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Image Formation on the Holy Shroud—A Digital 3D Approach

Cicero Moraes

Arc-Team, Chapecó, Brazil

Correspondence: Cicero Moraes (cogitas3d@gmail.com)

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ABSTRACT

This study investigates the origin of the image imprinted on the Shroud of Turin, a linen artifact displaying the frontal and dorsal figures of an adult man with marks of physical violence, using 3D digital simulations. Through free and open-source software, parametric modeling of a human body, fabric dynamics simulation, and contact area mapping were performed. Two scenarios were compared: the projection of a three-dimensional human model and that of a low-relief model. The results demonstrate that the contact pattern generated by the low-relief model is more compatible with the Shroud's image, showing less anatomical distortion and greater fidelity to the observed contours, while the projection of a 3D body results in a significantly distorted image. The accessible and replicable methodology suggests that the Shroud's image is more consistent with an artistic low-relief representation than with the direct imprint of a real human body, supporting hypotheses of its origin as a medieval work of art.

1 | Introduction

The Shroud of Turin is a piece of linen measuring approximately 4.4 m × 1.1 m, which displays the frontal and dorsal images of an adult man with a beard, long hair, hands crossed over the genital region, and marks indicative of physical violence. Since its first documented appearance in 1355, in France, the artifact has been the subject of intense debate between those who suggest a potentially divine origin (Bevilacqua et al. 2015; Fanti 2010; Fanti 2024a, 2024b; Moreno 2017) and others who point to it as a human-made object (Garlaschelli 2010; Damon et al. 1989; Rodríguez 2024).

1.1 | Datings and Controversies Involved

In the late 1980s, a carbon-14 (C14) dating study was conducted, rigorously following established protocols, with material collection supervised by representatives of the Catholic Church and textile experts. Additionally, fabric thread samples from different historical periods were analyzed, including one from an Egyptian mummy approximately 2010 years old. The dating was performed by three independent laboratories, whose results converged significantly, placing the date within the range of 1260 to 1390 AD (Damon et al. 1989). Following the release of the results, Cardinal Anastasio Ballestrero, from the Archdiocese of Turin, stated: "I see no reason for the Church to put these results in doubt," as reported in an article published in the journal *Science* (vol. 242) (Waldrop 1988). He also emphasized that the Roman Catholic Church never claimed the Shroud of Turin was more than a "representation" of Christ's burial cloth. In a more complete transcript, the Cardinal stated: "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" (Waldrop 1988). Furthermore, according to the same publication, at least until 2019, the C14 dating study remained the only one officially recognized by the Catholic Church, which consistently denied any scientific value to tests conducted with unofficial samples of the Shroud of Turin (Borrini and Garlaschelli 2019).

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Rogers (2005) presented a counterargument to the results of Damon et al. (1989), asserting that the sample region used for C14 dating had undergone repairs and thus did not correspond to the original fabric of the Shroud of Turin. Based on data from previous studies and fabric thread samples provided by researchers who worked directly with the Shroud, the author conducted mass spectrometry tests, as well as microscopic and microchemical observations. These tests indicated that the fabric of the sample used for C14 dating differed from other areas of the piece, which would preserve the original linen composition. The absence of vanillin in the lignin of the original fabric would suggest an older age, estimated between 1300 and 3000 years, contrasting significantly with the range obtained by Damon et al. (ca. 1050 BC—650 AD vs. ca. 1260–1390 AD). Rogers emphasized that, even considering potential measurement errors, it is unlikely that the fabric is less than 840 years old. He also noted that the lack of information about the temperature conditions under which the fabric was stored hinders precise dating, necessitating new radiocarbon analyses with multiple carefully selected samples (Rogers 2005). As early as 2005, it was perplexing that a later repair, performed on a region of a significantly older fabric, was executed so skillfully that it went unnoticed by the experts responsible for sample selection (Ball 2005).

In 2022, a study employing a new dating method based on Wide Angle X-ray Scattering (WAXS) analyzed a single thread measuring 0.5 mm × 1.0 mm, inferring that the fabric was produced between 55 and 74 AD. The authors classified the results as experimental, emphasizing their proximity to the period in which Jesus Christ is believed to have lived (De Caro et al. 2022). According to the publication, other methods would support attributing the Shroud of Turin to the first century AD, although the cited references, except for Rogers (2005), are works by the last author of the WAXS dating study. The foundational methodology stems from a 2019 publication, involving all the authors and published in the same journal (De Caro et al. 2019). This practice was widely questioned in an academic debate related to an analysis of the bloodstains on the Shroud of Turin (Borrini and Garlaschelli 2019).

1.2 | Academic Clash

A study examining possible bloodstain patterns (BPA) on the Shroud of Turin identified several inconsistencies and physical behaviors distinct from those expected. These observations led the authors to conclude that such discrepancies questioned not only the veracity of the piece but also its authenticity, suggesting it is an artistic or didactic representation from the 14th century (Borrini and Garlaschelli 2018). The authors' incisive conclusions prompted the publication of letters to the editors, in which other experts vehemently criticized the article, in some cases presenting their own technical analyses as elements of refutation (Bevilacqua et al. 2019). The authors' response maintained the sharp tone adopted by the critics, offering not only technical arguments but also pointing out practices of self-citation, publications in potentially predatory journals, and a case of article retraction, all associated with the opponents and materials related to their research on the Shroud of Turin (Borrini and Garlaschelli 2019).

This episode clearly reveals how the topic of the Shroud of Turin fuels intense debates, not only among the general public but also among academics with extensive experience in their respective fields.

Although some researchers maintain that the image on the Shroud undoubtedly presents anatomical coherence and that science has not yet fully explained its formation or reproduced all its elements in an integrated manner (Fanti 2010; Fanti 2024b; Fanti et al. 2010; De Caro and Giannini 2017; Tamburelli 1981; Fanti 2011; Bevilacqua et al. 2015; Campion and Fanti 2018; Fanti 2024a, 2024b), structural analyses have pointed out anatomical inconsistencies, such as one arm being significantly longer than the other, with a difference of 7–10 cm (Rodríguez 2024). Furthermore, according to Rodríguez (2024), the body's position was considered anatomically unfeasible, whether due to the influence of gravity or the absence of structural fixation markers, such as traces of clothing that would support the hands in the observed position. However, the same author notes that such a position could be justified in an artistic context, as it would emphasize the sacredness and reverence associated with Jesus Christ and other holy figures, with nudity in this case potentially seen as disrespectful and contrary to the spiritual message conveyed (Rodríguez 2024).

The argument frequently put forward by defenders of the Shroud's authenticity—that the image's creation cannot be explained at macroscopic and microscopic levels—has also been contested in the aforementioned academic debate. Opponents argued that the exact reproduction of an ancient artifact would be unfeasible, given that simulating all the chemical and physical processes accumulated over time presents a considerable set of technical challenges (Borrini and Garlaschelli 2019).

1.3 | An Alternative Approach

An alternative approach to the controversy between authenticity and deliberate fraud is proposed by Dale (1987), who considers the Shroud of Turin one of the masterpieces of Christian art, possibly created between the 10th and 12th centuries (Dale 1987). The author addresses the issue of three-dimensional projection onto a flat surface, highlighting the distortion effect, comparable to the Mercator projection. He suggests that the projection of the Shroud of Turin could only be explained by processes such as the action of ammonia vapor on the fabric or an electrical discharge, both occurring in parallel lines across the flat surface of the shroud. Regarding the frontal arrangement of the body and the characteristic representational style of the period, Dale cites the epitaph of Milutin Ures (Belgrade, Serbia), a work dated between 1282 and 1321, which depicts the figure of Christ in a frontal view, with a cloth draped over the genital region and hands crossed displaying marks of the crucifixion nails. Another mentioned work is a low-relief from the 11th or 12th century, depicting Saint John the Baptist, held by the Victoria & Albert Museum (London), which portrays the religious figure in a refined and vivid manner, according to the author. This piece suggests that artists of the time possessed the technical skill to create the matrix that could have originated the Shroud of Turin. Published before the well-known C14 dating tests, which pointed to the 14th century, Dale's work, without access to this information, estimated that the shroud was created between 969 and 1169 AD (Dale 1987).

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1.4 | Scope of the Present Study

This study primarily aims to create and analyze two digital models (target structures) based on the characteristics of the image present on the Shroud of Turin. The first model represents a three-dimensional human body, preserving its anatomical volume, while the second model consists of a low-relief. A digital fabric, with dimensions corresponding to those of the Shroud of Turin, will be simulated in contact with both models to map and compare the resulting interaction patterns. The analysis focuses exclusively on investigating the contact and proximity patterns between the digital fabric and the target structures, using 3D simulation tools, with the purpose of determining whether the shroud's image can be reproduced from a human body or another source, such as a low-relief or similar technique.

The study does not address physical or chemical aspects related to the image's formation, such as the presence of pigments, microscopic analyses, or material properties of the fabric, nor does it investigate the dynamics of bodily fluids, such as blood flow. The focus is strictly methodological, centered on digital modeling and the comparative evaluation of the observed contact patterns.

2 | Materials and Methods

The process was carried out using open-source (and free) software, available for download. This approach allows the technique to be replicated by anyone interested (provided they have basic or intermediate knowledge of 3D computer graphics), without spending resources on licenses, regardless of the operating system, as the programs used are available for Linux, as well as Mac OS and Windows.

Initially, a human body was parametrically adjusted in the MakeHuman (https://static.makehumancommunity.org/) software with the following parameters: male, adult, slim, and approximately 1.80 m in height (Figure 1A) (Dale 1987). The model was exported as a Collada (.dae) file containing the armature for articulating the body.

The model was imported into the 3D modeling software Blender, resized to the real scale of 1.1 × 4.4 m, where the body was adjusted and articulated as closely as possible to the 1931 Giuseppe Enrie image, which is in the public domain and available on Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Shroudofturin.jpg—613 × 2325 pixels). To match the model of the Shroud of Turin, the beard and hair were modeled. The eyes, mouth, nose, chest, and other structures received minor structural corrections to make them compatible with the target individual, involving the use of digital deformation tools to approximate the model's facial structure to that present in the shroud's image (Figure 1B). When comparing the 3D model with the two-dimensional figure, a general similarity can be observed, except for the left hand, which is significantly more displaced in the shroud, as noted by Rodríguez (2024) (Figure 1C). The reflected position of the model was maintained, as originally the hand positioned above is the left, not the right, as in the current study's model. This approach simplifies the creation of visual material, focusing on the contact behavior in relation to the most well-known photos of the Shroud of Turin, without compromising the article's focus, which is the approach to the marks in relation to contact with the body models.

A plane of 1.1 m × 2.2 m was created, subdivided into 31,400 four-sided faces (Figure 2A). The body, rotated 180°, was configured as a fixed and collision element, meaning it is a static object that behaves as a solid body in the simulation (https://docs.blender.org/manual/en/latest/physics/soft_body/collision.html). The upper

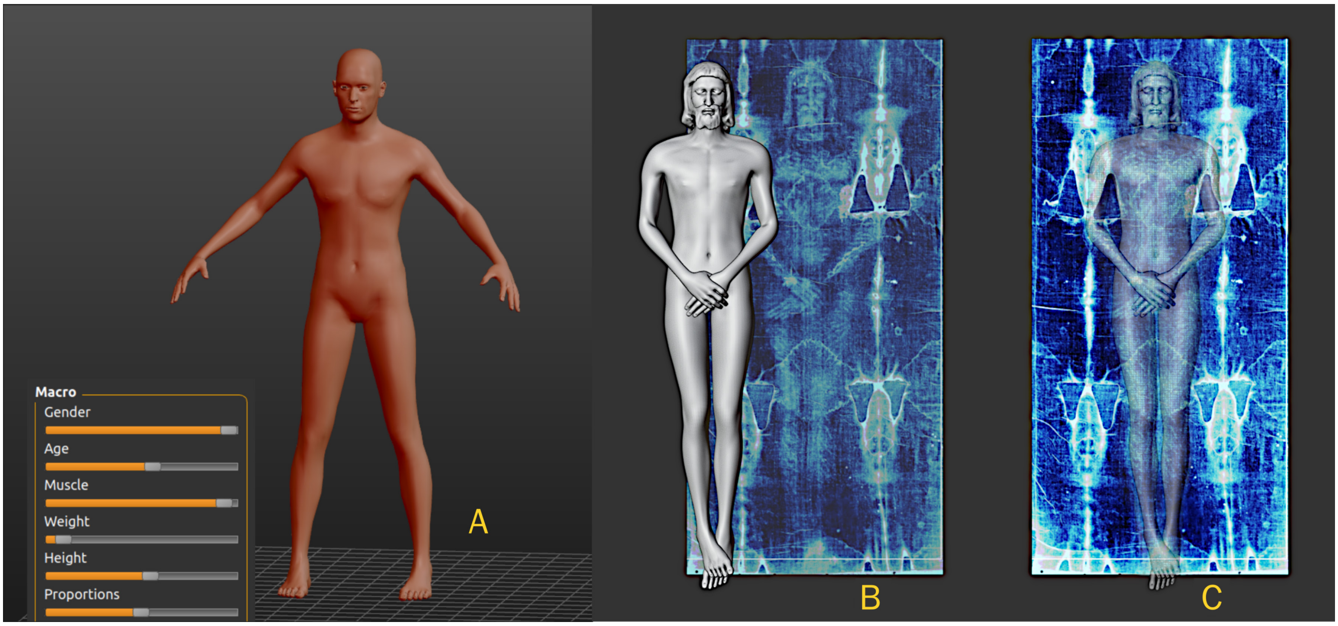

FIGURE 1 | (A) Parametric adjustment of a human body based on data from the Shroud of Turin observed by Dale (1987). (B,C) Three-dimensional model adjusted to the figure of the Shroud, derived from an image available on Wikimedia Commons and edited in the software The GIMP to invert the color and enhance contrast.

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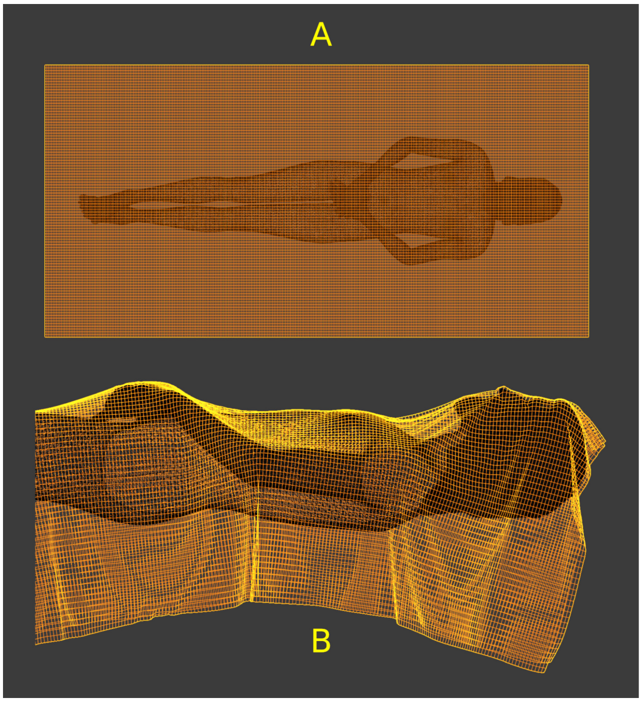

FIGURE 2 | Simulation of the fabric. Top part: Top view with the fabric mesh positioned over the body. Bottom part: Side view of the fabric simulation draped over the body.

plane, configured as a dynamic fabric, using Blender's default settings for a generic cotton fabric (https://docs.blender.org/manual/en/latest/physics/cloth/introduction.html), was influenced by gravity, which caused it to fall onto the body and conform to its surface (Figure 2B). In both cases of physical simulation, both the solid element and the fabric, only the model was selected and the simulation was activated without altering the system's default settings, which facilitates the replication process of the technique.

The two models, the three-dimensional body and the fabric after dynamic deformation, were exported as stereolithography (.stl) due to its structural simplicity and imported into the CloudCompare software (https://www.cloudcompare.org/main.html), where a visual histogram was created on the fabric mesh, compared with the body, with only two states: (1) regions touching the body in red and (2) regions not touching the body in blue (Figure 3A).

Although the histogram is visually present on the 3D mesh through colors, it was necessary to apply this coloring as a texture to fix it and enable the visualization of the colors in external programs. For this reason, the 3D mesh histogram was converted into RGB color for the faces, and the structure was exported as a Polygon File Format or Stanford Triangle Format (.ply), a file format that allows vertex coloring (https://docs.blender.org/manual/en/latest/modeling/meshes/properties/object_data.html).

The file with the colored mesh (vertex color) was imported into Blender; however, this mesh was an independent object created in CloudCompare, with its own characteristics and fixed (a rigid body), unlike the model resulting from a dynamic fabric simulation (Blender). Due to this, it was necessary to project the texture (vertex color) onto a fabric with animation, from the flat state to the post-collision state (draped). This was achieved 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 of 1100 × 2200 pixels with two-dimensional color data (https://docs.blender.org/manual/en/latest/modeling/meshes/editing/uv.html). This way, it became possible to visualize the contact data both in the deformed state on the body (draped) (Figure 3B) and in the initial state when the fabric is flat, before the physical simulation (Figure 3C), while maintaining the same texture.

To simulate a low-relief version, the non-retentive object creation tool from OrtogOnBlender, a Blender add-on, was used (Moraes et al. 2020). This tool is employed to create models that can serve as a basis for generating guides and surgical splints (due to the required non-retentiveness), coins, medallions, and simulations of wood carving or other types of low relief, as in the present case.

Due to the non-retentive final characteristic, the base for generating the model was not placed at the lower limit of the back but slightly below the middle of the arms, aiming to maintain more visible details on the back without creating a model too tall along the *Z*-axis (Figure 4A). The resulting model (at real scale but non-retentive) was rescaled to 0.25, that is, 1/4 of the original size along the *Z*-axis (Figure 4B). Unlike the 3D body, which was not positioned on any surface, the current model has a base, simulating a stone, wood, or metal plate. Next, the low-relief mesh underwent the same process applied to the three-dimensional body, receiving the fabric simulation in Blender, which was exported to the distance comparison software CloudCompare (Figure 4C) and imported into Blender to incorporate the distance texture onto the shroud mesh with the fabric simulation.

3 | Results

To evaluate the compatibility of patterns formed by the contact between the fabric and three-dimensional models, comparative images were generated from physical collision simulations and distance mapping. The analysis involved two distinct scenarios: (1) contact with a three-dimensional human body and (2) contact with a low-relief matrix of the same figure.

In the simulation with the three-dimensional body, the fabric deformed around the volume, resulting in a projected image with visible distortions, particularly an widening of body proportions, which created a more robust figure than that represented on the Shroud of Turin. The orthogonal view (Figure 5A, left) highlights these distortions compared with the real model (right). The top view (Figure 5B) demonstrates that the effective contact area between the fabric and the body was relatively small, concentrated on the most prominent anatomical points.

In the second scenario, using a low-relief model with its height reduced to 1/4 of the original size, the fabric was able to adapt more uniformly to the surface of the matrix. The result was a projection with more accurate anatomical proportions and visually similar to the image observed on the Shroud. This image

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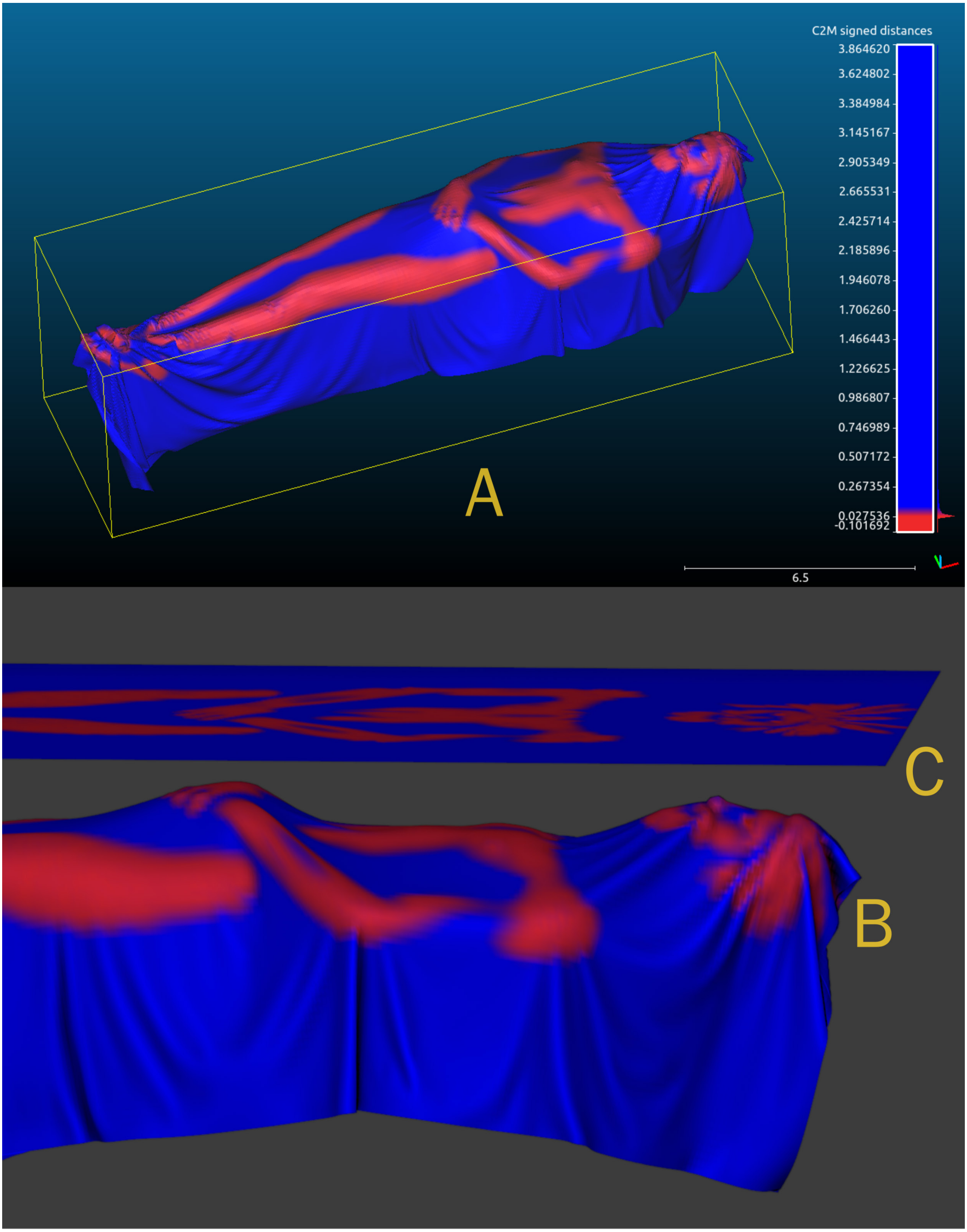

FIGURE 3 | (A) Comparison of meshes regarding proximity. (B,C) Fabric simulation with contact-based coloring.

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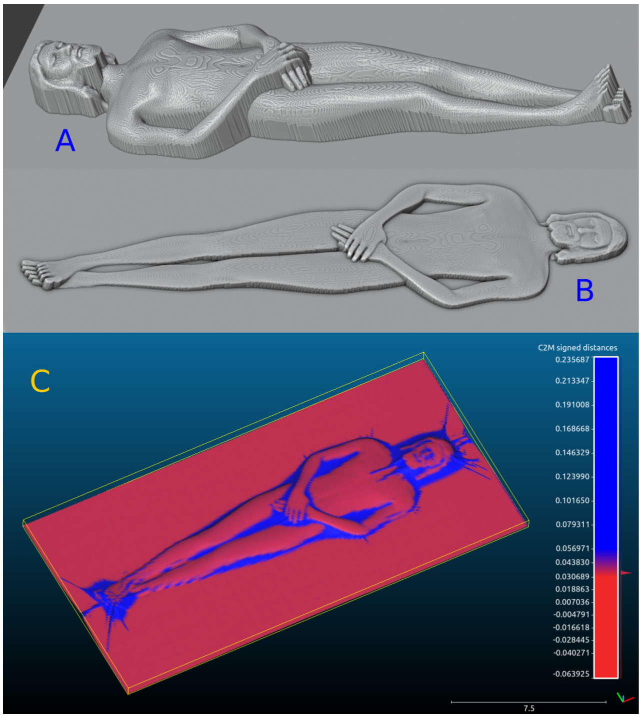

FIGURE 4 | Process of creating the low-relief mesh and comparison of the physical fabric simulation.

maintained consistency in the proportions of the limbs and head, in addition to presenting a larger and more evenly distributed contact area (Figure 5A,B).

To isolate only the body region and exclude irrelevant areas of the matrix base, a selective mask was applied to the generated textures, highlighting only the zones compatible with intentional direct contact (e.g., pigmentation with dye or another substance). This filtering reinforces the hypothesis that the pattern visible on the Shroud could have been produced from a physical low-relief matrix rather than a real human body.

Visual overlays of the simulated textures with the image of the Shroud of Turin (Figure 6) demonstrated that the pattern generated by the low-relief matrix shows far superior morphological alignment compared with the three-dimensional body. The anatomical regions—head, torso, and upper limbs—are better defined and compatible in position and shape, except for a slight discrepancy in the left hand, which is addressed later in the discussion.

Finally, a didactic video was produced for scientific dissemination to both lay and specialized audiences. The material visually and accessibly presents the dynamics of the fabric simulation, the interactive application of pigmentation by contact, the animated comparison between the results obtained with the three-dimensional body and the low-relief matrix, as well as a practical and replicable example of the technique used. This last part is inspired by Campion and Fanti (2018) and explanation of the so-called "Agamemnon mask effect." The video is available for public access at the following link: https://drive.google.com/file/d/1o3pJ-iQ5WXK6yzl33X50dbAvpOt_epxq/view?usp=sharing.

4 | Discussion

The most evident characteristic observed in the projections is that, when adjusting the linen to an adult human body, the resulting image from the contact regions would present a significantly more robust body than the original, due to the effect of converting a three-dimensional object into a two-dimensional surface, termed by Campion and Fanti (2018) as the "Agamemnon Mask effect." This phenomenon, compared with a metal mask with a stretched face (https://upload.wikimedia.org/wikipedia/commons/c/c8/MaskOfAgamemnon.jpg), was explained in a visual and replicable manner in a didactic video mentioned in the Results section.

The printed image, generated from the contact regions in low relief, shows high compatibility with that present on the Shroud of Turin, significantly corresponding to its contours, even considering a not entirely flat base. However, the main discrepancy lies in the left hand, as discussed in the Introduction, which pointed out a pronounced asymmetry (of 7–10 cm) between the two arms (Rodríguez 2024).

Even researchers who defend the authenticity of the Shroud of Turin have produced images that exhibit the expected structural deformation when projecting marks and the body onto a two-dimensional plane (Fanti 2024b; Campion and Fanti 2018), which aligns with the current analysis, highlighting greater robustness if the source of the imprint derives from a three-dimensional human body. For example, an investigation that adopted an experimental approach based on corona discharge generated a model from a three-dimensional body, revealing the structural deformation that results in a more robust representation (Figure 2, p. 241 of Fanti 2024b).

The approach based on electrical discharge is, therefore, a point to address, as even in Dale (1987), a comment on such a possibility can be observed. However, the hypothesis of image formation by corona discharge depends on complex and difficult-to-occur conditions, as according to Fanti et al. (2010), the process would rely on an energy discharge triggered by an earthquake, acting on the shroud arranged in a specific manner, with flower lining, allowing the orthogonal imprint of the frontal and dorsal figures on the fabric. This imprint would require a power low enough not to burn the linen but high enough to mark the image (Fanti 2010). However, even if such a discharge occurred and an image was recorded, any three-dimensional displacement in the structure would cause deformations, not resulting in an orthographic representation. Furthermore, the 2024 study (Fanti 2024b) does not clarify the methodology employed for the experimental creation of the body image, especially considering that, in 2010, the same author stated it was impossible, at the time, to experimentally reproduce such an image, presenting examples limited to low-relief objects, such as a coin and a small snake (Fanti 2010). The complexity of the proposed hypotheses, combined with the practical difficulty of replicating the image formation according to these mechanisms, reinforces the plausibility of a simpler and technically feasible explanation: the generation of the image by contact.

An attempt to recreate the imprint patterns of blood marks and anatomy was made by Garlaschelli (2010). In this study, the

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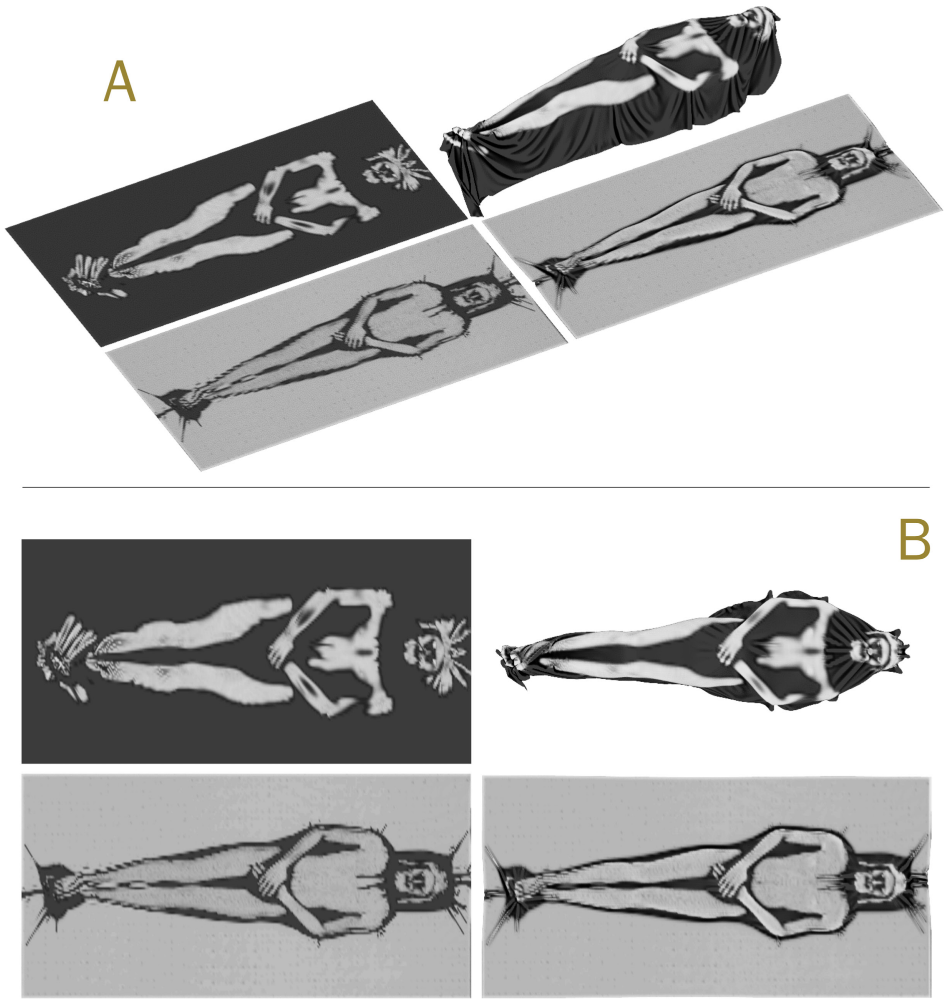

FIGURE 5 | (A) Comparison between the contact patterns generated by the three-dimensional model (right) and the low-relief model (left), in an oblique orthographic view. It is noted that the three-dimensional model results in a distorted projection, with more robust body features. (B) Top view of the same simulations, highlighting differences in the contact area: smaller in the 3D model and broader in the low-relief model.

result of the body pattern, pigmented over a wider area and surrounded by fabric, presented the same imprint pattern, which was much more robust than the base individual (Figure 3, p. 4 of the reference). Therefore, it became clear to the researcher that the only way to reproduce something close to the shroud's design would be to pigment only certain regions of the body, replace the face with a low-relief reproduction, and later complement the missing region of the left hand with another technique (Garlaschelli 2010). Even so, the final image, which received more localized pigmentation in the higher regions of the body, generated a model with fewer details and slightly more robust (stretched) along the *X*-axis in the torso and legs (Figures 6 and 7, p. 9 of the reference) compared with the body of the Shroud of Turin (Garlaschelli 2010).

Regarding the use of three-dimensional models, Fanti et al. (2010) conducted a digital simulation but did not present in the article a view of the texture projected onto the two-dimensional plane of the shroud, making an objective comparison between the original and the digital model impossible (Fanti et al. 2010).

Moreno (2017) dedicated years to studying the Sudarium of Oviedo and, according to the author, this piece would have covered the head of the body whose image is imprinted on the Shroud of Turin, forming a set with it. The publication presents a projection of the blood marks from the Sudarium of Oviedo, accompanied by a drawing of the facial structure overlaid, highlighting the nose, mouth, and ears, clearly evidencing the structural deformation when transferred to a two-dimensional plane, a phenomenon associated with the aforementioned "Agamemnon Mask effect" (Moreno 2017). However, as is known, this effect is not observed in the Shroud of Turin, which, according to this analysis, implies a refutation of the orthographic image. This is due to the fact that, if the Sudarium of Oviedo were indeed related to the Shroud of Turin and exhibited the distortion effect (see p. 18 of the citation, with the link available in the references), the same pattern of deformation would be expected in the shroud.

De Caro and Giannini (2017) proceeded with a digital restoration of the hand region, through which they claimed to have located part of the thumb and the scrotum of the individual imprinted on the shroud (De Caro and Giannini 2017). However, there is a condition of low clarity in the original shroud image that can lead to mistaken interpretations of some features, such as the human brain's tendency to fill in missing data, like pareidolia

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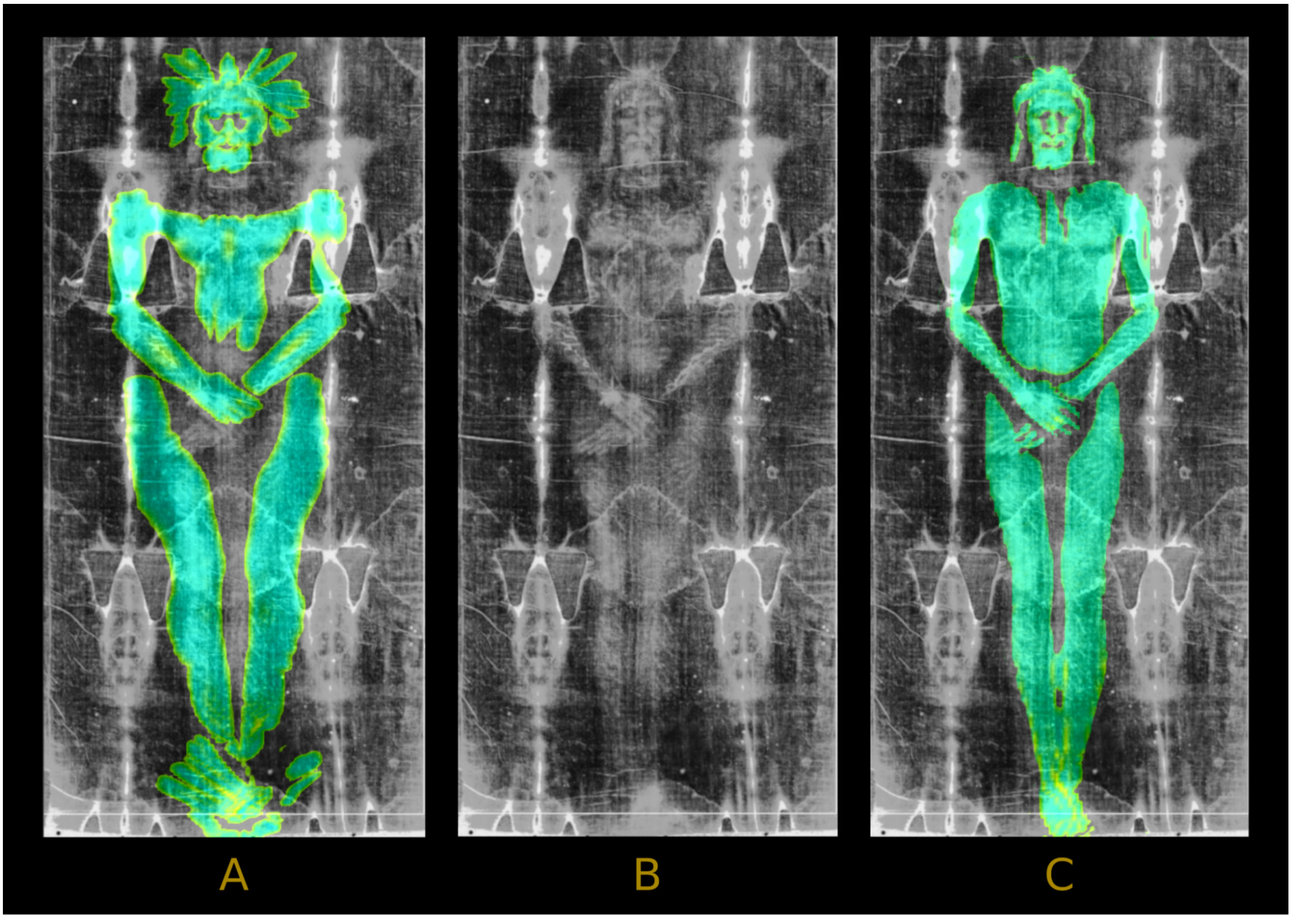

FIGURE 6 | (A) Overlay of the texture generated by the 3D model onto the image of the Shroud of Turin, showing misalignment in anatomical proportions. (B) Original image of the Shroud. (C) Overlay of the texture generated by the low-relief model, demonstrating greater compatibility with the Shroud image, especially in the torso and head regions.

and perception (Di Lazzaro et al. 2013). An example that well illustrates this situation is another study, also published in 2017, but which, unlike the one cited above, indicates that in the location just below the pelvis, the marks would be too long to be scourge marks and could, in fact, be folds of a fabric, similar to a loincloth (Farey 2017).

Regarding the artistic approach as opposed to the hypothesis of a human structural source for the Shroud of Turin's matrix, although several authors argue that the origin could not be artistic but rather a human body, due to its proportions and anatomical coherence (Fanti et al. 2010; De Caro and Giannini 2017), it is plausible to consider that artists or sculptors with sufficient knowledge could have created such a piece, either through painting or low relief. This possibility is viable both in the period indicated by C14 dating tests, which place the shroud between 1260 and 1390 (Damon et al. 1989), and in earlier periods, as suggested by Rogers (2005), and even in a time compatible with the life of Jesus Christ (De Caro et al. 2022). The skills of artists in terms of realism and techniques comparable to those currently in use can be observed over millennia, even in cultures known for stylized styles, such as in Ancient Egypt, exemplified by the statue of Kaaper, dated approximately 2465–2323 BCE (Egypt 2024).

Between the year zero and the year 1000, numerous works of art depict the human body in various forms, evidencing the remarkable mastery of specialists in the materials and methods of the time, as illustrated in various pages of the book *A History of Private Life*, which, although addressing other aspects, presents images of representative works from the period (Veyne 1987). In the later period, corresponding to the C14 tests that indicated the shroud as a medieval creation, there are also works that may have inspired its making. An example is the pose of Adam and Eve covering their genitalia as a sign of modesty or shame, present in the work *Beatus of Liébana, Commentary on the Apocalypse*, originally composed in the 8th century and reproduced in subsequent copies, such as an 11th-century manuscript that displays a hand position notably compatible with that of the Shroud of Turin (https://gallica.bnf.fr/ark:/12148/btv1b52505441p/f1.planchecontact#). This observation supports the approach to the modest pose highlighted by Rodríguez (2024) and the propositions of artistic influence suggested by Dale (1987).

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 could be seals and tomb effigies. The technique of using human figures in tombs has

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been employed since antiquity but reached a significant level of refinement in Europe from the late 12th century (ETS 2024) and achieved a high artistic standard in the 14th century (Badham 1980; Vitolo 2021; Ďoubal et al. 2018; Munk 2011). Hands crossed over the lap are a recurring theme in religious figures, as well as verbal and nonverbal information about their lives (ETS 2024; Vitolo 2021; Munk 2011). If we consider 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 Troyes to Pope Clement VII, there is a section addressing "the truth being attested by the artist who painted it" and being presented by the Pope as a "representation" (Garlaschelli 2010; Borrini and Garlaschelli 2019), linking this to the C14 examination that dates it between 1260 and 1390 (Damon et al. 1989), it seems reasonable to infer that an entire artistic system was already available for the creation of the piece. Regarding the location of the first documented occurrence, there is a suspicion that, for example, the first bronze relief effigy in England, created in 1279, may have been forged in France (Badham 1980), reinforcing its status as a radiating center of artistic technology, even though similar productions already existed in other regions of Europe.

Regardless of the age of the fabric, whether it was created 3000 years ago or during the medieval period, the remote possibility that it is an imprint of a three-dimensional human body still remains. As for the nature of its composition, although there may be general controversy over whether it is an authentic item or a forgery, Luigi Gonella, scientific consultant to the Archdiocese of Turin, shortly after the C14 test results, when asked if it was 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" (Waldrop 1988). The response seems consistent with the approach that indicates it is an icon composed during the medieval period and is, in fact, a masterpiece of Christian art (Dale 1987).

5 | Conclusion

This study demonstrated, through 3D digital simulations, the feasibility of reproducing the contact patterns observed on the Shroud of Turin, using open-source tools such as MakeHuman, Blender, and CloudCompare. The comparative analysis between the three-dimensional and low-relief models revealed that the Shroud's image is more compatible with a low-relief matrix, showing less anatomical distortion and greater fidelity to the observed contours, in contrast to the distorted projections generated by a three-dimensional human body. These results support the hypothesis that the Shroud may be an artistic representation, possibly created during the medieval period, aligning with funerary art practices and artistic techniques of the time.

The proposed methodology is accessible and replicable, requiring only basic or intermediate knowledge of 3D computer graphics. Using the free and open-source tools described, anyone with such knowledge can recreate the fabric dynamics and contact mapping simulations, exploring the presented scenarios. This work not only offers another perspective on the origin of the Shroud of Turin's image but also highlights the potential of digital technologies to address or unravel historical mysteries, intertwining science, art, and technology in a collaborative and reflective search for answers.

Data Availability Statement

The data that support the findings of this study are openly available in Figshare at https://doi.org/10.6084/m9.figshare.29645060, reference number 29645060.

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