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Tradition and Innovation: From Worksite Plans to Digital Models

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Abstract

The study and analysis of archaeological elements often ranges from very large sites to small objects. This difference in size and type is also present during survey and representation. This idea sparked the proposed study of worksite plans that constitute the only firm link between historical architecture and its representation. The objective is to develop a new interpretation of worksite plans merging massive acquisition technologies with digital representation. The topic is associated with studies on the origins of architectural drawing based on the interdisciplinary union between architecture and archaeology. The objective is to critically interpret worksite plans in order to establish and classify a study methodology. Based on these premises, we examined the key relationship between the metric/formal construction of a 2D drawing (plan) with a 3D model (ideal model). The study is part of the now consolidated drawing/survey/design process which is based on objective/real drawings and leads to a 3D/ideal model.

Keywords: tracings, 2D/3D models, integrated survey

Introduction

The method of incising in stone the working drawing of structural and decorative elements at the real scale (Αναγραφευζ, Anagrapheus, see Inglese 2012) goes back to ancient times. Many archaeologists were immediately attracted to this subject because the study of worksite plans uncovered the process of combining and juxtaposing architectonic elements and provided precious information on stages of work on site. Quite soon the interest in the formal genesis of worksite plans as well as their correspondence to construction elements made necessary in-depth studies of a more distinctively architectonic character: the history of the construction on site was taken into account and researchers understood how the executive design was drafted when there was no light and versatile material like paper at the builders' disposal (Inglese 2016, Inglese 2000).

Already in ancient Greece and then in ancient Rome the necessity to control the project by means of incisions linked architects to the building site. Later, in the Middle Ages, this practice was widely followed at the construction sites of great Romanesque and Gothic cathedrals. Preserved in the cathedrals of Reims (Branner 1957, 1958, 1963; Deneux 1925), Clermont-Ferrand, Noirlac as well as in other cities in France, Spain (Ruiz de la Rosa 1987, 1997), Italy and England, are evidences – incised in stone – of an attempt at working out a common methodology of controlling architectonic elements (Brunet 1928; Bucher 1973,1979; Ferguson 1979). Inside the cathedral of York, for example, one of the most eloquent examples of a tracing house has been preserved: a room of 4x7 m where the whole paved floor is covered by incisions at real scale. Although they still have not been interpreted univocally, it is still possible to recognize the profiles of two rounded arches, a tracing of a

Figure 1. The church of Santa Maria Assunta Cathedral at Terni.

great ogive, a whole series of stained window decorations and of some polylobate fenestration (Harvey 1968; Wright 1985).

In Italy, on site working plans prepared between the Middle Ages and the XVII century are especially widespread in Umbria (Docci and Gurgone 1977; Chiovelli 2011) and in Puglia (Ambrosi 1988). The church of San Salvatore at Campi (Norcia, Umbria) is of great importance in this context. The church was raised to the ground by the earthquake of August 2016, but had already been damaged by the earthquake of 1859, which struck Norcia and its environs. Inside the church, incised on the paved floor of the right nave, there is a complicated drawing in which it is possible to recognize a bell tower complete with its pinnacle, a small lantern and a weathercock with a flag on top. The drawing was executed at the scale 1: 1 and provides in orthogonal projection, the plan and elevation of the original bell tower (Gurgone 1983). In fact, it is a two-dimensional model created for the purpose of cutting blocks of stone to be used in constructing the edifice. The incisions represent decorative elements of the highest part of the church's tower, which some remains preserved in the space under the iconostasis seem to confirm. A "lace" of embellishment of the gabled roof at the pinnacle has been found. It most probably survived when the church tumbled down in 1859. The stone "lace" exactly coincides with the drawings of the very same element to be found in the incisions.

The worksite plans were realized with the commonly used instruments such as the triangle and the compass while construction and decorative elements were represented through planimetric schemes and – at times – through perspective drawings and sections. The application of orthogonal projections of architectonic artefacts provides precious information for the knowledge of the historical epoch in the aspect of architectonic representation. This piece of information proves that the use of essentially bidimensional models had been decisive since antiquity. The practice of preparing worksite drawings was not aimed only at resolving static and construction problems. They ensure stereotomic aid to stone cutters. From this point of view, it becomes clear how important was the study of the geometrical construction of the worksite drawings to be able to understand to what extent they influenced the realization of architectonic elements. To grasp the range of application of these drawings and the part they played in the process of constructing a building, we decided to articulate the problem by identifying two principal types of signs: the first group is composed of assembly drawings or drawings in situ whose role is to help control the po-

Figure 2. Tracings detected on the counter-façade.

sitioning of architectonic elements; the second group has been termed as design drawings for architecture and is composed of the drawings whose role is to design in advance and control elements to be assembled.

Worksite Tracing at Santa Maria Assunta at Terni

The present research concerns the survey of worksite drawings, a practice which has not yet been formed into a definite and well-defined process. In this particular context, the methodology chosen integrates the competences of architects and archaeologists in order to attain as complete knowledge of the object of study as possible. The integrated competences are further supported by techniques applied: the most innovative instruments of 3D capturing (laser scanning and Structure-from-Motion [SfM]/Image-Matching [IM]) have been coupled with direct surveying methods (traditional pouncing[1]). Massive acquisition has been applied for surveying real architectonic elements as well as the worksite drawings. The latter have been surveyed additionally by traditional pouncing in order to achieve results at the scale 1:1. This choice was dictated by the need to experimentally apply the well-established methodology of surveying three dimensional artefacts at architectonic scale. Whereas in this particular setting the use of the laser scanner has become almost a common practice, the subject of worksite drawings raises problems non-investigated so far. In a context where the whole process of cognition – from acquisition to communication – is carried out totally through digital systems, there appeared the necessity to entrust the first registration of data to traditional surveying processes. This stage immediately triggered off a critical and interpretative reading establishing a link between profound knowledge and the analysed elements.

The stage of data capturing is introductory in relation to the realization of 2D and 3D models. Their stylistic analysis and decomposition into constituent geometric elements is – at least at present – an innovative procedure of the research devoted to worksite drawings. The choice of the type of model, of the set of objective data to be selected as well as of the representation code are not, therefore, independent of the quantity and the quality of the data to be com-

1 Pouncing is an art technique used for transferring an image from one surface to another. It is similar to tracing, and is useful for creating copies of a sketch outline to produce finished works

municated.[2] Considering the enormous value of the drawings as testimony, we have raised the problem of utilizing these drawings for reconstructing – both physically and virtually – represented elements. Moreover, the system of incised executive drawings offers us an opportunity to study, analyse, and reconstruct the constitutive elements of an architectonic organism. They can serve as the point of reference when the edifices collapse, are destroyed or there is no information about them because of no maintenance. This is all the more important in the historical period when earthquakes that shook central Italy caused enormous, often irreparable damage. This is precisely the basis for our research which initiated with the worksite drawings on the counter-façade of the Santa Maria Assunta Cathedral at Terni (Figure 1).

Most probably the church was founded in the IX century. Its Romanesque façade was constructed with materials stripped from Roman edifices preserved in the area. Renovation of the church started in the second half of the XVI century, thanks to the artist Sebastiano Flori, and was completed only in the middle of the following century. The new order imposed, with its modern façade and the front portico was completely ready in 1963. The construction of the belfry in the thirties of the XVIII century concluded definitively the great cycle of renovation of buildings in the area (Angelelli 2006; Sturm 2012).

Five worksite drawings were identified on the Romanesque counter-façade with a homogeneous extension on the whole lower strip up to 2 meters (Figure 2). The stone support has composite texture both chromatically and typologically. The represented elements seem to confirm to the hypothesis that they were executed at the time when the façade was being renovated: the correspondence between the incised element and the architectonic one realized on the XVII century portico is easily retraceable.

Among the tracings, we can detect a plan of a binate column and of a half column leaning against a pillar, a section of an entablature and of the column base, an elevation of a column (the shaft and part of the capital, excluding the base). The incisions might have been realized with some blade tools, a hypothesis compatible with the typology and depth of the tracings: the grooves of the incisions rarely exceed a millimetre, which makes difficult their reading and interpretation with the naked eye.

Surveying: Integrated Data Acquisition and Methods

The worksite tracings have been studied with a double objective in mind: to confirm the correspondence between the design drawings and the corresponding built elements and to develop a classification of various typologies of rediscovered signs, a procedure that has not been attempted so far. This result depends on the data acquisition, which has to be reliable and correct typologically. To achieve this particular aim, the study of the worksite drawings has been carried out by applying the processes of integrated surveying. This methodology is already well-established and seems to be more suited to construct an articulated and verifiable system of knowledge. Problems involved in every process of acquisition are compensated by integrating them. Even though instrumental capturing operations prove to be completely mechanical, the operator's experience is fundamental in organizing the stage of the surveying project designed as a function of the final product. The first experimental approach was a massive acquisition of worksite drawings with a laser scanner[3] (Figure 3).

Although acquisitions of details were duly carried out, the massive survey proved to be unsuitable in this case because the grooves of worksite drawings incised in stone are not deep enough to be adequately captured. In order to optimize the results of scans we decided to trace the signs incised in stone with char-

2 The survey operations (in the stage of data acquisition) provide objective information that describe the elements analysed in quantitative terms (coordinates, position, geometry). Instead, the next stage of the survey (data elaboration) describes the quality of the object analysed with reference to the properties contingent of permanent and to any formal aspect concretely determined within a given reality (Bianchini 1995; Bianchini et al. 2016).

3 Leica Geosystem, Leica ScanStation C10, sample spacing 2x2 mm, 3x3 mm and 10x10 mm.

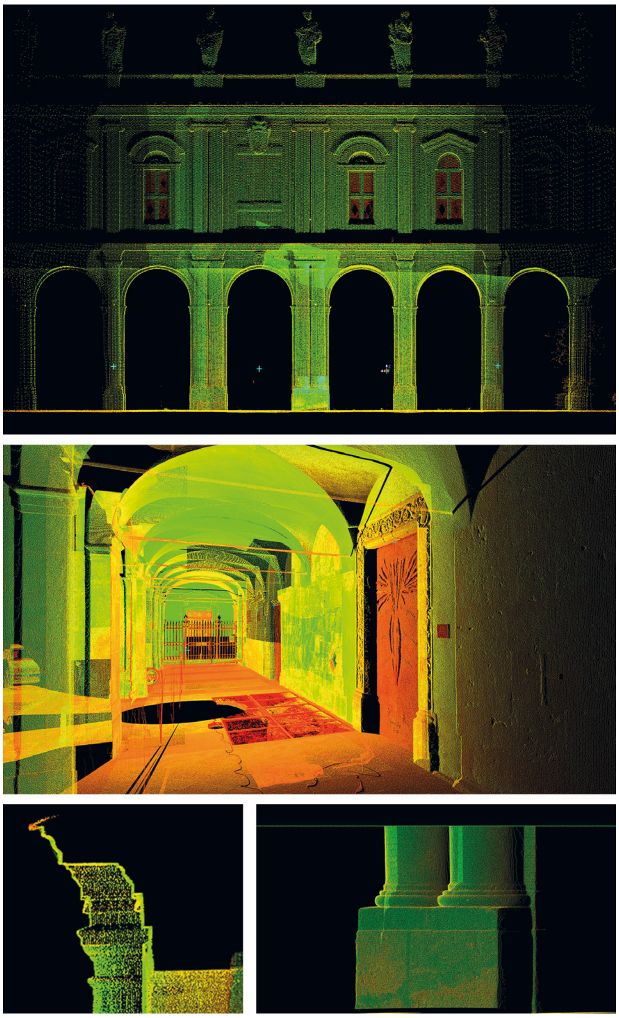

Figure 3. Surveying of the architectural complex. The structured point cloud of the church obtained by laser scanner surveying.

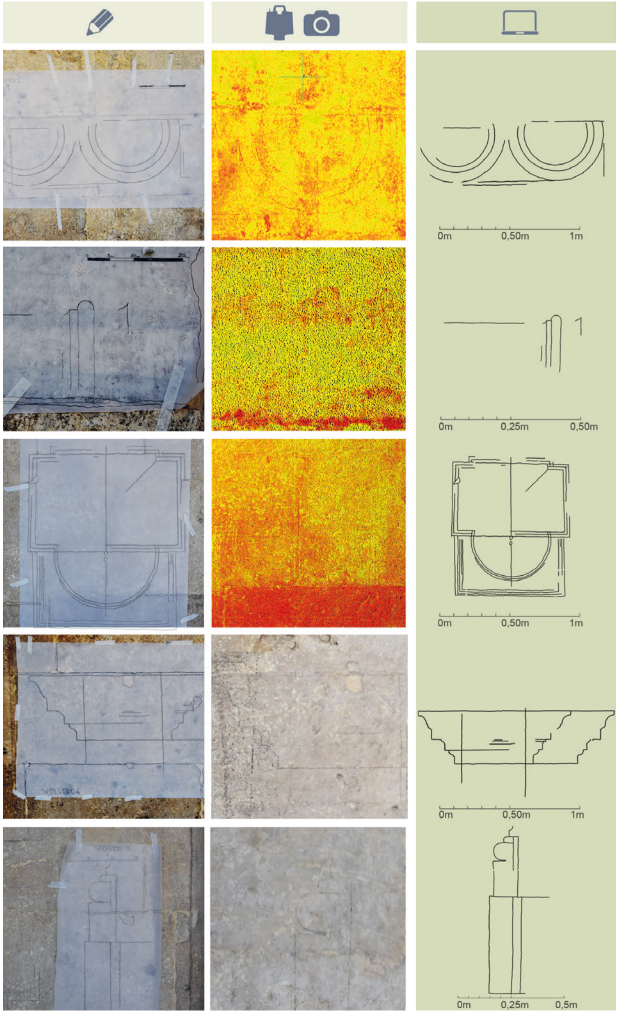

Figure 4. The integrated surveying process of tracings.

coal. This manoeuvre changed the reflectance values[4] of the parts to be surveyed and made the drawings clearly visible. Apart of detail scans of individual drawings, laser scanner survey of the whole portico and the façade of the church were carried out. It proved necessary for a systematic documentation as well as for the acquisition of architectonic elements realized in the façade and found comparable to those represented in the worksite drawings. Massive data capturing with a laser scanner was supplemented by a photographic campaign with the view to realising models of the counter-façade by photogrammetric methods, of architectonic elements of major interest and of a part of the front colonnade. This particular surveying technique proves especially interesting when combined with a numeric model[5] obtained with a laser scanner. Integrating the two methods makes it possible to obtain a metrically controllable orthophotograph of the counter-façade culled from the data from laser scansions and the textured surface from high-resolution photographs. Specifically, although RGB data were acquired with a laser scanner, it was found preferable to entrust the mapping if

4 A fraction of the power that a small superficial area struck by an electromagnetic wave is able to reflect (re-emit). In the case of laser scanning this value can play a predictive role in relations to the physical characteristics a given material (typology, state of preservation) of which the surface of incidence is made or composed.

5 Synthetization of survey datum in which is registered every single information acquired be it metric or chromatic. The term refers to a model whose shape is described by points characterized by their spatial coordinates x, y, z, also known as point cloud.

the surface to the image-based model because of the superiority of the photographic sensor.

For surveying the worksite drawings, the proper techniques for architectonic survey were supplemented by its traditional variety, i.e. pouncing. Tracing incised signs on transparent foil completed information capturing. It was indispensable to acquire data at 1:1 scale in order to make all the signs on the surface legible: because of the irregular nature of stones at the base, it was necessary to add a preliminary stage of recognizing the signs. Pouncing makes possible a direct interpretation of representations at real scale by recognizing the features of architectonic objects hardly visible to the naked eye and made evident through the contrast of graphite and paper.

Surveying operations carried out were planned with the objective of defining a methodology applicable to analogous cases. One again, integration of more techniques and methods yields the most extensive possible knowledge of the sign under analysis and makes it possible to take advantage of the potentialities inherent in each individual methodology (Figure 4).

The Survey: Data Elaboration and Models

Virtualization of survey data enabled the construction of 2D/3D models to compare the ideal datum with the real one in order to verify whether the worksite tracings for constructing the physical element were used adequately (Figure 5). Such an operation is possible by rigorously applying rules of geometry that constitute the only control instrument in this case. Nowadays, digital models become more and more heterogeneous and dynamic both in their creation and management. This proves they could be virtual substitutes of real objects. They come to be expressed through various forms of representation which – by optimizing the univocal transmission of information (metric, geometric, concerning colour, concerning reflectance, etc.) – are applied to simulate more varied operations and make it possible to carry out increasingly more profound analyses.

Construction of models derived from survey data was carried out along two lines: 3D models based on 2D data, for the incised drawings, and 2D models derived from the elaboration of 3D models, for corresponding architectonic elements of the porch. In the former case, the datum at the point of departure is a representation in orthogonal projections. At the initial stage, the 2D data were reproduced in a digital environment. The operation was carried out by interpolating information gleaned from various surveying processes. As concerns worksite drawings, the data provided by visualizing numeric models in reflectance were found to be insufficiently detailed; the signs were hardly visible while their level of detail was not adequate in comparison with the data obtained through pouncing. This acquisition methodology, as has been explained above, is at real scale of representation. The view in reflectance, on the other hand, adds no information of any kind. Precisely for this reason, pouncing results were adopted as the datum of departure for the analysis of ideal models: they were elaborated with the aim of obtaining vector designs. This furnished the basis for elaborating 3D and 2D ideal models (Figure 6).[6]

Design drawings by their nature refer to an ideal model, so their three-dimensional representation cannot be executed through mathematical models: each architectonic element designed follows the rules of descriptive geometry and therefore is well represented by mathematical equations. Such a practice ensures material form and substance to a drawing: one virtually goes once again through the process which connects the stage of designing to that of production of the architectonic artefact on site. In the other case, the data taken as the point of departure were provided by a three-dimensional numeric model of the architectonic elements selected. In this setting, the process of elaboration proceeded from the extraction of two dimensional profiles from a three-dimensional model in which the metrically objective datum proved to be clearly legible.

Elaboration from Structure-from-Motion and Image-Matching completed the cognitive panorama of the area of study: the orthophotograph of the counter-façade was applied to verify whether the photographic acquisition of pouncing had been correct. Photograms for SfM/IM were acquired with a lens focal length of 18 mm (sensor APS-C, equivalent focal length of 27 mm) at the average distance of

6 Model where the shape is described continuously through the parametric equation of the surface from which it is composed. NURBS surfaces are currently one of the most widely used mathematical figures used for this purpose.

Figure 5. Construction of real 3D/2D models of the half column and the binate column.

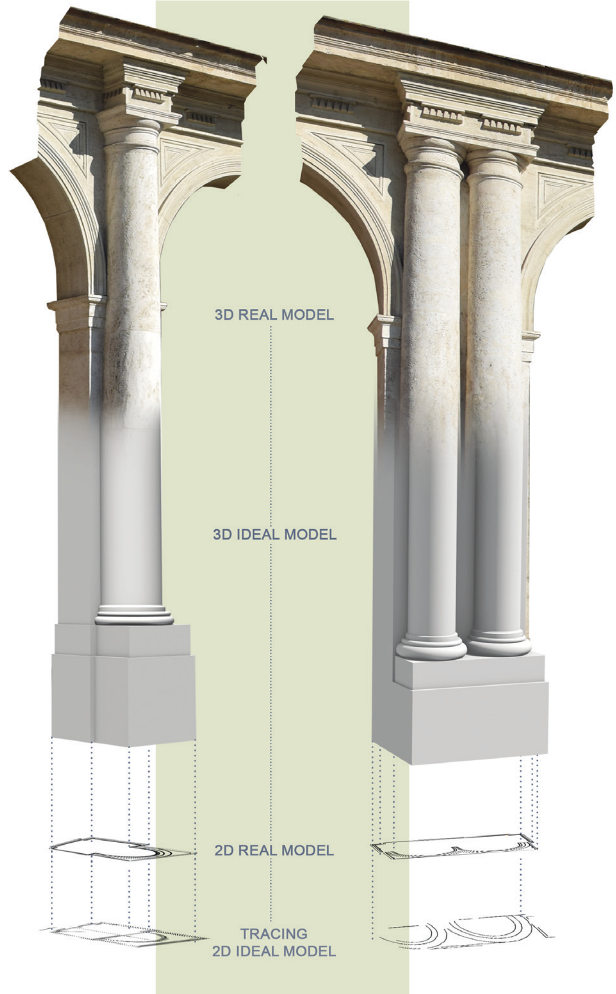

Figure 6. Construction of ideal 3D/2D models of the half column and the binate column. The information that could not be deduced from the worksite tracings are integrated with the images of the real elements.

a meter and a half from the surface. The parameters obtained made it possible to generate a legible model at 1:50 scale.[7]

The problem of scale has become decisive in surveying worksite drawings: pouncing made possible the acquisition of data at 1:1 scale, whereas the restitution scale of the mathematical model depends on the quantity of information contained in the incision. This seems to be a peculiar problem of this subject: the choice of the scale of the model is a function of the objectives to be achieved, but simultaneously this very choice depends the acquisition (of which adequate methodologies take advantage). It follows that for some architectonic elements represented by the incisions, the 3D reconstruction proves to be complete and corresponds to the information recovered from the tracing. This is precisely the case of the mathematical model of a coupled column (Incision 1): the signs of the tracing correctly represent all the mouldings and, consequently, the realized model contains all the information necessary to carry out a typological and stylistic analysis. In other cases, 3D modeling rested on reconstruction hypotheses and data integration starting with other incisions. We refer here to the model of the half column on the pillar (Incision 3) for which the information gained from the survey proved to be partial (according to the authors' interpretation of the incision 3, it represents three diameters of a column, they could refer to the sommoscapo, the entasis and the imoscapo; in the same incision, mouldings at the base of the column

7 The scale of the model depends on the quantity of graphic information it contains as well as on representation quality. In the field of digital photogrammetric processes, the parameters that determine the scale are the following: focal length and the distance of the photographic image acquisition from the object.

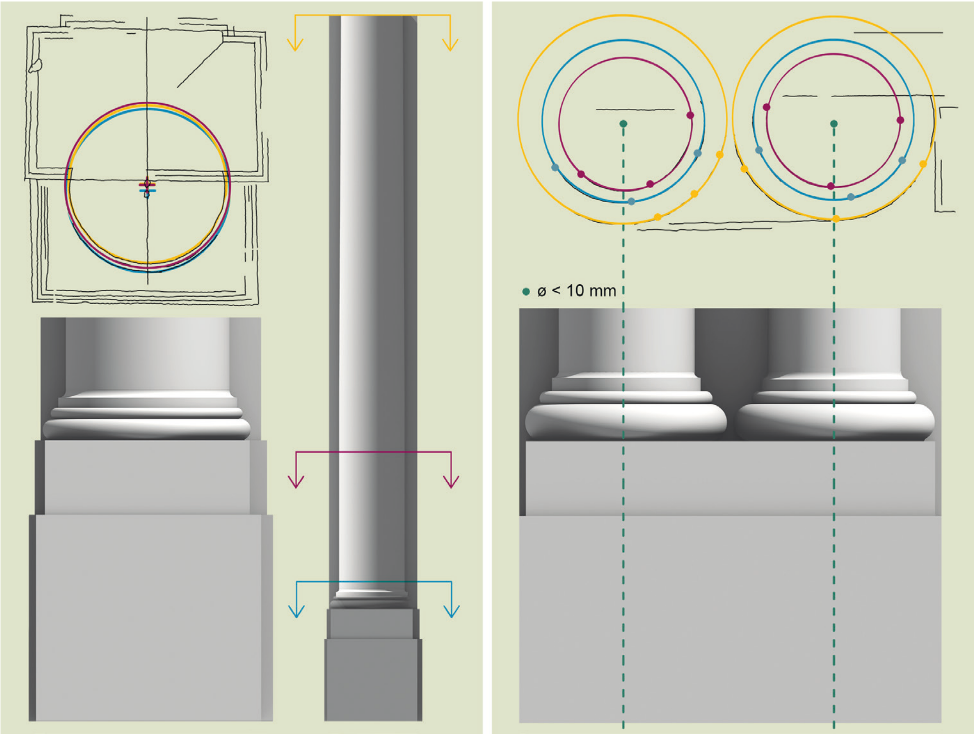

Figure 7. Analysis and geometric constructions of the half column and the binate column. For half column, the mouldings have been modeled on the basis of the surveying of the real element and of the tracing 5, since it is not possible to obtain enough information just from the worksite tracing 3.

are not represented). In these circumstances, the data were integrated with the information obtained from the adjacent drawing (Incision 5) contributing considerably to the construction of the model that would be topologically and formally complete (Figure 7).

Data Analysis: Real and Ideal Models

The stage of analysis was focused on comparing 2D ideal models with their corresponding real ones. The elaborated 2D and 3D models constituted the basis for the analyses of geometries and proportions. The analysis of the coupled column (Incision 1) revealed considerable differences between the ideal and the real model. The planimetric incised design shows three arches of circumference for both the coupled columns. Most likely, the arches correspond to the section of the column and of the mouldings represented in the projection. The two coupled incised columns are completely separate while the diameter of the shaft of the column appears to be reduced in proportion to the bases. Parts of the arches made it possible to construct diameters for three points. Their analysis demonstrated that all the centers, even though they do not coincide perfectly, are included in all the diameters shorter than 1 cm. The numeric model demonstrates the fusion of the two coupled columns in harmony with the lower moulding. The upper mouldings are adjacent while the shafts of the columns are brought closer to each other. What is more, the study of the horizontal section of the numeric model have diagnosed a flattening of the lower moulding in relation to the arch of the ideal circumference. The comparison of the coupled column represented through a survey with the column as realized showed no correspondence between the two elements.

The same kind of analysis was conducted on the other blueprints, and the comparison of real and ideal models yielded different results. The representations in elevation of the column shaft and of a part of the capital (Incision 2) proves to be similar to the one built for the porch. The analysis was conducted comparing both the real and ideal 2D models and verifying that the proportions between elements were equivalent. The column depicted lies on a horizontal axis, it is remarkable that the distance between the jamb of the church left door and the tracing of the capital perfectly corresponds to the total length of the built column shaft (Figure 8). This probably means that they used an architectural element – the jamb of the door – as a point zero of their tracing.

Regarding the single half-column (Incision 3), three arches of circumference are recognizable. This is probably a representation of the diameter of the

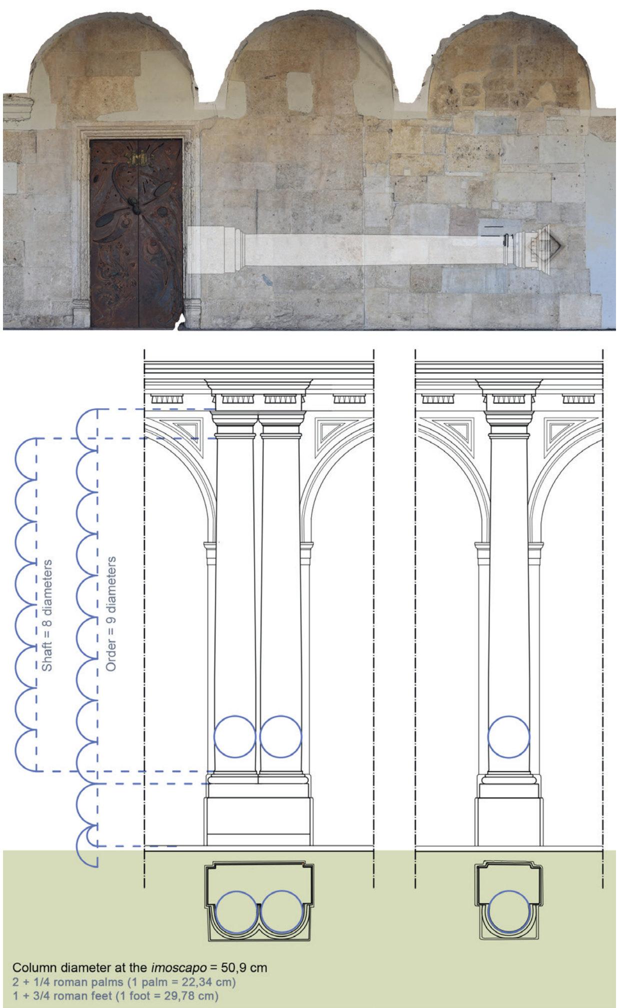

Figure 8. Proportion of the architectural order. The half column and the binate column. The total length of the order matches the distance between tracing 2 and the jamb of the left door of the church.

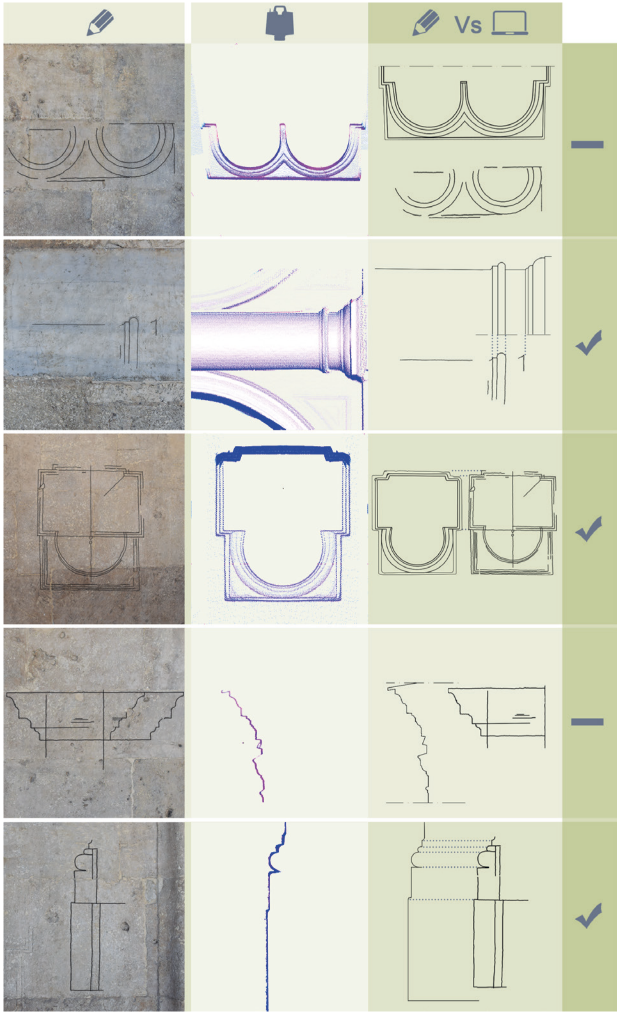

Figure 9. Comparison between real models and ideal models.

column at sommscapo, at the height of the entasis and the imoscapo. The incision is likely to have been realized on the basis of two rotation centers: the semi-circumference of the imoscapo seems to be off center in relation to that of the entasis and the sommoscapo. This evaluation is confirmed by two profound gaps in the stone which correspond to the two identified centers. A comparison with the numeric model of the real element confirmed the initial hypothesis: the diameters of the sommoscapo, the entasis and the imoscapo are comparable with those represented in the incision. The established correspondence between the two elements leaves no doubt that the incision represents the model of the semi-column realized at scale 1:1.

Conversely, in the case of the entablature (Incision 4), the built element does not completely fit the drawing. Recognizable on the incision are different solutions for the trabeation, some of which are incomplete. The axis of vertical symmetry has also been retraced. The drawing of the column base (Incision 5) is probably connected to the one illustrating a plan of the same architectural element (Incision 3). Mouldings of the base match the built ones in terms of category, dimension, and proportion. The information obtained suggested a comparison – in terms of proportions – first with the half column and then with the whole portico. The diameter of the single and the twin-column of the portico at its imoscapo amounts to 50.9 cm (Figure 9).

Verification procedure is being carried out to identify the unit of measure applied for sizing the diameter of the column. The diameter was used as a basis for the metrological-proportional study of the

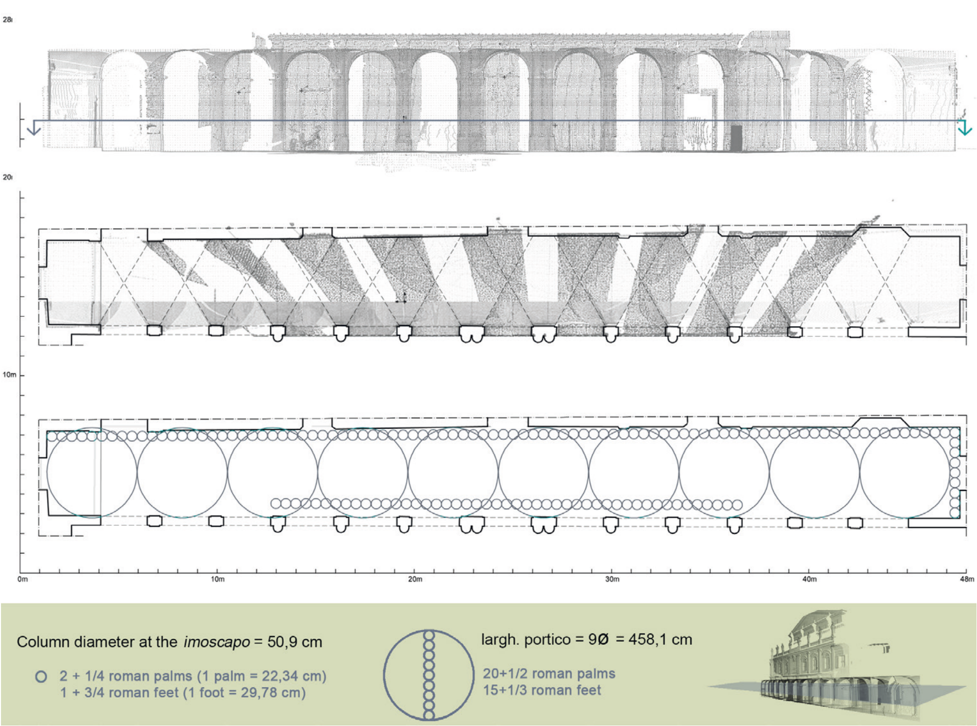

Figure 10. Proportion of the portico. The length, 46.31 m, corresponds to 91 modules; the width, which varies between 4.27 m on the left and 4.61 m on the right, completely match 9 modules in the central part of the facade, axis with the main portal.

portico to investigate the current formal appearance (Figure 10). The value is consistent with the structure sizing: the ratio between the sides of the façade is about 1/10, the one between the façade and counter façade by just over 1/2.

Conclusions

The analysis of the worksite drawings is complex because of the need to correctly interpret them. Often, even when just partially preserved, they are the only trace of documentation at our disposal. It requires an effort to abstract the signs and to interpret the design idea behind the construction, which not always corresponds to the existing constructed element.

All these activities prove to be strictly connected with the methodologies that aid cognition, documentation, and communication of cultural heritage through the interaction of acquired data and the elaboration of 2D and 3D models (which are increasingly more complete and complex). The procedures of the study constitute the basis for a methodology that can be applied in different contexts, from the verification of studies as to the adequate formal correspondence between real and ideal models to the verification of a possible relationship between incised representations and architectural models even when this association is not direct or immediate. It was made possible by the processes of model construction and the subsequent metric, geometric, formal, and stylistic study indispensable for extending the level of cognition (knowledge), ever more connected with the possibilities to archive, communicate, and spread the information on cultural artefacts, and also for their protection and preservation. A significant surplus value emerges from the approach that integrates competences of architects, art historians, and archaeologists. It has made it possible to catalogue Romanesque and Gothic incised drawings, to analyze their practical application in building, as well as to study the relations obtained between worksite drawings and the realization of architectonic elements by constructing and comparing real and ideal models.

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