THREE-DIMENSIONAL DIGITAL MODELS FOR ARCHITECTURE'S DOCUMENTATION: BADIA DI S. AGATA IN CATANIA

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ABSTRACT

The use of laser scanner 3D in the architectural survey and the procedures of obtained data allow, collecting and memorizing with extreme quickness a large quantity of information, the construction, through computer digital systems, of complex high precision three-dimensional models navigable in every part.
This methodology resulted particularly operative in the application to survey of Badia di S. Agata, one of the G. B. Vaccarini's masterpieces and valuable example of catanese baroque of the reconstruction of '700.
The volumetric complexity of shapes, the refined architectural composition and the richness of decorative system suggested the use of laser scanning for an accurate survey finalized to a faithful and detailed documentation on which is possible to execute studies and analysis about formal, geometrical and morphological aspects.
The various operative steps were projected and executed depending on the condition of places, on the instrumental features and on registration and orientation process. The partial overlap of different scansions and the connection with suitable gram control points permitted the data's assembling with a continuous error checking statistically and punctually executed.
The result has been a discreet digital three-dimensional model constituted by a 20 million points cloud surveyed, that, beyond to be a high quality document, is an excellent knowledge instrument of architectural organism in the complex of the monument as well as in the constituting detailed parts.
The realization of a mathematical model constitutes a subsequent study step: this is the process result of data analysis and interpretation that, overlapped to the discreet model, allows a constant control of hypothesis, individuating and quantifying the gaps for going back to the reasons that originated them.

1. BADIA SANT'AGATA

St Agata's church faces Vittorio Emanuele street, an eighteen century road axis that crosses Catania city from east towards west, being tangent to Cathedral square. The facade of St Agata's church stays opposite to the north Cathedral front. The church takes up a whole block, together with the adjoined ex-monastery (that today is public property), and it was built on the rests of an ancient church and convent consecrated to St Agata, in 1620, by Erasmo Cicala and collapsed as a consequence of the earthquake in 1693.
Badia Sant'Agata is an art work of G. B. Vaccarini, author of some of the best masterpieces that enriched Catania, during the eighteen century reconstruction. His interpretation of baroque style is a product of union between his cultural store and Sicilian, and especially catanese, climate, character and materials, with its chromatism and physicalism.

The church has a lenghtened Greek cross plan, inscribed in an oval with the longest axis perpendicular to the façade, and is overcame by a dome with lantern. The principal front is subdivided in two horizontal bands: a giant order, divided into three parts which alternate convex-concave-convex surfaces, and where, in central position, Vaccarini "didn't refuse to mount into the tight wave of the concave wall a double columns and very detailed decoration portal, that abbes had yet made realize" (Giuseppe Pagnano da "La pietra di fuoco", 1994), and an attic floor, with a three times concave development. This conformation is a very significant example of typically baroque movement exaltation.

Fig. 1 Badia di Sant'Agata facade.

2. RESEARCH AIMS

The baroque architecture, for choosing proportions between different parts of a building, very often follows well determined geometric rules.
The survey, that is the searching and verifying backwards the project way for architectural monument conceiving, requires a high accuracy level.
For reaching a complete, deep and correct knowledge of articulate and lively forms, often characterized by concave and convex surfaces, we can find a lot of difficulties in and we need to have a lot of dimensional information: the laser scanner use allows to realize an accurate survey, aiming to a faithful and detailed documentation to study and analyse geometric-aesthetic and morphologic- composing aspects.

3. THE OPERATING METHOD

The survey first phase was the shot plan, that had to care about instrument technical characteristics, places conditions, building dimensions and requested accuracy level.
The used laser scanner allows very high resolution scansions, because it reaches a minimal angular precision of 60 mrad, but it has also a limited shot field of ± 40°.
The church facade is about 25 m high and 27 m large; the street where it fronts has an about 12 m large section; in the interior, the Greek cross plan has two arms respectively 34 and 23 m long, while the dome is about 50 m high.

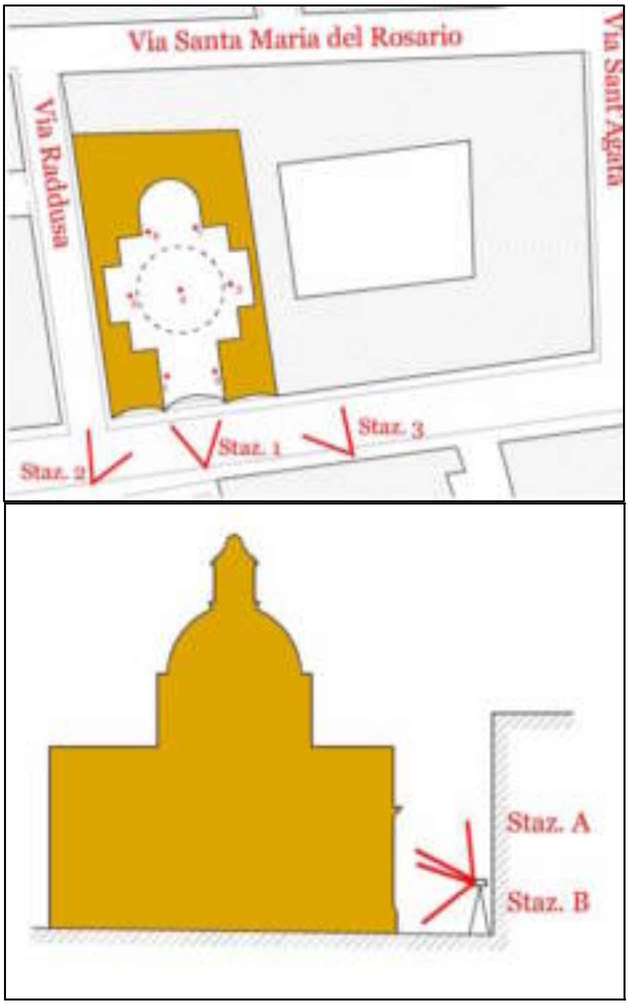

Fig. 2, 3 Shot project in plan and section

For covering with the laser-brush the entire object surface, 8 scansions were made outside, from 5 different stations situated on the pavement opposite to the church: two far away from the object (about 30 m), with one scansion from each one, for having a general framing that take as the facade, so the lateral walls and the dome together; four from two stations in lateral position, for scanning respectively the lower and the upper parts of the facade from the two sides; other two from a station in axial position, one for the upper and one for the lower part, with a higher resolution, to increase the cloud density in connection with the splendid enter portal.
Inside, 13 scansions were made: two from the hall and two symmetrically from the apse; eight in the central zone, from stations radially positioned, for scanning all the vertical elements under the dome; eventually, a scansion in central position, in zenithal direction.
The 21 obtained clouds assembling, with their 20 millions points, has been realized by a procedure of registration by picking equivalent overlapping points.
Finding and picking it was very easy, because the architecture is rich in overhangs and decorative elements, and above all a very high precision level was granted, even if, as regards this matter, there were different results on interior and exterior parts of the church.
Because of the planimetric and vertical setting up dimensions, excluding the dome, the scanned points inside were not more than 15 m far from the instrument, so that it gave an average distance between points of about 6 mm.

Fig. 4 View of one of the scansions in grey scale

Outside, it was not possible to put the laser scanner near the front of the church, because it couldn't scan the upper parts, too high, and for the presence of the road; so the minimal distance between the scanner and the object was among 12 and 30 m, and with the same resolution of the inside, we had a max distance between points of 9 mm.

Scansions were connected and integrated into a single coordinate system, using a system of constraints, which are pairs of equivalent overlapping point data that exist in two ScanWorlds. The constraining process was made on couple of clouds, in a circular way, tidily in sequence, until the closing of entire model. The sufficient overlapping points number for constraining clouds in all 6 degrees of freedom was different between scansions couples, depending on the geometric characteristics of overlapping region: where it was planned, with little overhangs, number of points had to be increased, always distributing it uniformly on the whole common zone; instead, where the spatial conformation was dynamic, 6-8 points on different postures were enough.

The Registration command computes the optimal alignment transformations for each ScanWorld in the global model, so that all constrained objects are aligned as closely as possible.

The Registration Diagnostics allows to control the statistic data about errors and precision, and more constraints can be added, or the ones yet introduced that present a inconceivable error can be visualized and modified, to improve results.

At the end, the adjusting constrains operation has been made more times, to compensate errors.

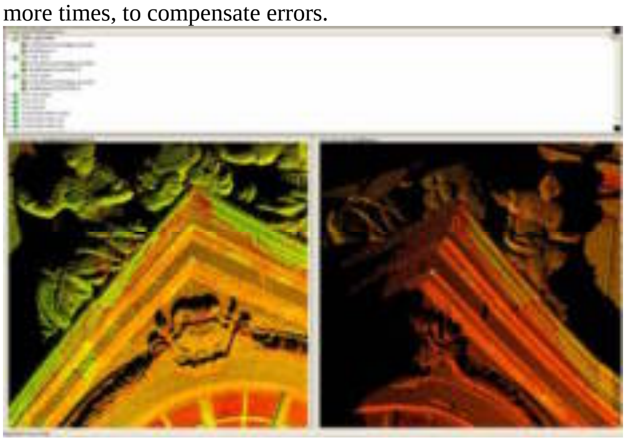

Fig. 5 Overlapping points picking

After a lot of attempts, the optimum values for parameters that influence the adjusting process precision were founded experimentally: the best cloud registration max search distance value, that fix the gap around the point collimated by the operator where software search the equivalent object for collection between two Scanworlds, was among 5 and 10 mm, while the cloud registration sub-sampling percentage, that specifies a speed-versus-accuracy trade-off in the performance, was fixed in 50%.

Fig. 6 View of the whole model in grey scale

Main difficulties were founded for outside, because of two reasons: a lot of noise in the lower part of scansion, created by the vehicles and pedestrian traffic on the street; the lack of information on parts covered by the overhangs of giant order and portal, that should have demanded to be scanned from a high position, from the opposite building, where we couldn't enter. So, for maintaining a good level of accuracy, we had to increase the number of overlapping points on the object parts that were well scanned. About 12 points for each couple of scansions were collimated on the façade, while inside we didn't find this problem, because we could made all the necessary scansions, and we have been able to connect scansion with only 6-8 overlapping points.

The survey was integrated by topographic measures, for controlling error, but also for connecting the outside model with the inside one.

We realized an open polygon, starting from a point outside, on the pavement, in front of the central portal, and arriving in the centre of plan, passing by an intermediate station point in the hall.

Outside, we measured 24 points on the façade, uniformly distributed, that were integrated in the same coordinates system of scansions, so the average error was reduced and became about 7 mm.

Inside, we measured 16 points, that we used as for controlling the cloud constrain, as for connecting the interior discreet model with the outside cloud, with whom there was non overlap.

The max error of entire discreet model so obtained was about 9 mm.

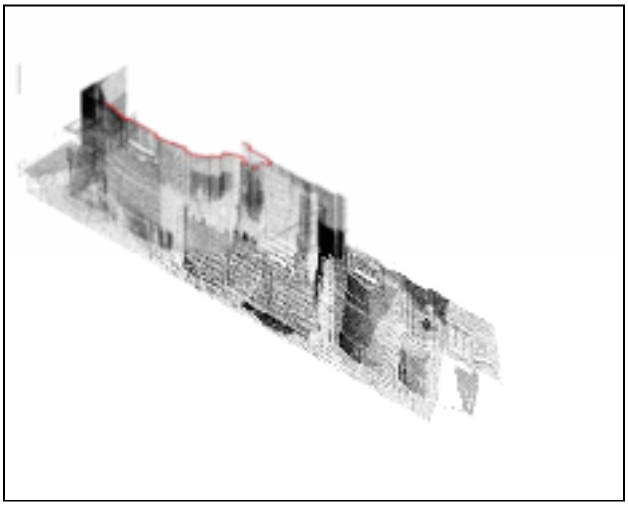

Fig. 7 Horizontal profile drawing

It was fast and accurate to analyse the dimensional relations between the different part of the church on the discreet points model.
We could easily realize vertical and horizontal profiles, to obtain a lot of information: control the alignment of different elements, or the vertical superimposition, for searching possible distance from plumb-line; measure the thickness of the walls; draw plan and vertical section, with a high accuracy and richness of information.
We could also find the exacts proportions among the different parts of the church: i. e. on the façade we discovered that the measures of the two order, with their three division, are based on *section aurea*; also on the horizontal profiles of the façade, we found that it isn't symmetric and that on all the floors there is a difference between left and right side of about 46 cm.

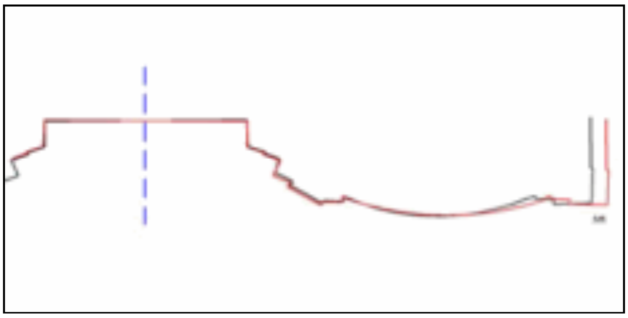

Fig. 8 Symmetry check.

4. THE ANALYSIS

The realization of a global discrete model of the church, resulted by the automatic optimization of the assemblage of scans, allowed to effectuate further deepenings taking advantage by the high precision and objectivity of data, by the high density of surveyed points and by the possibility to analyze all of them in a single digital and global three-dimensional model.
The possibility to move the instruments of examination into a digital space allowed to transfer the analysis of the artefact to desktop through interface generated by dedicated software.
Analysis and considerations started by a uniform block of data by different detail scales and founding elements, highlighting one by one framing and geometrical characteristics.

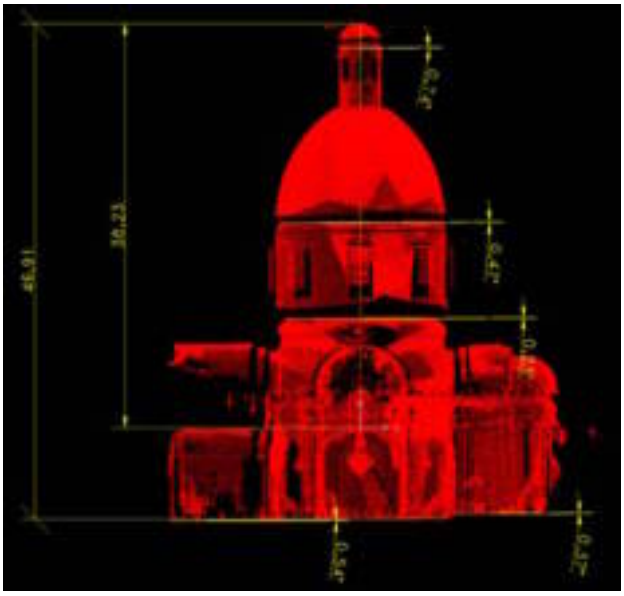

Fig. 9 Preliminary deformation analysis

Initial evaluations were realized after a preliminary process of orientation of the model as resulted rotated in the digital space in an accidental way because of instrument's lack of horizontal settlement.
It was present inside the church a big ancient iron pendant hanged by a strong rope that from the top of cupola holds it by the total length of 38 meters; rope plank, resulting easily detectable thanks to his length and to surveying precision, has resulted to be an excellent plumb wire usable to collocate the global vertical plank.
A so obtained orientation of the model and the possibility of automatically generating a lateral section orthogonal view allowed to valuate with high precision the even minimal inclination of by first sight horizontal elements like pavement, base planes of vaulted spaces, loft paths of fillers; thus the whole architectural complex revealed the presence of a moderate slope towards the entrance, as well as an almost constant lean of the whole building towards the same direction, deformation obviously not wanted but due to differential partitioning of the ground.

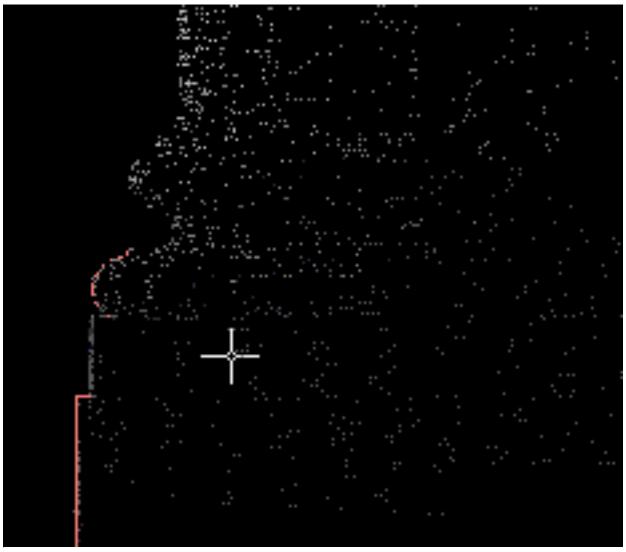

Fig. 10 Location of shapes and mathematic silhouette

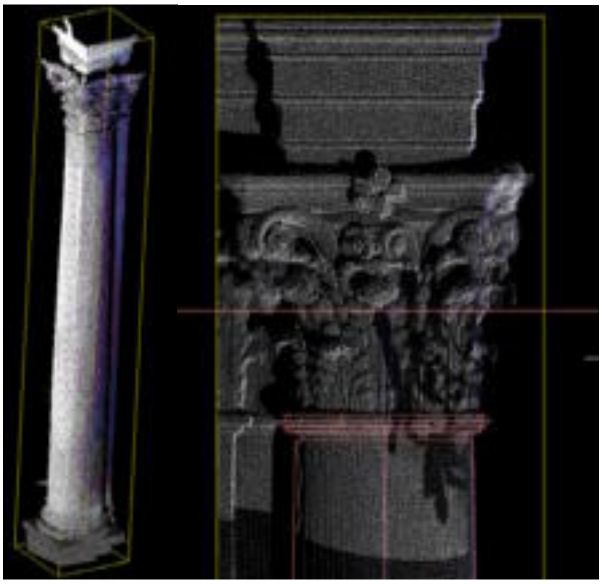

Fig. 11 Critical study of architecture by de-composing, modeling and re-composing of elements

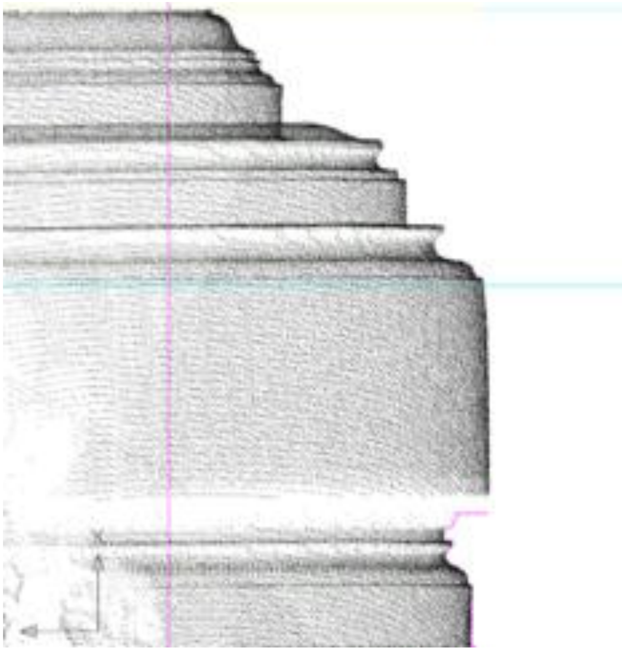

Fig. 12 High precision and density of points allows to distinctly detect silhouettes of decorative system.

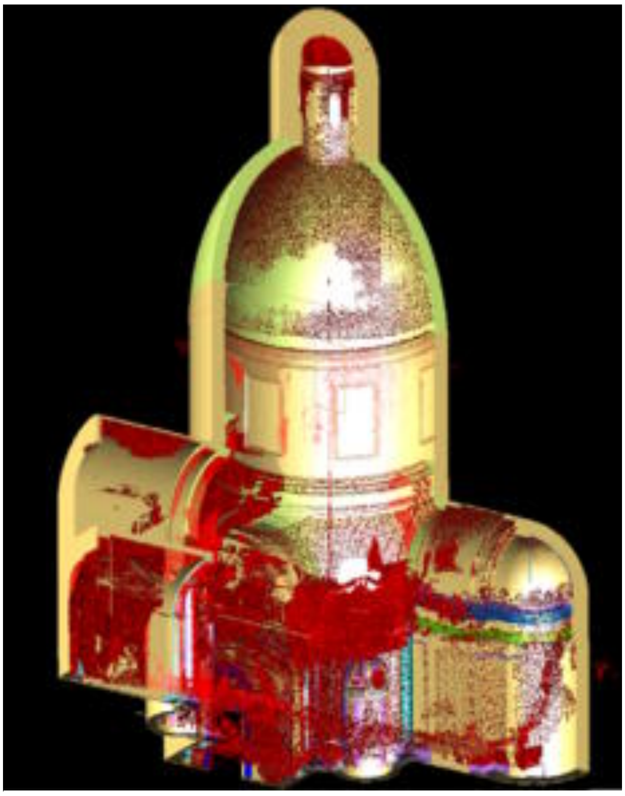

Fig. 13 Constant and diffused face off between discrete and mathematical model.

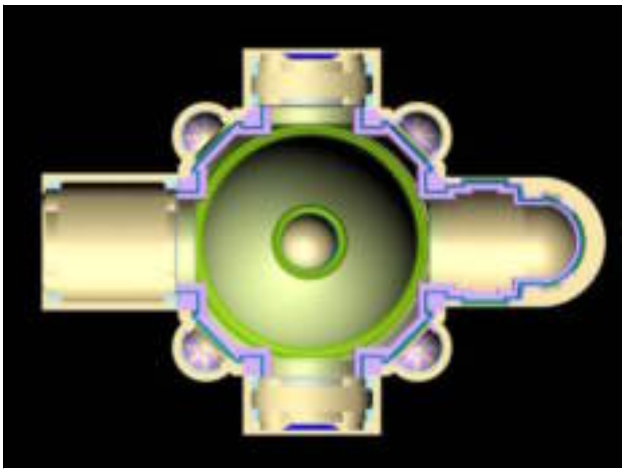

Fig. 14 Bottom view of mathematical model in a non-photorealistic rendering.

The mathematical model reconstruction has been the successive deepening step of geometrical study of architectural organism.
This is a formal model originated by adapting to discrete point data mathematical objects, symbolizing ideal abstractions of real entities by a subjective process of acknowledgement, regularization and synthesis. These mathematical objects are geometrical ideal shapes taking part to designer framing style, as well as to cultural environment and constructive techniques of the creation age of the building. For these reasons the chosen methodology has been not to realize only an automatically statistical adaptation but by the analysis at the same time of metrical data of the details and the complex of building and of historical, stylistical and metrological studies.
The constant and diffused face off between discrete model, faithful description of existing object, and his interpretation obtained through the modelling process allowed to de-compose and re-compose the object in his components studying reciprocal relations. For example by punctual analysis on silhouettes of decorations emerged how the realization often doesn't respect classic rules, as well as the real geometry often doesn't correspond to the perceived one.
The used elaboration software, differing by the most part of dedicated software for point clouds managing, allowed to easily handle the enormous quantity of metrical information surveyed by the scanner laser, avoiding any point filtering and decimation: this permitted, thanks to the precision of instrument, to succeed in every analysis of every even very little and detailed silhouette by a critical and continuous facing. In the complex the creating operation of the mathematical model has been realized by a hard interpretation, synthesis and research process, seeking regular shapes that are, not only corresponding to surveyed data, but that also able to trace the origin of object geometrical matrix and framing algorithm.

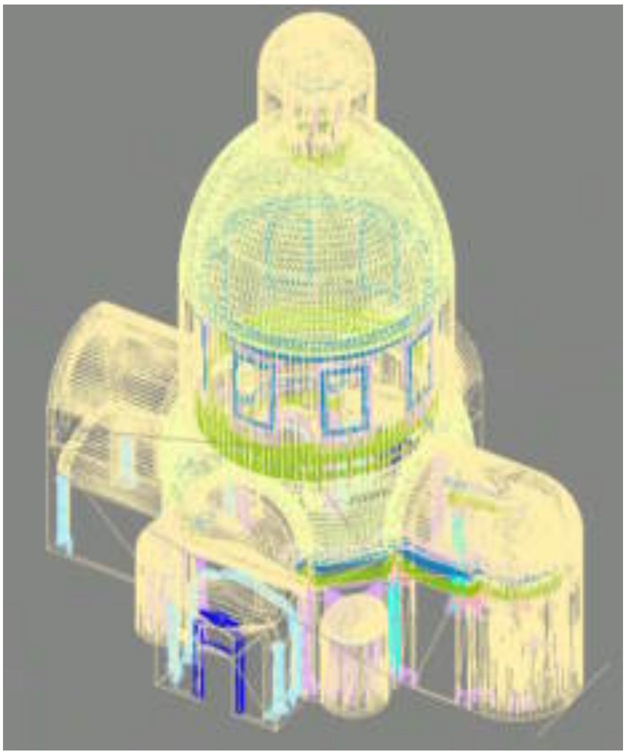

Fig. 15 Wire frame view of meshed mathematical model.

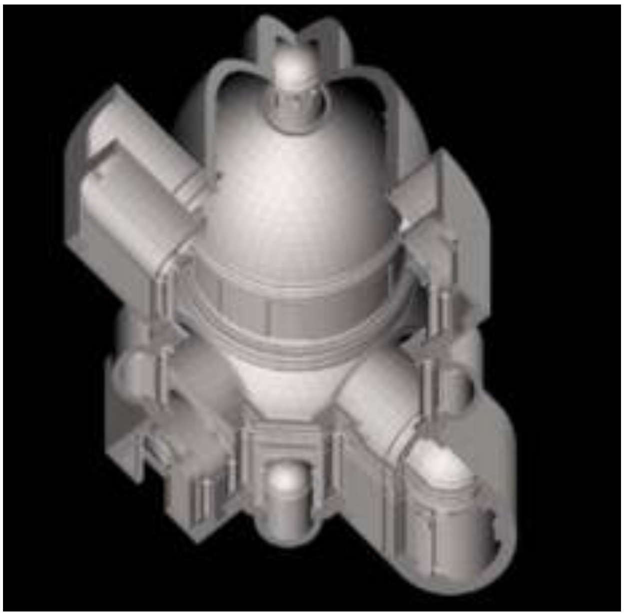

Fig. 16 Assonometric view of rendered sliced model

Thus the discrete model results to be accurate, detailed and objective documentation of surveyed surfaces, while the mathematical model results at the same time interpretation and creative hypothesis, establishing a mutual correspondence between ideal and real.
The face between hypothesis and measured data puts in evidence correspondences and gaps between the two digital models. The diffusion and entity of correspondences as well as the localization and quantitative and qualitative valuation of gaps, over that on the quality of the two models, allows to deduct important information on global and punctual deformations of the building, important clues for further deepening over surface survey, to a deeper knowledge of the object and of the transformations that have characterized its existence since his conception to the survey date.

5. CONCLUSIONS

The use of instruments like the laser scanners and the analysis of discrete models automatically generated by it, beyond to reduce the time of measuring as well as to increase the quantity of precision of data, allows to obtain a precise study of the complex geometry of architecture and to consider the survey a experimental scientific discipline, where the observation of architectural phenomenon happens through a precise and repeatable measurement, while the analysis happens through the experimental research of a mathematic law able to synthesize, regularize and explain the phenomenon.
The use of the described process has allowed to realize an accurate and faithful document of the complex architectural object surface, as well as to realize a critical analysis of its geometry that can be considered an optimal starting point for a deeper knowledge.

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