Highlights

Image Formation on the Shroud of Turin - a Digital 3D Approach

Cicero Moraes

- Fabric dynamic simulation and distance texturing of meshes allowed the generation of patterns that simulate the possible structure that generated the image on the Shroud of Turin.
- The pattern of the spots indicates that the source of the impression on the Shroud of Turin is more compatible with a low-relief base.
- The volume of the human body would generate a distorted and significantly more robust image pattern than that present on the Shroud of Turin.
- European funerary art from the medieval period shows elements very compatible with those present in the Shroud of Turin.

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Cicero Moraes

Arc-Team Brazil, Sinop, Mato Grosso, Brazil

Abstract

Many people believe that the Shroud of Turin is the cloth that was used to wrap Jesus Christ after his death, while others consider it a medieval work or even a forgery from that period. This artifact has generated significant controversy and debate, especially with the advent of new technologies and the recent popularity of social networks. This study seeks to present a simple and objective explanation about the element of origin that imprinted in a fabric the figure of an adult man with signs of physical violence, indicating that the pattern corresponds more to a low-relief origin than to the volumetry of a real human body in a post-mortem state. The work is based on a digital environment, with free and open-source 3D modeling software.

Keywords:

Graphic collision patterns, 3D computer graphics, fabric dynamics simulation, collision simulation, Shroud of Turin, open-source software

1. Introduction

The Shroud of Turin is a linen piece measuring approximately 4.4 m x 1.1 m that illustrates the front and back image of an adult man, with a beard and long hair, with his hands over his genital region and marks that would indicate great physical violence suffered. Its first appearance took place in France, in 1355 and since then, the piece has been the center of a heated debate. In general terms, one side claims that it is the authentic shroud of Jesus Christ, and the other claims that it is a work or even a forgery of the medieval period [1][2][3].

In an article published in *Nature* in the late 1980s, C14 (carbon-14) dating suggested that the Turin Shroud originated in the medieval period [2]. This finding seemed to extinguish hopes that the shroud was an authentic relic associated with a biblical figure. However, over the years, this study has faced significant criticism from experts. They pointed out issues with the material collection process and proposed an older dating that aligns with the time when Jesus Christ is believed to have lived [4]. As the years went by, the controversy intensified due to new publications and the rise of social media, which facilitated a broader debate among experts and the general public.

In one such online debate, in a discussion group of individuals with high abilities and giftedness, the test of how the figure may have been designed for the fabric was proposed to the author, who had not worked with the Shroud of Turin previously.

In the first visual analysis two elements caught the author's attention, on the one hand, the rigid and straight shapes of the body, somewhat incompatible with the anatomy of an adult human, therefore looking more like the work of an artist than an impression of a real person; and on the other hand the three-dimensional appearance of the body, as if it were an orthogonal projection onto the fabric and not the formation of a pattern resulting from the contact of a body with the fabric, therefore suffering the structural deformation expected when a 3D element is projected onto a 2D plane.

The first inference was that the image could be either a painting on the fabric or a print from a bas-relief. To test and illustrate the approach, two projection scenarios were proposed on a digital 3D fabric, one with a three-dimensional body and the other with a body in low relief.

2. Material and methods

The process was carried out entirely on the *Ubuntu 20.04* Linux operating system (https://ubuntu.com/), using open source (and free) software, available for download. This approach allows the technique to be replicated by those who wish, without spending resources with licenses, regardless of the operating system, since the programs used are available, in addition to Linux, for Mac OS and Windows.

Initially a human body was parametrically adjusted in the *MakeHuman* software

(http://www.makehumancommunity.org/) with the following parameters: male, adult, ≈33 years old, thin and ≈1.80m tall (Fig. 1). The model was exported as a Collada (.dae) file containing the armature to articulate the body.

The model was imported into *Blender* 3D modeling software (https://www.blender.org/), where the body was adjusted to scale and articulated as closely as possible in relation to the image by Giuseppe Enrie, 1931, in the public domain and available on Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Shroudofturin.jpg). To match the model of the Shroud of Turin, the beard and hair were modeled. The eyes, mouth, nose, chest and other structures received small structural corrections to make them compatible with the target individual (Fig. 2, A). When comparing the 3D model with the two-dimensional figure, a general similarity can be seen, except for the left hand which is significantly more displaced on the shroud (Fig. 2, B). It was decided to keep it this way, since the limbs are symmetrical and the right hand conforms significantly well to that of the shroud. The didactic aspect had great weight in the choice of the model's reflected position, since originally the hand that is above is the left, and not the right like the model in the current study. This approach simplifies the creation of visual material by focusing on contact behavior in relation to the best-known Shroud of Turin photos.

A plane measuring 110 cm x 220 cm was created, subdivided into 31,400 4-sided faces (Fig. 3, A). The body, rotated 180 degrees, was configured as a fixed and collision element (https://docs.blender.org/manual/en/latest/physics/soft_body/collision.html) and the upper plane, was configured as a dynamic tissue (https://docs.blender.org/manual/en/latest/physics/cloth/introduction.html), receiving influence from gravity, whose calculation made it fall on the body and conform to the surface (Fig. 3, B).

The two models, the three-dimensional body and the fabric after dynamic deformation, were exported as stereolithography (.stl) and imported into the *CloudCompare* software (https://www.cloudcompare.org/main.html), where a visual histogram was created on the fabric mesh, compared to the body, with only two states: 1) regions touching the body in red and 2) regions not touching the body in blue (Fig. 4). The mesh histogram was converted into RGB color for the faces and the mesh was

exported as a Polygon File Format or the Stanford Triangle Format (.ply) file, as it allows vertex color (https://docs.blender.org/manual/en/latest/modeling/meshes/properties/object_data.html), the type of coloring used in the process.

The file with the colored mesh (vertex color) was imported into *Blender* and the shroud with the dynamic fabric simulation received a color data transfer using the bake tool (https://docs.blender.org/manual/en/latest/render/cycles/baking.html), where the vertex color was converted into UV texture color, that is, into an image file with 1100x2200 pixels, with two-dimensional color data (https://docs.blender.org/manual/en/latest/modeling/meshes/editing/uv.html). In this way, it became possible to visualize the contact data both in the state of deformation on the body (Fig. 5, A), and in the initial state when the mantle is flat, before the physical simulation (Fig. 5, B).

To simulate a low-relief version, the non-retentive object creation tool of the *OrtogOnBlender*, a *Blender* add-on [5] was used and the model's generation base was not at the lower limit of the back, but rather a slightly below the middle of the arms, aiming to keep the details more visible at the back without generating a model that is too high in the Z axis (Fig. 6, A). The resulting model was resized by 0.25, that is, 1/4 of the original size on the Z axis (Fig. 6, B). Unlike the 3D body that was not placed on any surface, the current one has a base, simulating a stone, wood or metal plate. Then the low-relief mesh went through the same process carried out on the three-dimensional body, receiving the fabric simulation, which was exported to the distance comparison software (Fig. 6, C) and imported in order to incorporate the texture of the distances to the shroud mesh with fabric simulation.

3. Results

A series of images were generated with a didactic approach regarding the patterns left by a three-dimensional body and one in low relief.

The 3/4 orthogonal view allows the observer to contemplate the volumetry of the two models (Fig. 7 on the right) and the patterns left on a two-dimensional plane (Fig. 7 on the right). While the three-dimensional model is printed in a distorted

way, generating an individual with more robust body characteristics, the impression resulting from the low relief preserves the shape of the original with enough detail for the observer to identify the anatomy in question.

An orthogonal top view of the structures further highlights the robustness of the pattern resulting from the three-dimensional model, in addition to a smaller surface contact area, when compared with the pattern resulting from the low relief (Fig. 8).

It is important to emphasize that the contact approach evaluated the points of touch of the shroud in relation to the models and, as the bas-relief was wider than the three-dimensional body loose in space, this resulted in a clearer image of the bas-relief than that of the three-dimensional body. To illustrate only the region of interest, another image was created (Fig. 9) showing only the contacts corresponding to the body region, since, if the objective was to generate an impression, the pigmentation liquid would be placed just on the body part and not outside it, that is, on the rest of the base in low relief.

An overlay of the prints on the Shroud of Turin image reinforces the issue of the remote possibility of a three-dimensional original source, since the pattern coming from the volume appears distorted in relation to the Shroud of Turin figure (Fig. 9 on the left), while the pattern coming from the low relief fits with significant compatibility (Fig. 9 on the right), except for the final portion of one of the hands, which will be discussed later.

4. Discussion

The most obvious element that can be seen in the projections is that, if the piece of linen were adjusted to the human body of an adult individual, the resulting image of the contact regions would be that of a body much more robust than the original by account of the effect of converting a three-dimensional object into a two-dimensional one, well known on world maps and more popularly called “Agamemnon’s mask” because it resembles the piece of metal with the face stretched out (`https://upload.wikimedia.org/wikipedia/commons/c/c8/MaskOfAgamemnon.jpg`).

The printed image, resulting from the low-relief contact regions, is much more

compatible with that present on the Shroud of Turin, corresponding significantly with its limits, even though it comes from a base that is not completely flat. The point of greatest incompatibility is on the left hand, a situation already explored by Rodríguez (2024), who indicated a large asymmetry (7 to 10 cm) between the two arms [3].

Other studies corroborate the issue of deformation in two-dimensional space, even though their original objective was not to evaluate such a situation, such as the one that presents an experimental version based on a corona discharge and the model, generated from a three-dimensional body, contains the structural deformation that makes the body more robust [7]. The very hypothesis of creating the image from the corona discharge depends on a series of concomitant elements that are difficult to achieve, such as an energetic discharge that occurred from an earthquake and that would affect the shroud, arranged in a specifically more open way by flower fodder and that in this way, it would make possible the orthogonal printing of the front and back figures on the fabric, with a power low enough not to burn it and high enough to mark the fabric with an image [6]. The problem is that, even if there was such a discharge and an image was recorded, any three-dimensional displacement in the structure would generate an image deformation, not an orthographic body; furthermore, the 2024 study, composed by the same author [7], does not explain how the body image creation experiment was carried out, since in 2010 it was claimed that it would not be possible at that time to carry out an experimental reproduction to produce such an image and the examples shown were either very localized or were low-relief objects, such as a coin and a small snake [6].

An attempt to recreate the print patterns of blood marks and anatomy was made by Garlaschelli (2010) [1]. In that study, the result of the body pattern, pigmented over a wider region and surrounded by fabric, presented the same print pattern that was much more robust than the base individual. Therefore, it became clear to the researcher that the only way to reproduce something close to the design of the shroud would be to pigment only some regions of the body, replace the face with a reproduction in low relief and complement the missing region of the left hand later, with another technique. Even so, the resulting model did not include the robustness necessary for an orthographic view of the body, as some regions such as the legs and arms were thinner than those on the Shroud of Turin, due to limited structural selection [1].

Regarding the use of three-dimensional models, Fanti et al. (2010) carried out a digital simulation, but did not present in the article a view of the texture projected on the two-dimensional plane of the shroud, making it impossible to objectively compare the original with the digital model [8].

Moreno (2017) studied the Shroud of Oviedo for many years and, according to the author, this would be another piece that would have involved the head of the body printed on the Shroud of Turin, making it a set with this one. The publication presents a projection with blood marks from the shroud of Oviedo, and a drawing of the structure of the face on it, where the nose, mouth and ears appear, clearly denoting the issue of structural deformation when transported to a two-dimensional plane, highlighting the already discussed effect of "Agamemnon's mask" [9]. However, as is known, such an effect is not present in the Shroud of Turin.

De Caro & Giannini (2017) proceeded with a digital restoration of the region of the hands, and through which they would have located part of the thumb and scrotum of the individual printed on the shroud [10]. There is, however, a condition of low resolution in the shroud that can generate misinterpretations about some characteristics, such as the tendency of the human brain to complement data, such as pareidolia, perception, etc. [11]. An example that illustrates the situation well is another study from 2017, which, unlike the one mentioned above, indicates that in the location just below the pelvis, the marks would be too long to be scourges and could, in fact, be the folds of a tissue, similar to a thong [12].

In addition to problems related to the issue of resolution, there are those that involve the forensic area, such as a study that analyzed possible bloodstain patterns (BPA) for the Shroud of Turin case, finding a series of inconsistencies, and physical behaviors that differed than expected, which led the authors to conclude that such inconsistencies pointed against not only the reality of the piece itself, but also its authenticity, suggesting that it was an artistic or didactic representation from the 14th century [13]. The authors' blunt observations motivated the publication of letters to the editors, where other experts also criticized the article head-on, presenting in some cases their own technical production as elements of refutation [14]. The response followed the hostile tone taken by academic opponents, not only presenting the technical arguments, but

also highlighting cases of self-citation, publication in potentially predatory journals and citing a case of article retraction, all involving the opponents and materials related to the research of those with the Shroud of Turin [15].

This episode illustrates, in a very didactic way, how the subject is a constant source of heated debate, not only among the public, but also among academics with extensive experience in the areas of activity. For this reason, this study took care to share as much information as possible about the techniques used and, since the programs used are free, open-source and run on the most popular operating systems for computers (Windows, MacOS and Linux), those interested in replicating, improving or even refuting the technique have all the necessary information to do so.

Care was also taken to consult numerous publications on the Shroud of Turin. Not all of them, obviously, could be mentioned, since the approach here is more focused on the issue of contact and not, for example, on microscopic elements of linen, or the blood fluid dynamics. The feature that draws the most attention is precisely the shape of the contact on the original shroud, which is little compatible with the pattern left by a real body and very compatible with a two-dimensionally pigmented element or generated from low-relief art. Although some authors usually indicate that it is a structure, without a shadow of a doubt, anatomically coherent and that until now science has not been able to explain how it would have been formed or how to reproduce all the elements together [6][7][8][10][16][17][18][19][20]. The fact of not explaining in detail, both at the macro and micro level, all the elements that involve the formation, does not invalidate some inconsistencies linked to the piece does not imply in not illustrating evidence of how it may have been created, since the copy perfect of such an old piece, it is still impossible [15].

Even authors who advocate the authenticity of the piece generated images with the expected structural deformation when they projected the marks and body onto a two-dimensional plane [7][19]. Furthermore, it is reasonable to assume that there were artists or sculptors with sufficient knowledge to compose a piece like that, whether by painting or bas-relief, both in the period alleged by dating tests, which covers 1260-1390 [2], as for the one who claims to have been before [4] and even the other compatible with the period in which Jesus Christ would have lived [21]. The skills of

artists in relation to the issue of realism or techniques compatible with those in vogue today, can be observed over the millennia, even in cultures that excelled in stylized structures such as that of Ancient Egypt, most notably in the case of the statue by Kaaper composed in ca. 2465-2323 BC [22]. From the year zero to one thousand, works of art abound that illustrate the human body in the most varied ways, denoting great control by specialists in the materials and methods used, as can be seen in many of the pages, for example, in the book *A History of Private Life*, which deals with other aspects, but illustrates the articles with images of works from the time [23]. In the later period, which corresponds to the C14 tests that indicated that the shroud was, in fact, a medieval work, it is also possible to find works that may have inspired the creation of the piece, as is the case with the pose of Adam and Eve covering genitalia as a sign of modesty or shame at work *Beatus a Lieban, Commentary on the Apocalypse*, originally composed in the 8th century and copied over the following years, as a remnant from the 11th century containing a hand position very compatible with that of the Shroud of Turin (`https://gallica.bnf.fr/ark:/12148/btv1b52505441p/f1.planchecontact#`, see folio NP). According to Rodriguez (2024), the position would not be viable in the anatomical context, either due to the action of gravity or even the absence of structural fixation markers, such as traces of clothing that would support the hands in the current position. However, the position would be justified if it were a work of art, as it would emphasize the sacredness and reverence associated with Jesus Christ and other sacred figures and nudity, in this context, would be seen as disrespectful and would harm the spiritual message conveyed. Add to this the already discussed significant difference between the arms [3].

An alternative approach to the dispute between authenticity and deliberate fraud is that in which Dale (1987) points out the Shroud of Turin as one of the masterpieces of Christian art, potentially created in the 11th century [24]. The author also addresses the problem of three-dimensional projection on a flat surface, citing the deformation effect that would generate a distortion similar to Marcator's projection ("Agamemnon's Mask" effect), and that the projection as it is could only be explained by a action such as ammonia vapor on the fabric or even an electrical discharge, both in parallel lines on the flat surface of the shroud. Regarding the frontal arrangement of the body and the

line of representation used in the period, he cites the epitaph of Milutin Ures (Belgrade, Serbia), a work dated between 1282 and 1321 that presents the figure of Christ seen frontally, where a carpet is superimposed over the genital region and the crossed hands showing the marks of the crucifixion nails (https://www.kornbluthphoto.com/images/BelgradeEpitaphios_Center.jpg). Another work cited is the bas-relief from the 11th or 12th century, representing Saint John the Baptist, belonging to the Victoria & Albert Museum (London) and which illustrates the religious figure, according to the author, in a refined and vivid way (https://commons.wikimedia.org/wiki/File:St._John_the_Baptist_and_saints,_c._1000_CE._Ivory_with_traces_of_gilding._From_Constantinople,_Byzantine_Empire_(Istanbul,_Turkey)._Victoria_and_Albert_Museum.jpg), indicating that artists of the period could have created the matrix from which the Shroud of Turin could have derived. Dale's study was published before the famous C14 tests, without period information he inferred that the shroud would have been created between 969 and 1169 AD [24].

The context of funerary arts must also be addressed; a source of inspiration or even technique for creating a matrix that would have given rise to the shroud would be tomb seals and tomb effigies. The technique of using human figures on tombs has been used since ancient times, but found a significant level of refinement in Europe from the end of the 12th century [25] and reaching a high artistic standard in the 14th century [26][27][28][29]. Hands folded on the lap are a constant theme in religious figures, as well as verbal and non-verbal information about their lives [25][27][29]. If it is taken into account that the first documented appearance of the Shroud of Turin was in 1355 in France, and that in a later report written by the Bishop of Troy for Pope Clement VII there is a part addressing *""the truth being attested by the artist who had painted it"* and being presented by the Pope as a *"representation"* [1][15], linking this to the C14 exam that presents a date between 1260 and 1390 [2], it seems reasonable to infer that there was already an entire artistic system available for making the piece and in relation to the location of the first documentary occurrence, there is a suspicion that, for example, the first bronze effigy in relief in England, created in 1279 may have been forged in France [26], corroborating its status as a center that radiates artistic technology, even though there were already similar productions in other regions

of Europe.

Regarding dating, the late 1980s study appears to have followed the protocol coherently, since the collection of the material was carried out under the eyes of representatives of the church and specialists in the textile field. In addition, other line samples from different eras were tested, one of which, belonging to an Egyptian mummy, was ≈2010 years old. The dating was carried out in three different laboratories and the results were significantly similar, reaching the known range of 1260-1390 AD [2]. After the initial results, there was a statement from Cardinal Anastasio Ballestrero, of the Archbishopric of Turin, about the results where he said that *"I see no reason for the Church to put these results in doubt"*, he also emphasized that the Roman Catholic Church has never stated that the shroud was something more than a *"representation"* of the fabric from Christ's burial, according to a story published in *Science* (vol. 242) [30]. There is an even more complete transcript where the Cardinal stated that *"I do not think we should question these results. And there is no point in nitpicking scientists if their response does not fit with the reasons of the heart"* and also, according to this publication until the year 2019 at least, the study involving C14 had been the only one officially accepted by the Catholic Church and what this would always have firmly denied any scientific value to tests using samples from the Shroud of Turin not officially delivered [15].

Rogers (2005) [4] presented a contrast to the Damon et al. (1989) [2] results, indicating that the region where the sample was collected had undergone repairs and therefore did not belong to the original tissue. Using data from previous research and some threads received from researchers who worked directly on the Shroud of Turin, he proceeded with mass spectrometry tests, along with microscopic and microchemical observations that would have indicated that the fabric of the sample used in the C14 test was different from other areas of the piece, which would contain the original composition of the linen. The lack of vanillin in the lignin of the original tissue would denote an older age for it, being calculated at 1300 to 3000 years old, differing significantly from the compared test (ca. 1050 BCE - 650 AD vs ca. 1260-1390 AD). Rogers (2005) adds that even if potential errors in measurements are taken into account, it is unlikely that the tissue is less than 840 years old. Furthermore, he indicates

that the lack of knowledge about the temperature at which the tissue would have been stored prevents a precise date to be carried out, requiring new radiocarbon analyzes with several carefully prepared samples [4]. Already that year, it caused concern that a subsequent concert in the region of a significantly older tissue was carried out in such a cunning way that it went unnoticed by the specialists who selected the area for the sample [31].

In 2022, research involving a new dating method based on Wide Angle X-ray Mirroring (WAXS) used a single 0.5 mm x 1.0 mm wire, inferring that it had been created between 55 and 74 AD. The results, indicated as experimental by the authors, were very close to the period in which Jesus Christ would have lived [21]. According to the study, other methods would agree with the attribution of the Shroud of Turin to the first century AD, but the references cited, with the exception of Rogers (2005), are works published by the last author of the study. Furthermore, the base reference for the methodology is a 2019 study with the participation of all authors and in the same journal [32]. This practice had been widely criticized in response to a letter to the reader, whose last author was coincidentally the last author of the 2022 study [15].

Regardless of the age of the fabric, whether it was created 3000 years ago or during the medieval period, the remote possibility of it being a print from a three-dimensional human body still remains. Regarding the nature of the composition, although there may be a general dispute whether it is an authentic item or a forgery, Luigi Gonella, scientific advisor to the Archbishopric of Turin, shortly after the results of the C14 test, when asked whether it is a forgery stated that *"A forgery is for the specific purpose of deceiving people"*, later amending *"It could be possible, but there is no proof. This could be a medieval icon. We don't even know how it was made."* [30]. The answer seems consistent with the approach that indicates that it is an icon composed during the medieval period, and is, in fact, a masterpiece of Christian art [24].

It is not possible to know what actually happened, but it can be speculated that perhaps at first the impression of a real body or a statue on fabric was sought, but the results where the anatomical figure was deformed sounded unpleasant in the eyes of the target audience of the work. As funerary art was well-developed in the period and served the purpose of conveying the intended message, it was adapted to create a visual

icon, with objective non-verbal elements that instigated the sensitivity of observers. To create the final work, a fabric compatible with literature and religious art was chosen, and may even have been acquired in more distant regions, perhaps close to the place where the biblical narrative developed. In this context, the work was very successful and has served the religious purposes of the message, without having to resort to texts, which makes it accessible to a much larger audience, keeping interest and debate alive, throughout centuries and centuries of history.

5. Conclusion

The present work sought to highlight the flat or low-relief origin of the source of the print, known as the Shroud of Turin. The successful approach was to use open-source, free, and multiplatform programs to simulate the wrapping of the shroud and the contact of both a human body compatible with an adult individual and a low-relief version, which offered more compatible results in comparisons with the Shroud of Turin. This study corroborates with Dale (1987) approach, which would indicate that the piece *"may well be recognized as one of the masterpieces of Christian art"* [24].

6. Conflict of interest

None Declared.

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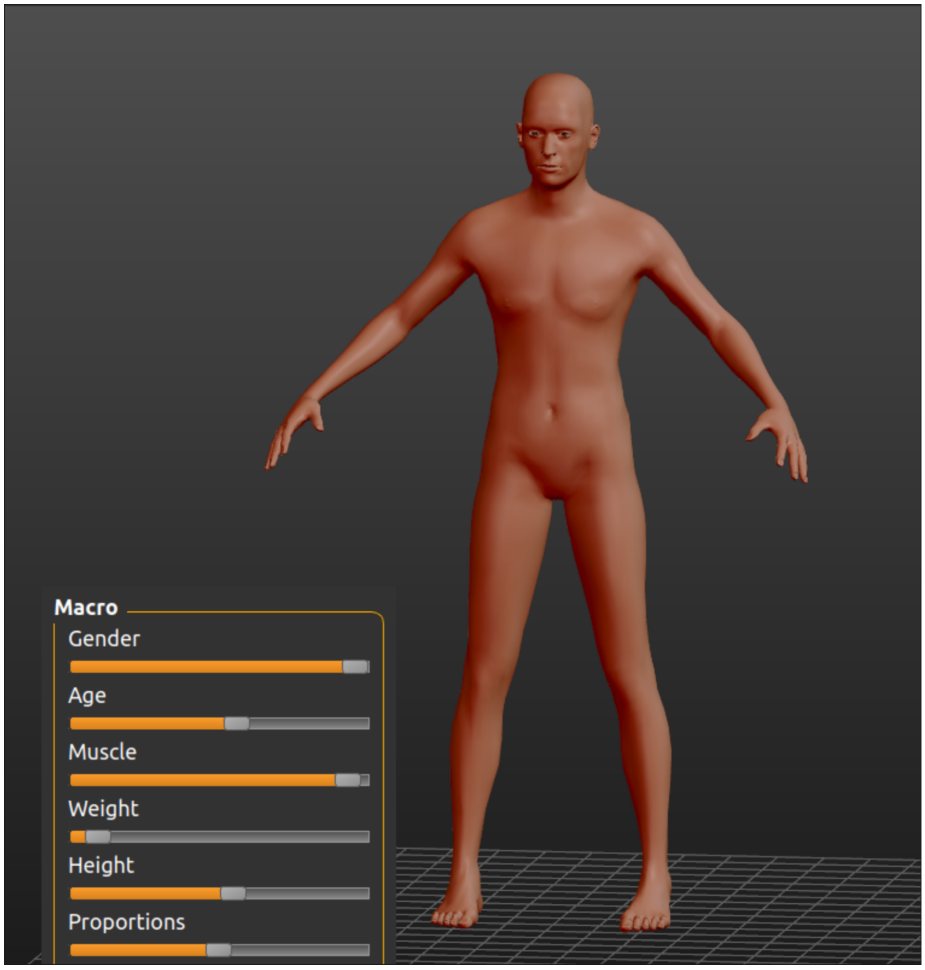

Figure 1: Parametric adjustment of a human being according to data from the Shroud of Turin.

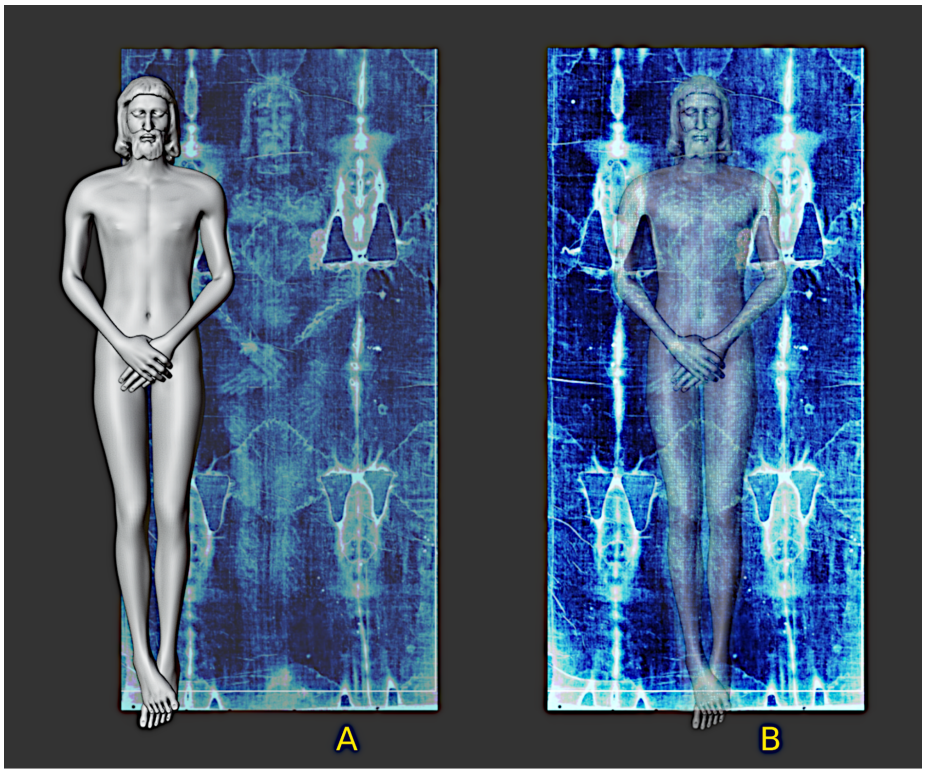

Figure 2: Three-dimensional model adjusted to the figure of the shroud, coming from an image available on Wikimedia Commons and edited in the software The Gimp (`https://www.gimp.org/`) so that the color was inverted and presented greater contrast.

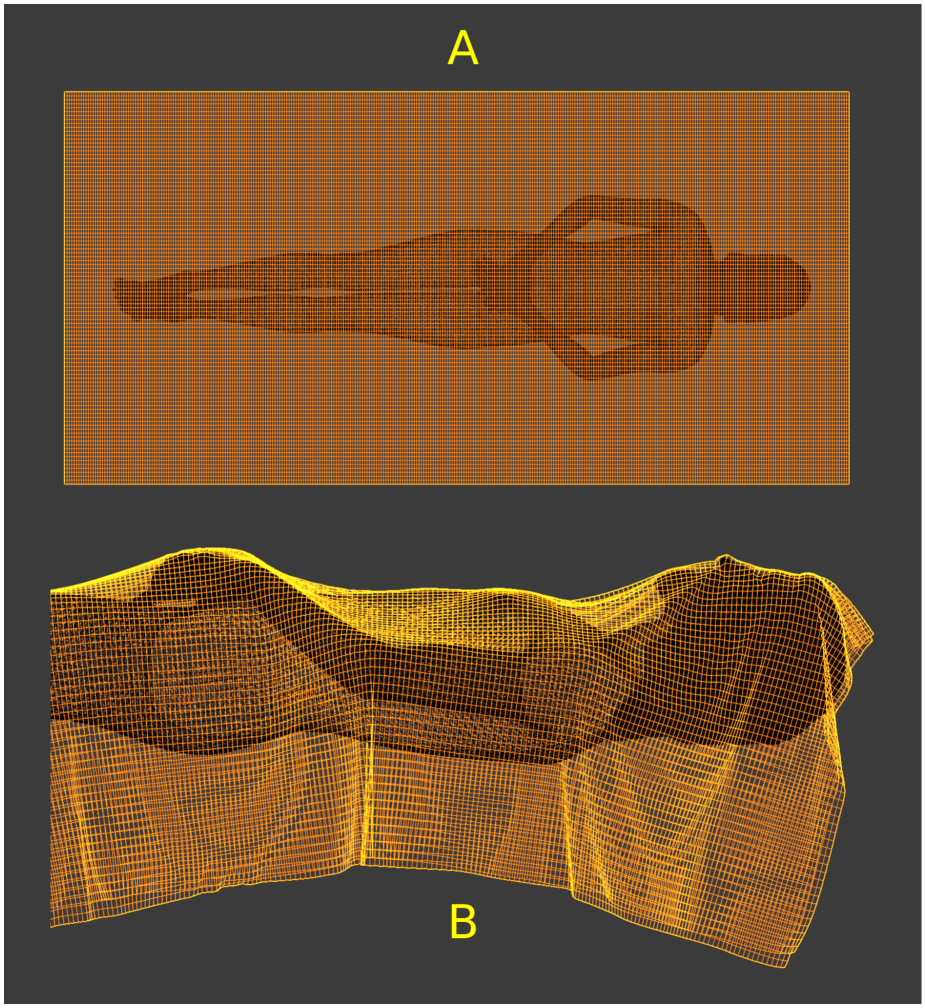

Figure 3: Fabric dynamic simulation.

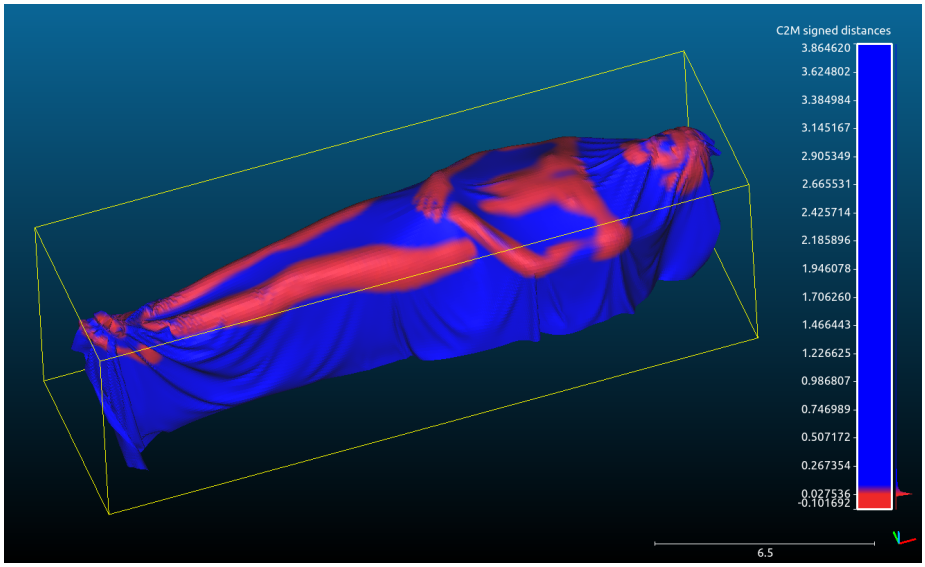

Figure 4: Comparison of meshes in relation to proximity.

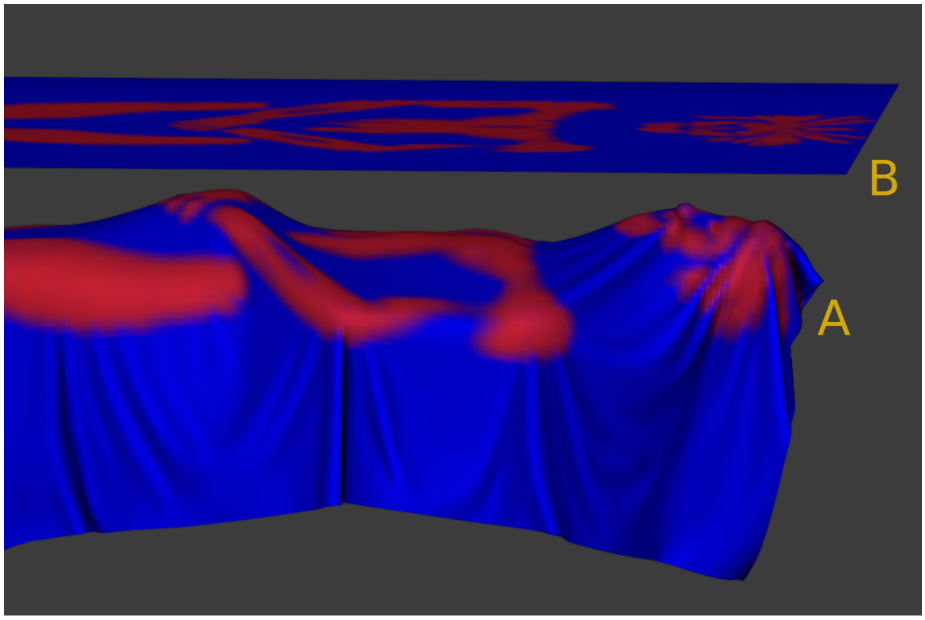

Figure 5: Simulation of fabric with contact coloring.

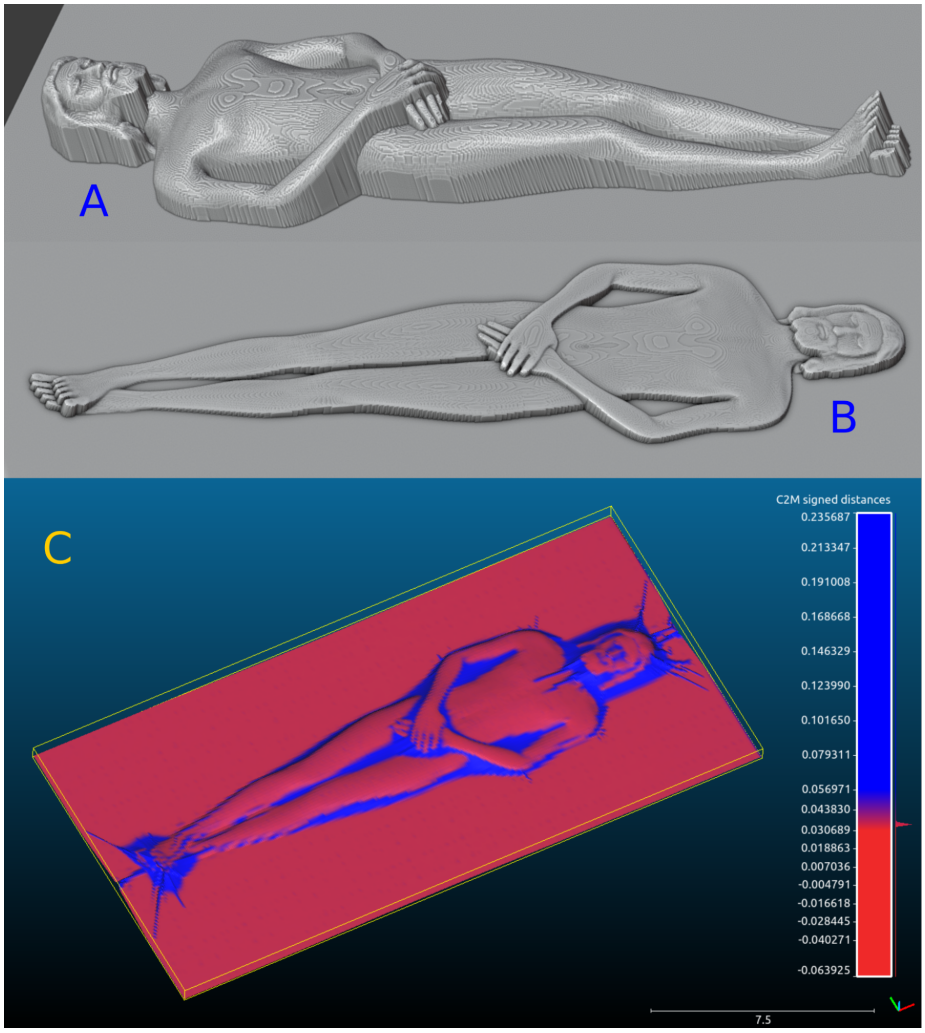

Figure 6: Process of creating the low-relief mesh and comparing the physical simulation of the fabric.

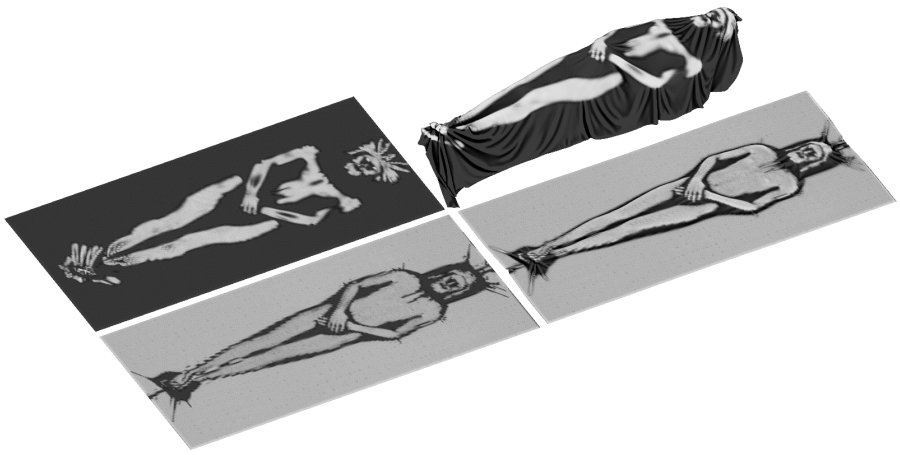

Figure 7: Comparison between the 3D model and low relief, lateral orthographic view.

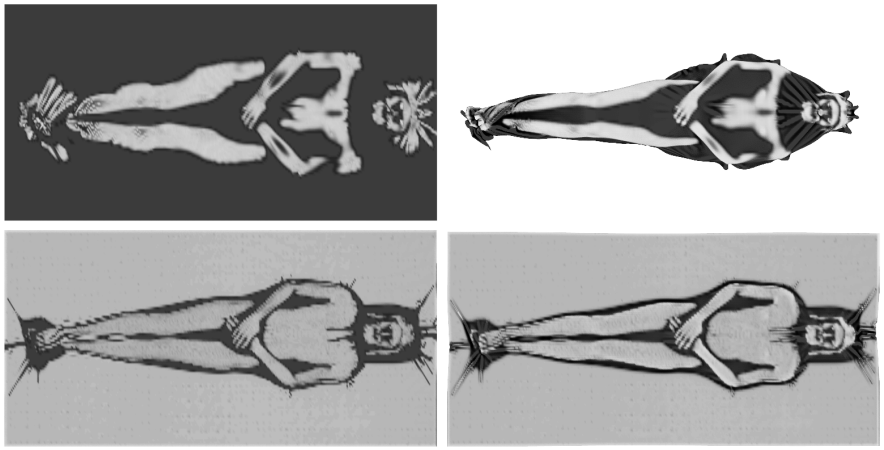

Figure 8: Comparison between the 3D model and low relief, lateral orthographic view.

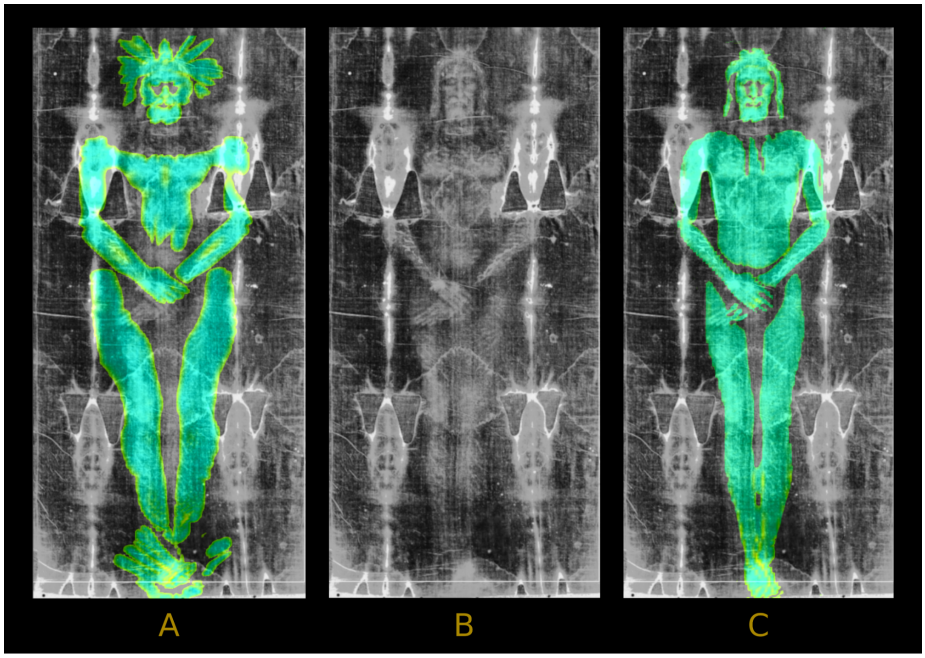

Figure 9: A) Touch texture in the three-dimensional model on the image of the shroud. B) Texture of the Shroud of Turin. C) Texture of the model in low relief over the image of the shroud.