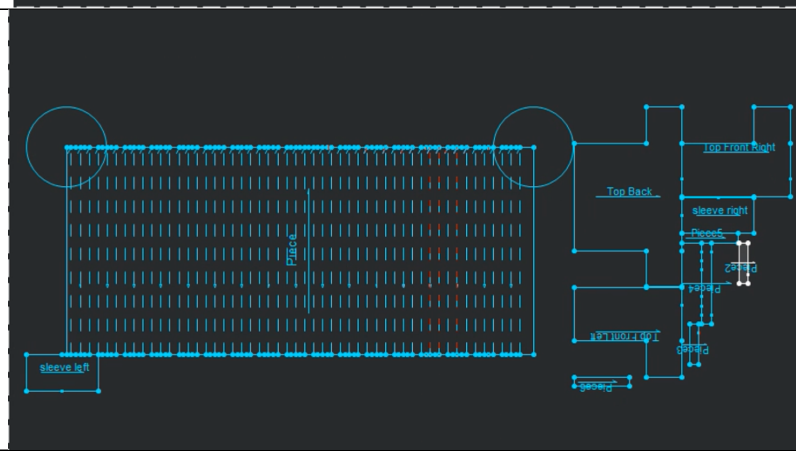
Qipao	
Hanfu	

Figure 13 The virtual patterns of Qipao and Hanfu.

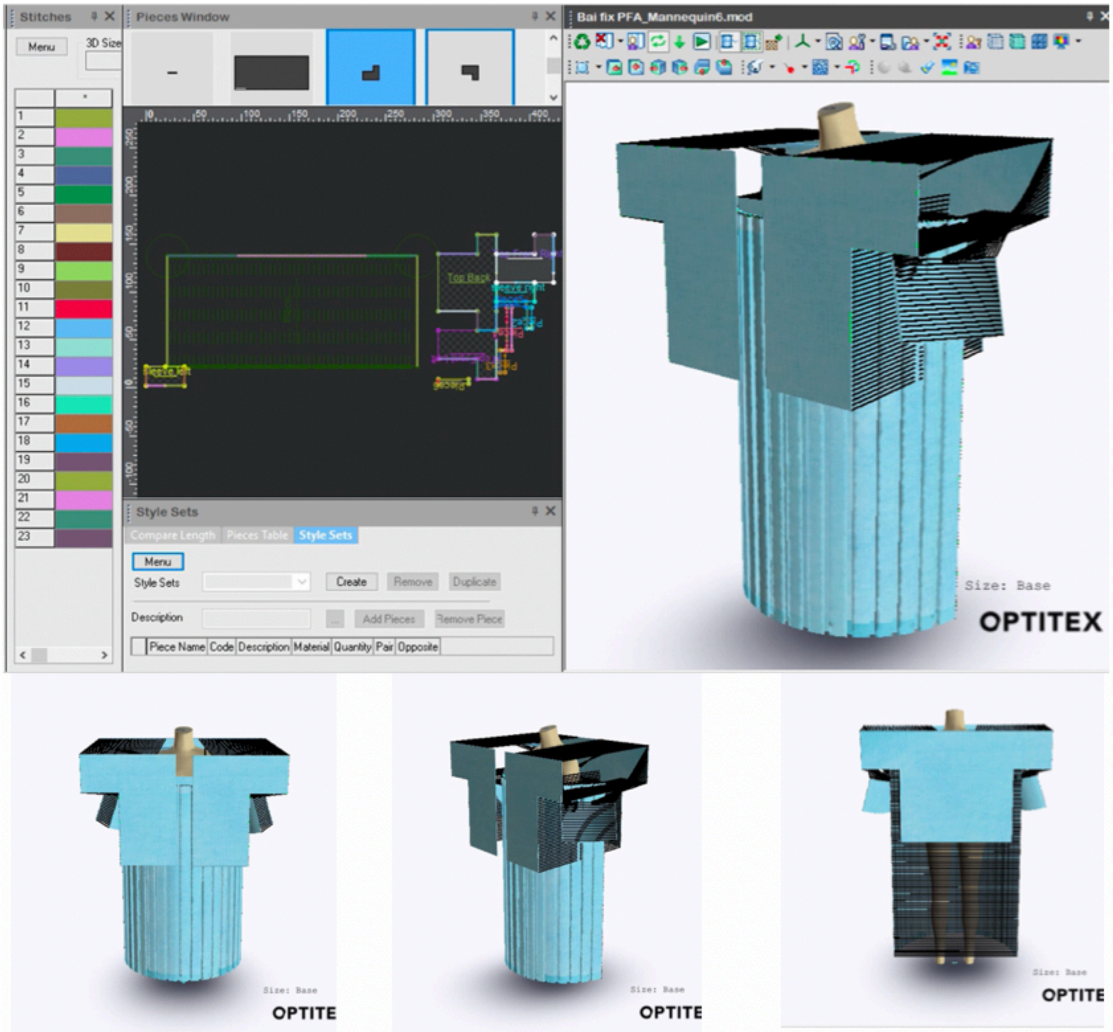


Figure 14 The definitions of stitches and seamlines.

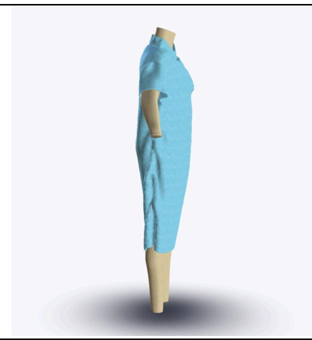
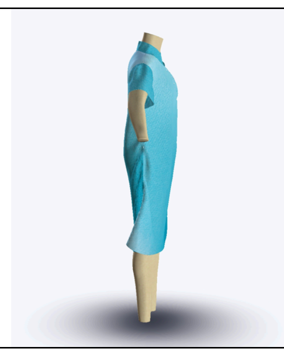
Cotton		
Front	Side	Back
		
Hemp		
		
Silk		
		

Figure 15 The virtual prototypes of the Qipao

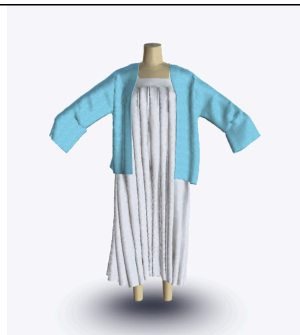
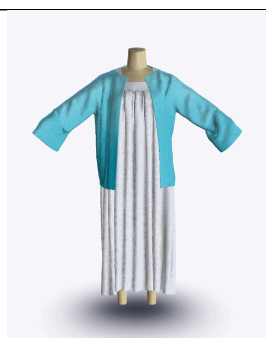
Cotton		
Front	Side	Back
		
Hemp		
		
Silk		
		

Figure 16 The virtual prototypes of the Hanfu.

4.6 Quantitative analysis

Ninety participants from the Fashion and Apparel Studies Department and 8 students from other departments at the University of Delaware subjectively compared the physical and virtual multi-layered cultural garments through an online survey. The students in the fashion department had a good knowledge of patternmaking and draping. Institutional Review Board (IRB) was acquired by University of Delaware IRB (HUMANS) on IRBNet before progressing with the study. Most of the participants were undergraduate students (93.9%). The undergraduate participants include 18.9% freshman (n=17), 43.3% sophomore (n=39) and 38.9% junior (n=35).

The responses for these independent variables were coded on 7-point scales ranging from 1 to 7, with 1 being extremely poor similarity and 7 being excellent similarity. The variables of measurement are ordinal; however, in the fashion field, it is always treated as interval. The researcher designed a between-subjects 3×2 factorial design, investigating the effect of fabric type (cotton, hemp, silk) and design (tight fit and loose fit) on the dependent variables. For fabric type, cotton was coded as 1, hemp as 2, and silk as 3; and for design, tight fit was coded as 1 and loose fit as 2.

The dependent variables for this study include: the overall appearance similarity between virtual and physical garments, the appearance similarity of critical areas between virtual and physical garments, the overall fit similarity between virtual and physical garments, and the fit similarity of critical areas between virtual and physical garments. The mean and standard deviation are shown in the following tables, but for the analysis purposes of this study only the relationship between the variables are described.

The researcher developed two different types of multi-layered cultural garments in three different fabrics, constructed physically as well as simulated via EFI Optitex 3D technology. According to Figure 16., the overall fit and appearance of the virtual garments was relatively acceptable. This study provided empirical support that multi-layered garments can be developed in 3D simulation software.

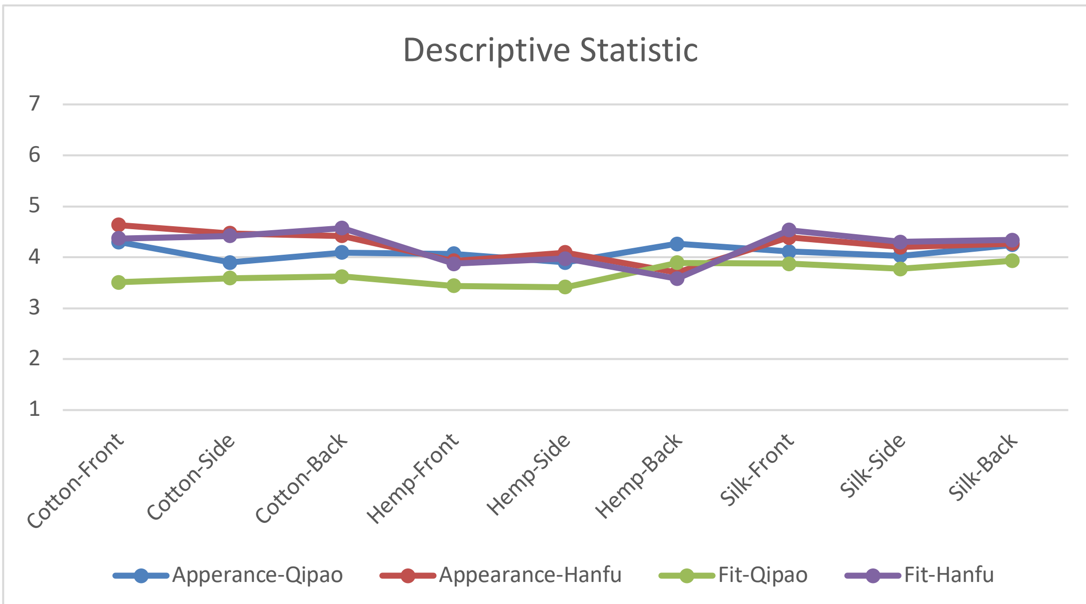


Figure 17 Descriptive Statistic of physical and virtual garments similarity.

4.6.1 Appearance similarity quantitative analysis

The mean and standard deviations data of appearance similarity quantitative analysis are presented in Tables 7 and 8. The researcher analyzed appearance similarity and fit similarity individually. For testing H1 and H2, two-way ANOVA tests were conducted to examine whether the two independent variables, fabric and garment design, significantly affected the appearance similarity in multi-layered cultural garments. The p-values of these two-way ANOVA test results are in Table 9.

Table 7 The appearance similarity for descriptive statistic of front, side, and back views.

Fabric	View	Design	N	M	S.D.	Design	N	M	S.D.
Cotton	Front	Qipao	85	4.30	1.30	Hanfu	88	4.63	1.50
	Side		86	3.90	1.30		88	4.47	1.50
	Back		87	4.09	1.50		90	4.42	1.40
Hemp	Front		87	4.07	1.40		89	3.93	1.50
	Side		87	3.90	1.50		89	4.09	1.50
	Back		86	4.26	1.20		89	3.70	1.40
Silk	Front		88	4.11	1.40		89	4.39	1.60
	Side		88	4.03	1.40		89	4.20	1.50
	Back		88	4.24	1.50		89	4.27	1.50

M: mean, SD: standard deviation

Table 8 The appearance similarity for descriptive statistic of different design points

Fabric	View	Design Point	Design	N	M	S.D.	Design	N	M	S.D.
Cotton	Front	Collar	Qipao	93	4.62	1.40	Hanfu	93	4.53	1.60
		Sleeve		93	4.30	1.30		93	4.44	1.50
		Xiejin		93	4.48	1.60		/	/	/
	Side	Collar		93	4.41	1.50		91	4.34	1.60
		Sleeve		93	4.17	1.50		91	4.29	1.80
	Back	Collar		93	4.68	1.60		93	5.24	1.40
		Sleeve		93	4.35	1.50		93	4.63	1.50
Hemp	Front	Collar		93	4.14	1.60		91	4.52	1.50
		Sleeve		93	4.42	1.40		90	4.17	1.60
		Xiejin		92	4.34	1.50		/	/	/
	Side	Collar		93	4.29	1.60		93	4.18	1.50
		Sleeve		93	4.67	1.46		93	3.94	1.60
	Back	Collar		92	4.37	1.55		93	3.69	1.80
		Sleeve		93	4.28	1.52		93	3.73	1.70
Silk	Front	Collar		92	4.17	1.70		89	3.96	1.60
		Sleeve		92	4.59	1.60		89	4.34	1.40
		Xiejin		91	4.60	1.60		/	/	/
	Side	Collar		92	4.63	1.60		93	4.05	1.60
		Sleeve		92	4.66	1.60		93	4.03	1.60
	Back	Collar		93	4.61	1.60		93	4.70	1.50
		Sleeve		92	4.85	1.50		93	4.49	1.50

M: mean, SD: standard deviation

Table 9 Two-way ANOVA results (p-values) to test the effects of fabric type and design on overall appearance similarities in front, back and side

View	Corrected Model	Fabric (Cotton, hemp, silk)	Design (loose fit, tight fit)	Fabric* Design	LSD post hoc results on fabrics
Front	0.021*	0.010*	0.234	0.273	(C=S)>(S=H)
Side	0.089	0.470	0.014*	0.350	Hanfu>Qipao
Back	0.000*	0.018*	0.694	0.001*	Qipao: p>.05 (H=S=C) Hanfu: p<.05 (C=S)>H

*. The mean difference is significant at the 0.05 level.

For the overall appearance similarity in the front view, there was no significant interaction between the two independent variables, fabrics and design (p = .273). There existed a significant effect of fabric type (p = .01), but no significant effect of design (p = .234). The result showed that cotton fabric's mean front similarity was the highest and hemp fabric's mean front similarity was the lowest. A post hoc Least Significant Difference (LSD) test showed that the fabric type can be classified into two groups from high to low: cotton and silk (no significant difference), silk and hemp (no significant difference).

For the overall appearance similarity in the side view, there was no significant interaction between the two independent variables (p = .35). There existed no significant effect of fabric type (p = .47), but a significant effect of design (p = .014). The results showed that the Hanfu's mean side similarity was significantly higher than.

For the overall appearance similarity in the back view, there was a significant interaction between the two independent variables (p = .001). There existed a significant effect of fabric type (p = .018), but no significant effect of design (p = .694). As clarified in Table 9, which presents the adjusted mean scores across the six cells. Because the interaction is significant, the researcher separated the two design conditions and conducted two one-way ANOVA tests on fabric types. The researcher found the significant effect of fabric for both the Qipao, $p > .05$, and the Hanfu, $p < .05$. For the Hanfu, the results presented that cotton fabric's mean back similarity was the highest and hemp fabric's mean back similarity was the lowest. A post hoc LSD test showed that the fabric type can be classified into two groups from high to low: cotton and silk (no significant difference), and hemp.

To test the effect of independent variables, fabric type and design, on the appearance similarity of different design points, i.e, collar, sleeve, and xiejin (for Qipao only), the researcher conducted several two-way ANOVA tests for front, back and side. However, most of the ANOVA tests have significant interaction between fabric type and design. Also, the design of Qipao and Hanfu's collars and sleeves are different. Therefore, the researcher separated Qipao and Hanfu data and conducted one-way ANOVA tests to investigate the effect of fabric type on the appearance similarity on different design points. The p-value of one-way ANOVA tests are in Table 10.

Table 10 One-way ANOVA Correlations between independent variables and appearance similarities

View	Design Point	Fabric (Cotton, hemp, silk)	Design	LSD post hoc results on fabrics
Front	Collar	0.058	Qipao	/
		.023*	Hanfu	(C=H)>S
	Sleeve	.399	Qipao	/
		.469	Hanfu	/
	Xiejin	.508	Qipao	/
Side	Collar	.332	Qipao	/
		.473	Hanfu	/
	Sleeve	.036*	Qipao	(H=S)>C
		.329	Hanfu	/
Back	Collar	.337	Qipao	/
		.000*	Hanfu	C>S>H
	Sleeve	.022 *	Qipao	S>(C=H)
		.000*	Hanfu	(C=S)>H

*. The mean difference is significant at the 0.05 level.

For the appearance in the front view, there was no significant effect of fabric type on the Qipao collar, p=.058, but there existed a significant effect of fabric type on the Hanfu collar, p= .023; the results showed that the cotton fabric's mean for the Hanfu front-view similarity was the highest and the silk fabric's mean was the lowest. A post hoc LSD test showed that the fabric type can be classified into two groups from high to low: cotton and hemp (no significant difference), and silk. For the appearance in the front view, there were no significant effect of fabric type both on the Qipao sleeve, p = .339, the Hanfu sleeve, p=.469, and the Qipao Xiejin, p= .508.

For the appearance in the side view, there were no significant effect of fabric type both on the Qipao collar, p = .332, and the Hanfu collar, p= .473. There was no significant effect of fabric type on the Hanfu sleeve, p=.329, and there existed significant effect of fabric type on the Qipao sleeve, p= .036; the results showed that the hemp fabric's mean for the Qipao side-view similarity was the highest and the cotton fabric's mean was the lowest. A post hoc LSD test showed that the fabric type can be classified into two groups from high to low: hemp and silk (no significant difference), and cotton.

For the appearance in the back view, there was no significant effect of fabric type on the Qipao collar, $p=.337$, but there existed a significant effect of fabric type on the Hanfu collar, $p=.000$; the results showed that the cotton fabric's mean for the Hanfu back-view similarity was the highest and the hemp fabric's mean was the lowest. Also, there was a significant effect of fabric type on both the Qipao sleeve, $p = .022$, and the Hanfu sleeve, $p= .000$. For the Qipao sleeve, the result showed that the cotton fabric's mean for the back-view similarity was the highest and the hemp fabric's mean was the lowest. A post hoc LSD test showed that the fabric type can be classified into two groups from high to low: silk, and cotton and hemp (no significant difference). For the Hanfu sleeve, the results showed that the cotton fabric's mean for the back-view similarity was the highest and the hemp fabric's mean was the lowest. A post hoc LSD test showed that the fabric type can be classified into two groups from high to low: cotton and silk (no significant difference), and hemp.

As the results show in Table 9, the front and back view's p-values supported H1, and the side view's p-value did not support H1. Fabric type significantly affected the appearance similarity of the front and back view of multi-layered cultural garments. However, the similarity of the back view of garments has an interaction between fabric type and design, as shown in Figure 18. The researcher conducted two one-way ANOVA and found that fabric type significantly affected the Hanfu appearance similarity of the back view. The side view of virtual appearance representations was inaccurate, however, the data in Table 10 cannot offer a reasonable explanation. When the researcher went back to compare the physical and virtual garments pictures, the virtual garments were not accurate in the waist area. Therefore, although the side view's p-value did not support H1, the analysis results in general support H1.

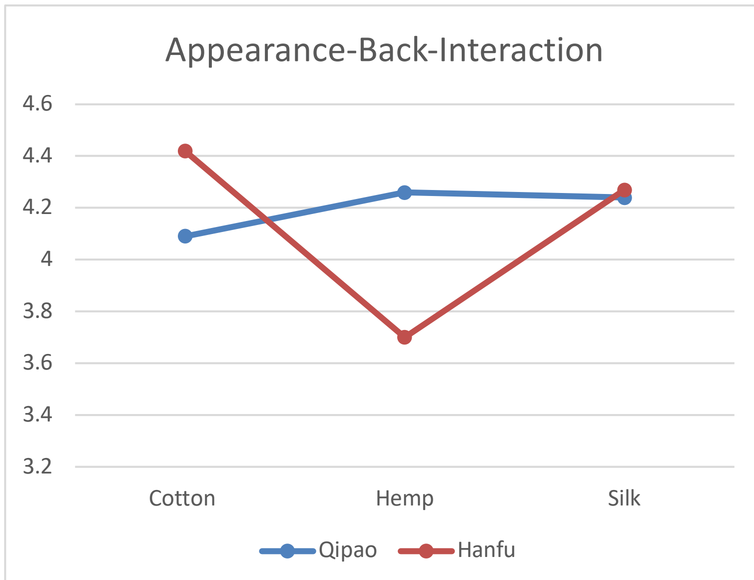


Figure 18 The interaction of the appearance similarity of back view of garments.

Further ANOVA analysis on selected points of measure found that the collar's front appearance, the Qipao sleeve's side appearance, the sleeve's back appearance, and the Hanfu collar's back appearance similarities' p-values were affected by the fabric type. Therefore, the fabric type significantly affected the front collar similarity, indicating that the fabric type significantly affected the front view. Additionally, the back view of sleeve similarity, contributes to the effect due to fabric type in the back view. However, the LSD post hoc results were different between the back views of the sleeve and the entire Qipao.

From two-way ANOVA, the side view's p-values supported H3, and the front and back's p-value did not support H2. Design significantly affected the appearance similarity of the side view in multi-layered cultural garments. The front and back view of virtual appearance representations were inaccurate based on the statistic result, however, the data in Table 10 cannot offer a reasonable explanation. This might have been attributed to the virtual simulation software's inability to represent the fabric wrinkles accurately. Overall, this research did not support H2. The result was different from previous studies by other researchers (Tao & Bruniaux, 2012; Kim & LaBat, 2013; Baytar & Ashdown, 2015), the reason might be the sample used here was multi-layered cultural garments, the structure for the cultural garments may be different.

Previous studies have support this result that fabric type affects the quality of garment appearance (Ancutiene et al., 2014 Rudolf et al., 2016). They found that materials' mechanical properties would influence the quality of virtual garment appearance. However, Buyukaslan et al. (2015) found that fabric type did not affect the quality of the garment appearance. They found that the virtual simulation system did not represent the relationship between different fabrics and body shape (Buyukaslan et al., 2015).

4.6.2 Fit similarity quantitative analysis

The mean and standard deviation data of fit similarity quantitative analysis are presented in Tables 11 and 12. The researcher analyzed appearance similarity and fit similarity individually. For testing H3 and H4, two-way ANOVA tests were conducted to examine whether the two independent variables, fabric and garment design, significantly affected the appearance similarity in multi-layered cultural garments. The p-values of these two-way ANOVA test results are in Table 13.

Table 11 The fit similarity for descriptive statistic of front, side, and back views.

Fabric	View	Design	N	M	S.D.	Design	N	M	S.D.
Cotton	Front	Qipao	90	3.51	1.4	Hanfu	92	4.37	1.3
	Side		90	3.59	1.3		92	4.42	1.4
	Back		90	3.62	1.4		91	4.57	1.3
Hemp	Front		91	3.44	1.3		92	3.87	1.4
	Side		92	3.41	1.3		92	3.97	1.5
	Back		91	3.89	1.2		92	3.58	1.5
Silk	Front		92	3.87	1.3		92	4.53	1.4
	Side		92	3.77	1.3		92	4.30	1.3
	Back		92	3.93	1.4		92	4.34	1.5

M: mean, SD: standard deviation

Table 12 The fit similarity for descriptive statistic of different design points.

Fabric	View	Design Point	Design	N	M	S.D.	Design	N	M	S.D.
Cotton	Front	Collar	Qipao	93	4.41	1.5	Hanfu	93	4.57	1.5
		Sleeve		93	3.99	1.4		93	4.24	1.5
		Xiejin		93	4.67	1.6		/	/	/
	Side	Collar		93	4.41	1.4		92	4.33	1.5
		Sleeve		93	3.9	1.5		92	4.09	1.6
	Back	Collar		93	4.55	1.6		93	5.15	1.4
		Sleeve		93	4.23	1.5		93	4.56	1.6
Hemp	Front	Collar		93	4.01	1.6		91	4.34	1.5
		Sleeve		93	4.40	1.5		90	3.91	1.6
		Xiejin		92	4.21	1.6		/	/	/
	Side	Collar		93	4.25	1.6		93	4.18	1.6
		Sleeve		93	4.62	1.4		93	3.81	1.5
	Back	Collar		93	4.47	1.5		93	3.78	1.7
		Sleeve		93	4.18	1.4		93	3.90	1.7
Silk	Front	Collar		92	4.10	1.6		89	3.94	1.8
		Sleeve		92	4.45	1.5		89	4.18	1.6
		Xiejin		92	4.53	1.5		/	/	/
	Side	Collar		92	4.49	1.6		93	4.09	1.6
		Sleeve		92	4.71	1.5		93	3.92	1.5
	Back	Collar		92	4.60	1.5		93	4.63	1.53
		Sleeve		93	4.71	1.6		93	4.40	1.45

M: mean, SD: standard deviation

Table 13 Two-way ANOVA results (p-values) to test the effects of fabric type and design on overall fit similarities in front, back and side

View	Corrected Model	Fabric (Cotton, hemp, silk)	Design (loose fit, tight fit)	Fabric* Design	Post hoc LSD test
Front	0.000*	0.001*	0.000*	0.313	(S=C) >H Hanfu>Qipao
Side	0.000*	0.026*	0.000*	0.494	(S=C)>H Hanfu>Qipao
Back	0.000*	0.009*	0.003*	0.000*	Qipao: p<.05 (S=C) >H Hanfu: p<.05 (S=H)>(H=C) Hanfu>Qipao

*. The mean difference is significant at the 0.05 level.

For the overall fit similarity in the front view, there was no significant interaction between the two independent variables (p = .313). There existed a significant effect of fabric type (p = .01), and design (p = .00). For design, the results showed that the Hanfu's mean front similarity was higher than the Qipao's.

For fabric type, the results showed that the silk's mean front similarity was the highest and the hemp's mean front similarity was the lowest. A post hoc LSD test showed that the fabric type can be classified into two groups from high to low: silk and cotton (no significant difference), and hemp.

For the overall fit similarity in the side view, there was no significant interaction between the two independent variables (p = .494). There existed a significant effect of fabric type (p = .026), and design (p = .00). For design, the results showed that the Hanfu's mean side fit similarity was significantly higher than Qipao's mean side similarity. For fabric, the results showed that the silk's mean side similarity was the highest and the hemp's mean front similarity was the lowest. A post hoc LSD test showed that the fabric type can be classified into two groups from high to low: cotton and silk (no significant difference), and hemp.

For the overall fit similarity in back view, there was a significant interaction between the two independent variables ($p = .00$). There existed a significant effect of fabric type ($p = .009$), and design ($p = .003$). For fabric type, the result showed that the Hanfu's mean back similarity was the highest and the Qipao's mean back similarity was the lowest. It can be seen from Table 13, which presents the adjusted mean scores across the six cells. Because the interaction is significant, the researcher separated the two design conditions and conducted two one-way ANOVA tests on fabric types. It was found significant effects of fabric types for both the Qipao ($p < .05$) and the Hanfu ($p < .05$). For Qipao, the result showed that the silk's mean back fit similarity was the highest and the hemp's mean back similarity was the lowest. A post hoc LSD test showed that the fabric type can be classified into two groups from high to low: silk and cotton (no significant difference), and hemp. For Hanfu, the result showed that the silk's mean back similarity was the highest and the cotton's mean back similarity was the lowest. A post hoc LSD test showed that the fabric type can be classified into two groups from high to low: silk and hemp (no significant difference), and hemp and cotton (no significant difference).

To test the effect of independent variables, fabric type and design on the design points' fit similarities of different design points, several one-way ANOVAs were conducted, as shown in Table 14. In this study, the researcher described and tested the effect of fabric type on the appearance similarity on different design points (collar and sleeve).

Table 14 One-way ANOVA Correlations between independent variables and fit similarities.

Dependent Variable	Design Point	Fabric (Cotton, hemp, silk)	Design	LSD post hoc results on fabrics
Front	Collar	0.667	Qipao	/
		.065	Hanfu	/
	Sleeve	.576	Qipao	/
		.501	Hanfu	/
	Xiejin	.481	Qipao	/
Side	Collar	.420	Qipao	/
		.258	Hanfu	/
	Sleeve	.082	Qipao	/
		.678	Hanfu	/
Back	Collar	.421	Qipao	/
		.000*	Hanfu	Hanfu: (C=S)>H
	Sleeve	.080	Qipao	/
		.001*	Hanfu	Hanfu: (C=S)>H

*. The mean difference is significant at the 0.05 level.

For the fit in the front view, there were no significant effect of fabric type for either the Qipao collar, $p = .667$, or Hanfu collar, $p=.065$. And there was no significant effect of fabric type both for the Qipao sleeve, $p = .576$, and Hanfu, $p= .501$. For the Qipao Xiejin, there was no significant effect of fabric type, $p= .481$. For the fit in the side view, there were no significant effect of fabric type both for the Qipao collar, $p = .420$, and Hanfu, $p=.258$. And there was no significant effect of fabric type both for the Qipao sleeve, $p = .082$, and Hanfu, $p= .678$.

For the fit in the back view, there was no significant effect of fabric type for the Qipao collar, $p= .421$. There existed a significant effect of fabric type for the Hanfu collar, $p = .000$; the result showed that the cotton fabric's mean for the Hanfu back-view similarity was the highest and the hemp fabric's mean was the lowest. A post hoc LSD test showed that the fabric type can be classified into two groups from high to low: cotton and silk (no significant difference), and hemp. There was no significant effect of fabric type for the Qipao sleeve, $p=.08$. There existed a significant effect of fabric type for Hanfu sleeve, $p= .001$; the result showed that the silk fabric's mean for the Hanfu back-view similarity was the highest and the hemp fabric's mean was the lowest. A post hoc LSD test showed that the fabric type can be classified into two groups from high to low: cotton and silk (no significant difference), and hemp.

For testing H3 and H4, two-way ANOVA and one-way ANOVA was used to examine whether fabric and design significantly affected the fit similarity in multi-layered cultural garments. The results were shown in Table 13, from the two-way ANOVA, the front, side and back view's p-values supported H3 and H4, which support the previous findings (Ancutiene & Sinkeviciute, 2011; Song & Ashdown, 2015). Fabric type and design significantly affected the appearance similarity of the front, side, and back views in multi-layered cultural garments. The simulation quality of loose fit multi-layered garment (Hanfu) is better than the tight fit multi-layered garments (Qipao). However, the back view has an interaction between fabric type and design, as shown in Figure 19. The researcher conducted two one-way ANOVA and found that fabric type significantly affected both the Hanfu and Qipao appearance similarity of the back view.

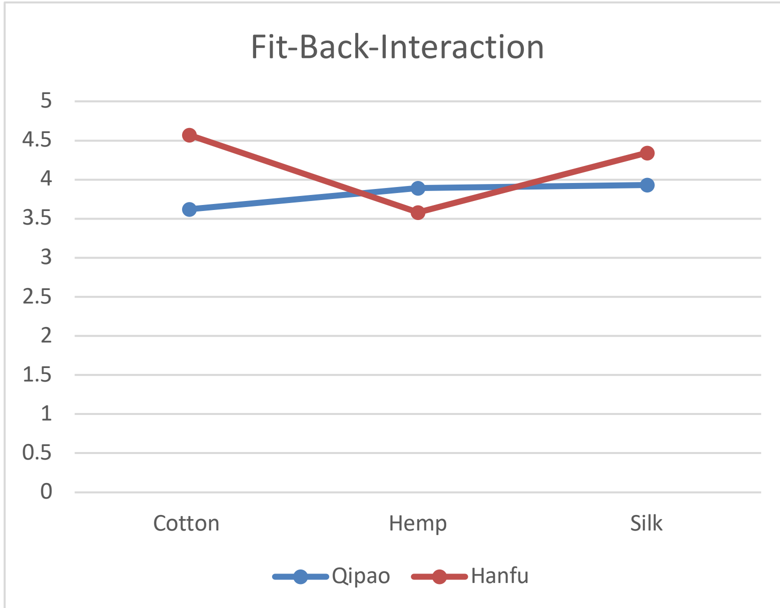


Figure 19 The interaction of the fit similarity of back view of garments

Further ANOVA analysis on the selected design points found that the sleeve's back fit and Hanfu collar's back fit similarity's p-values were affected by the fabric type. Therefore, the fabric type significantly affected the sleeve in the back view similarity, proving that the fabric type significantly affected the back view. However, the LSD post hoc results were slightly different from the back view of sleeve similarity and the back view similarity.

There are circumstances where fabric type and design significantly affected the appearance similarity of the front and side views, however, the data in Table 14 cannot offer a reasonable explanation. After comparing the physical and virtual pictures, the researcher concluded that the realistically fit presented in other areas, like waist and hip, makes the front, side, and back views were visible. In addition, dyeing and washing clothes causes shrinkage, which may have influenced the results. In conclusion, H3 and H4 were supported by this study.

Fabric type significantly affected the fit has been illustrated in the previous study (Stjepanovic, 2011). One study claimed that the laminated textile material would influence the accuracy of virtual garments (Stjepanovic, 2011). Also, previous studies have shown that design significantly affected the fit similarity (Ancutiene & Sinkeviciute, 2011; Song & Ashdown, 2015). They found that the virtual technology can be used effectively on tight-fitted garments (Ancutiene & Sinkeviciute, 2011). Also, Song and Ashdown (2015) identified that the different fit status will affected the fit similarity between virtual and physical pants.

4.6.3 Multi-layered Qipao similarity quantitative analysis

The researcher designed a between-subjects 3 × 3 factorial design to test the effect of fabric type (cotton, hemp, silk) and number of fabric layers (1, 2, and 4 layers as in Figure 20) on appearance and fit design points' similarity between virtual and physical Qipao. Two two-way ANOVAs were conducted, as shown in Table 15 and Table 16.

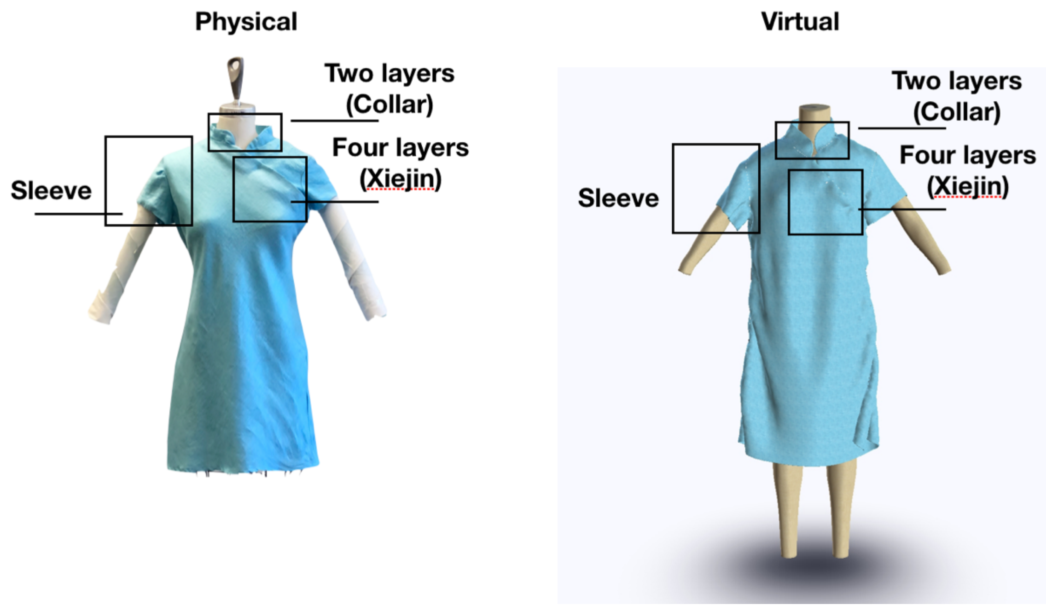


Figure 20 The number of layers of Qipao design points.

Table 15 Two-way ANOVA results (p-values) to test the effects of fabric type and numbers of layers on appearance similarities in front.

Source	Sum of Squares	df	Mean Square	F	Sig.
Fabrics	4.987	2	2.494	1.094	.335
Layers	3.994	2	1.997	.876	.417
Interaction Fabric*Layers	15.671	4	3.918	1.718	.144
Error	1876.286	823	2.280		
Total	18063.000	832			

R Squared = .013 (Adjusted R Squared = .003)

Table 16 Two-way ANOVA results (p-values) to test the effects of fabric type and numbers of layers on fit similarities in front.

Source	Sum of Squares	df	Mean Square	F	Sig.
Fabrics	1.217	2	.609	.253	.777
Layers	11.310	2	5.655	2.349	.096
Interaction Fabric*Layers	6.171	4	1.543	.641	.634
Error	1740.537	723	2.407		
Total	15782.000	732			

R Squared = .010 (Adjusted R Squared = -.001)

For the design points' appearance similarity, there was no significant interaction between two independent variables (p = .144), fabrics and number of layers. There existed no significant effect of fabric type (p = .335) and number of layers (p = .417). The hypothesis H5 is accepted, the number of layers does not significantly affect the appearance similarity between virtual and physical garments. And for the design points' fit similarity, there was no significant interaction between two independent variables (p = .634), fabrics and number of layers. There existed no significant effect of fabric type (p = .777) and number of layers (p = .096). The hypothesis H6 is accepted, the number of layers does not significantly affect the fit similarity between virtual and physical garments.

This result was supported by some single-layered virtual garments' studies, that virtual single-layered garments have been investigated effectively (Tao & Bruniaux, 2012; Kim & LaBat, 2013; Baytar & Ashdown, 2015); more studies related to multi-layered garments are needed. Specifically, Porterfield and Lamar (2017) created one multi-layered garment in their study and considered that different layers need to be unmistakably described in the virtual prototyping process. In contrast, researchers found that the virtual garments cannot be well presented in the virtual simulation software (Kim & LaBat, 2013; Buyukaslan et al., 2015). Kim and LaBat found that the abdomen and front crotch areas are different from the physical garments. Also, the hem line was inaccurate in the virtual simulation that led to the fit of garments to be not visible (Buyukaslan et al., 2015)

The researcher did not find previous the studies to investigate the relationship between number of fabric layers and similarity. This research found that multi-layers (e.g., 2 layers and 4 layers), has same appearance and fit similarity as one layer. This research finds that virtual garment can simulate effectively

Chapter 5

CONCLUSION

The purpose of this study was to expand the use of virtual technology to include multi-layered non-western cultural garments and to demonstrate comparisons of these complex garments, physically and virtually. The researcher worked to investigate the potential of virtual prototyping by customizing a virtual fabric library based on objective measurements of textile mechanical property data from cotton, silk, and hemp fabrics. The study was designed to analyze the similarity of appearance and fit between physically constructed multi-layered cultural garments and those that are virtually constructed. The results of the study formed the following conclusions:

First, this study found that multi-layered cultural garments could be relatively effectively simulated in virtual software, such as EFI Optitex. In addition, the simulation quality of a loose fit, multi-layered garment (Hanfu) is better than the tight fit multi-layered garments (Qipao). Therefore, this study suggested that the virtual simulation technology could be used for loose fit multi-layered cultural garment. Second, fabric type significantly affects the appearance and fit similarity in multi-layered cultural garments (H1 & H3). Therefore, the presented software could be used for garments with different kinds of fabrics. The quality of multi-layered virtual garments related to the materials. Third, design silhouette significantly affects the fit similarity in multilayered cultural garments (H4). Also, number of fabric layers does not significantly affect either appearance or fit similarity between virtual and physical garments. In addition, the researcher found that the results for fit similarity and appearance similarity were slightly different, specifically, the design silhouette does not affect the appearance similarity (H2). Besides, the researcher found the resolution function offer by the EFI Optitex to solve the penetration problem which is the general issue happened in the process of multi-layered garments simulation.

Based on these results it can be concluded that virtual presentation has great potential as a tool to evaluate the appearance of a garment in a relatively simple and quick way. One implication and conclusion from the study was about 3D simulation of non-western garments would be beneficial for the emerging market in China.

A limitation of this study was that the researcher only tested two cultural garment types with three different fabric types using a single garment simulation software program. Also, dyeing and washing clothes might cause shrinkage, which may have influenced the results. While the software program was from a leading company, findings from this study cannot be generalized to other 3D simulation software packages.

Future studies should consider comparing several programs using different garment and more fabric combinations for complete testing of 3D virtual garment simulation fidelity and accuracy. In addition, since the current study only tested female garments, a full range of multi-layered garment types and fabrics should be tested. The physical draping simulation will facilitate the future use of more diverse types of materials for garment production. Therefore, by using 3D virtual prototyping, companies can reduce product development time and the cost involved in multiple iterations of sample garment production.

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Appendix A

SURVEY

New: Comparing physical to virtual: appearance, fit, and drape of multi-layered cultural garments

Q1 Gender:

○ Male (1)

○ Female (2)

Q2 Major:

○ Fashion related major (1)

○ non fashion related major (2)

Q3 Academic standing:

◯ Freshman (1)

◯ Sophomore (2)

◯ Junior (3)

◯ Graduate Student (4)

◯ Online Student (5)

◯ Faculty (6)

◯ Non-student (7)

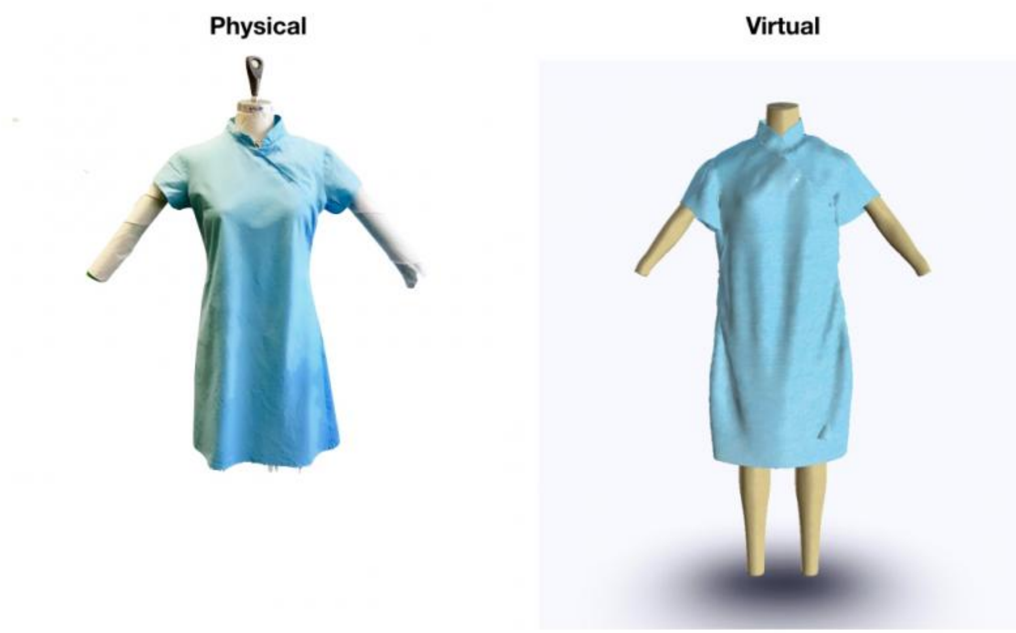
End of Block: Basic information

Start of Block: Overall Garment's Simulation- Qipao- Cotton

Qipao-- Cotton-- Overall Garment's Simulation Using the scale below, determine the similarity between the physical and virtual prototype garments. Definitions: 1. Appearance'The garment structure appearance includes many aspects such as pilling, wrinking, and puckering, and so forth'(Hu & Xin, 2005).2. Fit'Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer' (Chambers & Moulton, 1969).

3. Multi-layered garments: A way of dressing using many garments that are worn on top of each other

Q4



Qipao- Cotton- Front: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)							
Fit (2)							

Q5

Qipao- Cotton- Side: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

Q6

Physical

Virtual

Qipao- Cotton- Back: Scale of 1-7, Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

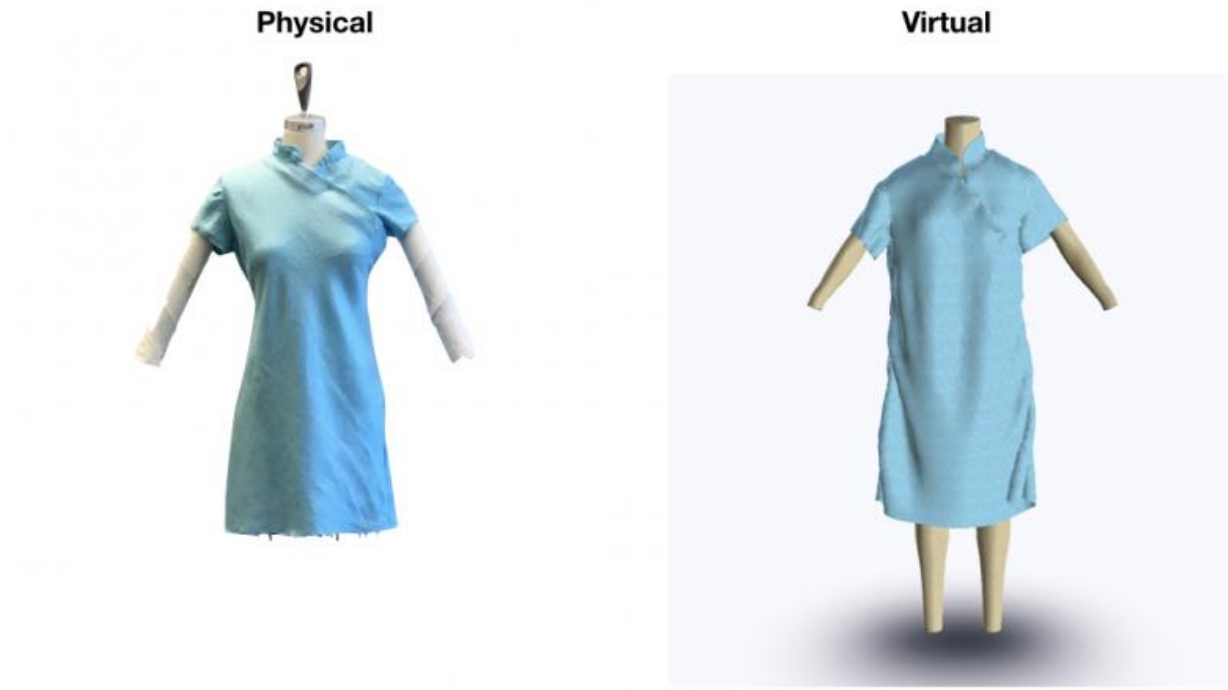
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

End of Block: Overall Garment's Simulation- Qipao- Cotton

Start of Block: Overall Garment's Simulation- Qipao- Hemp

Qipao-- Hemp-- Overall Garment's Simulation
Using the scale below, determine the similarity between the physical and virtual prototype garments.
Definitions: 1. Appearance‘The garment structure appearance includes many aspects such as pilling, wrinking, and puckering, and so forth’(Hu & Xin, 2005).2. Fit‘Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer’ (Chambers & Moulton, 1969).

Q7



Qipao- Hemp- Front: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

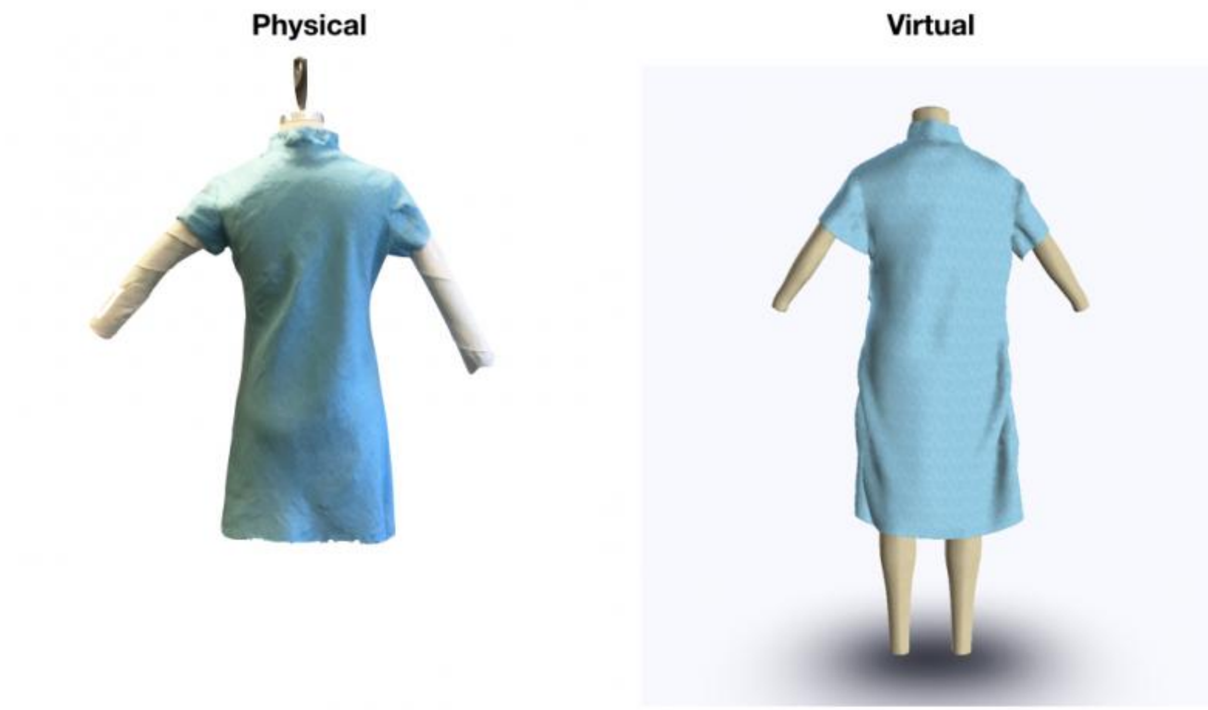
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

Q8

Qipao- Hemp- Side: Scale of 1-7, Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

Q9



Qipao- Hemp- Back: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

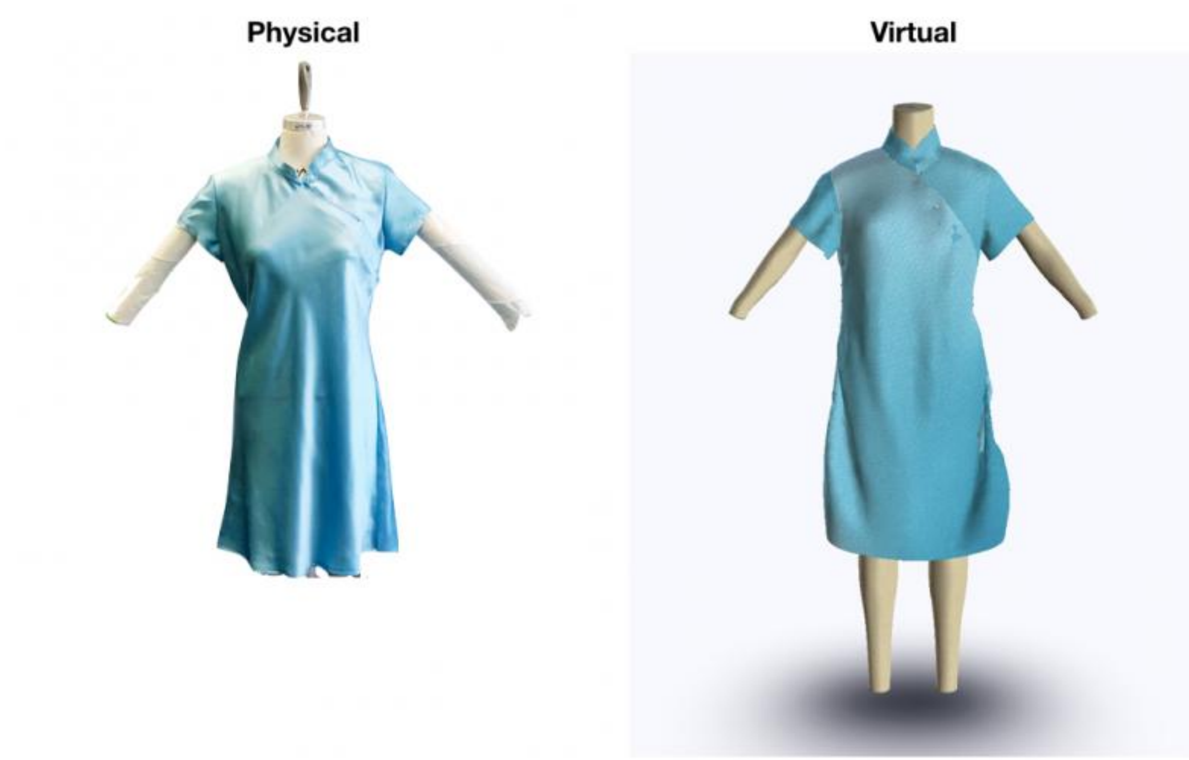
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

End of Block: Overall Garment's Simulation- Qipao- Hemp

Start of Block: Overall Garment's Simulation- Qipao- Silk

Qipao-- Silk-- Overall Garment's Simulation
Using the scale below, determine the similarity between the physical and virtual prototype garments.
Definitions: 1. Appearance'The garment structure appearance includes many aspects such as pilling, wrinking, and puckering, and so forth'(Hu & Xin, 2005).2. Fit'Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer' (Chambers & Moulton, 1969).

Q10



Qipao- Silk- Front: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

Q11

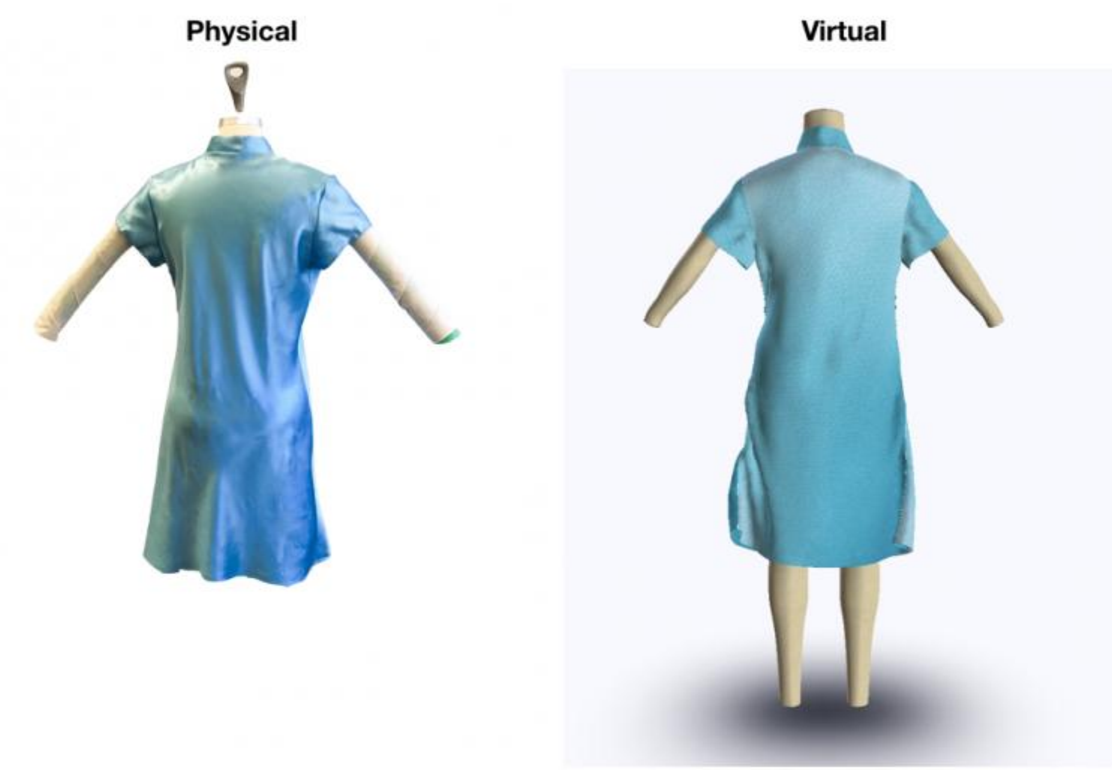
Physical

Virtual

Qipao- Silk- Side: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

Q12



Qipao- Silk- Back: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

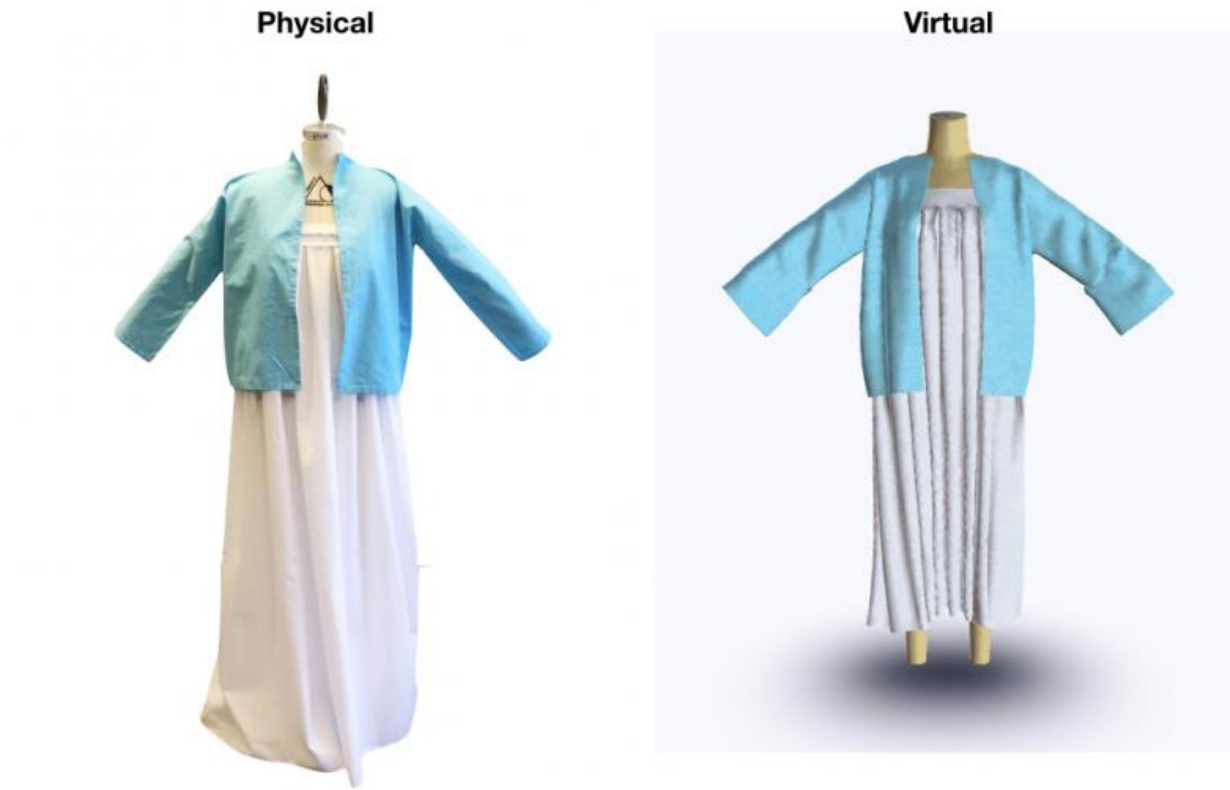
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

End of Block: Overall Garment's Simulation- Qipao- Silk

Start of Block: Overall Garment's Simulation- Hanfu- Cotton

Hanfu-- Cotton-- Overall Garment's Simulation
Using the scale below, determine the similarity between the physical and virtual prototype garments.
Definitions: 1. Appearance‘The garment structure appearance includes many aspects such as pilling, wrinking, and puckering, and so forth’(Hu & Xin, 2005).2. Fit‘Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer’ (Chambers & Moulton, 1969).

Q13



Hanfu- Cotton- Front: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

Q14

Hanfu- Cotton- Side: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

Q15

Hanfu- Cotton- Back: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

End of Block: Overall Garment's Simulation- Hanfu- Cotton

Start of Block: Overall Garment's Simulation- Hanfu- Hemp

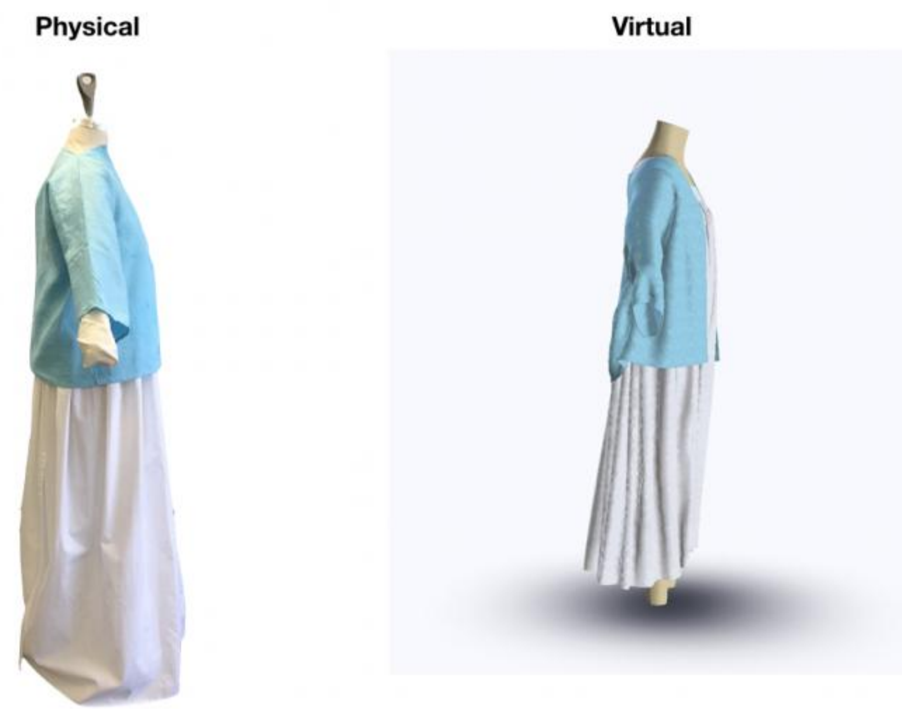
Hanfu-- Hemp-- Overall Garment's Simulation
Using the scale below, determine the similarity between the physical and virtual prototype garments.
Definitions: 1. Appearance'The garment structure appearance includes many aspects such as pilling, wrinking, and puckering, and so forth'(Hu & Xin, 2005).2. Fit'Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer' (Chambers & Moulton, 1969).

Q16

Hanfu- Hemp- Front: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

Q17



Hanfu- Hemp- Side: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7))

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	o	o	o	o	o	o	o
Fit (2)	o	o	o	o	o	o	o

Q18

Hanfu- Hemp- Back: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

End of Block: Overall Garment's Simulation- Hanfu- Hemp

Start of Block: Overall Garment's Simulation- Hanfu- Silk

Hanfu-- Silk-- Overall Garment's Simulation
Using the scale below, determine the similarity between the physical and virtual prototype garments.
Definitions: 1. Appearance‘The garment structure appearance includes many aspects such as pilling, wrinking, and puckering, and so forth’(Hu & Xin, 2005).2. Fit‘Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer’ (Chambers & Moulton, 1969).

Q19

Hanfu- Silk- Front: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

Q20

Physical

Virtual

Hanfu- Silk- Side: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

Q21

Physical | Virtual

Hanfu- Silk- Back: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Appearance (1)	○	○	○	○	○	○	○
Fit (2)	○	○	○	○	○	○	○

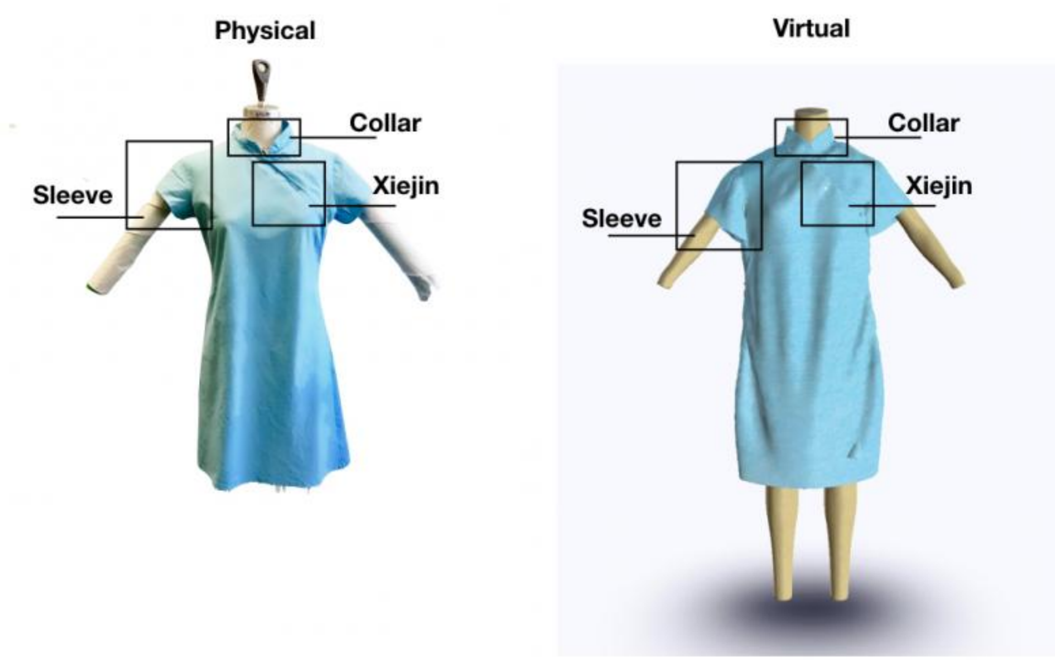
End of Block: Overall Garment's Simulation- Hanfu- Silk

Start of Block: Garment's Design Point Simulation- Qipao- Cotton

Qipao-- Cotton-- Garment's Design Point Simulation

The black boxes below feature specific points of measure and design features. Please compare the similarity of appearance and fit, using the scale provided below. Definitions: 1. Appearance'The garment structure appearance includes many aspects such as pilling, wrinking, and puckering, and so forth'(Hu & Xin, 2005).2. Fit'Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer' (Chambers & Moulton, 1969).

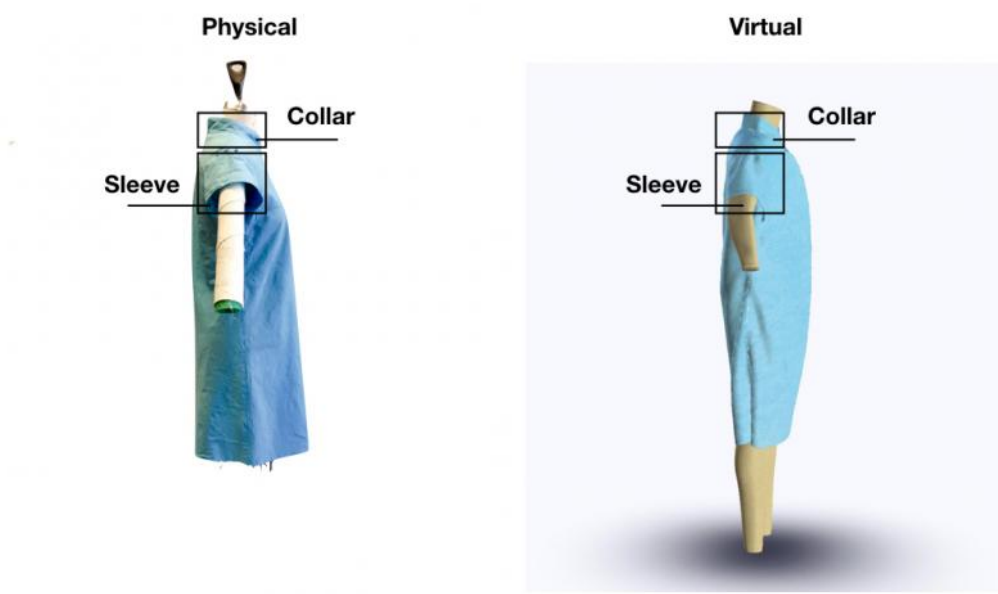
Q22



Qipao- Cotton- Front: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Xiejin (3)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

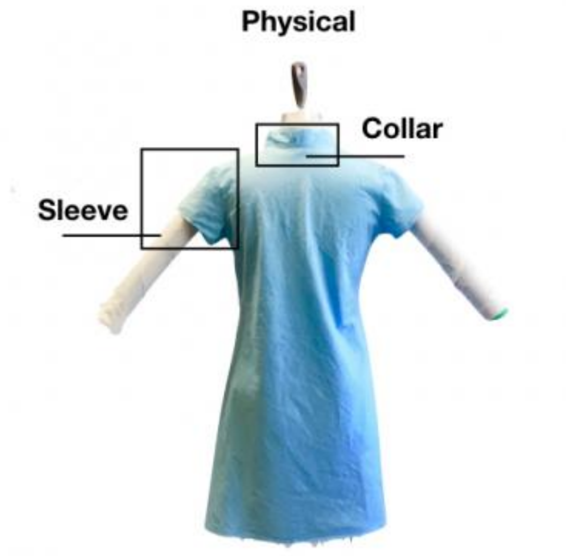
Q23

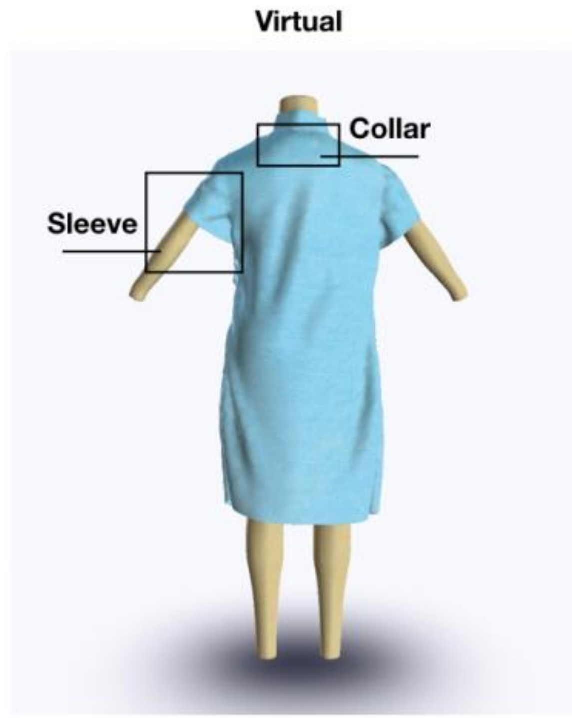


Qipao- Cotton- Side: Scale of 1-7, Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Q24





Qipao- Cotton- Back: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

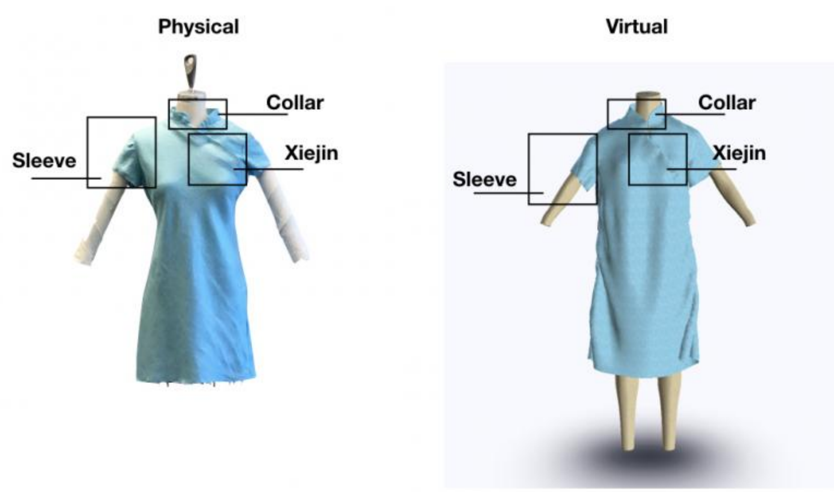
	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

End of Block: Garment's Design Point Simulation- Qipao- Cotton

Start of Block: Garment's Design Point Simulation- Qipao- Hemp

Qipao-- Hemp-- Garment's Design Point Simulation
The black boxes below feature specific points of measure and design features. Please compare the similarity of appearance and fit, using the scale provided below. Definitions: 1. Appearance'The garment structure appearance includes many aspects such as pilling, wrinking, and puckering, and so forth'(Hu & Xin, 2005).2. Fit'Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer' (Chambers & Moulton, 1969).

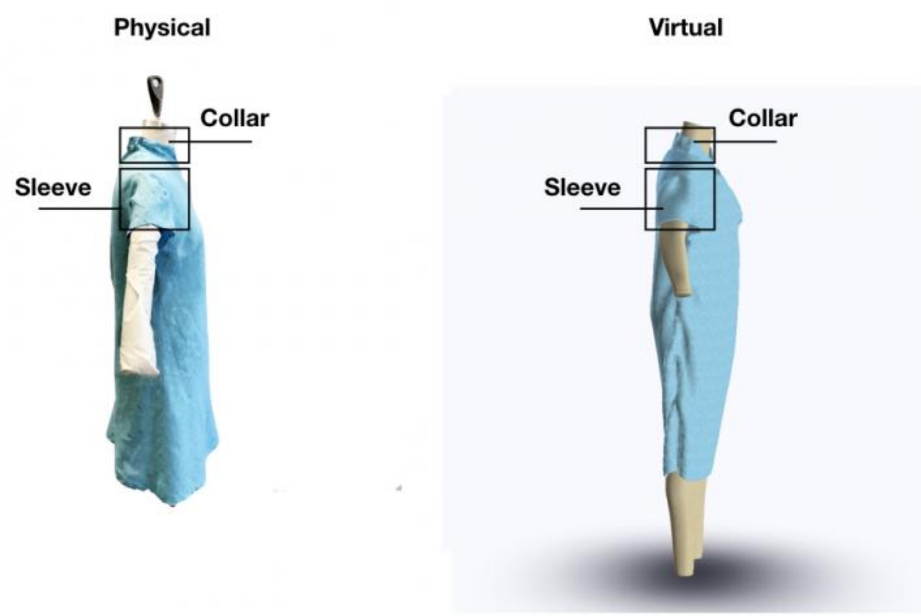
Q25



Qipao- Hemp- Front: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Xiejin (3)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

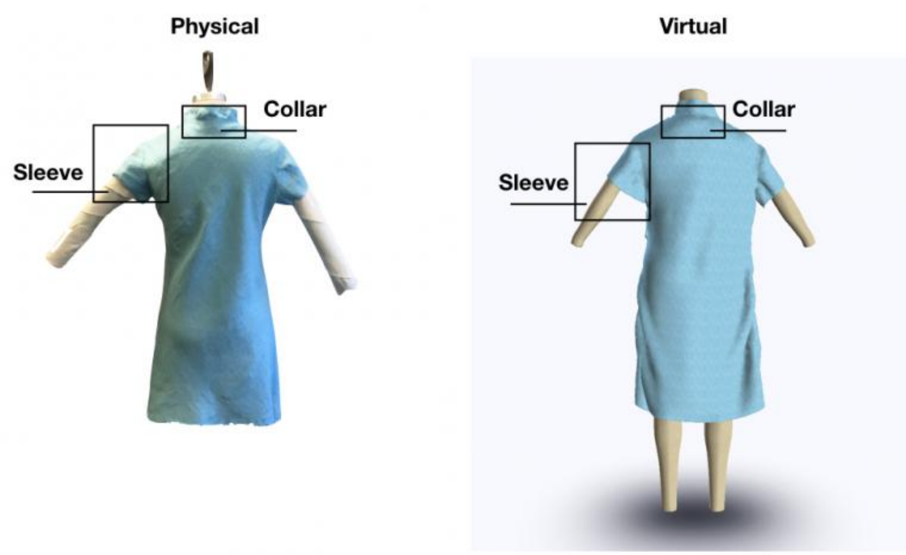
Q26



Qipao- Hemp- Side: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Q27



Qipao- Hemp- Back: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

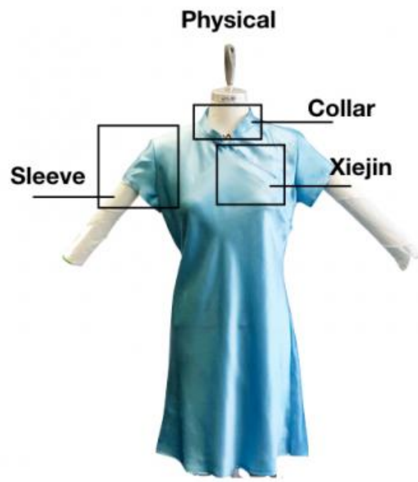
End of Block: Garment's Design Point Simulation- Qipao- Hemp

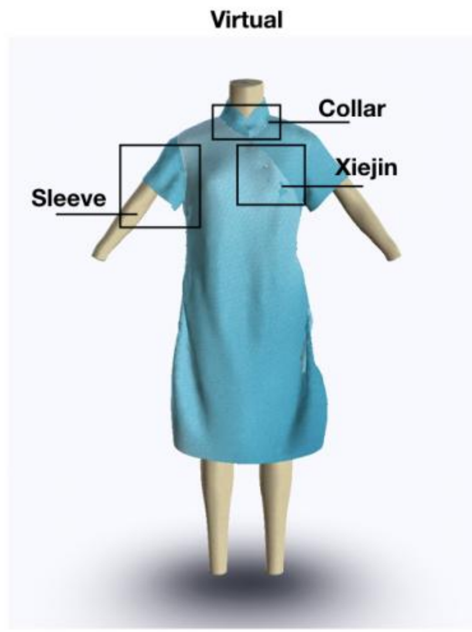
Start of Block: Garment's Design Point Simulation- Qipao- Silk

Qipao-- Silk-- Garment's Design Point Simulation

The black boxes below feature specific points of measure and design features. Please compare the similarity of appearance and fit, using the scale provided below. Definitions: 1. Appearance'The garment structure appearance includes many aspects such as pilling, wrinking, and puckering, and so forth'(Hu & Xin, 2005).2. Fit'Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer' (Chambers & Moulton, 1969).

Q28

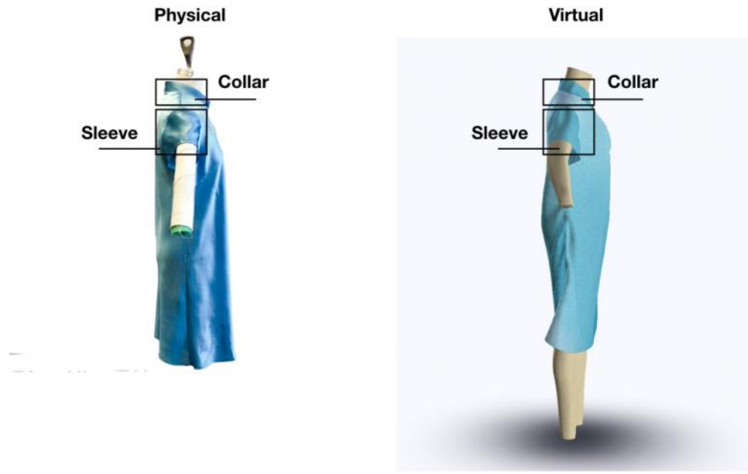




Qipao- Silk- Front: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Xiejin (3)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

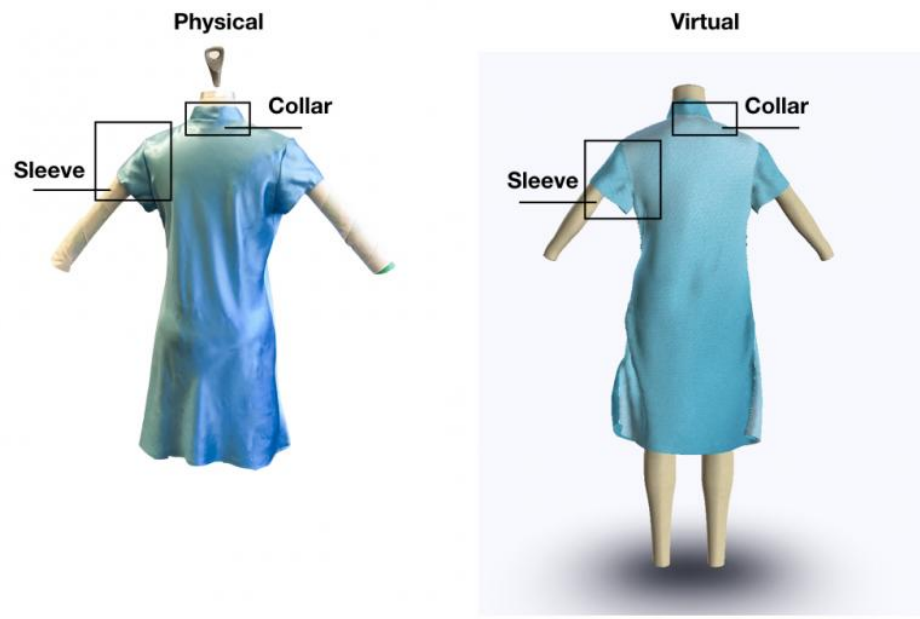
Q29



Qipao- Silk- Side: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Q30



Qipao- Silk- Back: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

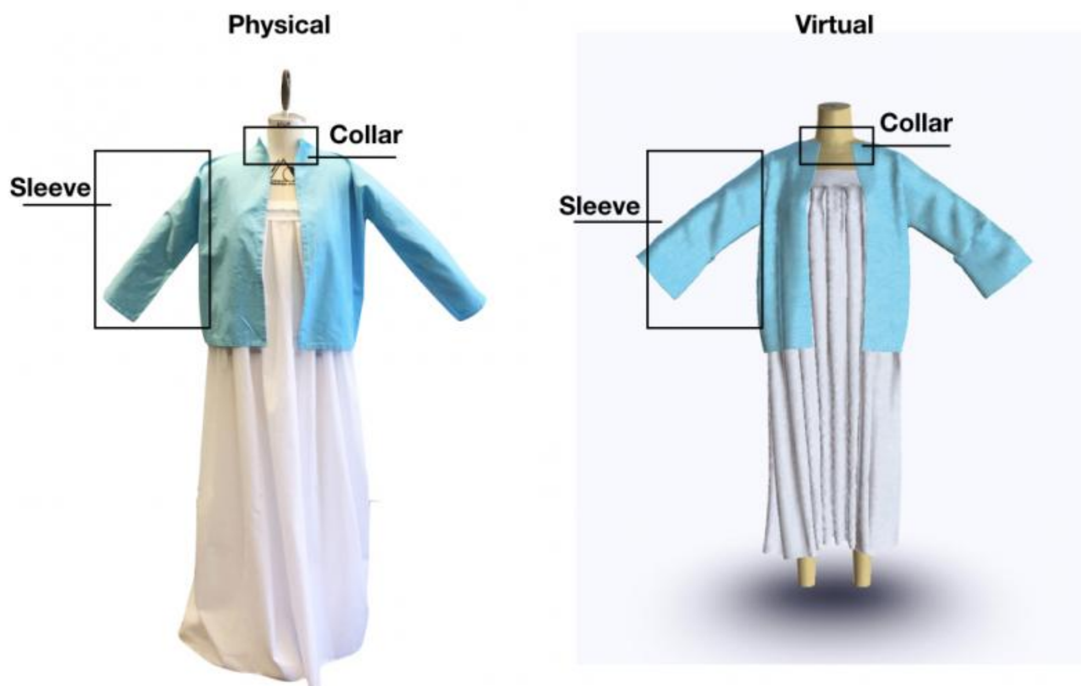
End of Block: Garment's Design Point Simulation- Qipao- Silk

Start of Block: Garment's Design Point Simulation- Hanfu- Cotton

Hanfu-- Cotton-- Garment's Design Point Simulation

The black boxes below feature specific points of measure and design features. Please compare the similarity of appearance and fit, using the scale provided below. Definitions: 1. Appearance'The garment structure appearance includes many aspects such as pilling, wrinking, and puckering, and so forth'(Hu & Xin, 2005).2. Fit'Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer' (Chambers & Moulton, 1969).

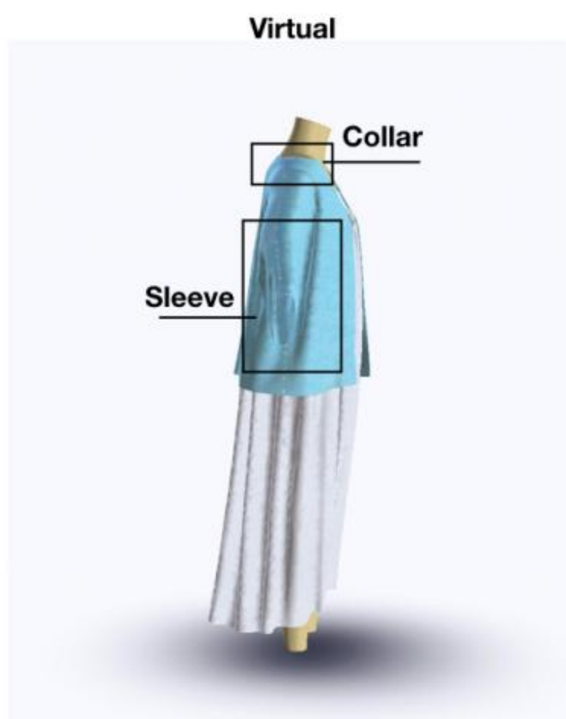
Q31



Hanfu- Cotton- Front: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

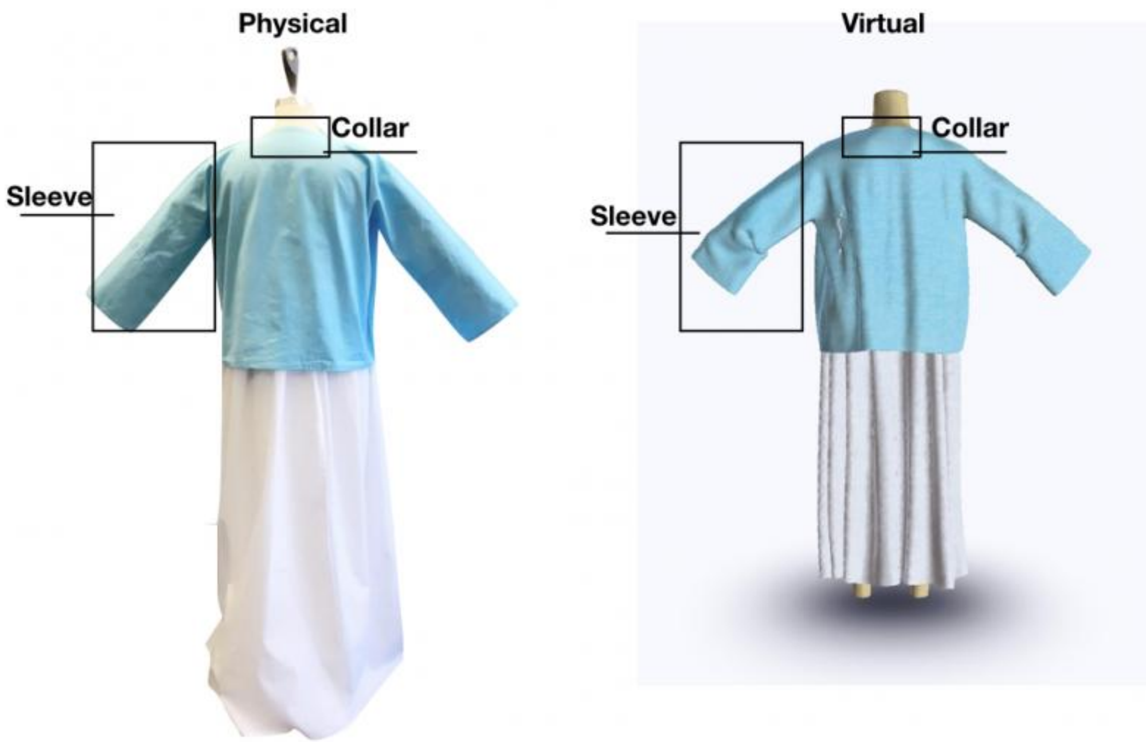
Q32



Hanfu- Cotton- Side: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Q33



Hanfu- Cotton- Back: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

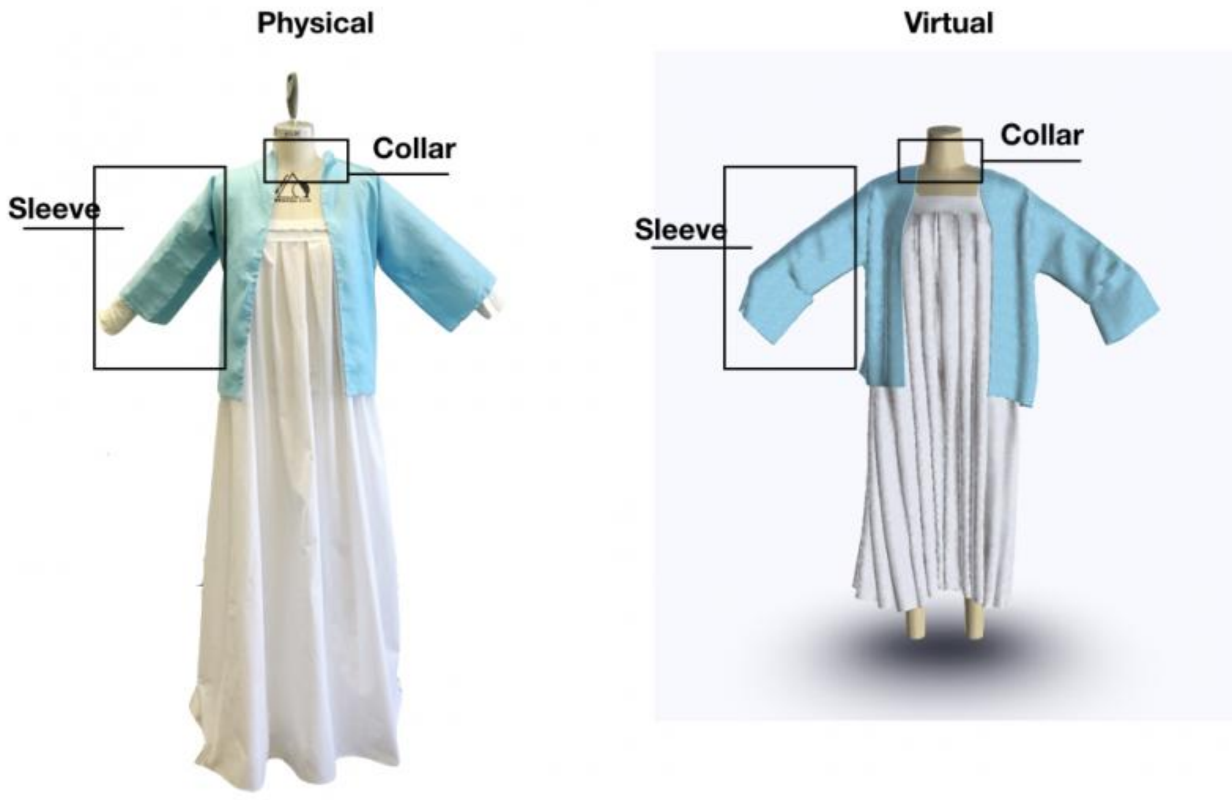
	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

End of Block: Garment's Design Point Simulation- Hanfu- Cotton

Start of Block: Garment's Design Point Simulation- Hanfu- Hemp

Hanfu-- Hemp-- Garment's Design Point Simulation
The black boxes below feature specific points of measure and design features. Please compare the similarity of appearance and fit, using the scale provided below. Definitions: 1. Appearance‘The garment structure appearance includes many aspects such as pilling, wrinking, and puckering, and so forth’(Hu & Xin, 2005).2. Fit‘Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer’ (Chambers & Moulton, 1969).

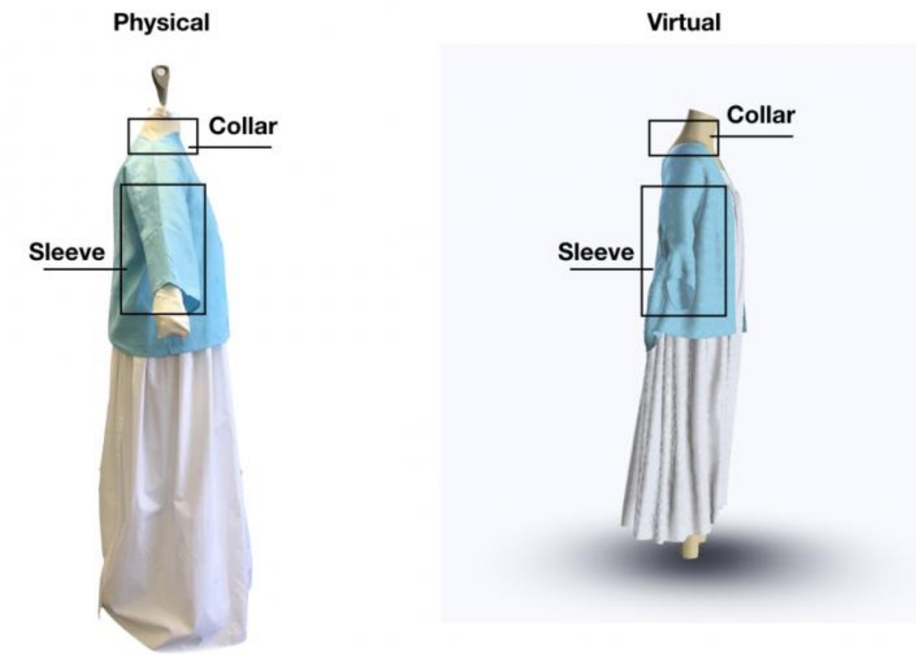
Q34



Hanfu- Hemp- Front: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

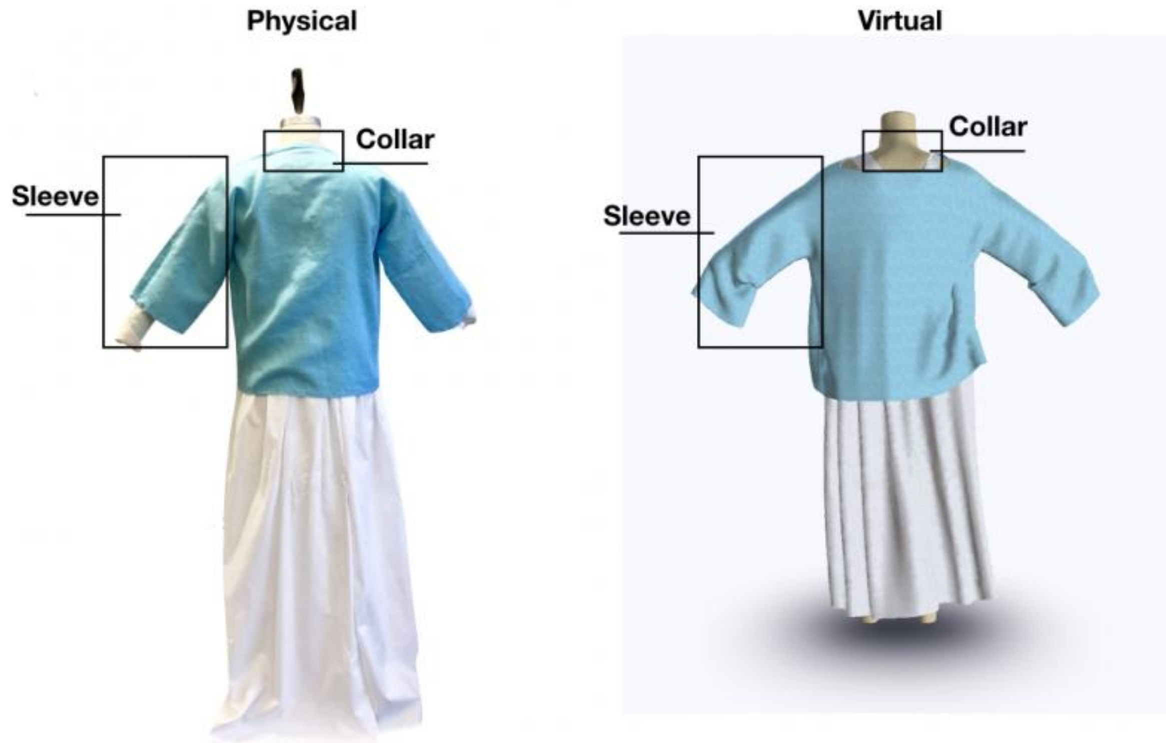
Q35



Hanfu- Hemp- Side: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Q36



Q209 Hanfu- Hemp- Back: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)

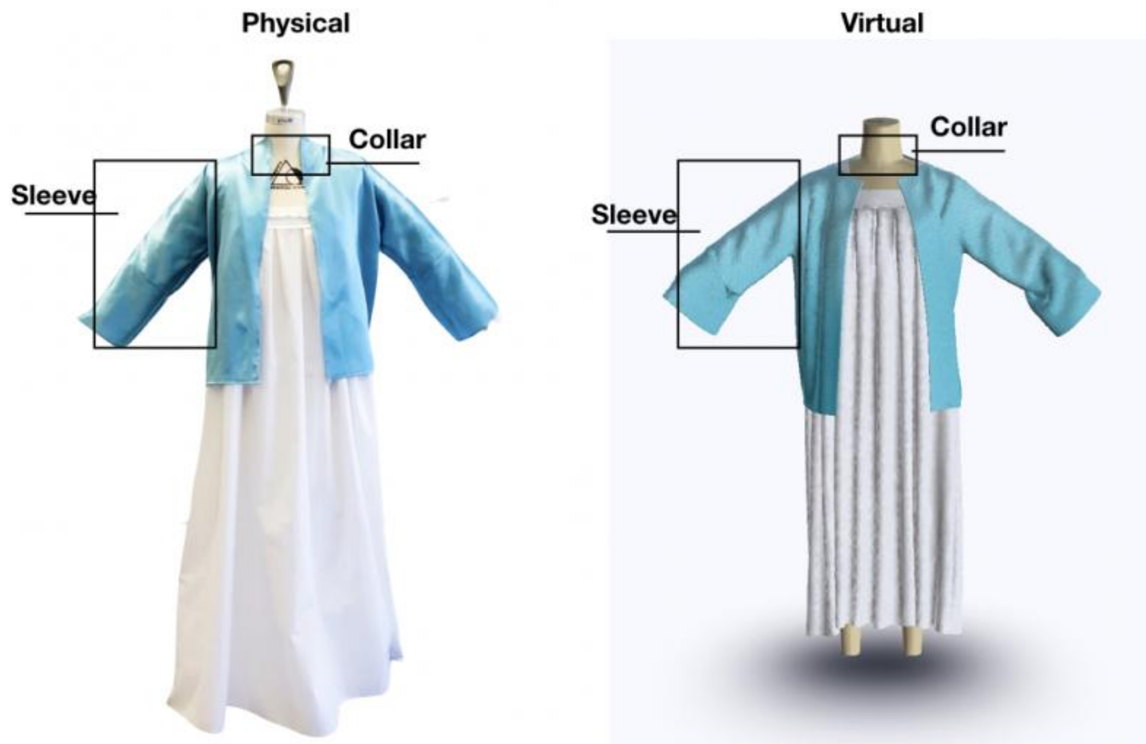
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

End of Block: Garment's Design Point Simulation- Hanfu- Hemp

Start of Block: Garment's Design Point Simulation- Hanfu- Silk

Hanfu-- Silk-- Garment's Design Point Simulation
The black boxes below feature specific points of measure and design features. Please compare the similarity of appearance and fit, using the scale provided below.
Definitions: 1. Appearance'The garment structure appearance includes many aspects such as pilling, wrinking, and puckering, and so forth'(Hu & Xin, 2005).2. Fit'Clothing that fits well, conforms to the human body and has adequate ease of movement, has no wrinkles and has been cut and manipulated in such a way that it appears to be part of the wearer' (Chambers & Moulton, 1969).

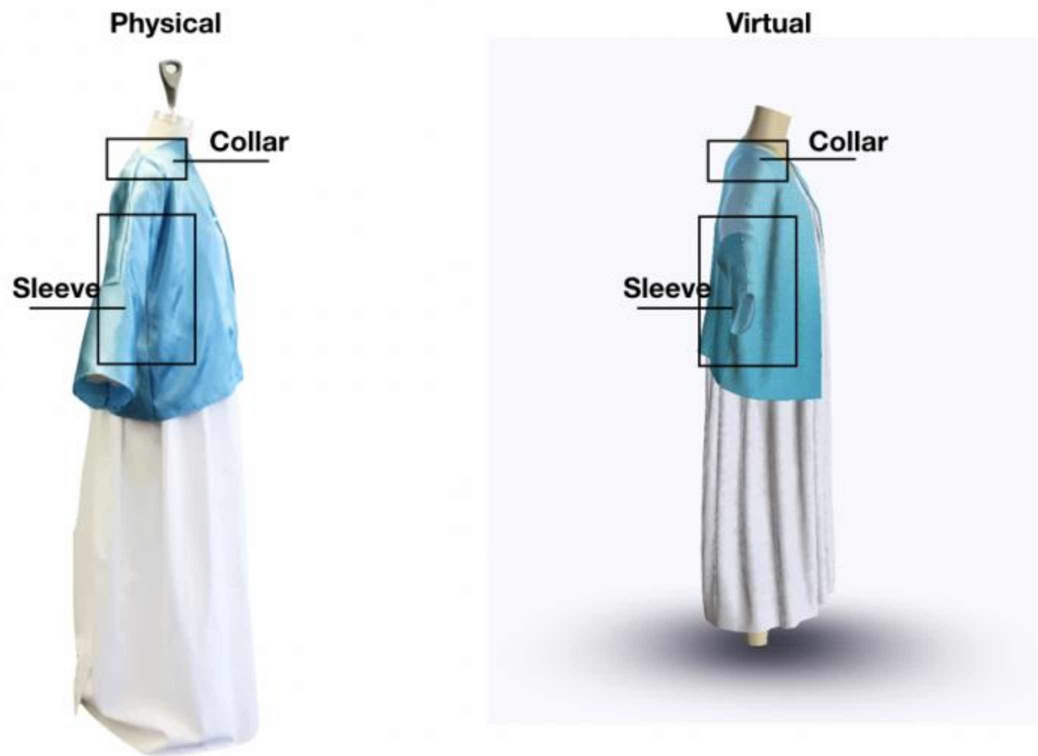
Q37



Hanfu- Silk- Front: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

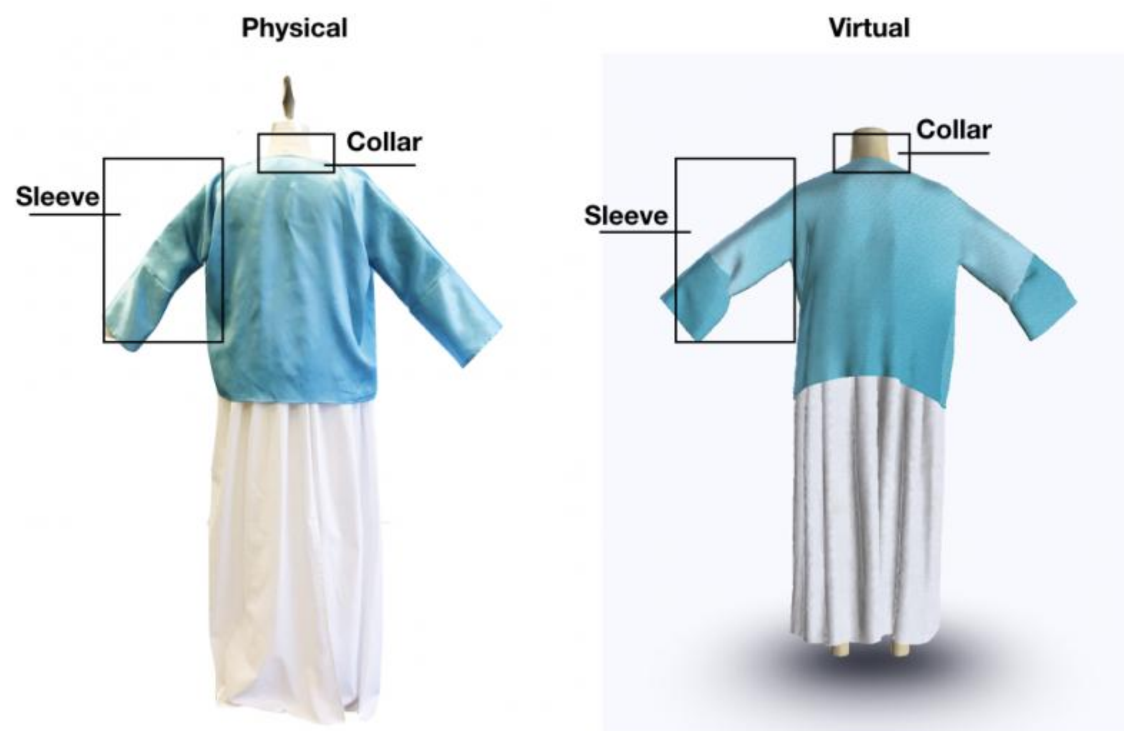
Q38



Hanfu- Silk- Side: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Q39



Hanfu- Silk- Back: Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)

	Appearance							Fit						
	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)

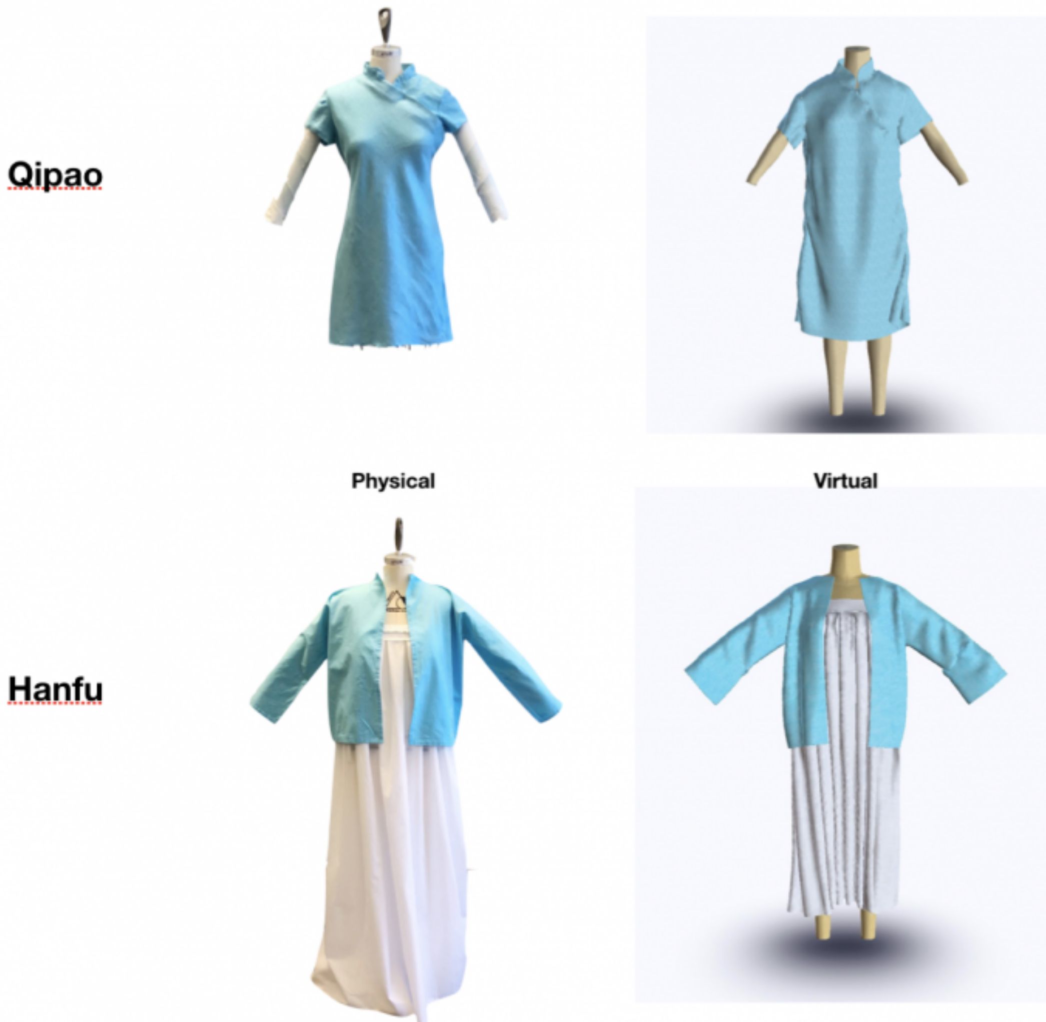
Collar (1)	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Sleeve (2)	○	○	○	○	○	○	○	○	○	○	○	○	○	○

End of Block: Garment's Design Point Simulation- Hanfu- Silk

Start of Block: Conclusion

Conclusion

Scale of 1-7, extremely poor similarity (1) and excellent similarity (7)


Qipao
Physical
Virtual
Hanfu

Q40 Final Question

(Drape means to become arranged in folds)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
All in all, do virtual garments look and “feel” visually like their physical counterparts. (1)	○	○	○	○	○	○	○
Is drape accurate?Multi-layered garments (2)	○	○	○	○	○	○	○
Is the texture reflective of the physical garment? (6)	○	○	○	○	○	○	○

Q42 In your opinion as a future fashion professional, would you conduct apparel product development using virtual prototyping? Why or why not?

____

Appendix B

INFORMED CONSENT TO PARTICIPATE IN RESEARCH

Title of Project: Comparing physical to virtual: fit, appearance, and fabrication of multi-layered cultural garments

Principal Investigator(s): Bai Li

You are being invited to participate in a research study. This consent form tells you about the study including its purpose, what you will be asked to do if you decide to take part, and the risks and benefits of being in the study. Please read the information below and ask us any questions you may have before you decide whether or not you agree to participate.

WHAT IS THE PURPOSE OF THIS STUDY?

This research study is to analyze the similarity of fit and appearance between physically constructed multi-layered garments and virtually constructed multi-layered garments. Based on findings, the researcher will develop recommendations for optimizing apparel product development via virtual prototyping method.

You will be one of approximately 60 participants in this study. You are being asked to participate because fashion major students might offer professional conduct of a series of comparison between physically constructed multi-layered garments and virtually constructed multi-layered garments.

WHAT WILL YOU BE ASKED TO DO?

As part of this study you will be asked to provide your response to the online questionnaires about two different multi-layered garments in three different material that is provided to you. The data collection may require approximately 20 minutes. The garments' evaluation questionnaire asks you about the fit and drape of 4 critical areas, design point, and overall drape and fit. This is a new experimental procedure; we hope to better understand its outcomes as a result of this study.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

the research team does not expect your participation in this study will expose you to any risks different from those you would encounter in daily life.

WHAT IF YOU ARE INJURED DURING YOUR PARTICIPATION IN THE STUDY?

No injured are foreseen

WHAT ARE THE POTENTIAL BENEFITS?

There is less than minimal risks to participants. Steps were taken to minimize risks and the direct benefits to participants would not applicable for this study

NEW INFORMATION THAT COULD AFFECT YOUR PARTICIPATION:

There is no new information that could affect your participation

HOW WILL CONFIDENTIALITY BE MAINTAINED? WHO MAY KNOW THAT YOU PARTICIPATED IN THIS RESEARCH?

The collected responses will be anonymous. Names won't be recorded while collecting data. The research doesn't include recording audio, video, or taking photographs of participants. The findings of this research may be presented or published. If this happens, no information that gives name or other details will be shared. The electronic research records will be secured to protect participant identity and how long records will be stored for. Sponsor or agency would have the right to view the research data at this moment. All the records and data transcripts related to experiments will be destroyed after 3 years.

WILL THERE BE ANY COSTS TO YOU FOR PARTICIPATING IN THIS RESEARCH?

There are no costs associated with participating

WILL YOU RECEIVE ANY COMPENSATION FOR PARTICIPATION?

There is no compensation.

DO YOU HAVE TO TAKE PART IN THIS STUDY?

Taking part in this research study is entirely voluntary. You do not have to participate in this research. If you choose to take part, you have the right to stop at any time. If you decide not to participate or if you decide to stop taking part in the research at a later date, there will be no penalty or loss of benefits to which you are otherwise entitled. Your decision to stop participation, or not to participate, will not influence current or future relationships with the University of Delaware.

As a student, if you decide not to take part in this research, your choice will have no effect on your academic status or your grade in the class.

"If, at any time, you decide to end your participation in this research study, please inform our research team by telling the investigator(s)

WHO SHOULD YOU CALL IF YOU HAVE QUESTIONS OR CONCERNS?

If you have any questions about this study, please tell Bai Li at (302) 268-5629 or Kelly Cobb at (267) 475-2263.

If you have any questions or concerns about your rights as a research participant, you may contact the University of Delaware Institutional Review Board at hsrb-research@udel.edu or (302) 831-2137.

Your signature on this form means that: 1) you are at least 18 years old; 2) you have read and understand the information given in this form; 3) you have asked any questions you have about the research and the questions have been answered to your satisfaction; and 4) you accept the terms in the form and volunteer to participate in the study. You will be given a copy of this form to keep.

Printed Name of Participant
Date

Signature of Participant

Bai Li

Person Obtaining Consent
Date

Person Obtaining Consent

(PRINTED NAME)

(SIGNATURE)

Appendix C

HUMAN SUBJECTS PROTOCOL

Protocol Title: Comparing physical to virtual: fit, appearance, and fabrication of multi-layered cultural garments

Principal Investigator
Name: Bai Li
Department/Center: Fashion & Apparel Studies
Contact Phone Number: (302) 268-5629
Email Address: baili@udel.edu

Advisor (if student PI):
Name: Kelly Cobb
Contact Phone Number: (267) 475-2263
Email Address: kcobb@udel.edu

Other Investigators:

Investigator Assurance:

By submitting this protocol, I acknowledge that this project will be conducted in strict accordance with the procedures described. I will not make any modifications to this protocol without prior approval by the IRB. Should any unanticipated problems involving risk to subjects occur during this project, including breaches of guaranteed confidentiality or departures from any procedures specified in approved study documents, I will report such events to the Chair, Institutional Review Board immediately.

1. **Is this project externally funded?** √ YES ☐ NO

   If so, please list the funding source:
   Graduate Essay Funding from our department.

2. Research Site(s)

√ University of Delaware

☐ Other (please list external study sites)

Is UD the study lead? √ YES ☐ NO (If no, list the institution that is serving as the study lead)

3. **Project Staff**
Please list all personnel, including students, who will be working with human subjects on this protocol (insert additional rows as needed):

NAME	**ROLE**	**HS TRAINING COMPLETE?**
Bai Li	Student	Yes
Prof. Kelly Cobb	Advisor	Yes

4. **Special Populations**
Does this project involve any of the following:

Research on Children? No

Research with Prisoners? No

If yes, complete the Prisoners in Research Form and upload to IRBNet as supporting documentation

Research with Pregnant Women? No

Research with any other vulnerable population (e.g. cognitively impaired, economically disadvantaged, etc.)? please describe

No

5. **RESEARCH ABSTRACT**

Few studies have verified the virtual fit, appearance and fabrication characteristics of virtually simulated multi-layered garments. Researchers determined a research gap, the simulation of cultural non-western garments provides compelling example for this research This study is designed to analyze the similarity of fit and appearance between physically constructed multi-layered garments and virtually constructed multi-layered garments. Optitex technology will be utilized to virtually simulate garment and render textile mapping. The procedure of research involves measuring the physical parameters of the fabric, and populate data into Optitex. Develop 2D and 3D patterns via Optitex PDS. It is hypothesized that 3D rendering of texture and silhouette of multi-layered garments enable a more realistic simulation of the fabric appearance. Concurrent with virtual garment construction, the researcher will analyze the virtual apparel prototypes through the online questionnaire. Based on findings, the researcher will develop recommendations in optimizing apparel product development via virtual prototyping methods.

6. **PROCEDURES**

To conduct the experiment, the professor of any selected large classes (two different classes, 40+) will be requested to give last 20 minutes of his/her class for conducting the study. Professor will be requested to include the study as a part of course works of that course for that certain day. All the questionnaires will be online based. The garments' evaluation questionnaire asks you about the fit and drape of 4 critical areas, design point, and overall drape and fit. Then the collected responses will be analyzed to derive significant influences of tweets upon the students' responses.

7. **STUDY POPULATION AND RECRUITMENT**
Describe who and how many subjects will be invited to participate. Include age, gender and other pertinent information.

For the sampling, non-probability convenience sampling method will be used. Some Professors from a certain department will be contacted to get their consent about letting the experiment take place in their classes (two). If the professors agree, then the class having at least 60 students will be selected finally for the data collection. Undergraduate class containing greater than or equal to 60 students will be selected for the collection of responses and all the students of that class will be selected as sample for this study. As undergraduate students are being taken as sample, their age will be between 18 and 23. Participants will be selected in the Fashion and Apparel Studies department, most respondents will be female.

Attach all recruitment fliers, letters, or other recruitment materials to be used. If verbal recruitment will be used, please attach a script.

Describe what exclusionary criteria, if any will be applied.

No exclusionary criteria will be applied.

Describe what (if any) conditions will result in PI termination of subject participation.

No specific condition.

8. **RISKS AND BENEFITS**
List all potential physical, psychological, social, financial or legal risks to subjects (risks listed here should be included on the consent form).

None

In your opinion, are risks listed above minimal* or more than minimal? If more than minimal, please justify why risks are reasonable in relation to anticipated direct or future benefits.

*(*Minimal risk means the probability and magnitude of harm or discomfort anticipated in the research are not greater than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests)*

None

What steps will be taken to minimize risks?

Not applicable

Describe any potential direct benefits to participants.

Not applicable

Describe any potential future benefits to this class of participants, others, or society.

Not applicable

If there is a Data Monitoring Committee (DMC) in place for this project, please describe when and how often it meets.

No.

9. **COMPENSATION**
Will participants be compensated for participation?

No.

If so, please include details.

10. **DATA**
Will subjects be anonymous to the researcher?

Yes

If subjects are identifiable, will their identities be kept confidential? (If yes, please specify how)

Subjects will not be identifiable.

How will data be stored and kept secure (specify data storage plans for both paper and electronic files. For guidance see http://www.udel.edu/research/preparing/datastorage.html)

Digital copies of the data will be kept on the researcher's main laptop that carries the statistical analyses tools, which will be protected by researcher's laptop password.

How long will data be stored?

3 years.

Will data be destroyed? √ YES ☐ NO (if yes, please specify how the data will be destroyed)

Will the data be shared with anyone outside of the research team? ☐ YES √NO (if yes, please list the person(s), organization(s) and/or institution(s) and specify plans for secure data transfer)

How will data be analyzed and reported?

Data will be analyzed to examine the research hypotheses. The aggregate form will be used to report data.

11. **CONFIDENTIALITY**
Will participants be audiotaped, photographed or videotaped during this study?

No

How will subject identity be protected?

No subject identification will be linked to the data or completed questionnaires

Is there a Certificate of Confidentiality in place for this project? (If so, please provide a copy).

No

12. **CONFLICT OF INTEREST**

(For information on disclosure reporting see: http://www.udel.edu/research/preparing/conflict.html)

Do you have a current conflict of interest disclosure form on file through UD Web forms?

No.

Does this project involve a potential conflict of interest*?

No.

* As defined in the University of Delaware's Policies and Procedures ,a potential conflict of interest (COI) occurs when there is a divergence between an individual's private interests and his or her professional obligations, such that an independent observer might reasonably question whether the individual's professional judgment, commitment, actions, or decisions could be influenced by considerations of personal gain, financial or otherwise.

If yes, please describe the nature of the interest:

13. **CONSENT and ASSENT**

__3_ Consent forms will be used and are attached for review (see Consent Template under Forms and Templates in IRBNet)

____ Additionally, child assent forms will be used and are attached.

____ Waiver of Documentation of Consent (attach a consent script/information sheet with the signature block removed).

____ Waiver of Consent (Justify request for waiver)

14. **Other IRB Approval**
Has this protocol been submitted to any other IRBs?

No.

If so, please list along with protocol title, number, and expiration date.

15. **Supporting Documentation**
Please list all additional documents uploaded to IRBNet in support of this application.

Questionnaire

Consent Form

CITI Training Certificates

Appendix D

HUMAN SUBJECTS PROTOCOL AMENDMENT

Protocol title: Comparing physical to virtual: Appearance and fit of multi-layered cultural garments

Principal Investigator: Bai Li

Advisor (if student): Kelly Cobb

Other investigators:

Investigator Assurance: By submitting this amendment, I acknowledge that this project will be conducted in strict accordance with the procedures described. I will not make any modifications to this protocol without prior approval by the IRB. Should any unanticipated problem or adverse event involving risk to subjects, including breaches of guaranteed confidentiality, occur during this project, I will report such incident to the Institutional Review Board immediately.

PROPOSED AMENDMENT Please provide a brief description in LAY language (understandable to an 8th grade student) of the purpose of the proposed amendment and the rationale behind the change(s).

1. **New Project Staff**

Please list any new personnel, including students, who will be working with human subjects on this protocol who are not on original protocol (insert additional rows as needed):

NAME	ROLE IN PROTOCOL	DATE HS TRAINING COMPLETED

2. **PROCEDURES**
Describe **all changes** to procedures involving human subjects for this amendment.

Cultural garments, Qipao (tight fit) and Hanfu (loose fit), were constructed and produced in order to investigate the appearance and fit of virtual and physical garments based on existing patterns. The research method used for this study was an online survey. In general, online surveys are an effective way to collect what people think with no research intervention. In this case, the researcher can get useful information about how people think about the appearance and fit of virtual and physical garments. The researcher compared virtual and physical garments by distributing an online survey sent to students in the fashion department.

The research procedure involved measuring the physical parameters of the fabric, customizing an Optitex EFI Fabric Library, developing 2D and 3D patterns via Optitex EFI pattern drafting software, creating physical and virtual garments, and conducting an on-campus survey. Samples for this study include a fit multi-layered garment (Hanfu) and a tight fit multi-layered garment (Qipao). Prototypes were developed in various fabrics. The researcher took into account the physical fabric mechanical properties, and the fabric objective measuring data such as weight, thickness, stretch, shear, bend, and friction through the Kawabata evaluation system of fabric (KES-F) and other instruments. Simulation technologies were researched and EFI Optitex technology was utilized to virtually simulate the garments.

3. **STUDY POPULATION AND RECRUITMENT**
Describe **any additional** subjects who will be invited to participate. Include age, gender and other pertinent information.

No.

Describe what exclusion criteria, if any, will be applied.

No.

Describe what (if any) conditions will result in PI termination of subject participation.

No.

4. **RISKS AND BENEFITS**
Describe **any new risks** to participants resulting from the procedures requested in this amendment (*risks listed here need to be included in the consent document and the revised protocol form*).

No risks

If risk is more than minimal, please justify.

What steps will be taken to minimize risks?

Describe any direct benefits to participants.

No direct benefits.

Describe any future benefits to this class of participants.

No direct benefits.

5. **COMPENSATION**
Will participants **receive additional compensation** for participation due to this amendment?

No

If so, please include details.

6. **DATA**
Are there **any changes to data** management as a result of this amendment?

No

7. **CONFIDENTIALITY**
Will participants be audiotaped, photographed or videotaped as part of the procedures requested by this amendment?

No

How will subject identity be protected?

The electronic research records will be secured to protect participant identity and how long records will be stored for.

Is there a Certificate of Confidentiality in place for this project? (If so, please provide a copy).

No

8. **CONSENT and ASSENT**

____ Consent form revisions are required and are attached for review.

____ Additionally, child assent forms will be changed and are attached.

____ No consent form revisions are required.

____ Consent forms will not be used (Justify request for waiver).

9. REVISED STUDY MATERIALS:

Please list ALL materials uploaded to IRBNet in support of this application. **Materials submitted** for review **must include** **a tracked-changes copy of the most current version of the protocol form** (available in Forms and Templates - IRBNet) to include the changes requested in the amendment, **the informed consent**, **and any other study documents previously approved and still currently being used, or added with this amendment**. **In addition** please upload **a clean copy of the informed consent in Microsoft Word** to be stamped once approved.

Appendix E

IRB APPROVAL FORM

UNIVERSITY OF DELAWARE

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE:	April 27, 2018
TO:	Bai Li
FROM:	University of Delaware IRB
STUDY TITLE:	[1197441-2] Comparing Physical to Virtual: Fit, Appearance, and Fabrication of Multi-layered cultural garments
SUBMISSION TYPE:	Amendment/Modification
ACTION:	DETERMINATION OF EXEMPT STATUS
DECISION DATE:	April 27, 2018
REVIEW CATEGORY:	Exemption category # *(2)*

Thank you for your submission of Amendment/Modification materials for this research study. The University of Delaware IRB has determined this project is EXEMPT FROM IRB REVIEW according to federal regulations.

We will put a copy of this correspondence on file in our office. Please remember to notify us if you make any substantial changes to the project.

If you have any questions, please contact Nicole Farnese-McFarlane at (302) 831-1119 or nicolefm@udel.edu. Please include your study title and reference number in all correspondence with this office.