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Three-Dimensional Construction Method for Two-Dimensional Film Pattern Design in Sustainable Rhinoceros Skin Coating Technology

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Abstract: In order to effectively save material- and time-related costs in sustainable rhinoceros skin lacquering technology, a three-dimensional construction method is developed based on optical microscope tomography and computer image recognition technology. By analyzing the influence of the underlying twisting method, the number of lacquer layers and the grinding process, the pattern presentation process of rhinoceros skin lacquer is shown in three-dimensional space, and the relationship between pattern style and process flow is further revealed. Computer-aided technology can design and simulate the presentation of the pattern in virtual space, providing a priori guidance for the production of rhinoceros skin lacquerware and new ideas for the innovation of process methods.

Keywords: rhinoceros skin coating technology; pattern design; 3D construction method

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1. Introduction

China was the first country to produce and use lacquer, and the discovery of natural raw lacquer can be traced back to more than 7000 years ago [1–5]. There are 471 kinds of lacquer art techniques [6], including rhinoceros skin lacquer. As an important craft of lacquerware, rhinoceros skin lacquer is one of the decorative techniques that has survived in traditional Chinese lacquer art with very high artistic and research value. Rhinoceros skin lacquer, because of its different polished patterns and brilliant colors, is often likened to tiger stripe lacquer and pineapple pattern lacquer. At present, there is still controversy in academia about the date of origin of rhinoceros skin lacquer. According to the literature [6], rhinoceros skin lacquerware appeared in the Tang Dynasty (618~907 AD). In 1984, a pair of rhinoceros skin lacquer ear cups were unearthed from the Tomb of Eastern Wu in the Three Kingdoms. Mr. Wang Shixiang believed that rhinoceros skin lacquer was present before the Three Kingdoms period. Rhinoceros skin lacquerware made great progress during the Song and Yuan dynasties (10th to 14th centuries AD), and the production technology matured day by day. During the Ming and Qing dynasties, the development of the rhinoceros skin craft reached the optimum level.

There are generally two kinds of traditional Chinese lacquerware production techniques: one is carved, such as carved red lacquer and carved red lacquer with a black layer, namely "TiHong" and "TiXi", etc.; the other is depicted with gold and silver. However, rhinoceros skin lacquer is a unique technique with a wonderful texture, and it is neither depicted nor carved. At present, there are two main theories about the origin of the rhinoceros skin lacquering technique: one is the "saddle origin theory", and the other is the "belt rhinoceros skin theory" [7]. Due to the unevenness of ancient saddles or belts, their color and pattern change with long-term contact with other objects. Lacquerware craftsmen were inspired to imitate this in the process of making lacquerware and developed the rhinoceros skin lacquer process. Rhinoceros skin lacquer technology has become more and more mature after many generations of development and inheritance [8–12], and the production of delicate rhinoceros skin lacquerware must go through the processes of scraping clay, cloth pasting, wrinkling, mane lacquer, grinding and so on. The production process is different for different materials. The whole process is complex and demanding, and the completion of a perfect piece of work takes many years. The final presentation of the piece of work will reflect the quality of the process in each element, such as whether the surface is flat, whether the grain is smooth, whether the grinding process is in place, whether the color lacquer is fresh, etc.

The beauty of rhinoceros skin lacquer lies in its varied and flowing lines, the vivid color between the layers of lacquer, and the rich layers, which make its pattern change and natural and flexible. The flow of the line changes depending on the shape of the twisting. The original meaning of “twisting” refers to a small hill made of soil, using tools such as loofahs to pile up the adjusted lacquer into a small hill of uneven height. Different twisting methods and different lacquer ratios will form different shapes, heights and dense mounds, which can produce many types of textures [13]. When the bumps are smoothed, a cross-sectional pattern of the lacquer layer is revealed, taking on a whirlwind eye or terraced shape [14]. Rhinoceros skin lacquer patterns are commonly decorated with flake clouds, round flowers and pine scales. In the production process of rhinoceros skin lacquer, dozens of layers of color lacquer should be applied. The richer the lacquer layer, the fuller the layer of pattern displayed. The color lacquer is mainly red, yellow and black. There is also gold cover lacquer, in which gold leaf is pasted on the surface after the mane lacquer, and then the color lacquer is covered with alternating colors [6]. Contrasting colors between layers are often used instead of the same color system. The traditional rhinoceros skin lacquer has different colors such as “red, yellow and black” and “red, yellow, green and black”, and the color of the lacquer layer is related to the vividness of the entire artifact pattern. Therefore, the design and production of beautiful lacquerware should take into account many aspects, as well as the coordination of texture and the shape of the utensils and materials.

Lacquerware production takes quite a long time; each main lacquer needs to be fully dried through the lacquer layer before the follow-up process. The production of rhinoceros skin lacquer is particularly complex, requiring dozens of repeated color lacquers, and after the completion of the lacquer layer, fine grinding, polishing and other processes also need to be carried out. The whole process takes months to years. An error in any of the stages can lead to imperfections in the lacquerware. Due to the difficulty of precisely controlling the process conditions and the lack of systematic theoretical guidance, many excellent techniques are on the verge of being lost, and the rhinoceros skin lacquer craft is one such technique. The comprehensive inheritance and development of lacquer art culture needs to explore new methods and directions [15–17]. Limited studies about twisting and surface structure have been reported recently, such as the variable coating technique and grinding technique [18–22]. At present, the research on the lacquer process focuses on art appreciation, lacquer composition, proportion, lacquer film properties and the control of lacquer layer drying conditions. This work attempts to use reconstruction and simulation technology from a new perspective to demonstrate the relationship between the presentation effect of rhinoceros skin lacquer pattern and the process flow from the perspective of three-dimensional space, providing a priori method guidance for rhinoceros skin lacquerware production [23–27]. On this basis, to a certain extent, it is expected to create more novel and exquisite patterns. The results can be foreseen, thereby resulting in saving materials, processes and time costs. This experiment focuses on the twisting and the number of color lacquer layers in the rhinoceros skin lacquer production process, exploring the relationship between the final presentation of the rhinoceros skin lacquer pattern and the shape, density and height of bottom twisting. At the same time, the relationship between the number of lacquer layers and the fullness of the pattern is also revealed. The results show the mystery and beauty of rhinoceros skin lacquer craftsmanship in an intuitive way.

2. Materials and Methods

The researchers first built and simulated a three-dimensional model of bottom twisting, and then laid the lacquer layer by layer, obtaining a three-dimensional simulation model. Subsequently, the model was polished from the top layer, from which the pattern display and change process could be seen. Autodesk Maya 3D animation software was used for 3D construction production. NURBS, POLYGON and SUBDIVISON tools in the Modeling module were adopted to build the initial shape of the model. Then, NURBS and POLYGON in the Artisan module were utilized to modify and sculpt the obtained model. At last, the final visual presentation was generated by the Rendering module. Detailed information about Maya is shown as follows: (1) Click the "File" option to build a simulation scene; Maya will automatically process a set of files. Import the design sketch or intent image into the "source images" folder, and then return to "View" in the operation interface to import the image and adjust the "Alpha Gain". (2) Select "Create Polygon" in "Mesh Tool" or "Create Polymorphic Cube on Grid" on the toolbar, and then click "Multi-Cut Tool" to modularize the initial surface and build a large paint base tire model. (3) Control the "vertices" of the plane with the "Offset" tool to pull out the surface, and flexibly adjust the bottom twisting of the lacquer according to the desired style. (4) Use the "Extrude" tool to pull out the bottom tire model and the bottom twisting model to the desired thickness, and control the keyboard "2" and "3" (corresponding to "Frame + Smooth Polygon Mesh Display" and "Smooth Polygon Mesh Display") to adjust the model "twisting" shape angle and height. (5) Repeat step 2 to make the "paint" layer, adjust the surface "vertices" according to the bottom tire and the model "twisting" to make the model fit completely, and then use the "Offset" option to pull out the thickness of the paint layer. (6) Repeat step 5. This step simulates the "painting" process. The "painting layer" model is stacked on the x-axis coordinate system until a satisfactory effect is achieved. (7) Open the "paint" mode to obtain the texture display and change process, and choose the depth freely and flexibly to simulate the sandpaper "grinding" process through the "Boolean operation" ("difference" or "cutting" of the model). (8) Render the model and add materials to simulate the color texture and distribution of the paint layer for the final presentation of the real object through the Hypershade interface. (9) Finally, export the model file to obj format or stl format, and print it through 3D printer equipment.

A square wooden block was selected. Scraping clay, cloth pasting, wrinkling, mane lacquer and other procedures were used to prepare a sample that was not yet polished. The color alternated between red, black and gold, following grinding with 800 mesh sandpaper layer by layer. A canon 6D2 camera with an old frog 1000 mm macro lens was used to record the polished image until the lacquer layer was all sanded off the end. The resulting series of images were calibrated with image processing software ImageJ, and the images were added to form a stack of pictures, and a side view of the stack images was generated. Starting from the unpolished top of the lacquer layer, the photo was displayed layer by layer. The change process of the pattern with the sanding process can be seen from the position of the preferred pattern, and the depth of the position of the image in the lacquer layer was located in the side view.

The picture stack was finally imported into the 3D reconstruction software Avizo. The middle part of the area was selected, and the bottom twisting shape was reconstructed in three dimensions to build a model of the twisting, which corresponded to its relationship with the surface pattern presentation.

3. Results and Discussion

3.1. 3D Model Aided Design

It was found that the presentation of the lacquer pattern has a great relationship with the shape, density or height of the bottom layer of twisting. The color setting of the lacquer layer and the number of layers are also directly related to the vividness and fullness of the lacquerware. In order to make the computer-aided design more instructive, we explored the influence of different twisting structures on the skin pattern. We firstly simulated the cases of point-type and linear-type twisting structures separately (Figures 1 and 2). The results show that the linear-type twisting has a better consecutive pattern. Random-point- and linear-type twisting structures have a more realistic surface structure (Figure 3). Furthermore, we could design the twisting structure to obtain more comprehensive and interesting structures (Figure 4). The skin pattern could be effectively adjusted by computer-aided means according to the needs, which provided guidance for subsequent rhinoceros skin coating technology development. Therefore, we developed a 3D construction method to virtually build a rhinoceros skin lacquer model in real space and analyzed the twisting and grinding process from a more intuitive perspective, so as to provide guidance for personalized design and practical teaching.

As a result, the bottom twisting style and lacquer layer color setting could be changed, and new models could be quickly obtained. It is expected that in subsequent design and production, the three-dimensional model of the designed underlying twisting can be directly imported into the 3D printing software as data, and the actual structure can be printed and directly used for lacquerware production. Three-dimensional scanning software can also be used to directly depict handmade twisting. The obtained data can be imported into the software, directly simulating the pattern shape that may occur in the later stage.

3.2. 3D Structural Analysis

The lacquer texture gradually changes with the grinding process, and the pattern gradually appears (Figures 5 and 6). It could also be clearly seen that the pattern does not reach the degree of fullness before the polishing is carried out to the position of Figure 6f. As the polishing progresses, the pattern of image 6f is optimal, and the colors and layers are the richest. By continuing to polish, the bottom twisting part begins to be exposed, and the image form evolves accordingly. After the polishing is carried out to Figure 6h, the image aesthetics are significantly insufficient. Figure 7 is a comparison chart showing the enlarged details of the high-definition picture. In this experiment, the three adjacent layers of red, black and gold lacquer are counted as a set of layers, and the number of circle layers around the vortex pattern gradually increase with grinding at the beginning. The number of lacquer layers around the vortex pattern in the observed area is gradually increased from 4 to 12, corresponding to the position of Figures 7c and 6f. With further grinding, the number of coil layers of the vortex begins to decrease, as in Figure 7c, and the number of lacquer layers is reduced to three.

In order to analyze the depth position of Figure 6f in the lacquer layer, we added this series of pictures together to make a stack and analyzed the side view of this stack. We browsed the photos layer by layer from the top floor down, then paused when we reached the best image position (Figure 6f), and finally analyzed the side view. The yellow cross in Figure 8a is positioned in a vortex pattern position, and the side views of Figure 8b,c show the specific depths corresponding to the side lacquer layer. The cross intersection is the selected vortex position. It can be seen that the image is the richest and most beautiful when the polishing is carried out to the highest point of the bottom twisting. In addition, from the side view Figure 8b,c, it can be seen that the overall thickness of the entire lacquer is higher than the highest part of the bottom layer twisting. It is easy to take into account the optimal pattern and the overall flatness of the lacquer surface.

Figure 9 shows the structure of the underlying twisting using a three-dimensional reconstruction method. Figure 9a is a three-dimensional model, and Figure 9b is the corresponding position display of the model. Figure 9c is the corresponding side view. The position of the bottom twisting protruding is on the surface image, showing a swirling pattern; the concave position between the twistings shows an irregular-shaped thread. The number of layers is small, and the spacing between the layers is wide, with many edges and angles. The junction between twistings is often a ridge-like protrusion pattern due to slight height undulations. Therefore, according to the pattern presentation of the utensils, it is possible to roughly guess the bottom twisting method. According to their own expectations, the display of the pattern can be designed to a certain extent.

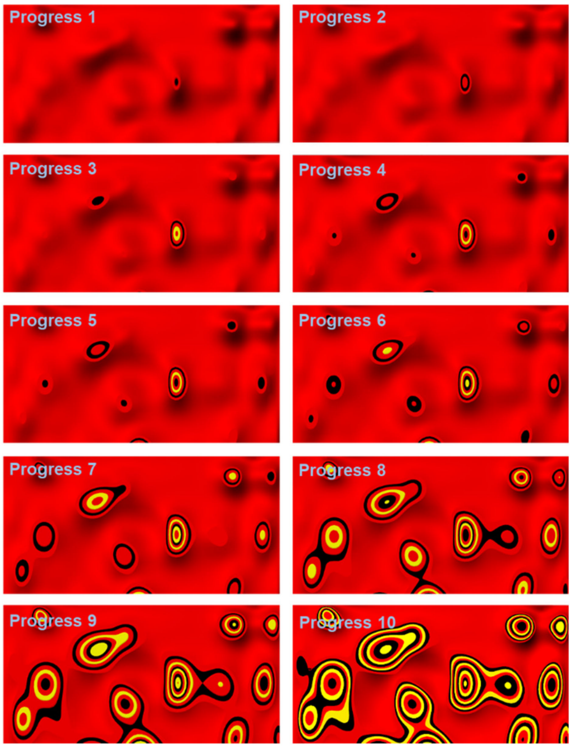

Figure 1. Three-dimensional structural simulation model based on point-type twisting with different layers.

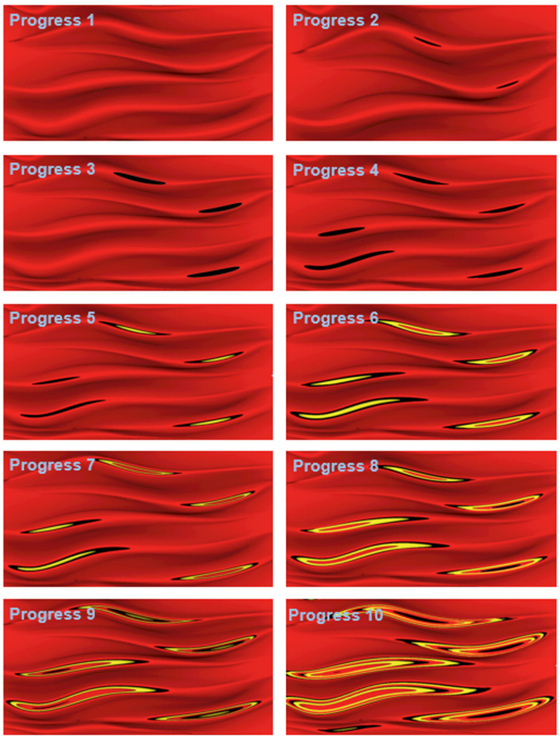

Figure 2. Three-dimensional structural simulation model based on linear-type twisting with different layers.

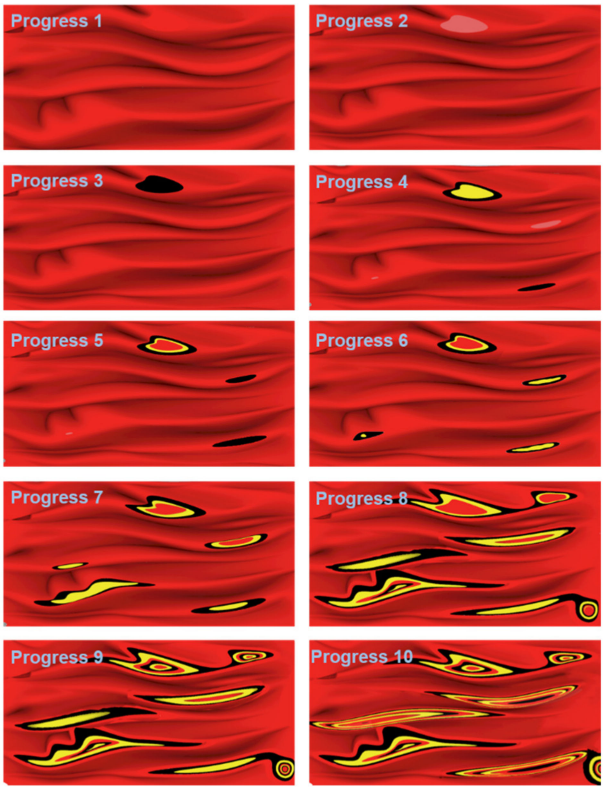

Figure 3. Three-dimensional structural simulation model on random-point- and linear-type twisting with different layers.

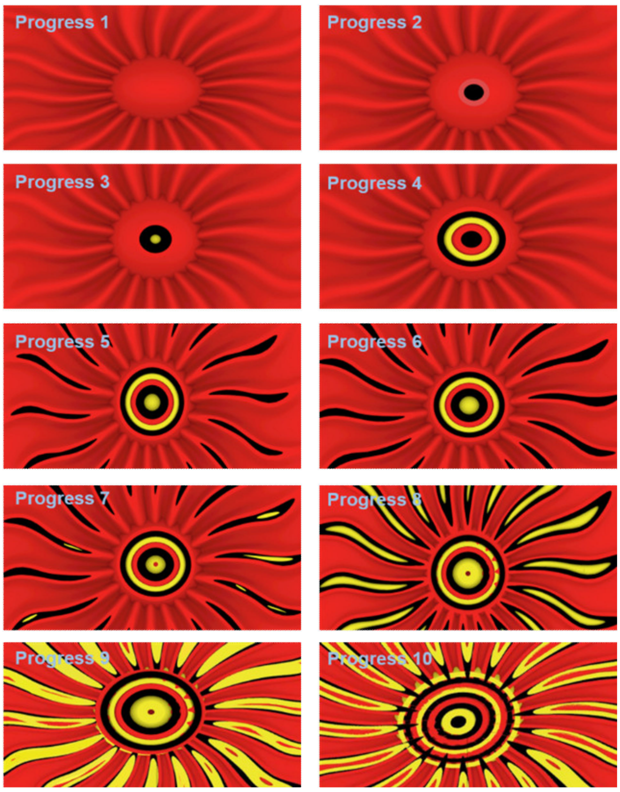

Figure 4. Three-dimensional structural simulation model on specific-point- and linear-type twisting with different layers.

Figure 5. The square wooden block with scraping clay, cloth paste, wrinkling, mane lacquer and other processes.

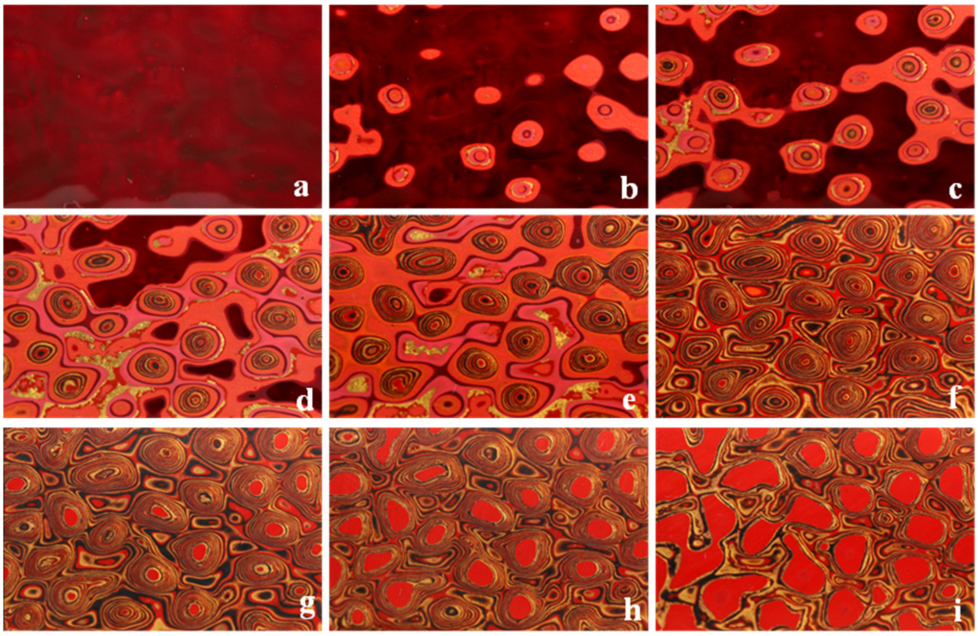

Figure 6. Representative patterns during the polishing of the lacquer layers. (**a**) Initial lacquer skin surface before polishing; the lacquer textures by polishing of the 1–10 (**b**), 1–19 (**c**), 1–28 (**d**), 1–40 (**e**), 4–53 (**f**), 12–53 (**g**), 26–53 (**h**) and 41–53 (**i**) layers.

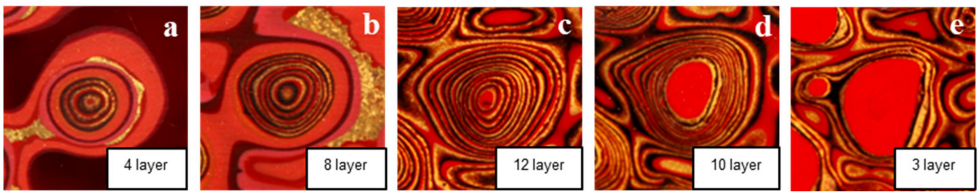

Figure 7. Evolution of local details of the swirling pattern during the polishing process with different layers (**a**–**e**).

3.3. Typical Rhinoceros Skin Lacquer Production

Through the above analysis, the mystery of the flow and change in rhinoceros skin lacquer can be revealed. In order to obtain exquisite lacquerware, craftsmen need to strictly control all aspects, from the beginning of lacquerware production to the presentation of the entire effect. Figure 10 shows several representative rhinoceros skin lacquer craft works from the author's studio, from which the diversity of bodies, shapes, colors, patterns, etc. can be perceived. Figure 11 is an optical picture of a cross-section obtained from a rhinoceros skin leather cup after being broken. The picture is a panoramic view obtained from more than 60 high-definition photos after being positioned, superimposed and combined, which can clearly identify the continuity, color and shape of different lacquer layers.

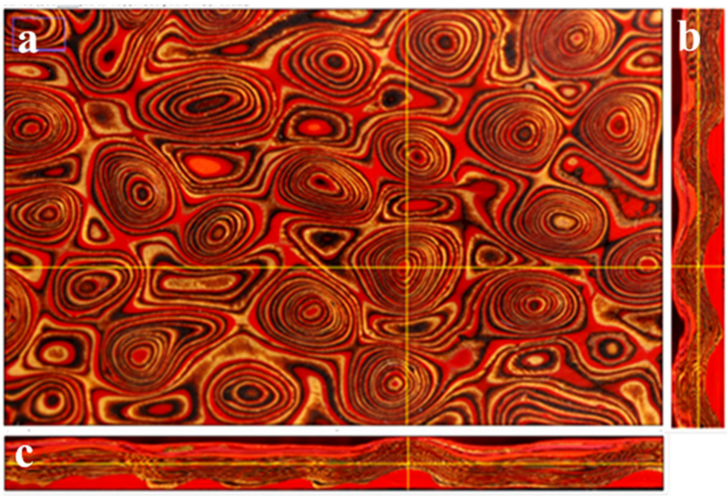

Figure 8. Analysis of optimal pattern and position from top view (**a**) and two different side views (**b**,**c**) of lacquer.

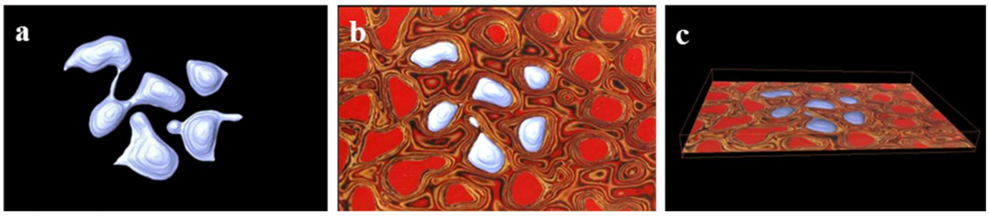

Figure 9. Three-dimensional reconstruction of bottom twisting (**a**) and bottom twisting in lacquer from different views (**b**,**c**).

Figure 10. Typical rhinoceros skin lacquer craft work.

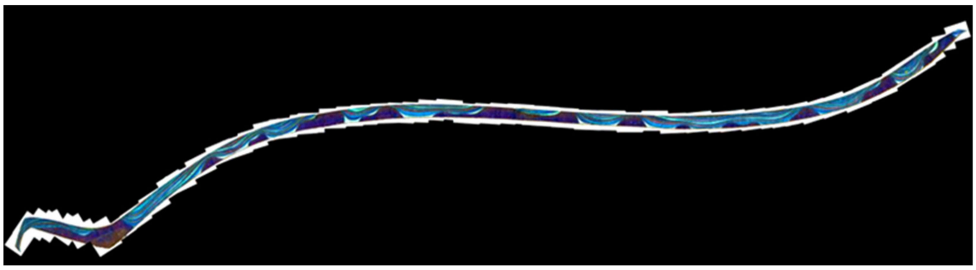

Figure 11. Cross-section lacquer layer of rhinoceros skin cup.

4. Conclusions

The presentation of rhinoceros lacquer is affected by many factors, and different parameters play decisive roles in its final appearance. Its pattern lies in its rich unpredictable changes in the thickness of the paint layer and the deformation of the paint layer after drying in the shade. Additionally, different manual polishing methods can create different presentations. The time of placing and the thickness of each layer of paint can also be adjusted manually to affect the presentation of rhinoceros lacquer. Therefore, a series of parameters could be set in a virtual three-dimensional space for testing, and the final effect of the actual paint art could become more specific and referable.

Although the rhinoceros skin lacquer process has a long history, records of its craft characteristics and expression methods are relatively rare. The related skills are generally inherited by master and apprentice, and few written records are left. It is necessary to provide rhinoceros skin lacquer a new era through the exploration and innovation of a variety of methods. Analyzing the process flow of rhinoceros skin lacquer based on the three-dimensional reconstruction method is an attempt to solve the current problem. It provides a new direction for craftsmen to design lacquerware and enriches the materials used for practice and teaching. It should be recognized that the beauty of rhinoceros skin lacquer lies in its rich unforeseen changes. Changes in the thickness of the lacquer layer, deformation after the lacquer layer is dried and different manual grinding techniques can create different presentation effects. Computer-aided design can only simulate the general outline to a certain extent and cannot fully interpret the beauty of rhinoceros skin lacquer. Interdisciplinary cooperation still requires continuous exploration and efforts from generation to generation of lacquer artists.

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