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Survey and representation of the parametric geometries in HBIM

Rilievo e rappresentazione delle geometrie parametriche per l'HBIM

In the formal analysis of historical architecture, different geometries could be distinguished, from simple (walls, beams, columns, slabs, etc.) to more complex ones which could hardly be modelled through regular geometries (predominantly sculptural character). There are some complex geometry elements which could be processed anyway by means of mathematical models. Some forms are then often recurrent, apparently different, but associated to common matrices, which could be therefore parameterized. In these cases the survey does not concern the form in its complexity, but only the parametric elements, then creating the needed relationship between the variable parameters in the Building Information Model and other models derived from point cloud. On this topic a first experiment was made in the survey of the "Scala Regia" in the Vatican.

Nell'analisi formale di una architettura storica si possono distinguere diverse geometrie, da quelle semplici (di muri, travi, pilastri, solai ecc.) a quelle più complesse difficilmente riconducibili a geometrie regolari (a prevalente carattere scultoreo). Vi sono alcuni elementi con geometrie complesse ma comunque traducibili per mezzo di modelli matematici. Alcune forme sono poi spesso ricorrenti, apparentemente diverse, ma riconducibili a matrici comuni, che possono essere pertanto parametrizzati. L'attività di rilievo in questi casi si esplica nel rilevare non la forma nella sua complessità ma solo gli elementi parametrici, facendo poi gli opportuni riscontri tra i parametri variabili del modello elaborato in ambiente HBIM e altri modelli ricavati da point cloud. Su questo tema è stata fatta una prima sperimentazione nel rilievo della Scala Regia in Vaticano.

Keywords: survey, parametrical modeling, 3d shape acquisition, Scala Regia, HBIM
Parole chiave: *rilievo, modellazione parametrica, 3d shape acquisition, Scala Regia, HBIM.*

INTRODUCTION

In the nineteenth century the architectural survey has been consolidated as a scientific discipline which include all the fundamental operations related to the knowledge of specific space context. Architectural survey is expressed throw the integration of multiple factors. Those factors participate together having different roles in the modelling process which are necessary for deep understanding of the Architecture.

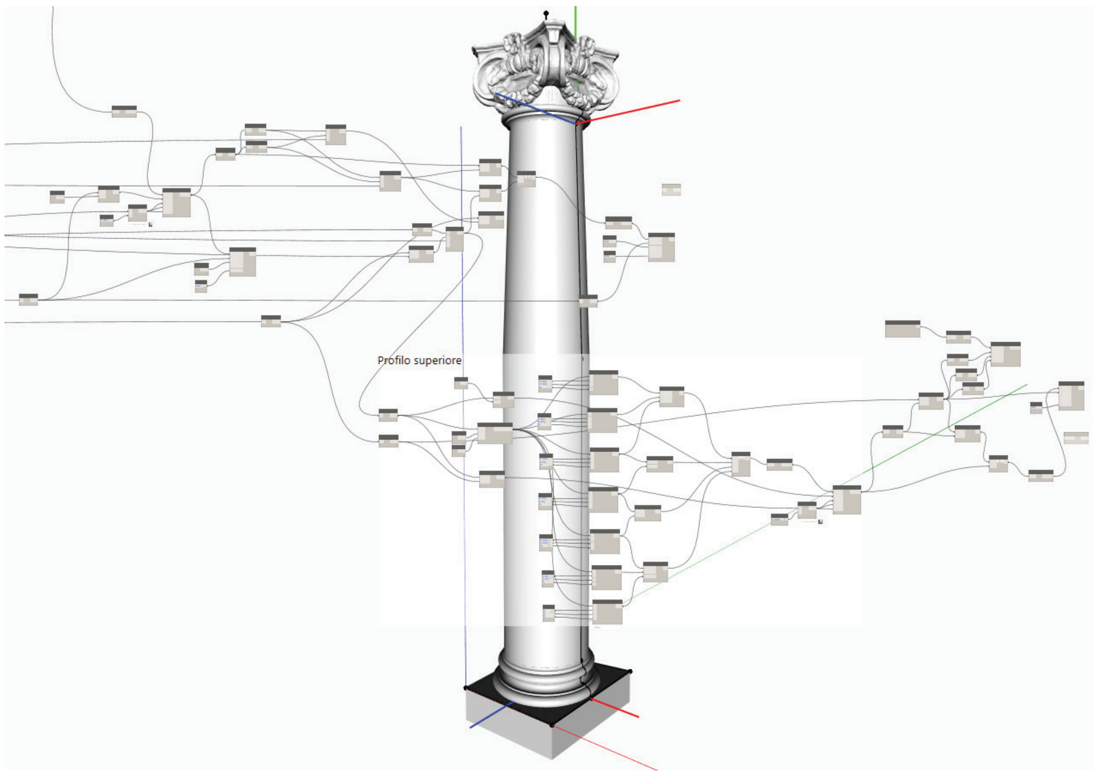
Digital metric survey technologies development, which started in the 80th of the last decade had a big impact on this discipline. the new technologies changed the rules in the relationship between the technique and the art which characterize architectural survey. the emerging use of the laser scanning and photogrammetric survey techniques moved the attention of the surveyor radically to the technical phase of this important knowledge process. Therefore, in many cases the comprehension phase of the form and geometry is strongly highlighted. therefore, the technical part is fundamental but it doesn't run out of the task of the surveyor.

Another important aspect in the digital survey and generally in the three-dimensional modelling field is the infographic models. Those information-rich models are related to most advanced emerging informatics tools for the digital representation in the building environment. This innovative representation method is taking place in the actual phase thanks to the frequent and demanding use of interoperable parametric infographic models in the fields of Architecture, Engineering and Design. Those infographic models are called Building Information Models (BIM) or in case of Heritage Buildings the acronym used is (HBIM).

European laws recently approved by the Italian government promote strongly the use of those proceedings in the developing build environment. Those proceedings are important in the conservation, restoration and enhancement of the architectural heritage. Due to its importance, it is worth to has the right attention of many users and researchers in different cultural fields. In the recent state two building information modelling approaches could be distinguished, the one related to the management of new construction projects and the one related to an existing structures modelling. The differences in the approaches are greater when it is related to a Heritage building information modelling due to the historical and architectural value. In this case, the integration of different digital survey technologies is fundamental. Those consolidated technologies refer often to computer platforms for model processing which could hardly adapt to the BIM standards.

An interesting area of research is the integrations between different models: from numerical models by points (point cloud) to the numerical surfaces (mesh), furthermore, from the mathematical NURBS models to the parametric-based ones. Those models usually are the product of a series of processes related to two factors: First, to the 3d shape acquisition methods such as laser scanning and image-based modelling or photogrammetry etc. [Paris 2010, 2014, 2015a, 2015c]; Second, to the use of the 3d modelling software which handle and process the acquired data. There is therefore the need to organize miscellaneous types of data such as historical, metric, formal, conservation state and materials properties which are not completely compatible with many digital platforms. This leads to an integration process of the incompatible data, and sometimes we need to redefine the model according to the different software and the requirements of its approach for the 3d modelling. It is possible to overcome those problems partially using geometry forms as transition elements. Classifying the geometries which

Fig. 1 - Parametric modeling of the colonnade of the "Scala Regia" in the Vatican



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compose the architectural space in types simplifies the work. Some geometries could belong to the same type where they have the same matrices despite the apparent different forms. Therefore, this would allow to decline these forms in parametric mode even within the architecture survey [Apollonio et al. 2012] [Valenti et al. 2012a] [Oreni et al. 2013] [Paris Valenti 2015].

PARAMETRIC SURVEY

In the survey process of a geometry we can distinguish two different and consequent phases: Data acquiring and restitution and analysis. The first one was conditioned in the last few years by the development of the digital technologies. The new technologies are able to acquire a huge amount of data of in a quite short time. Data are of different types: coordinates, reflection values, surface properties images, etc. The second phase which is the analysis and restitution to create the 3D models was conditioned by the development of the 3d modelling packages. Software packages can import the survey data and permits to process those data to produce and export models of different types. Exported models are based on the requested typology and the necessities for the Knowledge and the analysis of the heritage structure. In the first phase the information objectivity is requested and it is the main feature of the new technologies. Therefore, this phase is highly conditioned by the used survey instruments. Meanwhile, the second phase gives space for the interpretation of the operator while creating models. The choices the operator dose in this phase condition the resulting models subsequently it condition the future use of those models.

A significant aspect is the interpretation of geometrical surfaces used in the 3D modelling process. Point clouds which are the product of laser scanning or dense match photogrammetry are the numerical description of the surfaces. Which are to be processed to create a continuous surfaces and volumes of the architecture. Direct processing of meshes derived from point clouds are not able to produce right information about the geometrical properties of the surveyed surface. However, for many visualization proposes the mesh provide an effectual representation. The best model to represent the geometrical properties of both the project and the actual state of architectural structure is the mathematical model. Forms in the mathematical (NURBS) model are described by their mathematical equations and this guarantees the continuity of surfaces.

One of the most important goals of our research is to study and analyse the geometrical forms of the historic architecture. Classifying the architectural elements, we found in one side some architectural elements which could be traced back to simple geometries as walls, floors, beams, columns etc. In the other side there are some sculpture-like elements which are used for decoration functions. These forms usually are complex and are difficult to trace back to simple geometries. In between, there are some elements with composed geometries, more or less composed. Usually, they could be converted in mathematical models. Some of these models are repetitive, they appear to be different but they are able to be referred to a common matrix, then it is possible to produce them from one parametric model (fig1). For example, Architectural orders [Migliari 1991] have a frequent presence in the historical architecture. They have different types and variations but they could be traced back to their rules and proportions to reconstruct their parametric 3d models [Valenti et al. 2012b]. These elements in some cases are adapted to complex matrixes as the single and double curvature surfaces. In these cases, the parametric definition has to be adapted. Architectural orders are frequently integrated with other decorative and structural elements. Therefore, it is interesting first of all to define the geometrical matrix to construct a parametric mathematical model.

This new way to examine the historical architecture permits to reach another goal. It is to understand how this parametric approach could determine new methodology of survey in data processing phase.

The survey activities in these cases is defined in detecting not the entire complex form but only the parametric elements. Then, by creating the appropriate relation between the parametric model and the processed mesh derived from point cloud. The parametric model is to be used in all BIM environments and more generally in environments that use open exchange formats such as the IFC standard.

To test the effective potential of parametric survey a first experiment was done. It is inspired by the survey data of the Scala Regia (the Royal stairs) in the Vatican (figs. 2, 3). This architecture is partially studied [Paris 2015b] as part of the recent national research, coordinated by Riccardo Migliari, on architectural perspectives and concerns, in particular, the study of solid prospective.

THE SURVEY OF THE SCALA REGIA IN THE VATICAN

La Scala Regia is unique and innovative work of its kind in which the architect Bernini experimented the geometric deformation of the architecture to induce in the viewer's perception of an illusory space according to the principles of the solid perspective. It follows another solid perspective architectural work few years be-

Fig. 2 - The "Scala Regia" in the Vatican

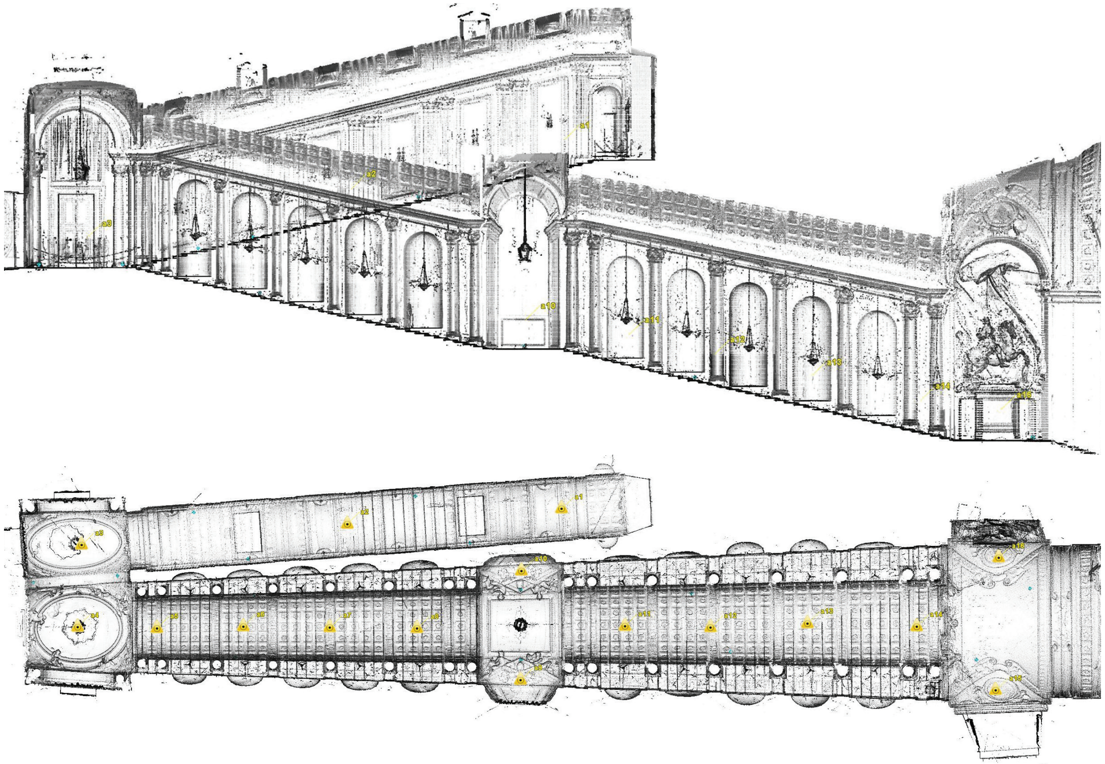

Fig. 3 - Point cloud of the "Scala Regia" with highlighted the 3D scanner stations. By Paris Wahbeh.

fore. That was the Gallery of Palazzo Spada, attributed to the Architect Borromini. La Scala Regia was built in 1666 at a time when Bernini, following the advent to the papacy of Alexander VII Chigi. At that time, he returned to take care of the construction of St Peter complex, realizing, among his famous works, the famous colonnade of San Peter.
The design of the Scala Regia is strongly conditioned by the constraints imposed by the existing area and its irregularities. Those irregularities interpose between the basilica and the Apostolic Palaces, which was already the subject of considerable work commissioned by Pope Paul V from 1607.
Architecturally the Scala Regia was conceived as part of a long connection way between the city and the heart of the apostolic palaces. The elevation of the stairs is one of the main elements that conforms the architectural articulation of the confluence of those who follow the long corridor and those coming from the portico of the Basilica. The backdrop of this visual axis ends with the equestrian statue of Constantine in the moment of his vision before the Battle of Ponte Milvio.
The survey (fig. 4) evidenced how the general plan of the Stairs is based on a double isosceles trapezium with different convergent angles sides. The motivation was to ensure a proper ratio of the proportional Serlian through the longitudinal development of the scale.
This solid deceptive perspective does not develop on a horizontal director-line, such as the case of the perspective Galleria Spada, but on inclined axes determined by the slope of the staircase, interrupted by the horizontal plane of the intermediate landing.
The transition between the horizontal and the inclined director-lines is solved architecturally. The solution obtained using two closely-spaced columns placed at the beginning and at the end of each ramp with a rhythm of four columns. The distance in-between decreases gradually as you go along the staircase, which also corresponds to the progressive reduction of column diameters. The architectural order and its proportions in the solid perspective undergo some adjustments.
The Ionic order refers to a model described in the Treaty of Vincenzo Scamozzi in 1615, with scrolls arranged on the diagonal lines coming out of an echinus decorated and connected by a garland. The height of the capital is equal to the diameter of the column. If we take it as proportioning module, The attic base is half module; The height of the first column is equal to 9 modules and 1/4; the entablature is special because it does not have the frieze. The aspect ratio of the capital and of the base remains unchanged for all columns, while this does not occur for the overall height due to the first two initial columns (for each of the two sides of colonnade). They have in the both ramps the capitals at the same height and the base at different heights because they follow the slope of the staircase. The diameter of the columns decreases proportionately in accordance with the convergence of the two opposite sides of the base trapezium, from 74 cm of the first column to 55 cm of the last one. The height of the first column is 685 cm, the last one is 547 cm high. The two ramps, as mentioned, are interrupted by a landing with two decorative frames splayed to the sides. They are very similar to those made a few years earlier at the Palazzo Barberini, apparently identical with each other but with different perspective depths, one with a window, the other is blind.
Detailed analysis of the plan of the Scala Regia (fig. 5) shows that the arrangement of the columns does not follow a strict perspective degradation into which the diagonals of successive trapezoids converge on a single point. However, from the survey emerges clearly the compositional rule for which the prospective trapezoids have parallel diagonal lines directions. The paral-

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lel directions are different for the first and the second ramps, while they are the same for the four trapeziums corresponding to the close-columns at the beginning and the end of the ramp.
Basing on these considerations which were emerged in the first phase of the graphical drafting, the idea to create parametric models of these repetitive elements came up. The concept was to experiment different methodology of 3D modelling. First of all, to identify the basic parametric geometric models, and then, to realizing the overall model by its parameters derived from the survey. The experiment was applied on the most frequent elements in the classical architectures, the columns, more specifically, in this case, the Ionic column.

COLONNADE OF SCALA REGIA

The Scala Regia consists of 16 columns for each side, all are different from each other but related to a single model of architectural order. These columns are all set on quadrilateral plinths which have a shape of scalene trapezium. The two bases of every trapezium are parallel to the direction of the steps, and the other two sides aligned according to lines of convergence of the solid perspective. The size of these columns, as revealed, are variable. In the landing at the end of the scale there are also four columns equal to each other with square base plinths. In correspondence of the columns, on the outer walls, there are also pilasters of the same architectural order.
The reference parametric model (Figs. 6, 7, 8) consists of three types of objects: First, variable parametric object that is the shaft of the column; Second, parametric objects that are proportionate which are the diameter of the column and the profiles of all the revolution surfaces in the base and the shaft; Third, the capital as numerical models of mesh types which is subject only to the change of scale.
The basic parametric model is related to the definition of input values which are extracted from the point cloud (Fig. 9) to construct the various elements of the column. Among these are the four vertices of the plinth, which, as mentioned, has a trapezoidal shape scalene. From the plinth the diameter d of the circumference is extracted. In this step a flatting procedure

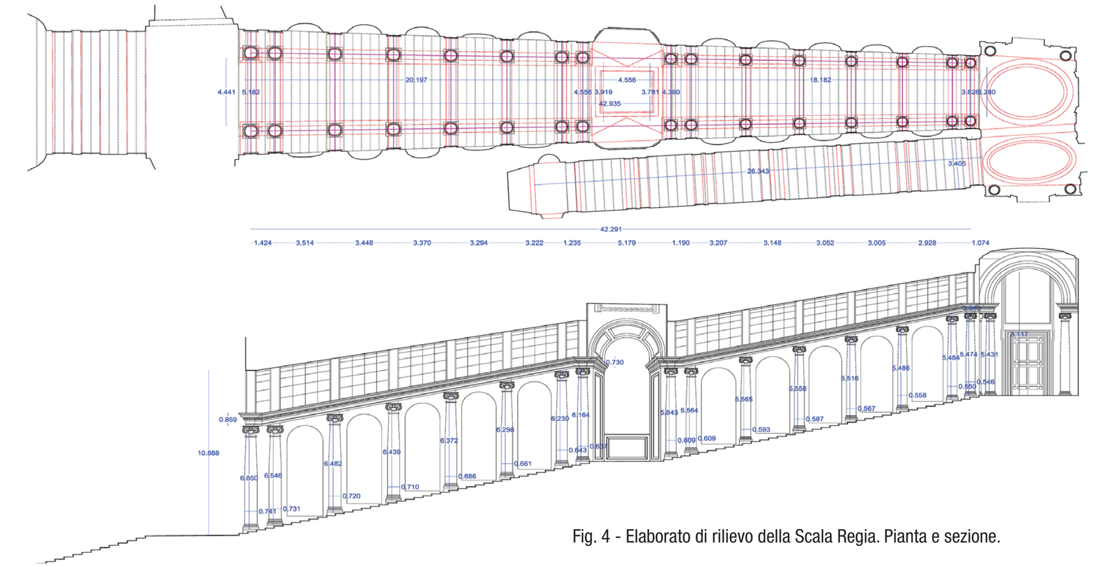

Fig. 4 - Elaborato di rilievo della Scala Regia. Pianta e sezione.

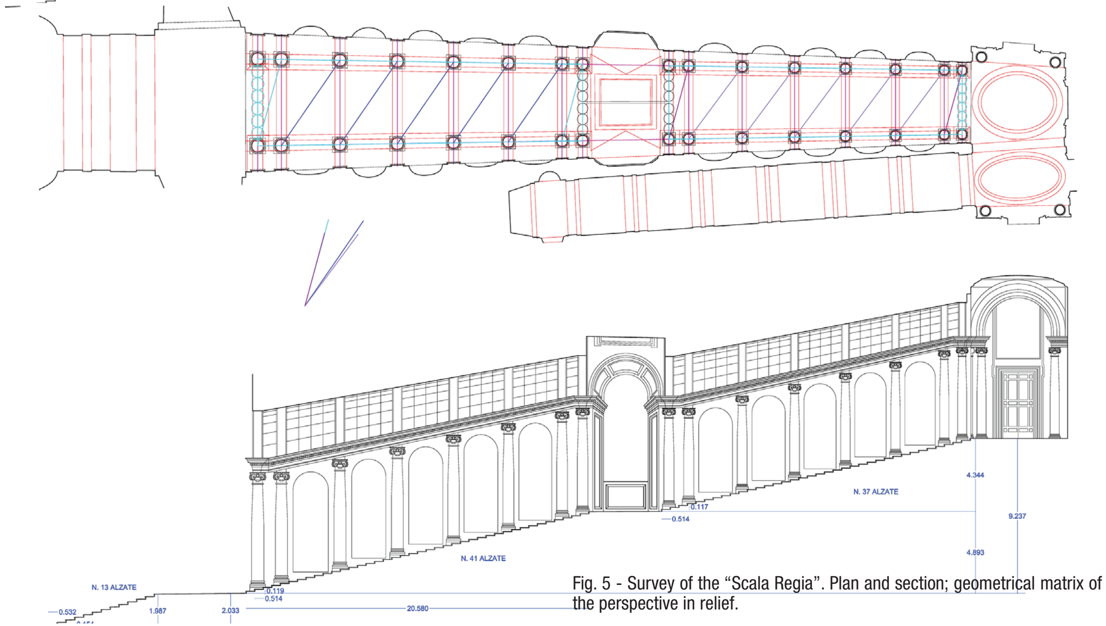

Fig. 5 - Survey of the “Scala Regia”. Plan and section; geometrical matrix of the perspective in relief.

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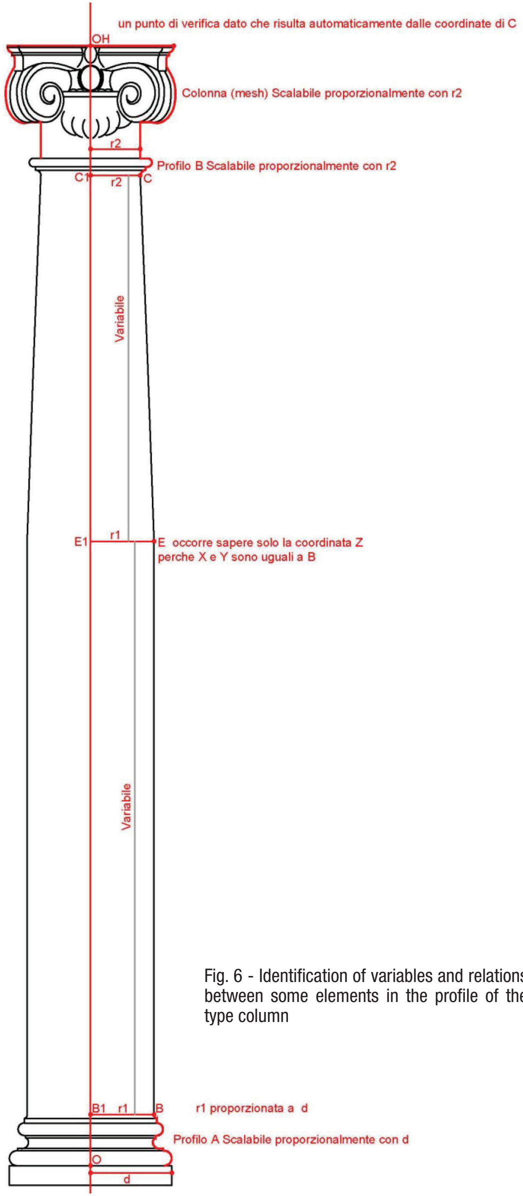

Fig. 6 - Identification of variables and relations between some elements in the profile of the type column

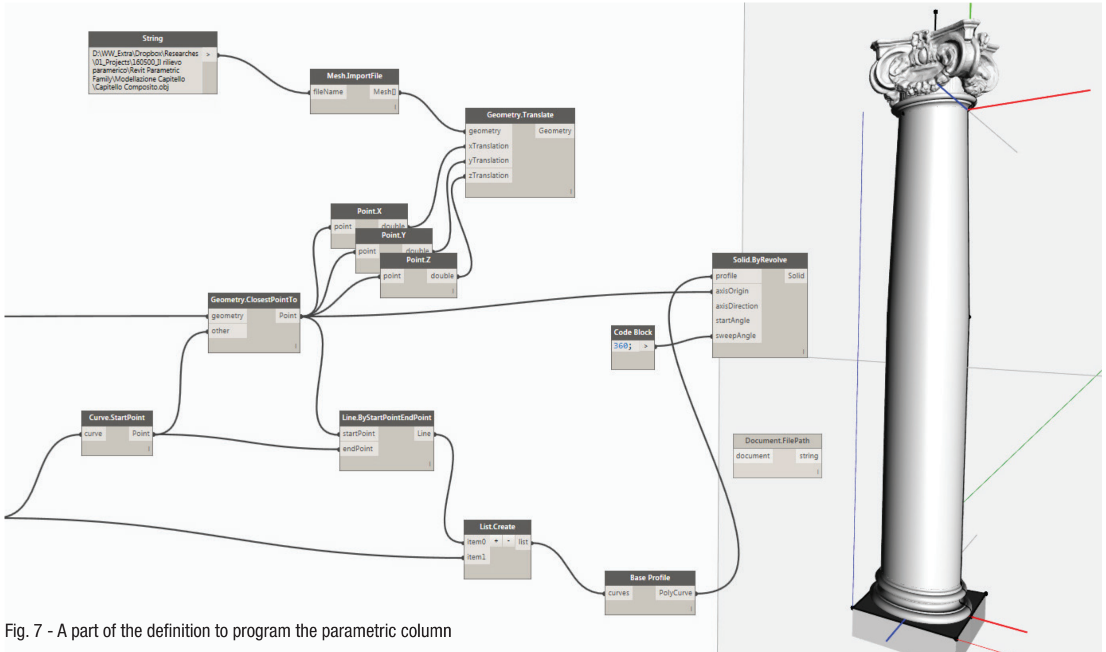

Fig. 7 - A part of the definition to program the parametric column

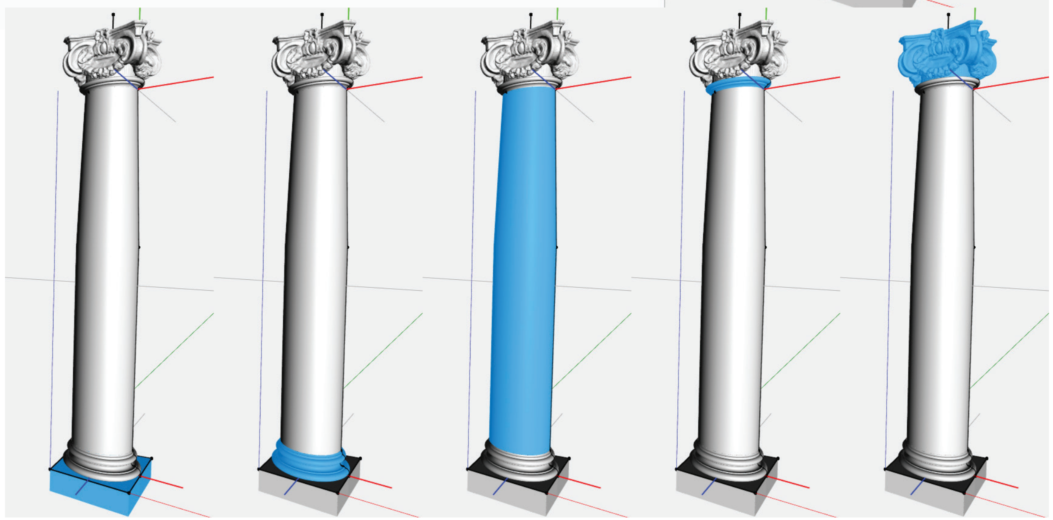

Fig. 8 - Visualization of the different elements of the parametric column.

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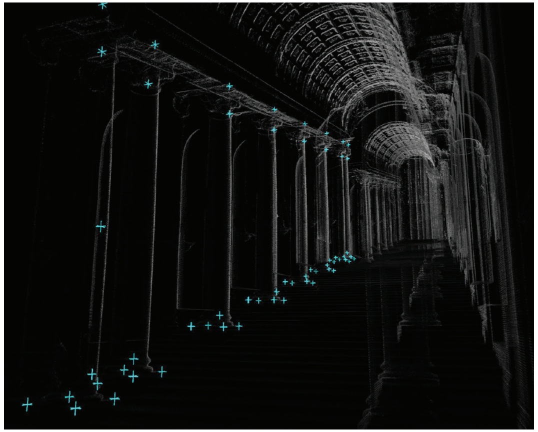


Fig. 9 - Points from point cloud

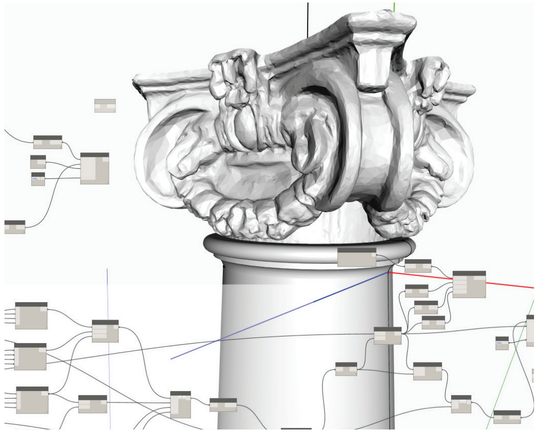


Fig. 10 - Mesh of the capital from point cloud. Inclusion in the parametric process with a scale variable for the radius r2.

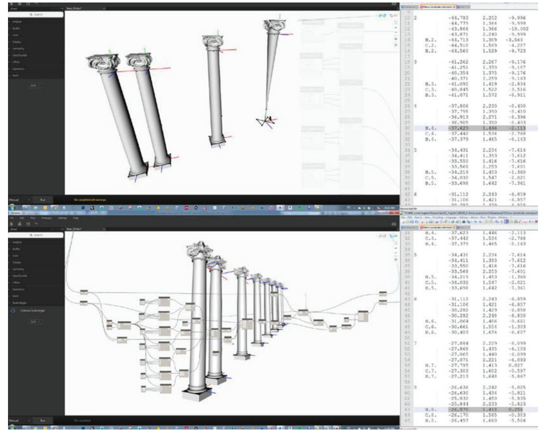
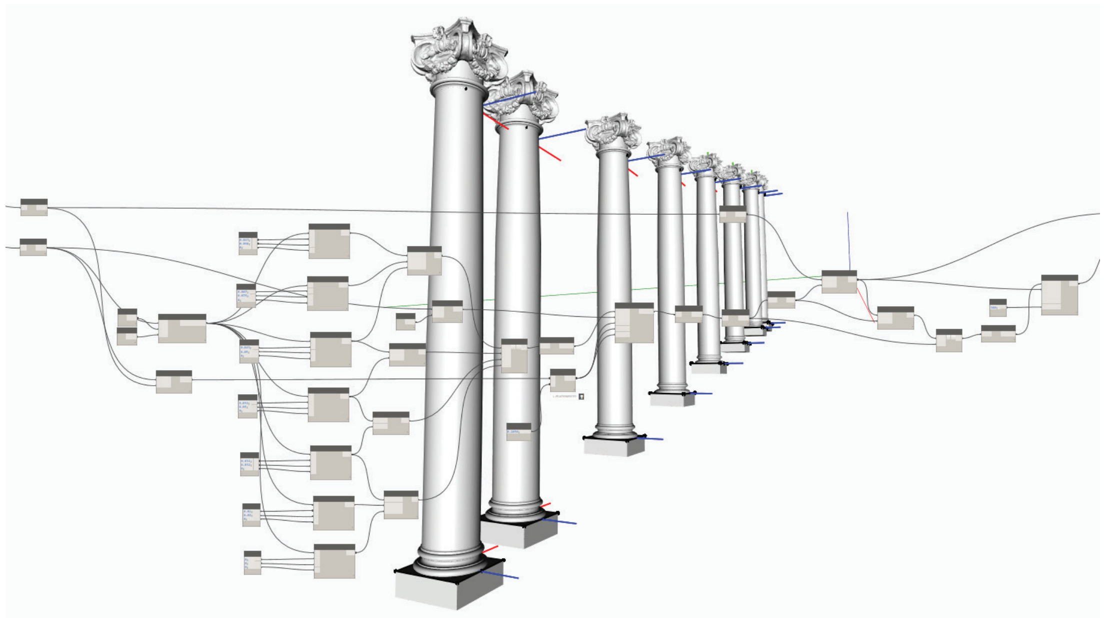


Fig. 11 - Entering the coordinates in the parametric model as a text file extracted from the point cloud

of the four points is applied to guarantee that they belonging to a same horizontal plane; if the slope is found irrelevant the plan is eventually normalized in a horizontal plan. The centre of the polygon is the center of the column on which the vertical axis is set up. This vertical axis is the centre of the revolution surface created from the profile of the column.

The profile belongs to a vertical plane which passes through the axis. To draw the parametric profile we have to take into account the different elements, their variables and relationships that make it up. For example, the defined base polygon (the plinth) automatically reconstruct some other geometries and define some variables, that is, the axis of the column and the vertical working surface which belongs to the profile. As variables, the dimension of the plinth defines the radius of the base d, the radius of the shaft and the scale factor of the basic profile drawn on the vertical plane. To model the shaft, after determining the base radius, the Z coordinate of the level where the entasis starts is needed. Then the coordinates of a point that define both the height of the shaft and the radius of the highest point of the shaft. The height of the shaft is obtained from the last point's Z coordinate and the radius is to be automatically calculated as the horizontal distance from the point to the axis of the column.

Fig. 12 - Part of the processing with the various copies of the column that change between them according to different variables related to the input data provided for each column



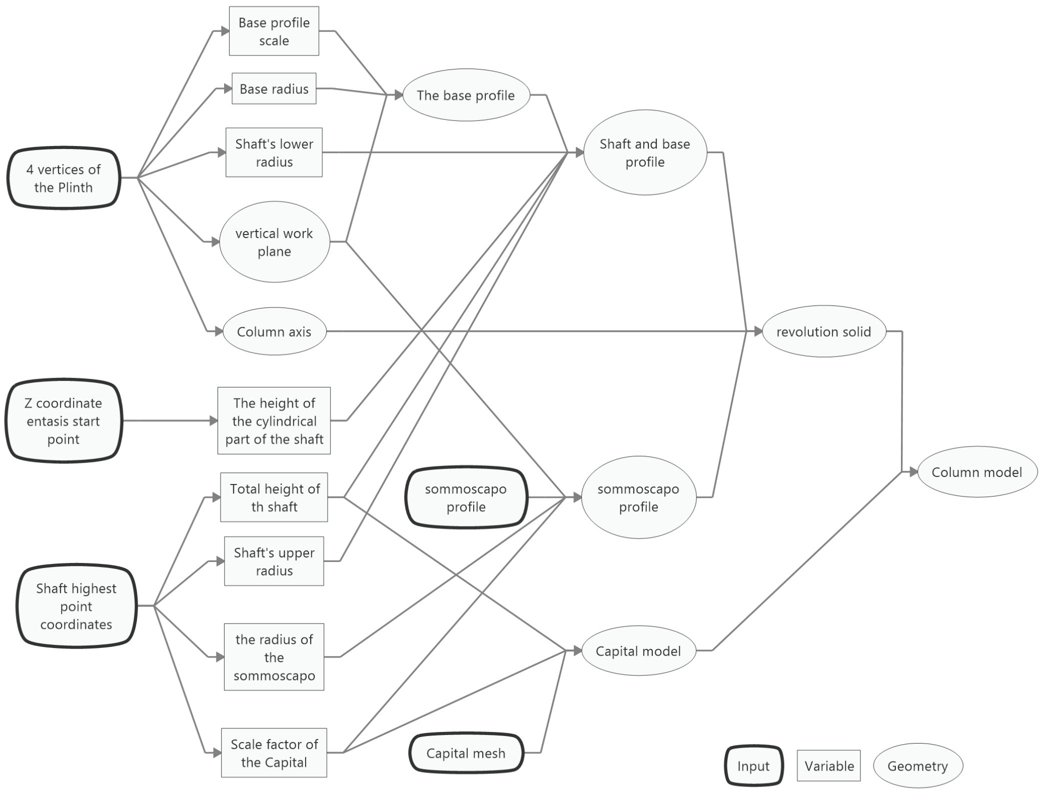


Fig. 13 - Logic map of the parametric model

Moreover, this value determines the scale ratio of the capital. The capital, as mentioned, is a mesh that is imported and scaled according to the upper radius of the shaft and its centre is aligned to the X, Y position according to the axis of the column and its lowest point is aligned to the highest point of the shaft (Fig. 10). The highest point of the entire column took from the point cloud actually is not requested for modelling but it could be used as additional input to verify the model dimensions.

The experiment was done in Autodesk Revit environment using the graphical programming interface Dynamo (fig.11). The whole colonnade was then processed (Fig. 12) using a single parametric model for the column. The parameters were inserted from time to time obtaining the values from the point cloud. The procedure could be automated by associating at this stage a script that can directly transfer the data extracted from the point cloud to the parametric model. The Revit has the ability to manage and view in the same work environment the two models types the point cloud and the 3D model. This ability permits to check in real-time the correspondence between the two models.

With this application we experimented already different method for managing the digital data acquired by laser scanner or photogrammetry, to produce 3D models processed automatically using programmed parametric models.

The actual standard feasible workflows, which are widely tested, are those which convert the point cloud into mesh-type numerical models. This type of processing is based on the application of algorithms, such as for example the Poisson. It needs a certain experience in the definition of some basic settings which has to be adjusted according to the type of the modelled surfaces. Some problems remain unsolved in this case in the post-processing related to the calculations to try to close the geometries subjected to shadow areas in the acquisition phase. A good mesh model is also often unable to return information about the form matrices that are frequently the basis of the representation. It is important overall when the survey is of historic architecture with clear geometry and it represent one of the main objectives of a survey in many cases.

The other mode of processing 3D models is related to mathematical models. In this case it is essential to obtain first of all the geometric matrices, general and detail, which conform a determined space. This means selecting significant parts of the point cloud to be converted into lines. Afterwards, the lines or generators must be processed to get NURBS surfaces. Even in this case it is important to emphasize the importance of the surveyor sensitivity deciding which items to be selected and criteria to adopt to normalize the model. Normalizing the model, unavoidably, will deviate it from its real space by that level of uncertainty. Uncertainty which is transferred by contact and discretized in point cloud.

Compared to these two modes it has been experienced, with the application made to the columns of the Scala Regia, a third solution. This solution provides first of all an analysis of the geometries that make up a given architecture and the possibility of the parametric models (Fig. 13). If the creation of parametric models is possible, once we develop these models, we proceed putting the values in. The values which are possible to

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obtain from the point cloud, will compose the model in all its parts, with the possibility to have an immediate check comparing it with the acquired digital data. The parametric models obviously can also be reused in other surveys. Therefore, this permits to create a library of frequently used object [Valenti et al. 2012b].

CONCLUSIONS

This experiment, even though limited to the colonnade, shows that it is possible to pursue new operational procedures associated to various problems of interaction between digital data. Moreover, to link the digital data obtained with 3D shape acquisition techniques (now widely established in the architectural survey field) with the processing and the management of the new HBIM models.
A careful interpretation of the geometric elements that make up an architecture (specifically architecture of historic value) allows the identification of the basic geometric elements. This interpretation leads to an easier translation and management of the models in BIM environment. This approach also provides different way to process the digital data obtained from point clouds. It allows, if properly handled, a considerable reduction in processing time and a more immediate control verifying the correspondence between the different models.

NOTES

[1] On this specific topic it was elaborated a University research project, awaiting funding, togheter to Elena Ippoliti, Tommaso Empler, Giulia Santucci, Maria Laura Rossi. The authors of this essay have edited together the general approach and the digital acquisition phase of the survey of the "Scala Regia" in the Vatican. Leonardo Paris oversaw the first phase of the survey. Wissam Wahbeh drew up the parametric model of the colonnade.

[2] On the difference between mathematical and numerical representation, cfr. Migliari 2009.

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