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Article

Research on Archaeology and Digital Restoration of Costumes in *DaoLian* Painting

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Abstract: Costume restoration is one of the important ways to study costume history and culture. The purpose of this paper is to show the characteristics of Chinese costumes more than 1000 years ago, through the research on the costume in the famous ancient Chinese painting *DaoLian painting*, and provide strong technical support for the research of Chinese ancient costume culture. *DaoLian painting* is the work of Xuan Zhang, a famous painter in Tang dynasty (618–907), China. From the perspective of clothing engineering, we analyzed the characteristics of costume style, color, and pattern and used the virtual fitting technology to realize digital restoration of the costume of 12 characters in the painting. The results show that it is a practical method to study costume from paintings. The colors, patterns, and character gestures in the paintings provide sufficient information for the archaeology and restoration of ancient costumes. The research results of this paper can provide a new idea for costume archaeology and a reference for modern fashion design and materials for the VR Museum of Ancient Costumes.

Keywords: virtual fitting; *DaoLian painting*; costume culture; costume restoration; costume archaeology



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1. Introduction

Historical and cultural heritage is the bridge between the ancient and modern, as well as the key for contemporary people to explore ancient civilization. They have important historical value, scientific value, cultural value, and artistic value, and they reflect the lifestyle, social system, and economic development of the ancients [1,2]. It is very important to protect precious historical and cultural heritage, which is the focus of every country and even the world [3]. Cultural heritage is a valuable nonrenewable resource and a carrier of historical inheritance [4,5]. Our reasonable development and protection of cultural heritage is not only conducive to the spread of culture and expanse of cultural influence, but it also can promote the development of local tourism economy [6].

As a special historical and cultural heritage, ancient costumes are mainly composed of organic matter. Humidity, temperature, light, dust, and other factors may cause them to decompose or fade. So, ancient costumes cannot be exposed to the air for a long time. Compared with other cultural relics, textile restoration takes a long time, and the results are unpredictable. Therefore, the preservation and protection of textile cultural relics needs to be very careful to avoid further damage to the costumes [7]. Because of the above factors, the exhibition time of ancient costumes is limited. Only a small number of professional staffs have the opportunity to get close contact with ancient costumes; ordinary people can rarely observe ancient costumes and lack of ways to understand the real charm of traditional costumes, which is not conducive to the spread of costume culture.

The emergence and development of digital technology provides a new technical means for the protection and development of cultural heritage. This makes the digitization of historical and cultural heritage become the focus of researchers in many disciplines. Digital technology transforms, reproduces, and restores cultural heritage into a digital form that can be shared and renewable. It plays an important role in the scanning and reconstruction [8], management [9], protection [10], and display [11] of cultural heritage. The digitization of historical and cultural heritage is an inevitable trend. The development of digital technology is changing the protection of traditional cultural heritage. It is conducive to the wider enjoyment of human cultural heritage by the public [12].

The digital restoration of ancient costumes is actually a multidisciplinary research field [13]. Archaeology, clothing engineering, costume history, and other fields of scholars are jointly promoting its development. The digitization of ancient costume usually relies on three-dimensional (3D) modeling technology to accurately restore costume color, structure, fabric, and size. At present, 3D virtual fitting technology has gradually matured and is widely used in the fields of pattern development [14], clothing comfort evaluation [15], interactive design [16–18], and costume archaeology and restoration [19–22]. In recent years, some achievements have been made in the restoration of historical costumes. For example, Aleksei Moskvina et al. conducted parametric modeling of skirts in the late 1850s and 1960s [13], and Victor Kuzmichev et al. conducted 3D reconstruction of historical men's costumes and late Victorian riding skirts [23–25]. In general, a virtual replica similar to the prototype can be constructed by using virtual fitting technology. This provides technical support for the establishment of a virtual costume museum [26].

Hanfu, the traditional costume of the Han nationality in ancient China, is a cultural heritage with a history of thousands of years [27]. The dress system and etiquette of Hanfu were different in each dynasty, which were influenced by the political system, economic conditions, and fashion trend of each period. Each dynasty formed a unique style of dressing. For example, the style of the Qin dynasty was elegant, the style of Tang dynasty was luxurious, the style of the Song dynasty was simple, and the style of the Ming dynasty was graceful. With the rise of the Hanfu movement and the support of Chinese government policies, more and more people similar to Hanfu and the market of Hanfu have been in short supply [27]. The rise of Hanfu provided Hanfu vitality again, but now the Hanfu are improved, not real copies. Additionally, with the popularity of the Hanfu market, there are some business opportunities; costume quality has been an uneven situation, and there has even been the phenomenon of design plagiarism. The cultural connotations, color patterns, and style collocations of historical costumes are the sources of inspiration for the modern design of Hanfu. Only by studying the historical costume can we design a good modern Hanfu.

Tang dynasty, which was founded in 618 AD and ended in 907 AD, was a prosperous period in Chinese history, with prosperous economy and open and inclusive culture [28]. The costumes of this period were elegant, colorful, and had unique charm [19]. Unfortunately, due to the long history, the unearthed costume relics are very rare. Therefore, the existing murals and books have become important materials for the study of Tang dynasty costumes.

The *DaoLian painting* is the work of Xuan Zhang, a famous painter in Tang Dynasty, China. *DaoLian painting* is an important genre painting in the prosperous Tang Dynasty, which is of great value to the study of the social and cultural fields of the Tang Dynasty, such as fine arts, costume, makeup, and so on. The painting depicts the working process of the ladies in Tang dynasty. The unique style, gorgeous colors, and exquisite patterns of ladies' costumes presented in the paintings are the treasures of contemporary research on women's clothing culture in Tang dynasty.

At present, there are no costumes unearthed from the Tang dynasty of China. Studying costumes from famous paintings in the Tang dynasty has become an important means. Currently, few researchers are engaged in this research. The main innovation of our research is that no one has yet restored the costumes worn by the characters in *Daolian painting* through digital technology. Another important innovation is that no one has studied the pattern of

the costumes in the painting at present, and we have carried out the corresponding research. This research was devoted to the transformation of costumes from two-dimensional (2D) images to 3D virtual costumes. Compared with other costume restorations, we restore the drapability and stiffness of digital fabrics by simulating the tensile strength, bending coefficient, and weight of fabrics. First of all, we analyzed the costume style and costume collocation in the 2D image and drew the style map of 12 sets of costumes. Then, with the help of virtual fitting technology, we made 3D models of 12 sets of costumes and obtained virtual copies of the historical costumes. Virtual costumes allow people to view at 360 degrees, which is not only conducive to the promotion and dissemination of costume culture, but also conducive to the protection and development of historical and cultural heritage.

2. Methodology

2.1. Technical Roadmap

Our goal was to transform 2D images into 3D virtual costumes. We used the virtual fitting technology to restore the historical costume from the perspective of color, pattern, style, and collocation. Virtual displays break through the limitations of static and single display of traditional costumes, and the display is not limited by time and space. There are several steps to transform 2D image into 3D costume: First, analyzing the age information, characters, and painting content of 2D image. Secondly, studying the clothing style and wearing collocation of the restoration object. Thirdly, drawing the clothing style map, based on the information of color and pattern. Fourth, using 3D virtual fitting technology, image editing technology, and image processing technology, 12 sets of clothes were recovered, in turn. First, the virtual fitting technology was used to build the clothing model layer-by-layer. Then, we debugged the physical properties of the virtual fabric to make it close to the real fabric. Finally, with the help of image editing technology and image processing technology, the texture and pattern of the fabric were processed to make it have a real luster and bump feeling. The technical roadmap of this paper is shown in Figure 1.

2.2. Recovery Object Analysis

As a genre painting in the prosperous Tang dynasty, *DaoLian painting* has a profound influence on the painting style of later generations, as shown in Figure 2. This painting is based on unique materials and focuses on women's daily life in the prosperous Tang dynasty. Although the original work of Xuan Zhang's painting has been lost, Ji Zhao, the Emperor Huizong of the Northern Song dynasty, copied the painting of ramming and training, which has been handed down and is now stored at Boston Art Museum.

Most of the ladies Xuan Zhang painted were rich and generous, which opened a new style of "curved eyebrows and plump cheeks" in the prosperous Tang dynasty. *DaoLian painting* is 145.3 cm long and 37 cm wide (Figure 2). The layout is ingenious and reasonable. Everyone's position, movement, and expression were carefully arranged. As a fine and colorful long scroll of meticulous figure painting, there are 12 figures in the painting. According to different work procedures, the division of labor of the 12 people in the painting included roughly three processes: pounding, sewing, and ironing.

"Lian", as a fine raw material of silk, was a kind of cooked raw silk or raw silk fabric in ancient times. After weaving, the texture was hard. First of all, it needed to be cooked, then pounded and ironed. There were four people in the pounding group. There were two sewing ladies and a squatting maid holding a cattail leaf fan. The group on the far left of the scroll was pulling and ironing, which was the last process. The four ladies in this group look mature and steady. Two of them tried their best to open the new "Lian", another one pressed the new "Lian" with an iron, and at the same time, a lady opposite her was responsible for stretching the new "Lian" with her back to the picture scroll. What is quite interesting is that, while everyone was working meticulously, a younger girl was drilling around under the new "Lian", with a charming naive appearance, which added a playful humor to the whole painting.

On the whole, the characters in Zhang Xuan’s *DaoLian painting* are vivid and interesting. The work truly shows the style of women’s dressmaking in Tang dynasty.

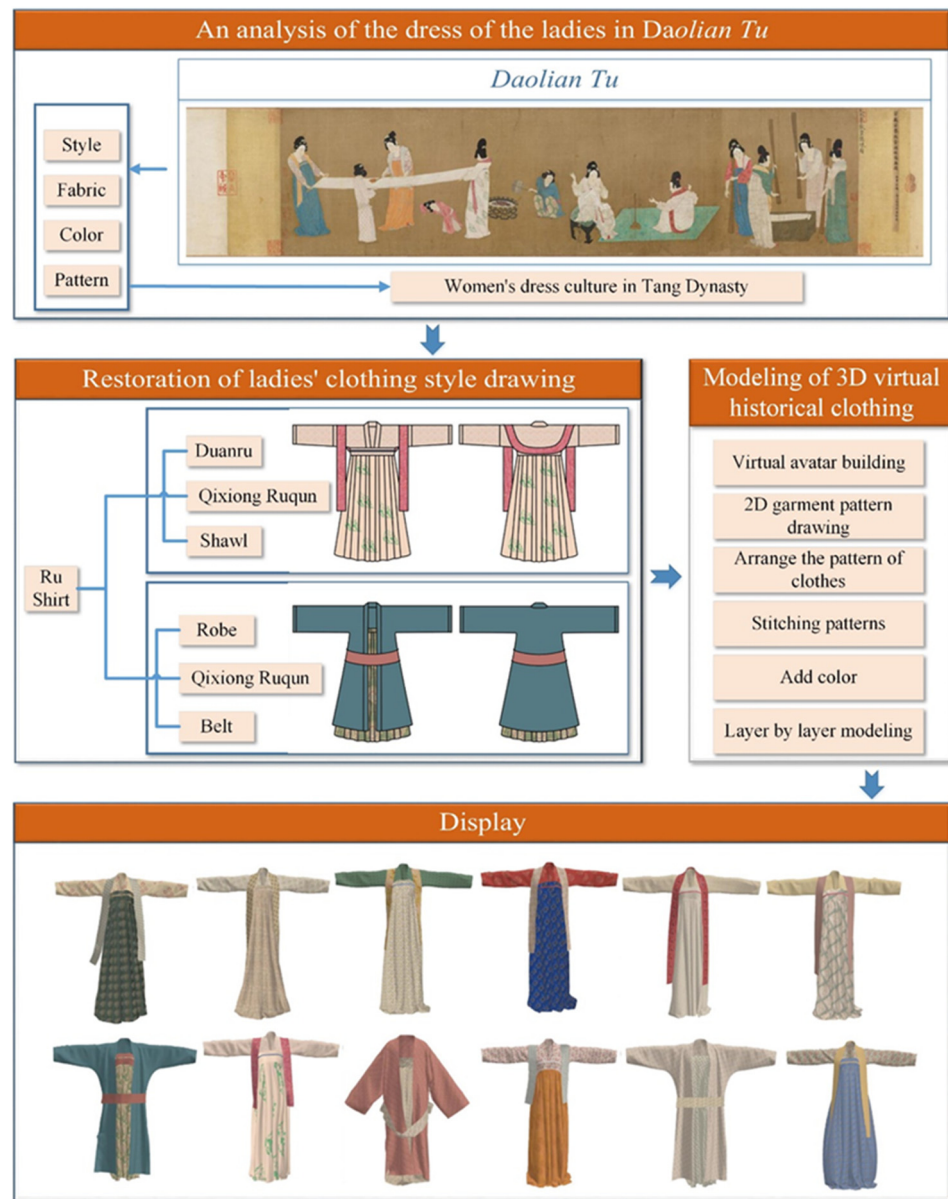


Figure 1. General Scheme.

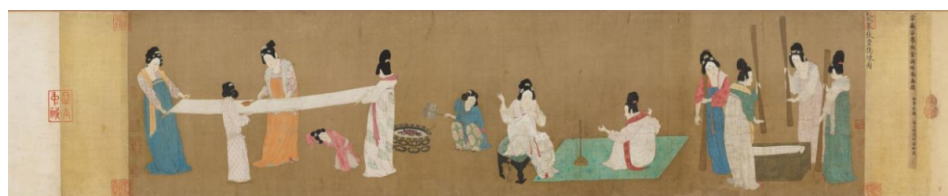


Figure 2. *DaoLian painting* (the painting was painted in the prosperous Tang dynasty, about 713 to 755; it is now at the Boston Museum, USA).

2.3. Color Application and Pattern Composition

The open thought of Tang dynasty promoted the richness of women’s costumes. Women liked bright and beautiful colors, mainly red, purple, blue, and green.

The color matching of costumes in *DaoLian painting* stressed the contrast of color purity and the contrast of cold and warm colors (Figure 2). The painter selected a variety of high purity colors, such as vermilion, blue, orange, scarlet, and grass green, as well as high brightness colors, such as moon shadow white and light yellow. The overall color of the painting is bright, full, soft, and beautiful. The whole painting depicts the elegant demeanor of women in Tang dynasty, which has a strong aesthetic sense of the times and caters to the mainstream aesthetic consciousness of the society at that time.

In the prosperous Tang dynasty, the patterns were mainly flowers and plants, which removed the restrictions and constraints of animals in the past and was more in line with women's aesthetic taste. Symmetry aesthetics have been advocated in China since ancient times. In Tang dynasty, women's costume patterns were mainly composed of beaded patterns, regimental patterns, rolled grass patterns, geometric patterns, and other patterns with rhythmic beauty and formal beauty, as shown in Figure 3.

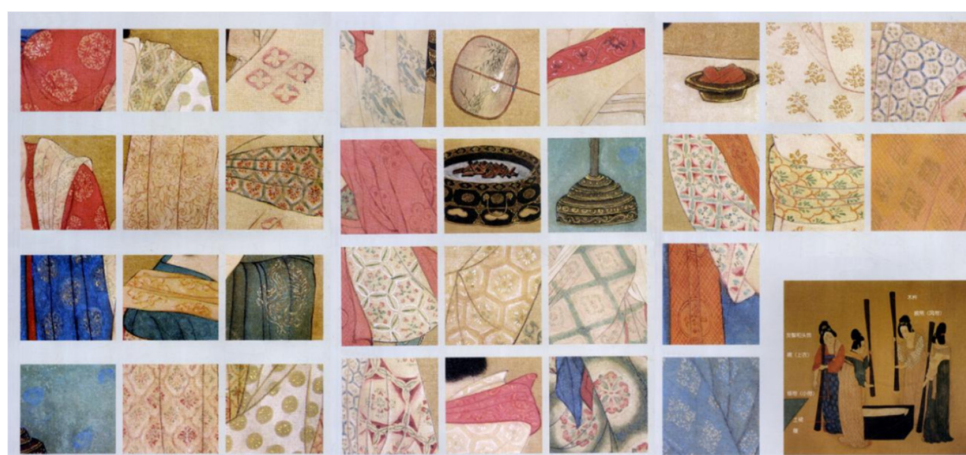


Figure 3. Patterns in *DaoLian painting*.

Regimental pattern refers to the round pattern formed by more than one pattern element, which has full aesthetic characteristics. Beaded pattern is a geometric pattern in traditional Chinese culture. Most of its styles are round, which is not only exotic, but also mellow, in Tang dynasty. Rolled grass pattern is one of the most representative plant patterns in Tang dynasty, which is often organized by waves and full of vitality. Geometric patterns are regular patterns composed of geometric patterns.

2.4. Style Wearing and Costume Matching

In the prosperous Tang dynasty, politics were clear and the country was stable. This was a prosperous and open age with developed economy. Due to the self-confidence of culture and the openness of folk customs, the social status of women in Tang dynasty was much higher than that of other dynasties, and the feudal bondage of women's lives was reduced. In addition to the influence of foreign culture, it has formed a few typical female images in Chinese history. Wide sleeve (coat with wide cuff), half sleeve (coat with only half sleeve length), Ru shirt (suit with short coat on the upper body and skirt on the lower body), and shawl (long strip fabric, similar to scarf) are the representative costume categories of palace women's costumes.

In *DaoLian painting*, women all wear typical Ru skirts. Ru skirts appeared as a fixed collocation in the Wei and Jin Dynasties and developed to its peak in Tang dynasty. There are two types of Ru skirts in the picture. One kind of Ru skirt is composed of robe, chest-level Ru skirt, and a belt. The other is composed of three parts: short Ru, chest-level Ru skirt, and shawl, creating a luxurious and elegant style. The robe is similar to a loose long coat, which is worn on the outer layer of Ru skirts. Short Ru is similar to long sleeve short jacket. Short Ru in the picture is closed in the opposite way, and the sleeves are narrow

and long with small sleeves. It is waist length. The hem is tucked into the skirt and is generally not exposed. Chest-level Ru skirt is a long skirt that is worn on the outer layer of short Ru. Its waistline rises above the chest. From the aesthetic point of view, the long skirt makes women appear taller, with a more aesthetic visual effect. Shawl is a long fabric with patterns printed on it, similar to a scarf. In the picture, the shawl is worn on the shoulder, and the two ends fall freely.

We numbered the ladies in the painting from right to left, marked A to L.

Lady A is a side figure, the color of short Ru is light yellow of warm color system, and the pattern is square and symmetrical geometric figure of four-leaf plum. The color of chest-level Ru skirt is cool green, and the pattern is regimental pattern. The moon shadow white shawl is covered with plant diamond patterns. The style restoration diagram is shown in Figure 4a.



Figure 4. Restoration of dress styles of 12 ladies in *DaoLian* painting.

Lady B is a positive image. The color of short Ru is litchi white, and the pattern is regimental pattern. The light orange chest-level Ru skirt is evenly covered with broken

flower patterns. There are geometric patterns of plants on shawl. The color of the whole suit is low saturation. The style restoration diagram is shown in Figure 4b.

The image of Lady C is sideways. The green short Ru is covered with beaded pattern. The light-yellow, chest-level Ru shirt is covered with “s” pattern. The yellow shawl is printed with ripple patterns. The style restoration diagram is shown in Figure 4c.

The red short Ru of Lady D is printed with regimental pattern. The blue chest-level Ru short is covered with geometric curly grass patterns. Low saturation color is used for shawl. The yellow gray shawl is printed with geometric patterns. The style restoration diagram is shown in Figure 4d.

Lady E’s yellow short Ru is covered with curly grass patterns. Chest-level Ru shirt and the short Ru are in the same color. The rouge red shawl is printed with twig pattern. The style restoration diagram is shown in Figure 4e.

Ladies F’s clothes are all low saturation colors. The style restoration diagram is shown in Figure 4f.

Lady G’s blue robe contrasts with the pink belt. The green chest-level Ru shirt is decorated with geometric patterns. The style restoration diagram is shown in Figure 4g.

The pink short Ru of Lady H is covered with the beaded pattern. Chest-level Ru shirt and short Ru are in the same color and are decorated with green patterns. The scarlet shawl adds highlights to the whole dress. The style restoration diagram is shown in Figure 4h.

The lady I’s pink robe is covered with geometric patterns. Chest-level Ru shirt is decorated with begonia pattern. The style restoration diagram is shown in Figure 4i.

Lady J’s pink shirt Ru is printed with beaded patterns. The color of chest-level Ru shirt is orange. The style restoration diagram is shown in Figure 4j.

Lady K’s pale pink robe is covered with rolled grass. The color of chest-level Ru shirt is moon shadow white. The style restoration diagram is shown in Figure 4k.

The pattern of Lady L’s coat is plants beaded pattern. The blue dress is covered with diamond pattern. The orange shawl is covered with geometric patterns. The style restoration diagram is shown in Figure 4l.

2.5. Size Determination and Pattern-Making

By measuring the head–body ratio of the ladies in the painting, it was found that the head–body ratio was between 6.5 and 7.5, which is in line with the basic proportion standard of Asians. Therefore, pattern-making can refer to the positional relationship between human body parts and costumes.

The traditional Chinese costume is cut in a plane and straight line. The structure of “cross shaped, integrated and flat” has never changed in China’s thousands of years of history. The costume structure of the Tang dynasty was no exception. It was a traditional cross-shaped plane structure, with the length of the through sleeve as the horizontal direction and the front and rear center lines as the vertical direction.

Ru shirt is a classic dress for women in Tang dynasty. From the perspective of garment engineering, this paper analyzed the style, color, and pattern of Ru shirt and carried out 2D structure restoration by using CAD technology. The pattern of the first kind of Ru shirt is shown in Figure 5a. The pattern of the second kind of Ru shirt is shown in Figure 5b. The 3D restoration of ladies’ costume is shown in Figure 6 respectively. Finally, with the help of 3D virtual fitting technology, the 12 kinds of clothes in the picture were restored, and the visual similarity between the virtual copies and the prototypes were high.

2.6. 3D Virtual Ancient Costume Modeling

The 3D costume model in this study was built by CLO 3D software. CLO 3D is one of the most advanced garment modeling software in the world. The steps of 3D costume digital restoration were as follows: firstly, the models of adults and children were selected to build virtual mannequins, in which the height and bust of adults were 170 cm and 92 cm, respectively, and the height and bust of children were 120 cm and 62 cm, respectively. The next step was to follow the pattern-making principle of “cross plane structure” and

draw the pattern of ladies' costumes without shoulder seams and darts. This step is very important. The third step was to arrange, sew, and try on the pattern. Because the restoration objects were wearing multi-layer costumes, the simulation restoration process should follow the order of modeling from top to bottom and from inside to outside. In the process of modeling, it is necessary to determine the stable state of the previous layer and then carry out the modeling of the next layer, as shown in Figure 7a. This avoids errors in the simulation process. Then, we used the instrument to measure the weight, tension, and bending coefficient of silk fabrics. On this basis, the physical properties of the fabrics were adjusted to achieve fabric's drapability, wrinkle shape, thickness, and stiffness similar to the clothes in the painting, as shown in Figure 7b. Finally, the textures and patterns of the fabrics were processed using image editing and image processing technology to make it have a real luster and bump feeling, as shown in Figure 7c.

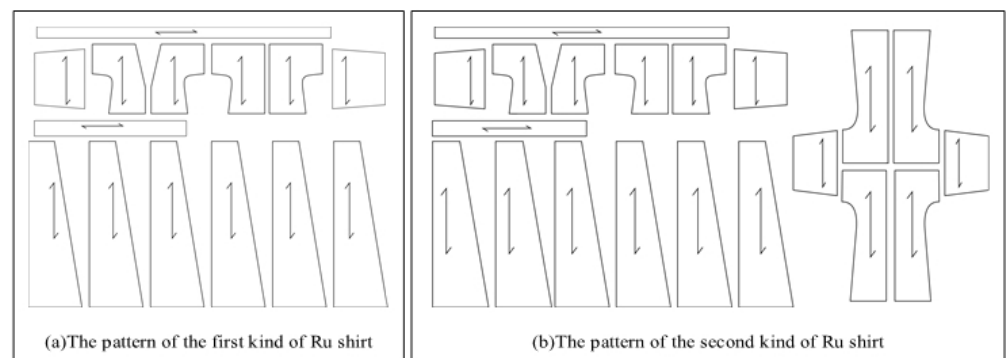


Figure 5. Different types of garment patterns.



Figure 6. Cont.



Figure 6. The 3D digital restoration of 12 ladies' clothes in *DaoLin painting*.

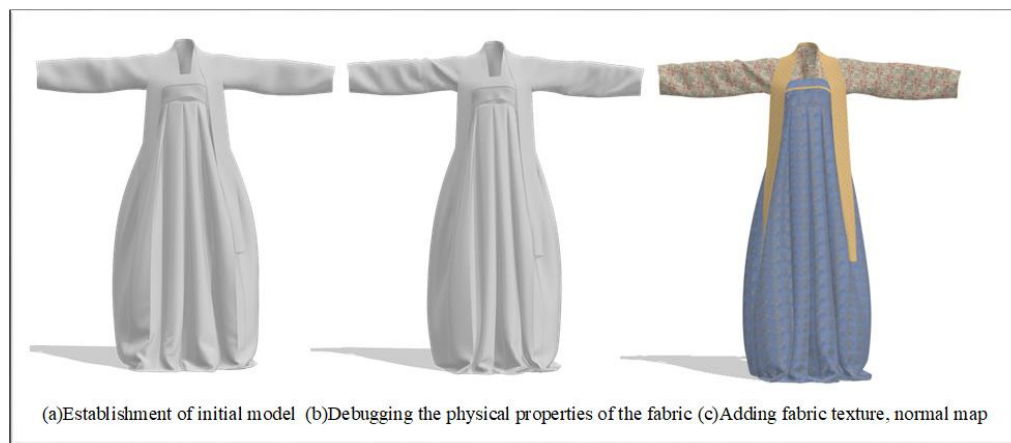


Figure 7. The 3D virtual ancient costume modeling.

3. Result and Discussion

We have digital modeling and virtual displays of ancient costumes. Compared with traditional historical costume displays, virtual displays have the following advantages. First, they break through the limitations of traditional displays, time and region, and can be displayed anytime and anywhere. Second, they break through the limitations of the traditional static display and can carry out 360-degree display. Third, they reduce the cost of the display. Fourthly, they increase the visual experience of visitors. If augmented reality technology and somatosensory technology are used in the future, they will greatly increase the interactivity [29].

After thousands of years of precipitation, Chinese ancient costumes embody distinctive national characteristics and profound cultural connotation, and they embody the aesthetic and humanistic spirit of the Chinese nation. However, due to the limited information, what we can do is restore them visually, and the information, such as costume sizes, remains to be investigated.

Nowadays, the digital technology of human body modeling, clothing virtual fitting, fabric simulation, and pattern design is basically mature. Digital protection of historical and cultural heritage is an inevitable trend. For the academic research field, this provides a technical means for the restoration of historical costumes and helps to build a virtual costume museum. For the field of fashion design, it promotes the construction of modern Hanfu personalized platform, increases interactions with customers, and improves customer satisfaction.

4. Conclusions

As a historical and cultural heritage, ancient costumes are the carriers of culture. The protection of these precious resources has been the focus of all mankind. In this study, we took the ladies' costumes in *DaoLian painting* as the research object and studied the style, collocation, colors, patterns, and structures of the costumes, and we used the 3D virtual technology to restore 12 sets of costumes. We came to the following conclusions: (1) The dresses of the ladies in the painting were typical Ru shirts in the prosperous Tang dynasty. (2) The costume colors in the picture were mainly blue, moon shadow white, green, orange, and scarlet. The color matching paid attention to the contrast between cold and warm colors and matched with the same color system. The patterns were mainly plants, which is more in line with women's aesthetic and reflects the promotion of women's status in the Tang dynasty. (3) It is feasible to use virtual fitting technology to restore historical costumes. This provides a new method for the digitization of historical and cultural heritage and builds a foundation for the establishment of a virtual costume museum. (4) From the perspective of cultural relics protection, the digitization of historical costumes can make the public enjoy the human cultural heritage more widely. From the perspective of fashion design, the study of ancient costumes can provide material for modern fashion design.

Author Contributions: K.L. and X.Z. developed the research idea. Q.Z., X.L., R.W. and C.Z. collected costume information and data. Q.Z. made style drawings, patterns, and 3D garments. B.Z., Z.L., X.X., Y.W., J.Z. and C.C. provided a lot of modification suggestions. All authors have read and agreed to the published version of the manuscript.

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