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COPY AND PASTE? A CASE STUDY ON A PAIR OF JAMB FIGURES OF THE FÜRSTENPORTAL BAMBERG AND THEIR CASTS

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KEY WORDS: non-destructive testing methods, structured light scanning, 3D surface comparison, historic moulding process, plaster copies.

ABSTRACT:

The focus of this paper is to determine whether it is possible to detect historical casting techniques on figural copies and distinguish differences due to these techniques from those caused by environmental influences after exposure to the weather. The figures from the Fürstenportal of Bamberg Cathedral of St. Peter and St. George, part of a UNESCO World Heritage site, have experienced much deterioration since the portal was erected in the early 13th century. For this reason, the jamb figures were moulded at the beginning of the 19th century and plaster copies made. These copies remained in safekeeping for over 90 years until they were used to make stone cast copies in the late 1990s. The copies replaced the outdoor originals, which were moved to a museum to protect them from further decay. It is therefore possible to observe different temporal states of the figures. Details of the moulding process could be identified with a workflow consisting of high-resolution 3D scanning, 3D surface comparisons and archival research. The plaster copies and the stone cast copies show different traces of the casting process. Both used flexible materials in the moulding process, which caused the copy to slightly deform from the originals. Furthermore, environmental influences could be separated from the moulding phenomena. Erosion from more than 90 years between the creation of the plaster copy and the translocation of the originals to the museum was observed, as well as erosion from the last 20 years on the stone cast copies.

1. INTRODUCTION

1.1 The Fürstenportal of Bamberg Cathedral of St. Peter and St. George

Sculptures on churches are often severely affected by natural weathering and mechanical damage. One way to protect the original masterpiece is to copy it and bring it into interior climate conditions, for example in a museum, while a replica is placed outside. These replica figures can be manufactured by stonemasonry or by moulding and casting the original. However, the moulding process, as well as natural erosion can result in deviations from the original.

Figure 1. The Fürstenportal of Bamberg Cathedral.

The figurative representation of the Fürstenportal of Bamberg Cathedral of St. Peter and St. George (Figure 1), part of the Bamberg UNESCO World Heritage site, serves as a case study for preliminary research into this phenomenon. The predecessor building of Bamberg Cathedral was destroyed in a fire in 1185, and the construction of the new building began immediately after. The new cathedral was consecrated in 1237 (Exner, 2015, Hubel, 2015, Hartleitner 2011). The construction of the Fürstenportal itself was finished in 1225 (Breuer, 1993, p. 7, Exner, 2015, p. 424, p. 443) and is a round arched portal with a delicate figural decoration. The jambs are alternately decorated with eleven ornamented columns and column figures tapering inwards on each side, above the lintel is a scenically designed tympanon. (Albrecht, 2015, p. 243)
The Fürstenportal was used to test whether it was possible to determine historical casting techniques on different figural copies and distinguish them from environmental influences.

1.2 The sculptures of the Fürstenportal

The total 22 columns of the vaulting correspond in position and structure to the pillars, which are divided into two halves in the middle by a shaft ring. A pair of sculptures decorates the upper section of every second column, the 12 apostles standing on the shoulders of 12 prophets. (Albrecht, 2015, p. 256). In the 19th century, there is ample evidence of the poor condition of these figures, which resulted in the precautionary creation of multiple plaster copies in 1903 and 1904. (Breuer, 1993, p. 7, Exner, 2015, pp. 285f.). For each jamb figure there were two to three plaster copies made. However, the plan to replace the original figures was abandoned and lost its importance during the World Wars and most of the 20th century. The originals weathered visibly in place during that time until it was decided to put them in a museum for their protection in the late 1990s and early 2000s.

1903 – 1904	1904 – 1999	1999 – 2002	Since 2002
• Moulding of the original • Creation of the plaster copy	• Original figures outside until 1999 • Plaster copy stored until 1990s	• Moulding of the plaster copy • Creation of the stone cast copy • Exchange of the original with the stone cast copy	• Original figure in the Diocesan Museum Bamberg • Plaster copy in the depot • Stone cast copy outside

Table 1. Timeline of the different variants of the jamb figures.

During this period, the idea of replacing the portal figures with copies was also revived. (Exner 2015, pp. 302f.) However, the question arose as to what should be placed in the original location. A further plaster casting of the original figures was considered to be potentially too damaging and excessively risky, since moulding can lead to residues on the originals, as well as erosion on the surface. Even though there were initial thoughts about digital 3D object acquisition (Dauer et al., 1994), it was not yet possible at that time to create a satisfying copy using a 3D printer, for example.

Therefore, the attention fell on the plaster copies of the portal figures made between 1903 and 1904, as they had been well preserved for the 95 years since their original casting. The goal was to make moulds of the plaster cast copies using latex and copy the jamb figures with stone substitute (stone cast).

Between 1999 and 2002, the original figures were replaced with stone cast copies at the original location of the Fürstenportal. (Hartleitner, 2011, p. 91) Due to this complex history, one can nowadays observe different temporal states and layers of time, on a single object (Table 1). First, there is a comparison between the original and the plaster copy, showing 100 years of wear, and then there is also the weathering of the stone cast copies over the last 20 years. In addition, it is also possible to illustrate weathering effects regarding these variants of the sculptures.

2. METHODOLOGY AND WORKFLOW

2.1 Archival research

In addition to 3D data acquisition, a review of the recent history of the object was necessary. Since we are dealing with a period of 100 years and three variants of one object - original, plaster cast and stone cast - that are tangled in a complex interplay throughout their history, research of the more recent measures in the archives of the local cathedral's workshop was essential. Here, reports and records of the copy-making were sought to shed light on the replacement and copying process of the Bamberg Fürstenportal. Special attention was paid to the measurement documentations since the 1990s. After the decision to replace the originals at the portal with copies was finally made in 1991 (Exner, 2015, p. 302), the subsequent process was documented in detail. From this documentation, several mappings of the condition of the figures have also been preserved, which were examined in more detail.

2.2 Structured Light Scanning (SLS)

SLS was initially used in industry for quality assurance but has been used increasingly in the cultural heritage sector over the last few decades. (Bellendorf, 2009, Rahrig et al., 2018, Montusiewicz et al., 2021) For data acquisition, a predefined structured interference pattern is projected onto a surface. This pattern is recorded with one or more cameras at a fixed angle and distance to the projector. Thus, by combining interference height measurement and triangulation, 3D coordinates for single points on the surface can be determined. The data of a single scan thus results in a point cloud. Numerous individual scans are overlapped in the data acquisition process to create an overall point cloud of the object. The finished object point cloud is triangulated and meshed in a post-processing step. (Gühring 2002, Rahrig et al., 2018).

To see if the proposed workflow is suitable it was decided to only examine one jamb of the Fürstenportal as a preliminary study, with two figures standing on top of each other, about 1.8 m high. A total of four different pairs of figures were scanned (Figure 2):

- original sculptures (exhibition Diocesan Museum Bamberg)
- two plaster cast copies (1903 – 1904, museums depot)
- stone cast copy (1999 – 2002, cathedral Fürstenportal)

A Comet L3D 5M from Zeiss Optotechnik (formerly Steinbichler Optotechnik) was used for the three-dimensional measurement of the surfaces of the Fürstenportal figures. By changing the lenses on the sensor, the measuring field of the scanner can be adapted to the desired surface resolution. The sculptures were recorded with the 250 mm lenses, which cover an area of 260 x 215 x 140 mm³ with a mean point spacing of 0.1 mm. Calibration ensures a mean object point error of less than 0.02 mm.

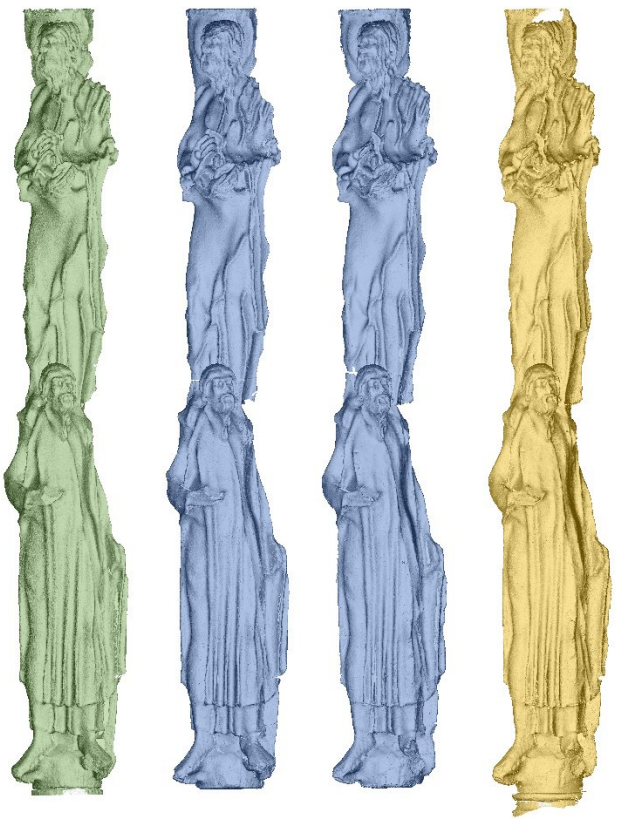

Figure 2. The four 3D Models of the jamb figures. From left to right: Original (green), plaster copy 1 (blue), plaster copy 2 (blue), stone cast copy (yellow).

The 3D measurements can serve as a basis for precise examinations of the objects. Since the texture information is not needed for the further analysis of the surface, it was decided to use a structured light scanner that specialises on accurate acquisition of the sculptures' surface. Without the texture

information, the surface structure is more obvious. In addition, a raking light can be generated from artificial light sources, which enables the investigation of the structure of the surface in greater detail. Due to the high-resolution documentation of the surface topography in the sub-millimetre range, surface features findings can be detected precisely. This is needed not only to record the status quo but also to visualise the differences between the various surfaces of the delicate sculptures and cast variants. The use of photogrammetry was rejected, primarily because effective lighting of the stone cast copy would prove difficult as there would be many different angles needed and event then parts of the sculpture would be shadowed. Also, for the necessary resolution the number of pictures would have been enormous and increase the postprocessing time as well as the overall capturing time.

The SLS used is not handheld but it is portable, and thus can be used on site. The portability, and the use of a scaffold, enabled the scanning of the stone cast copies installed at the Fürstenportal without having to remove the figures (Figure 3). The measurements are completely contactless; in this case, there is only a projection of blue LED light onto the surface.

Figure 3. The Comet L3D 5M on a scaffold for the scanning of the stone cast copy.

When recording the structured light scan data, it should be noted that changes in the surrounding light conditions can interfere with the recordings, as sunlight can fade the structured interference pattern of the blue LED. The images of the stone cast copy were therefore taken in December 2021, while the portal was in a winter enclosure for weathering protection. On a scaffold inside the housing, the scans of the object could take place undisturbed. The originals were recorded in the Diocesan Museum Bamberg and scans of the plaster copies were made in a depot of this museum in Bamberg. Approximately 60 to 90 individual scans were made for each sculpture, which were registered with each other on site.

The scans were further processed in the Centre for Heritage Conservation Studies and Technologies in Bamberg using CometPLUS v.9.96 software. The mesh resulting from the triangulation process was imported into Geomagic Wrap v.2021 to remove small components and align the model orthogonally along planes to simplify the export of views. Holes in the model were not closed and the surface was not smoothed to preserve the original surface accurately.

2.3 The 3D Comparisons

In addition, the surface models are used for a mathematical 3D comparison. The 3D comparison of data, for example securing the quality of prototypes has been used in industry for years (Gühring, 2002, pp. 141-145). Recently, deviation studies have also been used in the field of cultural heritage research as well as restoration and conservation, in order to better understand the relationships between objects of similar size and appearance. Subtle differences can be revealed that are not at all or only barely discernible. (Rahrig and Street, 2020, p. 277) The application of 3D surface comparisons is also used, for example, to monitor conservation measures or signs of wear. (Hein 2015, Holl et al., 2017, Rahrig et al., 2018, Rahrig and Torge 2019, Holl and Bellendorf, 2022)

Using 3D inspection software, two data sets can be examined to reveal differences in surface topography. With this workflow, differences in the 3D models down to the submillimetre range can be easily detected and visualised. In the case of the Fürstenportal figures, it was possible to compare the original figure with the plaster copy made in the early 1900s, as well as with the stone cast copy made in the late 1990s. In addition, the later stone cast copy was compared with the earlier plaster copy. The four data sets of the jamb figures variants were imported as .STL files into GOM Inspect, from GOM Software v.2022 in the Zeiss Quality Suite. A target-actual-comparison is performed and the differences between the actual model and the target model are visualised in false colour.

Initially, two data sets are roughly aligned using three pairs of points. Afterwards, surface areas could be selected on the actual model to serve as a reference for a best-fit algorithm. This algorithm then references the two models mathematically in the best possible way. It is important to mention that it was necessary to use only smaller reference areas for the best-fit process and analysing these. Using the whole figure for the best-fit, the large-scale deviations caused by the moulding process would render a proper interpretation of the results useless, as small-scale deviations due to wearing would be overpowered. Afterwards, the differences between the 3D models can be displayed in a false-colour image (Figure 4).

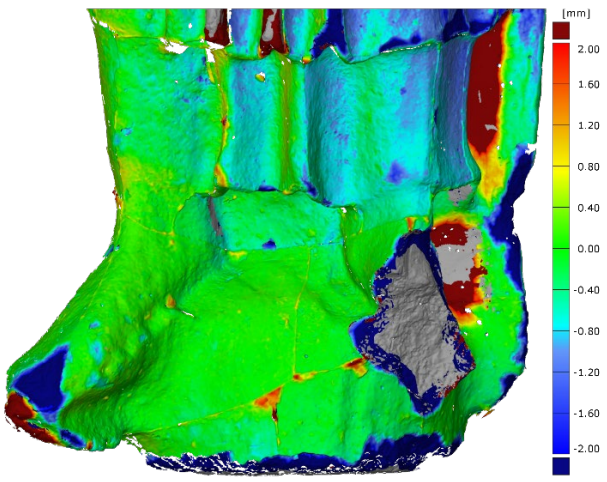

Figure 4. 3D comparison of the prophet's foot. The original is the target, and the plaster copy is the actual.

Yellow to Red	Green	Turquoise to Blue
+0.8 to +2.0 mm	0.0 to +/-0.4 mm	-0.8 to -2.0 mm

Table 2. Deviation range of the false colour images used in this project.

The green parts (Table 2) indicate the areas where changes are small, whereas yellow to red indicate areas where there is more substance on the actual model than on the target model. Turquoise to dark blue shows a deviation between the models from -0.8 to -2.0 mm, which indicates a loss of material. This allows the visualisation of spalling and other erosion effects on the surface, as well as the growth of cracks and crusts. These results, as well as several mappings from the cathedral's workshop archives were used for the further interpretation of the findings. This workflow, consisting of archival research, the analysis of the object surface and the surface comparison of the different jamb figure variants helped to understand the differences between the various mouldings and the various erosion times.
The ultimate interpretation of the results developed from an interplay of the three components: Archival research, surface analysis on the 3D model and surface comparison of the different figure variants.

3. ANALYSIS

3.1 Relation between original, plaster copies and stone casting

The first challenge was to unravel the exact relationships between the different versions of the pairs of figures in the Fürstenportal: The original, the plaster copies and the stone cast copies. The various sculptures were exposed to wind and weather for different periods of time, whereas the plaster copies were never exposed to the weather and represent the original condition of the figures around 1903 – 1904 (Table 1). The originals stayed outside until about 1999 and portray another 95 years of wear and tear. The stone cast copies show around 20 years of exposure to weather.
Since there were two different plaster copies of the same figure in the Diocesan Museum Bamberg's depot, the task was to find out which sculpture served as a model for the stone cast copies. Here the detailed mappings of the differences between the plaster casts and the originals were consulted. The considerations that led to the selection of a plaster model to be used for the stone casting were also noted. Since two plaster copies survived until the 1990s, a selection had to be made. This involved examining the two plaster figures for their fidelity to the original and recording any damage that had occurred during storage. This damage included, for example, breakages that must have occurred during transport, but also dripping damage caused by a leak in the roof (Figure 5). (Dauer et al., 1994)

Figure 5. Dripping damage on one of the plaster copies.

The fidelity mapping created in 1994 while preparing for the stone casting suggested one sculpture that came closest to the original. The figure selected for the stone casting therefore had fewer abrasions and detachments and still had both feet, for example. However, after combining the mapping from 1994 with a close examination of the 3D models of the plaster copies, it was possible to determine that the sculpture that was actually used as the mould for the stone casting was a different one (Figure 6). The recommended plaster copy (a) still had a foot and overall fewer damages, as well as less prominent casting seams. The reason for the change remains unclear, as it was not documented.

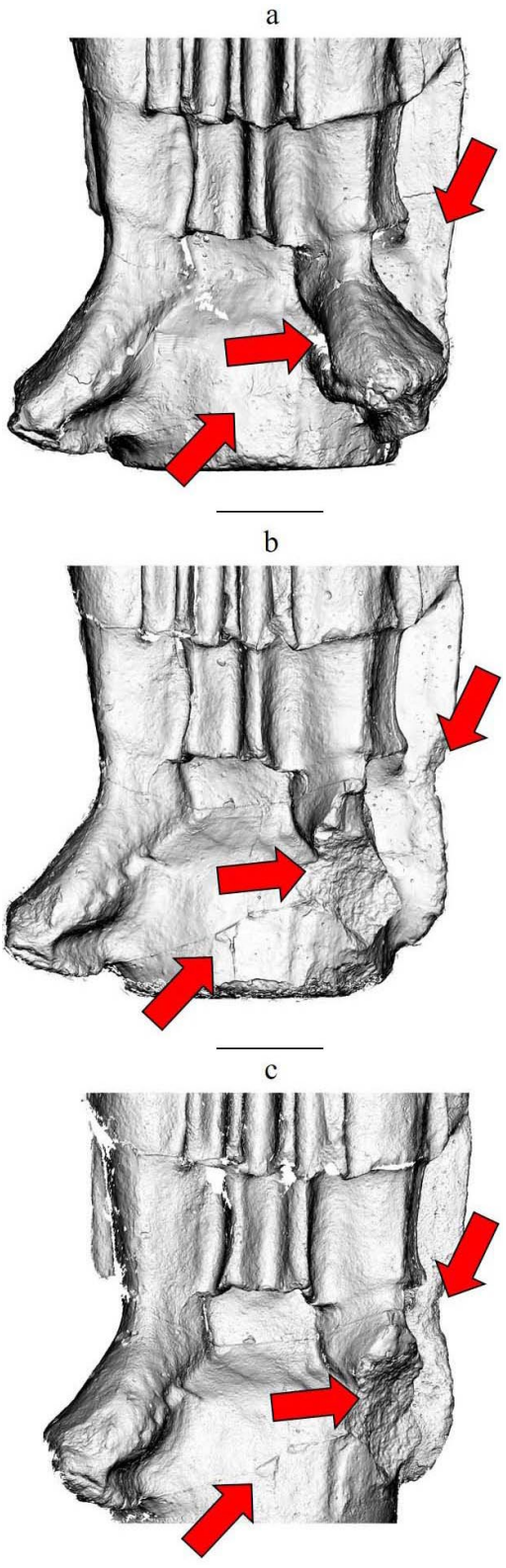

Figure 6. (a) plaster copy recommended, (b) plaster copy used, (c) stone cast copy.

3.2 Moulding processes and effects on different casts

For the moulding of the Fürstenportal figures in 1903 – 1904, glue was used. The original's surface was powdered with talcum powder and then coated with hot glue. (Bohnagen 1987, pp. 123-129) Later latex was used for the stone cast copies, as it was expected that it would leave less residue on the gypsum surface. (Dauer et al., 1994) Both workflows worked with flexible materials, which are necessary for moulding. It can happen that these moulds change their volume when casting under pressure. Therefore, the moulds may shift, and the proportions of the moulded figure may change, even though this is usually marginal. (Rahrig and Street 2020, p. 288) Therefore, the first challenge was to understand the process of the moulding and the individual traces on the plaster copies from 1903 – 1904, as well as those from the stone cast copies between 1999 and 2002.

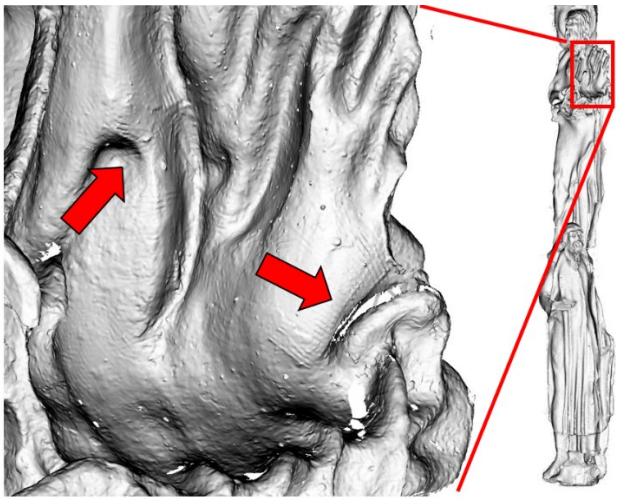

Figure 7. Detail of the plaster copy apostle. A casting seam was treated with a serrated chisel.

For this purpose, the 3D models were examined first. Numerous casting seams could be identified in the plaster copies (Figure 7), and these seams also stood out in the 3D comparison of the original with the plaster copy. In Figure 4, the seams can be seen as red lines, indicating an addition to the surface. In some places parallel indentations were located along the casting seams (Figure 7). Here, too, the archival research was able to make an important contribution to understanding the phenomena found. Particularly prominent cast seams were treated with a serrated chisel in order to conceal the seams.

In the 3D comparison it is shown that the moulds must have changed in volume during the cast process, as a +/-5.0 mm shift from left to right can be seen, starting from head to toe. As discussed earlier, the 3D comparison was performed for smaller areas to properly indicate changes on a smaller scale, as these deviations would be overshadowed by the larger volume changes of the overall moulding process. It turned out that the moulding was taken in individual steps. As the cast seams already suggest, the original was cast in individual parts. With this moulding process, it can happen that the parts no longer fit together exactly and shift in the flexible mould. This was confirmed by the 3D surface comparisons.

For example, the dimensions of the body of the apostle have shifted by 2.0 mm (Figure 8). The right lower part shifted from original to plaster copy (left) by 2.0 mm and from plaster copy to stone cast copy (right) by 1.0 mm. This is also an indication of the different moulding processes. The casting of the plaster copy resulted in a sculpture that was different to the original, albeit very subtly.

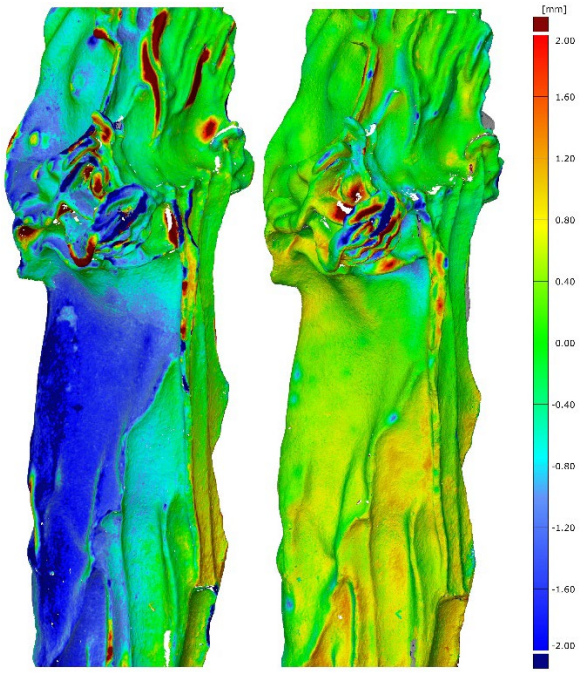

Figure 8. 3D comparison of the apostle, showing the flexible materials shifting during the casting process. Left: original as target, plaster copy as actual. Right: plaster copy as target, stone cast copy as actual.

The same can be said about the stone cast copy. The comparisons in Figure 8 both show the same area but differ greatly in their deviations. The comparison between the original and the plaster copy show reduced material on the surface over nearly the whole figure. The comparison of the plaster copy and the stone cast copy however shows an increase of the surface volume. Both moulding processes therefore show different results.

3.3 Analysis on the deviations caused by environmental influences and mechanical damages

In addition to the differences between the figures due to the moulding process, the 3D surface comparisons can also show the erosion caused by weather effects, and also mechanical damage. In the area of the right crook of the original prophet's arm, it was possible to detect erosion that must have been caused by the dripping direction of water. Over the years, water dripped onto the right crook of the prophet's arm in two round spots, hollowing it out (Figure 9).

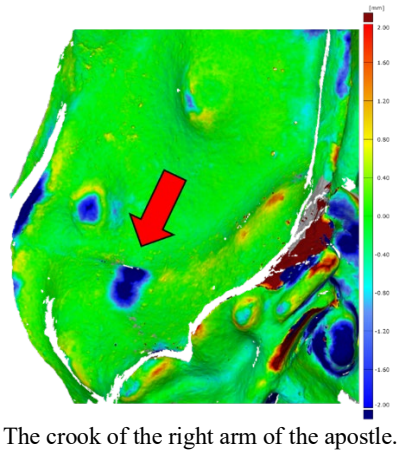

Figure 9. The crook of the right arm of the apostle. The blue dots marked with the red arrow indicate erosion. Original as target and plaster copy as actual.

The mechanical damage was easier to observe than the weather-related erosion, with many large pieces breaking off. By comparing the original apostle figure (target) with the plaster copy (actual), it was possible to find out that parts of the nose must have fallen off in the time since the moulding (Figure 10). In addition, parts of the column on the back left and parts of the neck on the right side of Figure 10 seemed to have been lost over time.

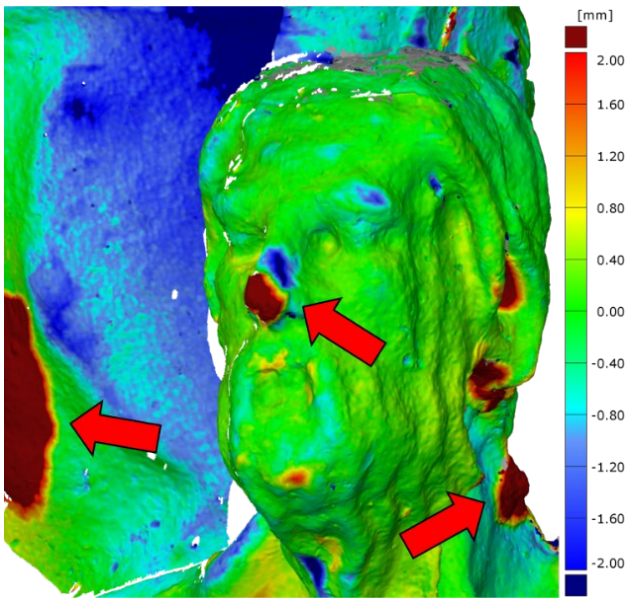

Figure 10. Surface comparison of the apostle head. The original as target and the plaster copy as actual.

4. CONCLUSION

The work on the jamb figures of the Fürstenportal at Bamberg Cathedral has shown that, in combination with archival research, a high-resolution 3D scan can provide valuable insights into historical casting processes and damage phenomena. The 3D surface comparisons created from the scanned models in particular provided information that shed light on the situation even in such a complicated case. The different temporal states of the three figure types investigated, the original, the plaster copy and the stone cast copy, each showed unique surface details. The wear and tear of the original, between the beginning and the end of the 20th century could be seen in a comparison between the original and the plaster copy. These findings differed from the 21st century wear and tear, as seen in the comparison between the stone cast copy and the plaster copy. These 3D comparisons successfully detected and determined the differences in the moulding and casting processes, as the moulding and casting of the plaster copy proved different from the stone cast copy.

The traces left by the casting could be identified in the form of cast seams. Cast seams are present over the entire plaster copy, some of which were later processed so as not to be too conspicuous. The differences in volumes caused by both moulding processes can be visualised and determined. The differences between the moulding of the original and the subsequent plaster copy, and between the plaster copy and stone cast copy, were clearly noticeable. Both processes caused distinctive deformations in the sculptures.

Furthermore, it was possible to show the erosion that occurred to the original during the 20th century, as well as the erosion that the stone cast copy underwent in the course of the 21st century.

An interpretation of the findings, such as the revision of the casting seams, was aided with precise archival research. Yet simply trusting these archival documents proved challenging as well. To determine the plaster copy used for the stone cast, the documents strongly suggested a specific subject, but the investigation showed that nevertheless, five years later the second one was chosen for the moulding.

Therefore, it can be stated that on this particular object it was possible to determine and to detect effects of historical casting techniques on different figural copies and distinguish them from environmental influences such as erosion caused by different temporal states.

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