LOD for Architectural Heritage: BIM Modelling for the Solimene Factory

Adriana Rossi, Umberto Palmieri

Abstract

The authors created a BIM model of a significant portion of the Solimene ceramic factory (Vietri, Salerno) based on an unstructured model obtained with phase-shift 3D laser scanning. The components, referred to standardized levels of development (LOD), are placed at the origin of a shared and interoperable workflow, suitable for comparing documents and models for design purposes and dissemination of architectural heritage.

Keywords: H-BIM, LOD, 3D Survey Technologies, Parametric Modelling, Points Cloud, Interoperability.

Introduction

The development of instrumental surveying techniques with 3D laser scanners and photographic datasets has introduced new methods to manage the complexity of the data acquired with high precision and quickness, also and above all for large architectures. The connected processes have profoundly modified the typical work of the surveyor: a professional once dedicated to the description and critical analysis of architectural/engineering works, today intensely involved not only as an expert in digital techniques but as the creator and administrator of the communication process of the project. In fact, the numerical model obtained from the data acquisition phases with active sensors is objectively representative of reality: rigorous measures can be taken from it and the quality of the survey products can be controlled, verifying –even afterwards– meticulous details. However, despite the certified precision, this model cannot be manipulated within a virtual space generated by a computer. To scale volumes and modify surfaces, or to enter geometric information of non-visible elements, the point cloud must be transcribed into continuous mathematically governable forms [Migliari 2004].
The techniques, the most common to implement this conversion, are based on algorithms that implement the triangulation of Delaunay: building grids of polygonal meshes with the vertices on selected points of the cloud, forms that establish relationships of connection and morphological identification are generated. The derived models are therefore suitable to support other types of operations

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and information, indispensable for professionals interested in adapting their modus operandi to technological development. Overcoming the resistance of the most traditionalists in the field of design, the law on public tenders commits, by decree, to manage the workflow with BIM platform. Overcoming the resistance of the most traditionalists in the field of design, the law [1] on public tenders commits, by decree, to manage the workflow with BIM platform.
This paper offers a good opportunity to verify the applicability of the method to historical buildings (H-BIM), to discuss the virtues and vices of the workflow based on the survey model, to support teamwork for the analysis of the possibilities of implementation and executive transcription of ideas.

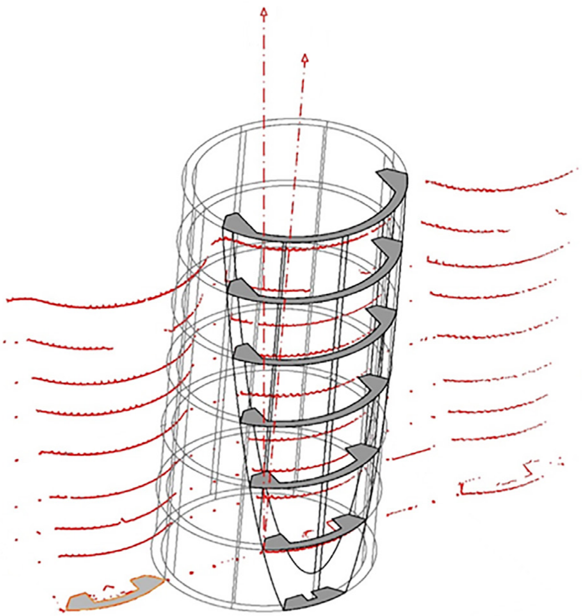
The case study

Unique in its conception, ambiguous in its form, irregular in its realization and incisively marked by time, is the Solimene ceramic factory, a work bound by LD 42/2004 and built between 1950 and 1955 in Vietri sul Mare (Salerno, Italy). The volume of the factory stands in the middle of

Fig. 1. South front of the Solimene factory (photo by the authors).

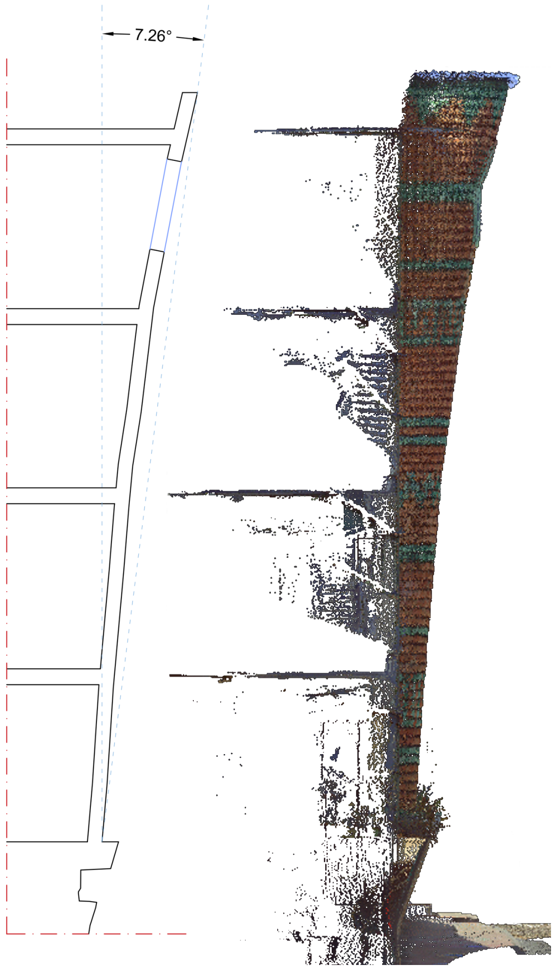
the Amalfi coast cliff overlooking the Gulf of Salerno, it is clearly visible from the sea with its characteristic front consisting of towering bodies and trapezoidal windows enclosing the deep cavity in which is produced and sold terracotta pottery decorated in local style.
The façade is dotted with bright green majolica and raw reddish terracotta (fig. 1): not a simple covering as it might appear from afar, but bottoms of thousands of 'bottles' set in the wall (about 16,000). A technique and a language resulting from experience, handed down and renewed preserving, also in this case, the indissoluble link between function, structure and aesthetics: by studying the static-dynamic behaviour of the building, the wall of bottles has proved to be a valuable solution for construction purposes as well as thermal and acoustic [Rossi 1995].
As the author, the architect Paolo Soleri (1919-2013), says, the design configuration is 'frugal' [Abbate, Spina, Zevi 2010] for its functional 'sustainability', respectful of the tradition of which it is a manifesto.

Fig. 2. The intersection between the oblique cylinder and the plane set on the pillars surface.



Soleri, applying the teaching of Frank Lloyd Wright, proposes an inexhaustible source of theoretical exercise: the abstraction necessary to interpret its formal structure generates mental elaborations that can still reconfigure the compositional aspect [Monteleone 2013].
Apparently, the high towers look like truncated cones erected like gigantic vases supporting the roof garden [Rossi 1995]. An idea confirmed by observing the perspectives painted in watercolour [2] by Soleri himself but clarified thanks to the critical survey [Rossi 2017]. Their real geometric configuration, in fact, has been explained by mathematical studies derived from the survey with total station (Trimble S6 Vision): these volumes are slightly oblique cylinders with the axis inclined by about six centesimal degrees respect to the horizontal reference plane.
From this, it follows that:
- the edge of each level the protruding floors is an arc of ellipse (not very pronounced because of the slight slope of the cylinder axis) (fig. 2);
- the intersection between the oblique cylinder and the surface of the pillars is a branch of ellipse not entirely on the oscillating pillar surface.
It seems likely that the vertical profile irregularities, evident as bottlenecks in the middle of the cylinders (fig. 3), rather than a bad execution, were a mandatory choice during the construction [Rossi, Palmieri 2018].
In order to answer the remaining questions, a new survey was carried out with a terrestrial laser scanner and photographic datasets. The technology and the device used, the Faro Focus 130 HDR [3], return an experimental certified model. The informative reliability of the method is derived from the remote sensing of millions of points, which indicates the distance from zero of all solid parts reached by the laser light [Rossi, Palmieri 2019].
This system is suitable for almost-Lambertian diffusive surfaces [Guidi, Russo, Beraldin 2010] but less reliable for reflective glass surfaces [Benedetti, Gaiani, Remondino 2011]. However, the acquired data are sufficient to address the descriptive reliability since the analysis is addressed to the description of the infill walls [4].
So, we did 10 outdoor (every 30 m) and 2 indoor scans. The targets allowed the instrument software (Faro Scene) to place 'hierarchically' the scans, the chronological steps of the operations and the photographic datasets. Final data were organized with RiScan Pro. To speed up the calculation, spherical targets along the road and flat squa-

Fig. 3. Schematic profile of large vase-shaped towering volumes.

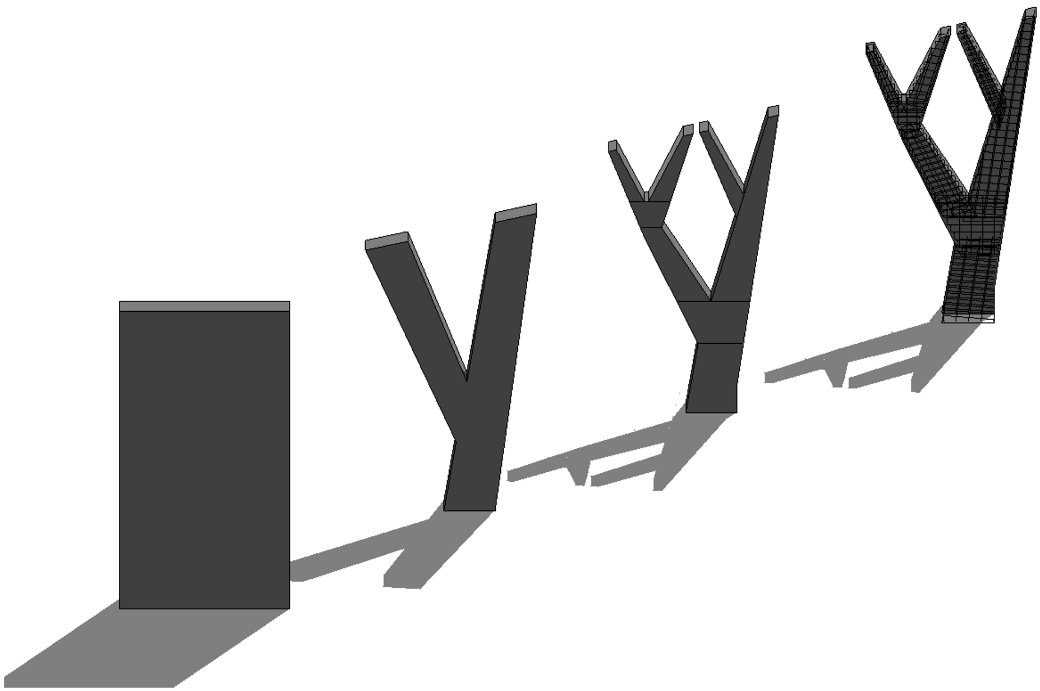


res on the façade were used during the acquisition phase (fig. 4). We proceeded to filter the point cloud from outlier points. The final output was an 'unstructured' model made of points (XYZ-RGB-i), then transformed into triangulated surfaces (meshes) on which textures were applied. In order to study the façade volumes morphology, it was necessary to transform the experimental (discontinuous) data into vector models that were ideally continuous. This transcription does not exempt from interpretation, even though it is methodologically well-founded. This model, explorable in three dimensions, allows both the measurement of distances and the connection to iconographic or alphanumeric documents.
The three-dimensional modelling of the levels, processed in the same descriptive context, was guided by the tools offered by the modelling software.
There are specialized environments suitable for BIM that boast the ability to assist the production of many –if not all– specialized sectors (structures, plants, security, costs etc.). These, however, have been programmed to handle

Fig. 4. Location of targets and survey station points.

forms and techniques currently used in both engineering and architectural design: parts of buildings generally made up of serial and essential shaped elements are modelled quite quickly and effectively with those software products. The modelling of the Solimene factory appears to be anything but rapid in our case.
Therefore, an advanced 3D graphics software (Rhinoceros) was preferred to rebuild the surfaces and, then, a BIM software to continue modelling and implementing the necessary information [Tang et al. 2010].
The application of BIM processes to historical buildings (H-BIM) represents a challenge: if the effectiveness of the BIM method is in the use of standardized database of objects, the digital re-construction, due to the atypical nature of the historical construction, starts from the necessary creation of components with an adequate level of accuracy in relation to the objectives.
The survey of the current situation, that is, the model created from objective data acquired with certified tools and techniques, is at the beginning of the workflow made shared and interoperable thanks to the use of oriented objects. In fact, each project presupposes a survey of the current situation [Banfi 2016] which, for historical artefacts, must even consider diachronic transformations. Putting a certified document at the origin of the shared chain offers the advantage of working with the same software both for the creation of components and for the engineering study related to their correct sizing. Therefore, the phases of acquisition and post-processing of the collected data are decisive in directing the organization of the BIM workflow.

Fig. 5. Development of the family of structural pillars.



Certified levels of development

Information modelling, if addressed to historical buildings (H-BIM), can only be carried out starting from the construction elements definition derived from the survey. The true form and size of buildings and the environment in which they are located are catalysts for the elaboration of navigable models, aggregative cores of historical-documental information, diachronic analyses of changes, studies on materials and technologies and the necessary multidisciplinary comparisons. What in the past was configured as an aggregative core of symbolic alphanumeric and iconic data, today, if placed at the origin of a shared and interoperable chain of work, transforms the photo-realistic model, descriptor of the underlying information system, into a real digital construction [Gaiani, Benedetti, Apollonio 2011]. In this perspective, the scientific nature of the acquisition procedures is crucial both for the creation of the parts database and for the development of projects aimed at restoration and maintenance.

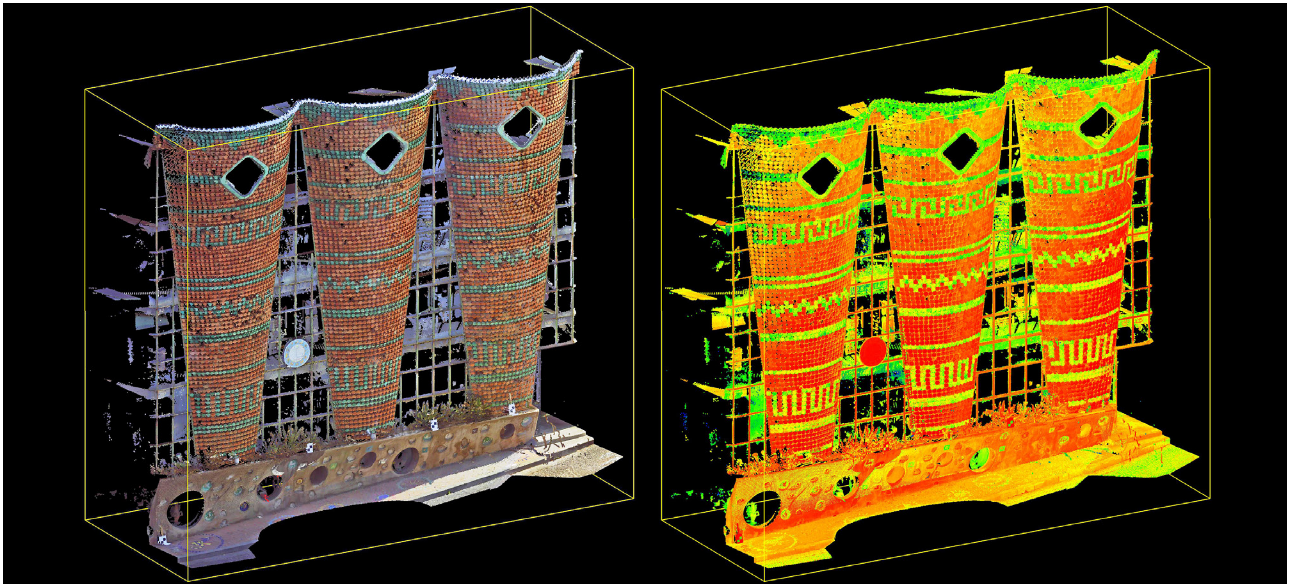
Coding the investigation process according to the agreed and signed knowledge level of analysis is the main action to be taken [5]. The standards, in fact, establish the geometric characteristics that objects must ensure (LOG, Level of Geometry) according to the related information aspects (LOI, Level of Information) in order to make

Fig. 6. Detail of the indoor pillars of the factory.

reliable the Level of Development (LOD) required by the project BIM oriented [6]. The same standards, however, show that graphic detail is a separate and independent issue [7]. However, it is desirable to have a sort of 'tolerance' of the detail in order to facilitate the transition between adjacent levels [Historic England 2017], satisfying the necessary precision. The level (LOG, LOD or LOI), obviously, does not coincide with the potential of modelling offered by the authoring BIM software, nor does it interfere with the quality of the certified survey, or with the deepening of the details modelled to create objects oriented in the sense explained above.
The uniqueness of the Solimene factory gives priority to the parametric construction of its components, pre-establishing their level of complexity. For this purpose, it is not always advisable to 'snap' directly to the point cloud [8]. In the absence of specific archives, form and geometry have oriented the primary decomposition for the recognition of serial characteristics, classifiable into cascade categories organized taxonomically.

The example shown in figure 5 clarifies a development by levels applied to the modelling of a pillar, element of original shape (fig. 6) and certainly not elementary (as could happen for new buildings). The operative practice foresees a development at different speeds of information and therefore of different geometries. If we look at the previous example, the tree-shaped pillar, we can see the unique LOD sequence that cannot be confused with the purely graphic detail: the element in Revit becomes a real vertical structure.
Modern BIM authoring software can model construction elements with different graphical abstractions, with detail according to the agreed LOD. They range, therefore, from a schematic visualization to a particularly high degree of detail [9].
Once the object has been created, it is possible to combine non-geometric information with it to make it uniquely identifiable: it can be named according to a classification system, to a position, possibly geo-referenced, and therefore correctly stored within the data model.

Fig. 7. Significant sample of the façade taken from the point cloud.



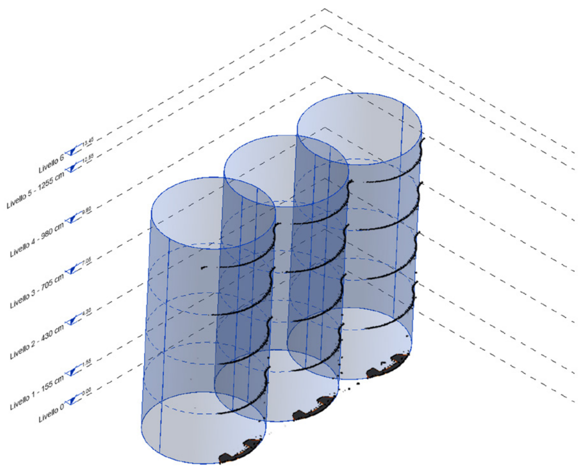
To define a parametric family, with objects aware of their characteristics, it is not enough to follow the logic of 3D vector graphics, but it is necessary to show and calculate (or describe mathematically) the geometric-constructive configuration of each component so as to make it 'intelligent', that is, accompanied by everything that fully documents what has been found on the subject.
From the very first phase, it is necessary to associate attributes to the 3D model that describe the nature of the objects present in the BIM model. Specifically, it is the creation of semantically defined geometries (walls, windows, doors) based on a typical architectural organizational structure referring to standardized levels of detail. This activity provides the taxonomic logic to develop the entire database made up of intelligent, questionable and interoperable objects for different purposes.

Building the information model

The absence of standardized BIM libraries [Arayici 2009] directly usable to assemble the components [Eastman 2008] has made it necessary to structure the elements of the case study specifically modelled and derived from the instrumental survey, in order to populate a database of parametric and interactive objects, formally homogeneous and always questionable for checks and inspections.
The construction of the model presented the difficulty of having to verify its geometric configuration before proceeding. The point cloud acquired with a 3D terrestrial laser scanner was the certified data for the (discontinuous) numerical model [Karmazyn 2017]. The file, processed and indexed after the survey phase, was placed in a BIM and georeferenced environment.
The point cloud connected to the project provided an extremely accurate visual and operational reference of the existing condition of the building, to be used as a guide for BIM data production operations.
In fact, each point detected is measurable, selectable and allows snaps for modelling. The cloud, once optimized and purged from useless information, allowed us to directly start the definition of the parametric elements, limiting the inaccuracies.
Having already discarded all non-functional points at the entry, the digital (re)construction of the Solimene factory was much faster. What was rendered in BIM is a significant sample of the facade (fig. 7) consisting of 3 of the 11 'towers' that mark the wonderful front. Each building element distinguished by name, number and position was associated with a type, therefore, correctly filed within the data model with a corresponding parametric family. The types prepared for the model were as follows:
- infill walls;
- external wall layer;
- glass walls;
- structural floors;
- structural pillars.

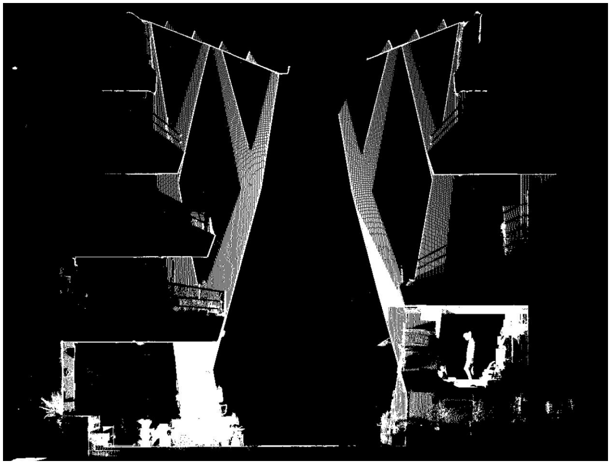
For this study the model was based on the symbolic aspect of its architectural elements, referring it to the standardised levels of development and referring to subsequent developments the possibility of reproducing also all the iconic beauty of the factory.
The principle was to use two languages in parallel: the first, technical, typical of architectural design and the second, informative, developed with alphanumeric data.
The components of the sample have been deconstructed in generic solids, only defined by their size corresponding to the volumes detected, thus matching the level LOD300. The progress of the modelling, however, was also related to the quantity and quality of information collected and actually transferred to the model: accurate descriptions

Fig. 8. Constructive references for the creation of parametric families.



and historical information associated with the various geometric types allowed us to increase the level of information (LOI), increasing the level of reliability (LOR) of the work.
The modelling phases were distinguished according to the construction logic, hoping that the (re)construction simulated in digital could also reveal the accidents that arose during fabrication.
First, the following reference elements were derived from the point cloud: the heights corresponding to each floor, the plane on which the glass walls are placed and the circumferences representing the intersection of the inclined cylinders with each floor. Subsequently, these cylinders were modelled to be used as intrados of the infill walls (fig. 8).
At this point it was possible to create the floors, the structural pillars, the infill walls and the large glass walls.
The floors modelling was made easily applying the 'floor' family at the desired level, having already the reference heights. The pillars of the facade, partly hidden in the curtain wall, were modelled by examining old photos of the construction, while the tree-shaped pillars were derived from the internal scan (fig. 9).
Infill walls were modelled from the surfaces of the cylinders and then detailed by inserting the rhomboidal windows and a texture depicting the distinctive red and green

Fig. 9. Orthophoto of the point cloud derived from the factory's internal scan.



terracotta bottoms. The glass walls, lying on the vertical plane, were quickly created with the specific 'curtain wall' family, remodelling the profile to give it a trapezoidal shape. At this point, the components were correctly sized and positioned with respect to each other, in perfect coherence with the results of the 3D laser scanner survey (fig. 10).
The possibility of extending the multidimensional model with additional information has encouraged the use of specific features of the BIM software, such as collaboration tools. In practice, the project was shared with professionals able to develop the structure of the factory. By creating a specific workset, reinforcements were added to the splendid branched pillars (fig. 11).

Objectives pursued and achieved

The case study provided an opportunity to test strengths and weaknesses of the H-BIM method at the basis of a workflow aimed at:
- integrate a plurality of professionals to support the analytical investigation: the 3D model (as a whole and in its components) becomes an exhaustive descriptor of the underlying articulated database, going beyond the character of a mere graphic interpretation tool;
- verify that the levels of development considered are suitable for the typical documentation requirements of tender specifications, up to the creation of the prototype that should constitute the entire data environment of the project.

In conclusion, it should be noted that processing the digitisation of project representation and documentation offers many further research developments:
- to digitally verify the construction hypotheses, to measure the differences between the numerical model and the ideal model, to reveal the reasons for unexpected events during the work;
- to subject the conformative hypotheses to inductive verification;
- use the information system and inter-operational models to allow inter and trans-disciplinary contributions to present the results in an impartial, logical and critical manner;
- to organize a process that converges towards the idea of the project, guaranteeing to future memory the detailed and truthful documentation of the as built;
- share all the data of the analytical survey.

Notes

[1] The public tender code (d.Lgs. 50/2016).

[2] In the Municipality of Vietri are kept the signed copies, signed with Eng. Immormino who verified the static calculation necessary to obtain the building permit, issued in 1954, as a variation of the project already approved [Zampino 1995].

[3] Phase-shift terrestrial 3D laser scanner, accuracy: ±2 mm; Range 0-130 m; Built-in high-definition metric camera (> 6 MP); Built-in GPS antenna; High acquisition speed: min. 976,000 pti/sec; Scanning angles: 360° horizontal - 300° vertical.

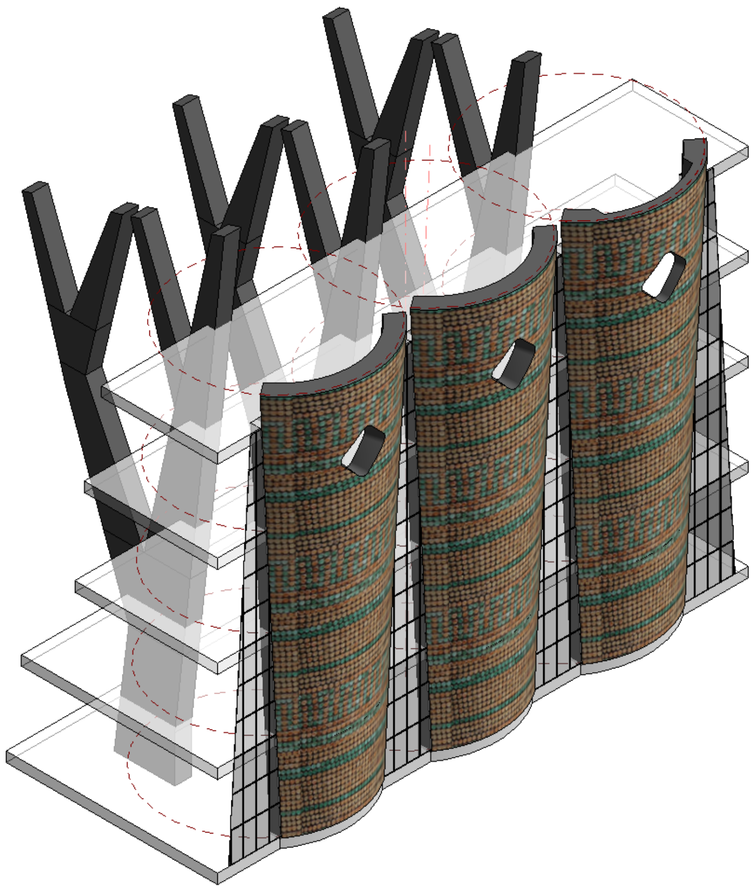
[4] The difference in signal return times allows the software to interpret the values as "peaks" and "valleys" of the surfaces and then convert them into points or polygons. The same is not true of reflective and transparent surfaces, for which acquisition is much more complex.

[5] BIM Execution Plan [BEP - PAS 1192-2:2013].

[6] UNI 11337:2017-4; AIA E202-2008: B.I.M. Protocol Exhibit.

[7] In particular, UNI 11337:2017-4.

Fig. 10. BIM model at LOD350.



[8] Since 2008, "AIA E202-2008: Building Information Modeling Protocol Exhibit"), a guide containing the contents of the main design elements according to the design phase they describe, has been periodically updated and published online.

[9] AEC (UK) BIM protocols.

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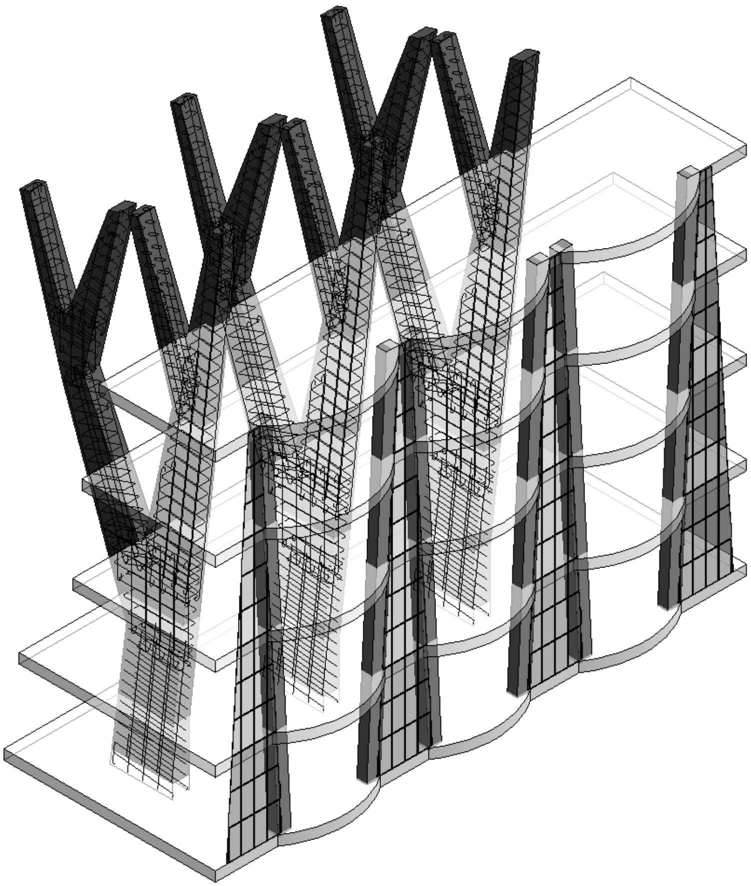
Fig. 11. BIM model at LOD400.



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