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DIGITAL DOCUMENTATION OF CONSTRUCTION DETAILS IN THE ARCHITECTURE OF MICHELANGELO AND GIULIANO DA SANGALLO

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Abstract

The paper presents two showcases in which construction details of ashlar butts, tool marks, and the respective surface treatment in the works of Michelangelo and Giuliano da Sangallo have been studied. One of the main challenges in both projects was to choose the appropriate documentation method for the capturing of the small scale traces. After the documentation the collected data was converted to 3D models in U3D format that have been embedded in pdf sheets. This enabled the three dimensional data to be made publicly available via the project homepages.

Keywords

3D laser scanning, Hand held scanners, Structure from motion (SfM) mapping, Stone masonry joints, Capitals

1. *Introduction*

In the field of archaeological building research, precise methods were developed at an early stage that allow a specific approach and interpretation of individual architectural forms.

This is probably due to the fact that, in an archaeological context, the structures to be investigated are often directly accessible to the researcher. In this context, excellent results have already been achieved, especially in the field of research on Roman capitals (e. g. Heilmeyer, 1970; Freiberger, 1990; Toma, 2018).

Here it is possible, for example, to identify individual workshops using tool and machining traces and to understand distribution channels. On individual (often even only fragmentarily preserved) components, proper systems of stone joining can also be partially reconstructed. On the basis of such structural elements, it is possible to successfully identify design principles and reconstruct construction processes.

With the increasing refinement of methods – also on the technical level – this work is constantly being continued and improved in the archaeological context. This provides the opportunity to develop new research questions. However, the improved technical documentation methods are also accompanied by risks that must always be taken into account in terms of serious scientific application.

In terms of research into the architecture of the early modern period, studies that implement methods established in the archaeological context are the exception. This is probably due to the fact that the corresponding parts are usually still *in situ* on the building, so that they are difficult to reach from all sides and the construction details are therefore not recorded. In two projects by the Institut für Baugeschichte at the Technische Universität Braunschweig, attempts are now being made to transfer the investigation methods established in archaeological building research to buildings of the Florentine Renaissance.

Different methods of digital documentation are used to capture architectural details with reasonable accuracy. In addition, a system was selected for the preparation of the three-dimensional research data that can guarantee easy storage and presentation.

Case Study: Stonework in the Biblioteca Medicea Laurenziana

The Biblioteca Medicea Laurenziana in Florence, designed and constructed by Michelangelo between 1524 and 1534, continued to be built by other architects after Michelangelo

Fig. 1: Comparison of window framing profiles in Florence: Palazzo Bartolini Salimbeni, west facade, ground floor (left); Biblioteca Laurenziana, reading room, inner framing (middle); Santo Spirito, Capella Corsini, Secondo Chiostro (right)

moved to Rome in 1534, extended and completed into the 20th century, is the subject of a project of the Institute of Architectural History funded by the German Research Foundation (DFG). Clement VII commissioned Michelangelo immediately after his election as Pope to incorporate a library for the Medici family's book collection into the monastery of San Lorenzo.

2.1 Question

Of the originally planned rooms (vestibule, reading room and *piccola libreria*) only the first two were built above the upper floor of the west wing. Determining the proportions of the architecture that were not only designed by Michelangelo but also constructed under his supervision, was a crucial question of the project approach.

Since numerous original sources (contracts, letters, drawings, accounts, own records, etc.) have survived from the creation of the Laurentian Library, individual design steps and project phases can be distinguished and analysed in detail if several structural elements are involved.

In the implemented ashlar architecture, construction principles could be demonstrated that deviate from the contemporary Florentine building tradition (Schulz-Lehnfeld, 2019a, pp. 188-191). In particular in the pedestal profile, but also in all other components of the *pietra serena* structure, elaborate three-dimensional joining points can be seen which suggest an influence of Michelangelo (as sculptor and stonemason) on the execution of the essential components. If a membering element consists of several joined stones, the joints of the ashlar are designed in such a way that the joint pattern affects the profiling as little as possible. The essential difference in appearance is illustrated in Fig. 1 using three examples of different window framings. Both at Palazzo Bartolini Salimbeni, which was built by Baccio d'Agnolo between February 1520 and February 1523 (Lingohr, 1997), and at Cappella Corsini in Secondo Chiostro by Santo Spirito, realised after 1564 on the basis of drawings by Bartolomeo Ammannati (Kiene, 2002), the ashlars butt in a straight horizontal joint. For the framings in the reading room of the Biblioteca Laurenziana, the stone butt is guided diagonally at a 45° angle to the outermost profile element in the intersection line of the wrap-around profiles. In the outermost strip, the butt joint is broken up and guided vertically.[1]

This stone jointing in Michelangelos designs becomes even more complex if the profiles not only break at right angles in one plane (as with the window framings from vertical to horizontal profiles) but, as in the pedestal profile of the Ricetto, are also to be led into the third dimension in the same form. Fig. 2 shows the profiling of one corner of the lower pedestal profile. On the one hand, the profile is bent into the depth of the wall niche following the outline of the floor plan, on the other hand, the upper end of this profile is led vertically upwards as a framing of the wall panels. Fig. 3 shows schematically the profiling of this design detail at the lower and upper end of the

[1] In the upper corners of the framing profiles, this last strip is usually joined horizontally, resulting in a complex stone joint which, unlike the joint at Baccio d'Agnolo, does not allow interchangeable stones for the left and right sides.

Fig. 2: Lower part of the pedestal profile in the Ricetto of the Biblioteca Laurenziana

pedestal. In the existing building recordings (Apollonj Ghetti, 1934; Portoghesi, Zevi, Argan, & Barbieri, 1964; Rossi, 1739) there are no indications of stone joints in the ashlar profiles, so that a comprehensive evaluation of the stone joints is not yet possible.

2.2 Challenge

The aim of the new documentation was to make the stone joining in the ashlar membering understandable. By means of terrestrial laser scanning, a point cloud was created which captured the space almost completely. The shading could be minimised through numerous viewpoints.[2]

The evaluation of the point cloud shows that the stone joints were worked so precisely that they cannot be traced in the noise of the surfaces.[3] Fig. 4 shows the point cloud of the lower pedestal profile. Details of the ashlar architecture < 3 mm such as the butt joints of the stone joining, and traces of work cannot be documented.

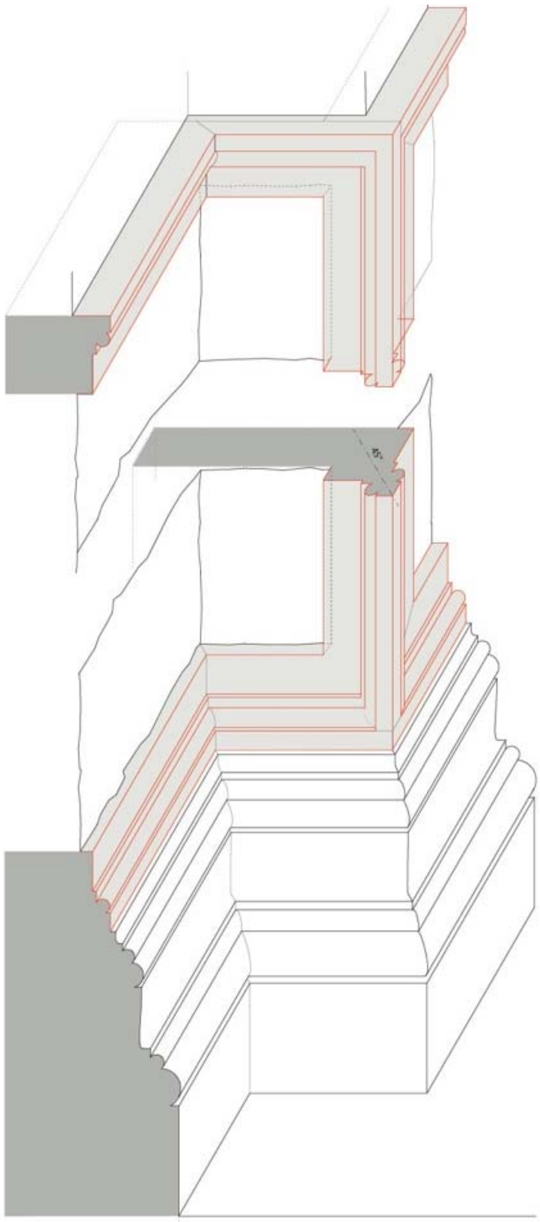

Fig. 3: Pedestal profile in the Ricetto of the Biblioteca Laurenziana, schematic representation after manual surveying.

2.3 Documentation

By capturing the profile details with a hand-held 3D scanner, the joining details could be documented more precisely.[4] In the model, stone joints become visible and measurable not only through the material differences recognisable by

[2] A Leica P20 scanner was used to create the point clouds. Targeting was used both for stationing and for registration in Cyclone, which were used in the Ricetto with a calculated error deviation of < 2 mm. The complete documentation of the creation of point clouds appears in the author's dissertation.

[3] The point accuracy in the most precise scan mode is at a resolution of 1.6 mm @ 10 m even at shorter distances > 2 mm. Straight edges blur and smooth surfaces are traversed by a uniform structure (noise).

[4] An Artec Space Spider with associated software Artec Studio 12 Professional (version 12.1.1.12) was used for the acquisition.

the RGB values, but also through the measurable deviations and offsets of small size (up to 0.5 mm) (Kersten, Starosta, & Lindstaedt 2018).

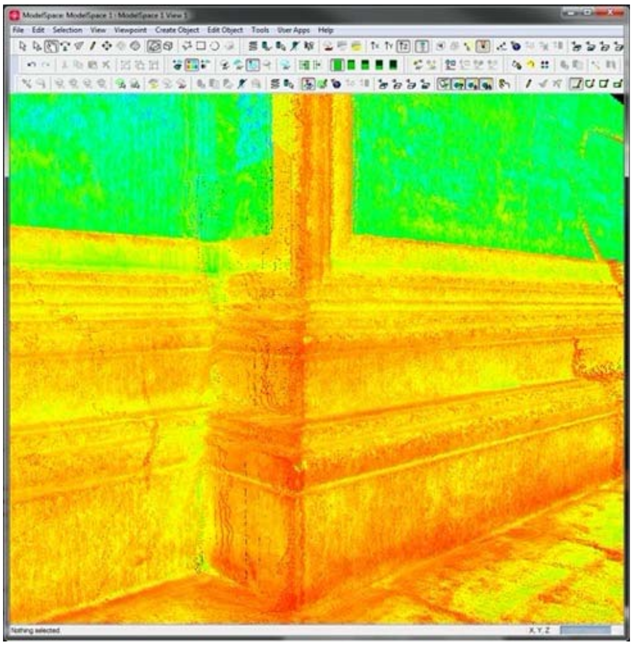

Fig. 4: Pedestal profile in the Ricetto of the Biblioteca Medicea Laurenziana, Hue intensity representation during the editing of the point cloud in Cyclone.

The digital model (Fig. 5) was integrated into a PDF document for publication purposes (Schulz-Lehnfeld, 2019b).[5] The advantage of this documentation method lies in the availability of the 3D model data for the individual review of the results by the reader. Each user can define their own view of the virtual documentation model and define sections through the model.[6]

If all stone insertions are analysed in this way in a pedestal section, the complex stone joining of all components can be reconstructed. Fig. 6 shows how the eight sides of a wall block set with ashlar are constructed from 4 stones and with which complex intersections the stones were joined. The end profile of the lower pedestal profile is part of the horizontal base stone on the front, but part of the vertical flank stones on the sides. The butt joints ensure that the individual bricks are supported in such a way that they cannot be moved.

Fig. 5: Pedestal profile in the Ricetto of the Biblioteca Medicea Laurenziana; see model embedded as U3D-Mesh at Fig. 11.

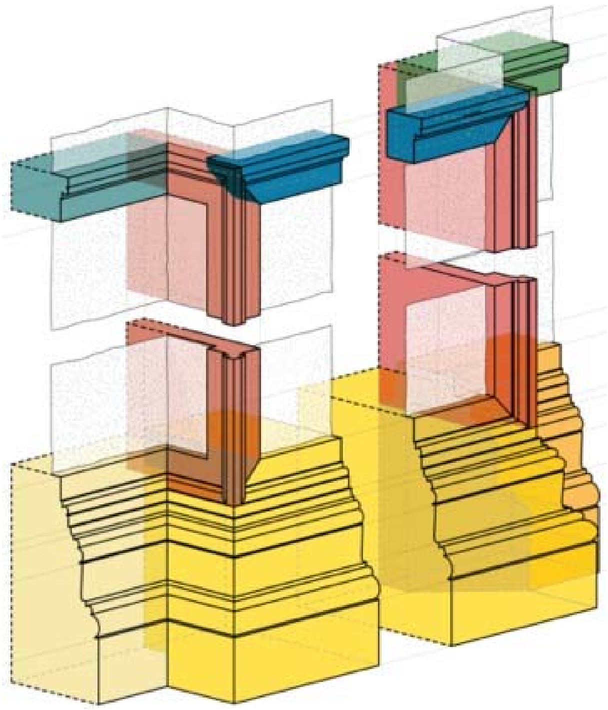

Fig. 6: Pedestal profile in the Ricetto of the Biblioteca Medicea Laurenziana, Reconstrucion model of the stone joints of a wall compartment. The different colours mark separate ashlars.

[5] From the point cloud in Artec Studio (LAZ format), a U3D file was created in Meshlab (Version 2016.12), which can be integrated into PDF documents. The gaps in the point cloud created during scanning were not closed by the mesh in order to minimise the effects of post-processing on the detailed documentation.

[6] The PDF of this documentation example is available on the website of the Institute for Building History.

2. *Case Study: Capitals in the Courtyard of Santa Maria Maddalena dei Pazzi*

3.1 Question

The architectural language and the related understanding of antiquity at the end of the 15th century developed in the field of tension between theoretical debate, building survey and own design work. This mixture becomes particularly clear in the work of Giuliano da Sangallo. For a deeper understanding of the multi-layered concept of antiquity and its relationship to the built architecture of the time, a differentiated consideration of the architectural elements in each individual case is necessary. It should be noted that the development and execution of a component was subject to a large number of influences during the entire design process, some of which significantly determined the final appearance of the building. These different influences might possibly be traced directly or indirectly on the individual elements using the methods of archaeological building research. In a research project by the Institut für Baugeschichte at the Technische Universität Braunschweig, the process from development to implementation of specific architectural details in Giuliano da Sangallo's work is examined. Of particular interest is the Ionic capitals (Frommel, 2014, pp. 106-107) designed by Sangallo for the courtyard of the Church of Santa Maria Maddalena dei Pazzi in Borgo Pinti in Florence around 1491 (Fig. 7). Due to their very peculiar overall type, the capitals lend themselves to such an investigation. In the Florentine environment, there are several capitals that also reflect this striking type and which may have served as a direct model for Sangallo (Frommel, 2014, p. 110; Amonaci, 1992, pp. 149-151; Corsi, 1992, p. 107; Zampa, 2012, pp. 192-193).

In addition to a capital in the Casa Buonarroti (Fig. 8), there are also four capitals in the crypt of San Romolo in Fiesole that correspond to this type (Fig. 9). In connection with the detailed examination of the individual pieces of the construction of the court complex in Borgo Pinti, the entire process from the (supposedly) antique model to the development of a contemporary adaptation of the design to the practical implementation of the design can be traced (Bauch, Forthcoming). The concrete goal of the documentation campaign was a detailed exploration of the Sangallos capitals and their models. Findings had to be made that provide information on the specific design and production processes. In addition to the analysis of the general shapes and proportions, tool marks and the respective surface treatment were the focus of the investigations.

Fig. 7: Columns in the courtyard of Santa Maria Maddalena dei Pazzi

Fig. 8: Capital in the Casa Buonarroti, Florence

3.2 Challenge

The particular challenge with the documentation was above all to achieve a level of detail that enables an evaluation in the sense of the project questions described. While the analysis of proportions and the general design language can be based on documentation using the traditional methods of hand measurement and photography, these methods reach their limits in the detection of specific tool marks. A reliable check of the existence of serial type production and the recognition of model templates cannot be guaranteed with these methods. Since the relevant traces on the object have sizes in the millimetre range, it was necessary to choose a method that could first grasp this level of detail and also display it.

3.3 Documentation

The capitals were examined in particular for direct traces of the production process. The observed individual findings were first recorded in detailed descriptions of the findings and then also documented photographically.

In order to capture the very small traces of the manufacturing process on the capital, various solutions are possible.

Fig. 9: Capital in the crypt of San Romolo, Fiesole

In addition to a photographic capture and the subsequent transformation into an SFM model, handheld 3D scanners are particularly suitable. Devices are now available on the market in different price segments and correspondingly different quality (Kersten, Starosta, & Lindstaedt 2018). In the project described, the capitals were finally documented using the Space Spider metrological 3D scanner from Artec. The manufacturer specifies a 3D resolution of 0.1 mm for the device with a 3D point accuracy of up to 0.05 mm. This scanner is therefore also suitable for the detection of the smallest drilling and tool marks. In this way, in particular the traces of a hand drill measuring just a few millimetres could be identified and compared on different pieces (Fig. 10).[7]

4. Accessibility of data

In both projects, findings were documented with the help of digital measurement methods, which were used to process the specific research questions. One goal of the basic research work in the projects is to make the collected data widely accessible and to secure it permanently. A major problem in the field of digital documentation is the interoperability of data. A solution was therefore chosen that works with widespread software applications. The three-dimensional data were embedded as models in U3D format in diagnostic sheets in PDF format. The files can be opened with Acrobat Reader. These PDF files are freely accessible on the project websites and can be accessed without restriction (Bauch, 2019; Schulz-Lehnfeld, 2019b). In addition, the PDF files can be stored in the digital archive of the university library of the Technische Universität Braunschweig in the long term.

A fundamental difficulty in capturing capitals using scanners was the multi-layered surface grading. While the upper relief levels could be easily reached by the device, gaps appeared in the scan in undercut areas. This affects a general problem of digital documentation of architectural features in historical building research. When visualizing the results, it is important to enable the user to make a "distinction between evidence and hypothesis" in the sense of the London Charter for the computer-based visualisation of cultural heritage by Denard (2009). Therefore, the technical defects were not filled in the visualisation of the plinth stones and the capitals. Thus, the visualisation only reflects the status of the documentation and does not require reconstructions – the representations are therefore solely evidence-based.

5. Conclusion

In the two case studies presented, construction details were examined in the context of Florentine Renaissance architecture. The respective questions required a particular level of detail in the documentation. It was shown that the

[7] Areas that are not coloured mark gaps in the scan that result from the intersection of the profiles and the distance working area of the scanner.

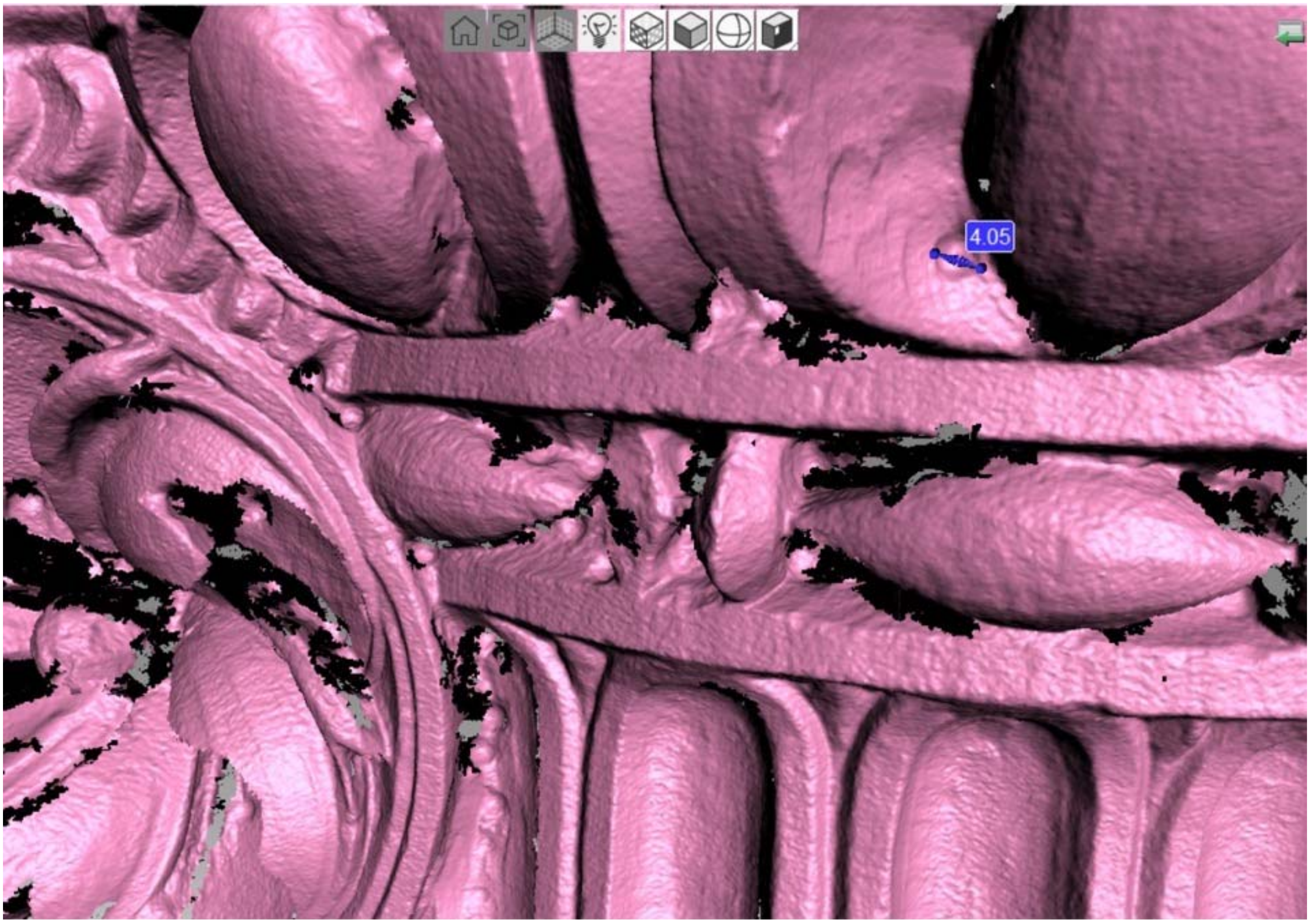

Fig. 10: Measuring drill holes on capitals from the crypt of San Romolo, Fiesole: see embeded U3D-mesh model at Fig. 12

initially chosen method of terrestrial laser scanning does not meet these requirements. With the help of hand-held scanners, the detected details of the stone joining, and tool traces could finally also be digitally recorded and evaluated. The case studies illustrate the challenges associated with the digital documentation of detailed findings of historical architecture. In particular, the accessibility of the results of basic research is an essential task. In both projects, a method was therefore chosen in which the three-dimensional scan results are embedded in PDF documents. The resulting models can thus be viewed with a simple PDF viewer. Another problem is the preparation of the scans. The software solutions offer simple procedures for surface reconstruction. However, since such interpolations mean falsification of the documentation of the findings, the inevitable holes in the surface models were accepted in the sense of a scientifically neutral and comprehensible documentation and were not revised.

Fig. 11: Pedestal profile in the Ricetto of the Biblioteca Medicea Laurenziana: U3D-Mesh model

Fig. 12: Capital from the crypt of San Romolo, Fiesole: U3D-mesh model

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