Solimene factory, Vietri sul Mare (SA, Italy). View of the main facade.

Experimentation of an Information Model

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ABSTRACT

Wanting to answer the questions unsolved by a previous study supported by a survey with total station, this article illustrates the results obtained with 3D laser scanning acquisitions and photo shot datasets. The precision provided by the phase shift ranging scanner technology has allowed to measure to the millimeter the deviation between the surveyed model (objective of reality, although discontinuous) and the geometric model on these data interpreted. In addition, the mathematical hypotheses useful for parametric modelling (geometry processing) are discussed. Virtualizations have been created by adopting knowledge filters and scientific tools that address to the digital (re)construction (HBIM) that allows to share and manage information and to integrate interoperable models in accordance with current public procurement regulations.

KEYWORDS

1. INTRODUCTION

The Solimene ceramic factory is a listed edifice[1] of Italian architectural heritage of the first half of the twentieth century. Considered one of the best expressions of organic architecture in Italy (Zevi, 2010), it is here adopted as a case study for disciplinary purposes, in view of its didactic value, but also for the actions demanded by its peculiarity to solve the problems concerning the restoration of buildings in reinforced concrete (Abbate et al., 2010).

The construction is the result of a coincidental encounter between the architect Paolo Soleri (Turin, Italy, 1919 – Cosanti, Arizona USA, 2013) and Vincenzo Solimene, an artisan from Vietri sul Mare (Salerno, Italy). The friendship between the two (Riley et al., 2007) and the passion for the production of terracotta inspired Soleri to develop the project, which was then realized between 1950-1955.

The factory stands out in the middle of the Amalfi Coast, against the green background of a rocky cliff and is clearly visible from the sea on which it faces with its trapezoidal glass walls alternating with towering structures.

The main front, to the south, is covered with disks of green majolica and raw terracotta: not just a simple veneer as it would appear from afar, but bottoms of thousands of "bottles" horizontally slotted in the infill wall (Lima et al., 2004). The design is "frugal", as Soleri himself states (McCullough, 2010), for its functional sustainability respecting the tradition of which it is a manifesto (Ryan, 2002). In schools of architecture this factory is an inexhaustible source of exercise in composition, but for us - involved in the Survey and Drawing - a significant field of speculative investigation.

Despite the large number of surveys of the building, even of certified precision, no one, as far as we know, has studied the geometric conformation of the façade, indispensable to know to model forms respecting the original design and to make them editable according to parametric laws.

No less interesting – for the purposes of the digital (re)construction – has appeared to investigate the flares that make the profiles of the infill walls showily irregular. So, in order to provide Soleri's work with a knowledge model that can be integrated with sectoral studies and iconic and alphanumeric information, the massive data acquisition obtained with 3D laser scanning technology has been placed at the origin of all the analytical phases. In addition to acquiring the morphological irregularities, the precision has allowed to measure the deviation between the model surveyed (objective of reality, although discontinuous) and the geometric model (continuous, but interpretative). The metric and conceptual comparison has shown the reliability of the mathematical hypotheses useful for the parametric (re)construction (geometry processing) (Migliari, 2004).

Therefore, the resulting virtualizations can adopt knowledge filters and scientific tools that lead to digital (re)construction supported by BIM methodologies (Historic England, 2017) to meet the almost universal principles (i.e. UNI 11337:2017; AIA E202-2008: Building Information Modeling Protocol Exhibit).

2. MATERIALS AND METHODS

The diversity of gnosiological objectives that have characterised the course of analysis and research on the Solimene factory has led, over time, to use different tools and methods of survey that the current work integrates and gathers in order to progress towards the organization of a shared and interoperable workflow.

The first survey carried out with a total station[2] (Rossi et al., 2018), was aimed at identifying the geometric-configurative model of the main front. The analysis of the relationships between building elements is essential to understand the articulation of the original infill walls and the development of their surfaces, responsible for the contradictions between the hypothesis of constructive feasibility and their actual execution, or the differences between design drawings and survey drawings. In that perspective, the data acquisition with the total station robotic video control had ensured direct measurement of hundreds of points at predetermined heights. For the rendering of the geometric model, a rigorous mathematical

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investigation had supported the interpretation of the data leading to the conclusion that the shape of the towering structures, originally considered portions of upside-down cones, are portions of straight cylinders. The optical illusion is generated by the inclination of the cylinder axis in relation to the geometric reference plane.

In order to investigate the reasons for the flared silhouette of the façade "towers", which is difficult to attribute to an approximate construction, the 3D survey with phase shift ranging scanner technology allowed the acquisition of a point cloud which, integrated with photo shots, guarantees an inexhaustible source of information, to be selected, cleared and interpreted (Tang et al. 2010). The instrument adopted[3] has allowed remote acquisitions ensuring the reliability appropriate to the new objectives. Thousands of coordinate points were captured in high definition. A total amount of 14 scans, 12 external and 2 internal, allowed to acquire the entire front and the internal vertical structures. This system works fine to detect the almost-Lambertian diffusive surfaces (Guidi et al., 2010) but is not suitable for reflective surfaces such as glass walls (Bendetti et al., 2011). However, wanting principally to model the infill walls, the acquired data were considered exhaustive. During the execution, some expedients were taken to verify the possibility of containing the number of stations, avoiding areas

of shadow that would have created problems in data processing. In order to speed up the alignment of frames (merging) with a single reference system, spherical targets were used along the road axis and quadrangular targets were used on the vertical walls. Moreover, from scanning points located with 30 m steps, multiple scans were recorded varying the resolution to facilitate the shots management.

A post-processing was carried out editing the acquired clouds to remove outlier points and generate a single unstructured model with multiple information (XYZ-RGB-i), such as point coordinates and the response of the materials in terms of reflectance. The density of the points acquired and the integration between indoor and outdoor 3D survey, have allowed the precise rendering of the architectural elements Moreover, thanks to some damaged bottles which lacked the bottom, has been measured the thickness of the concrete slabs (Karmazyn , 2017) .

The cloud allows to obtain precision measurements and verify even small details although it is not suitable to respond to the topological restrictions supporting the design and building process and essential to re-constructing digitally. Therefore, it was needed to "check" every single point to extract boundaries, surfaces, shells and volumes from the discrete data, to give value to the interpretation necessary to make the ideal model continuous.
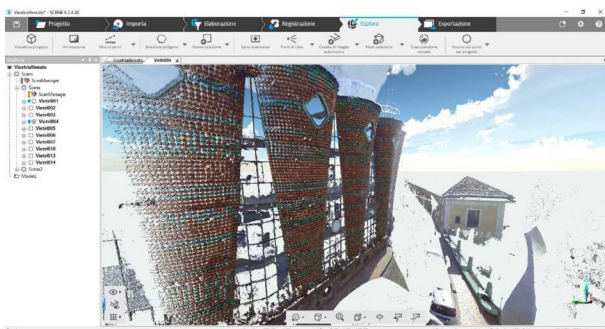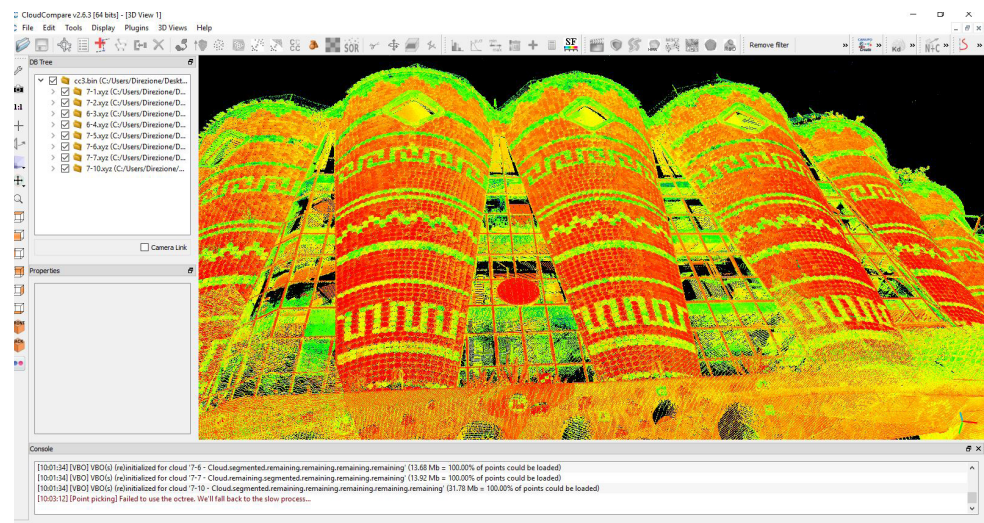

(a)
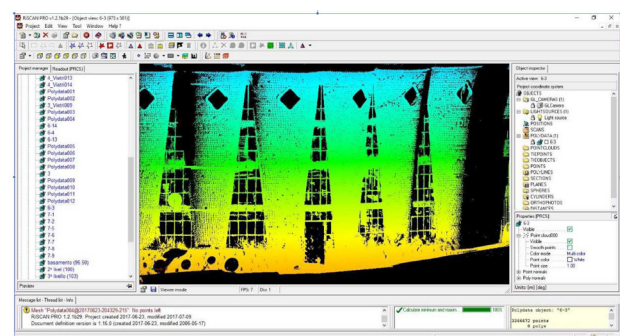
(b)

Figure 1.
(a) Point cloud management with Faro Scene software (Karmazyn 2017:85);
(b) Post-processing of the point Cloud with RiScan Pro software (Karmazyn 2017:67).

Figure 2.
Textured point cloud generated with CloudCompare software (Karmazyn 2017:88).

Initially, the Faro Scene software was used for automatic target recognition and quality control of registrations (Fig. 1a). RiScan Pro, has provided the useful tools for the visualization and the complete control of the 3D survey (Fig. 1b). The various filters and tools for editing point clouds have allowed the preparation of files for subsequent processing. With CloudCompare software has been generated one textured model (Fig. 2), then, through appropriate algorithms, transformed into a 3D model consisting of triangulated surfaces (mesh).

3.   RESULTS

The survey has showed that the vertical profile of the "towers" is a polyline with no constant slope, characterised by a slight concavity that amplifies at the top floor. To determine the real inclination of this polyline some vertical sections have been drawn on the "cylinders". The average percentage of inclination has resulted 7°. In addition, cutting horizontally the model with a series of cutting planes at an interval of 2.00 m from the reference plane (the top of the basement), variable sections were obtained according to the distance from the reference plane. The radius

of the circular sectors, measured at various heights, has resulted almost identical.
By integrating all the data obtained, it was deduced that the perceived optical effect of a reversed frustum is the result of an intersection between the 7° inclined cylinder in relation to the ideal vertical xz plane, coinciding with the glass walls.

3.1 ANALYTICAL VERIFICATION

This discussion is not based on the direct derivation of the equation of the inclined cylinder as this solid is not the result of a simple rotation as in the case of a straight cylinder. For this reason, it was decided to discretize the structure at several levels and then proceed to calculate the equation of the circumference at these heights. It was therefore necessary to define the equation of the circumference in terms of center and radius.
Horizontally sectioned the point cloud at three different heights
• H0 = 0,0 m (on the basement);
• H1 = 6,0 m (in the middle);
• H2 = 11,7 m (at the top);
and chosen the zy plane (x = 0) as the appropriate

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local reference system, it has been noted that the points cloud radius of curvature at each level is almost constant and equal to 2.3 m. Applying these data to the equation which expresses the circumference by the coordinates of the centre C = (x0; y0) and the radius r:

$$(x - x0)^2 + (y - y0)^2 = r^2 \qquad (A)$$

Values were obtained at each of the three fixed elevations. The results are given in Table 1.

Center	Equation
C_0 (0; 0; 0)	$x^2 + y^2 = 5,3$
C_1 (0; -0,7; 6)	$x^2 + (y + 0,7)^2 = 5,3$
C_2 (0; -1,4; 11,7)	$x^2 + (y + 1,4)^2 = 5,3$

Table 1.
Application of (A) to the given heights H0,
H1 and H2 with constant radius r = 2,3 m.

The following scheme (Fig. 3) shows on the horizontal plane the relationship between the three sections that identify three circumferences of the same radius. Maintaining the same reference system, the straight line passing through the centres of the circumferences has been determined in order to calculate its slope, relying exclusively on the position of these points.

Figure 3.
Relationship between the circumferences found by cutting the point cloud at heights H0, H1 and H2.
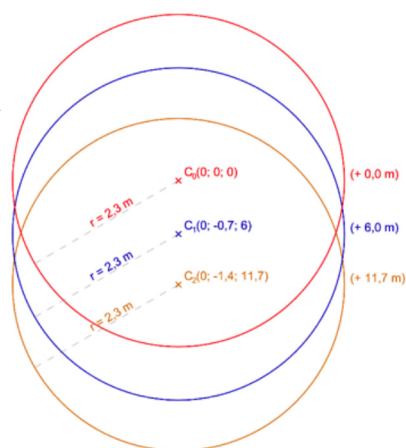
In general, the equation of a straight line in explicit form passing through the origin of the axes and referring to the plane, is defined as:

$$z = my \qquad (B)$$

where m represents the slope. Once two points are known, it is possible to calculate this coefficient directly with the relation:

$$m = (z_2 - z_1) / (y_2 - y_1) \qquad (C)$$

where zi and yi represent, respectively, the ordinate and the abscissa in relation to their belonging plane. The slope allows the calculation of the incline of the line to which it refers; in this case, the incline of the line represents the incline of the cylinder. In formulas, this concept becomes:

$$m = tg(\alpha) \qquad (D)$$

where α represents the slope of the line relative to the axis of the abscissae in the plane considered. Reversing this formula and reporting the value of the incline in relation to the angle of the ordinates it is obtained:

$$\alpha' = 180° - tg\text{-}1(m) \qquad (E)$$

where α' indicates, in fact, the incline of the line in relation to the axis of the ordinates in the plane considered. Applying equation (E) to the centres observed, the values shown in Table 2 are obtained, from which it results that the structure has an incline equal to 7° in relation to the vertical axis.

Line by points	Slope (m)	Incline (α')
C_0; C_2	8.125	7.01°
C_0; C_1	8.108	7.03°
C_1; C_2	8.142	7.00°

Table 2.
Derivation of the incline of the cylinder by calculating the slope of the straight line passing through the centers of the circumferences.

Therefore, here is confirmed the ideal shape of the oblique cylinder which intersects the plane of the façade and determines a parabola (Karmazyn 2017:103-113).

3.2 MODEL DEVIATION

Dedicated software environments allow to calculate the deviation of values between the survey model and the geometric model. Selected a specimen of the façade consisting of the three towers in the middle of the front, by superimposing the point cloud (unstructured model) on the ideal surfaces (in our case, the cylinder based on the geometric considerations previously deduced), specific tools for comparison have allowed to confront the real surface with the ideal one. This comparison was made in the xyz space, in the vertical plane yz and in the horizontal plane xy (Fig. 4).

After mapping the deviations for each tower, a mapping was determined indicating the deviation from the ideal surface of each individual point of the area under consideration. The histogram represents the various distances measured and the distance obtained from the average of the measurements.

The comparative analysis has revealed dichotomies that only an interdisciplinary analysis can correctly define. Here is the need to organise an interoperable workflow, based on the certified survey, mainly for the purpose of sharing and managing information, archiving the massive acquisition of data, directing restoration and maintenance works, and preserving a work of exceptional historical and artistic value for the future.

4. DISCUSSION

The BIM procedure, conceived to assemble standardised elements (Eastman, 2008), has imposed - in our case - the preliminary organization of the BIM resource library following the principle that an accurate point cloud can guide the creation of parametric families. Thus, the laser scanner survey was considered the initial link in the workflow for the implementation of the informative modeling of the case study, allowing the database to be populated with a specific language, suitable for creating typical and original components. To digitally reconstruct the Solimene factory, a stable and explorable parametric model has been created. The identification of control parameters has been done by characterizing the architectural components by means of reverse engineering. Determining the relationship that each acquired data has with the entire building and its

Figure 4.
Model Deviation a) on the plane xy; b) on the plane ZY (Karmazyn 2017:100).

(a)

(b)
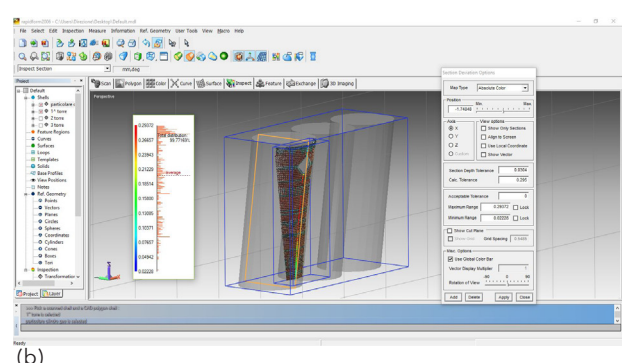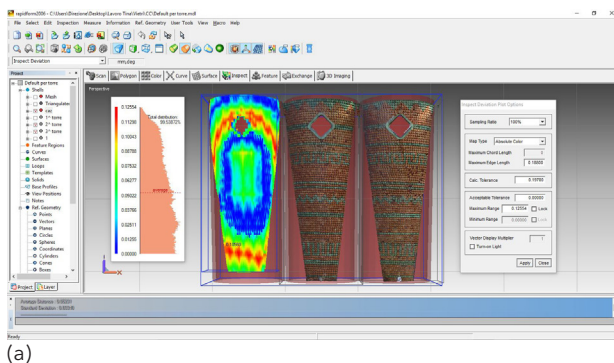
Figure 5.
Comparison of the detected model with geometric model (Karmazyn 2017:88).
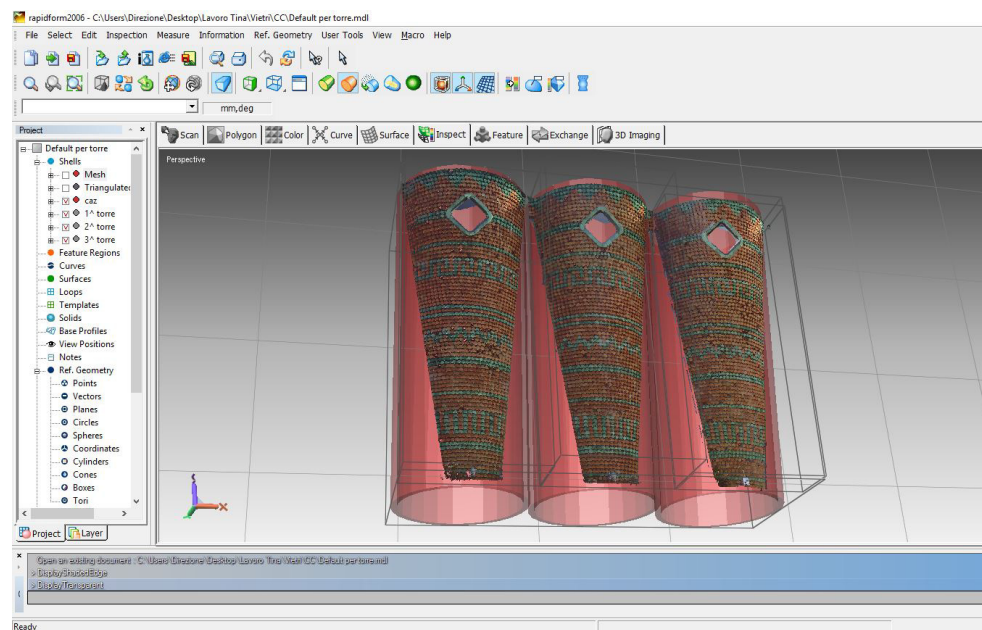
parts makes the data itself informative.

Faced with such an atypical building without a recurring technological backing, the creation of BIM resources based on typical architectural categories referred to standardised levels of development (LOD) was the substantial action. In fact, the objects characteristics as the geometric aspect (LOG, Level of Geometry) and the relative information level (LOI) are established by standards to make the LOD - required by the BIM-oriented project - reliable. Pursuing the quality of the information model means precisely adapting to the directives of standardised levels of development.

Figure 6 shows the development in levels applied to the example of the inner pillars of the factory, elements with a completely original shape. Looking at the extracted example, the pillar that imitates the branching of a tree, it is evident a LOD sequence that cannot be confused with a mere increase in the graphic detail. Once the object has been created, non-geometric information has been combined with it to make it uniquely identifiable: it has been named in accordance with a classification system and a position,

then geo-referenced, correctly arranged within the general model.

In order to constitute a parametric family - an object aware of its characteristics - it is necessary to show and calculate, or rather to describe mathematically, the geometric-constructive configuration of the component and to provide it with everything that fully documents what has been found on the subject. In fact, since the first phase of development, the attributes to describe the nature of the objects present in the BIM model have been associated to the 3D model. Specifically, the creation of semantically defined geometries (walls, windows, floors…) was implemented, based on a typical organizational structure referred to standardised levels (LOG, LOI, LOD). This activity provided the taxonomic logic (Arayici, 2009) to develop the entire database made up of intelligent, interrogatable and interoperable objects for different purposes.

The point cloud - processed and indexed after acquisition - was imported into the BIM authoring software. Coordinated points were used as dimensional references necessary for the modeling of each architectural and structural element. Proceeding from the
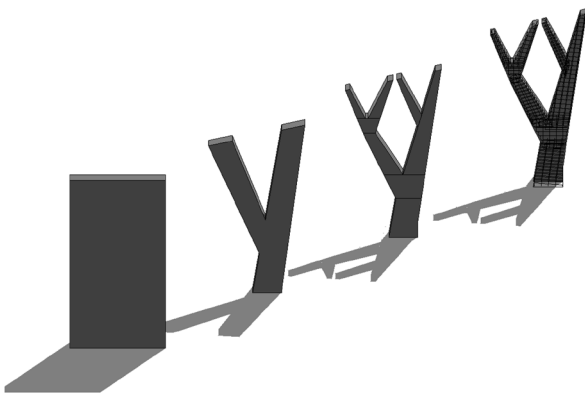
Figure 6.
Level of Development for the internal pillar type of the Solimene factory (Palmieri 2019).

general to the particular, the experimental model has been discretised hierarchically in parts. In fact, in order to create, manipulate and manage information models, it is necessary to prioritize the identification and description of their components to be oriented according to the pre-established information level. Therefore, the key to the initial transposition was to select the point cloud portions affiliated to a homogeneous class of building elements identified as a single family. The creation of parametric families then made it possible to archive information (alphanumeric, iconic and narrative) useful to enrich the shared and interoperable workflow according to taxonomic logic. To increase the Development Level (LOD) as well as the reliability of the entire model (LOR), virtualization must become real building elements, assuming the real rules of manufacture.

For the case study, wanting to build a model collector of all the information and executive hypotheses useful for maintenance and restoration, it was decided to discretize the whole according to structural and building logics to simulate a sort of digital (re)construction. Therefore, the modelling started by identifying the vertical (pillars) and horizontal (floors) structural elements and, subsequently, the altimetric heights to

characterize the glazed plane and the infill walls. Because of the lack of adequate libraries, ad hoc oriented objects have been created to meet the LOD requirements (UNI 11337-4:2017). The parametric families identified were named as follows:
1. structural pillars;
2. structural floors/roofs;
3. glazed walls;
4. nfill walls.

The boundary surfaces between the parts have outlined the overall dimensions to define the components as volumes suitable for a level of development that the standards indicate as LOD 300. For the modeling of the floors, the real height level was traced and applied to it the Floor family (system family). For the pillars, on the other hand, it was necessary to distinguish between the internal ones, obtained from internal laser scans (Fig.7), and those embedded in the infill walls, referred to the drawings of the original project and the photos of the construction.

The curtain walls were modelled starting from the ideal surfaces (cylinders with oblique axis): the cylinders were modelled and used as the intrados of the walls, then detailed with rhomboidal windows and the cha-
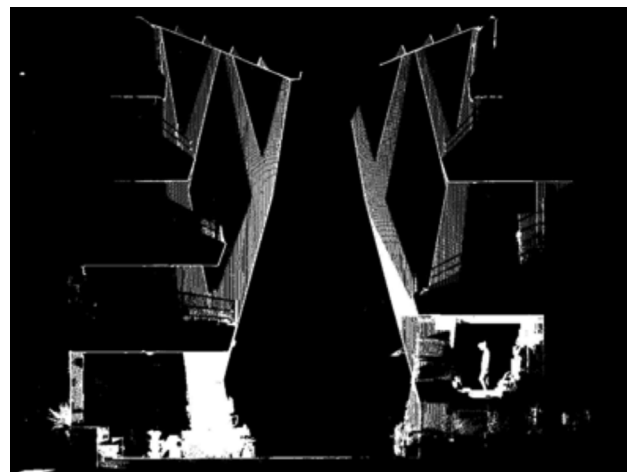
Figure 7.
*Orthophoto derived from the internal 3D scan (Karmazyn 2017:101).*

racteristic red and green finish. The windows, lying on the vertical plane, were quickly made with the special Curtain Wall family, reshaping the profile to give it a trapezoidal shape. These components were correctly assembled and positioned in relation to each other, in perfect coherence with the results of the 3D laser scanner survey, obtaining a model corresponding to the LOD 350.

The possibility of developing the multidimensional model with additional information and, therefore, advancing in LOD, has encouraged the use of specific software features such as collaboration tools. In practice, the project has been shared with experts able to perform an in-depth study of the structure of the Soleri's work. By creating a dedicated workset, reinforcements were added to the branched pillars (Figure 8)..

5. CONCLUSIONS

The massive acquisition of three-dimensional coordinates surveyed with millimetric accuracy thanks to a phase shift terrestrial scanner based on laser technology, allowed the geometric model to be considered precise and reliable according to the study objectives. Specific softwares have permitted analysis such as the Formal Deviation Mapping able to explain the causes of the trompe d'oeil (the perceived upside-down cones of the façade), directing the knowledge process towards the BIM methodology.

The case study has also offered the opportunity to test the effectiveness of the BIM method applied to historical architectures (HBIM). These edifices, although atypical and without a technological backing, can adopt knowledge filters, tools and procedures that, in accordance with public procurement regulations, can anticipate the building phases and, therefore, prevent and solve the unexpected construction events. The variability of the formal, technological, structural, material aspects pushes towards multidisciplinary readings and interoperability that, due to the peculiarities of the method, can be at different development (not simultaneous) between families. Remains the value of a single model that collects iconic and alphanumeric information, potentially
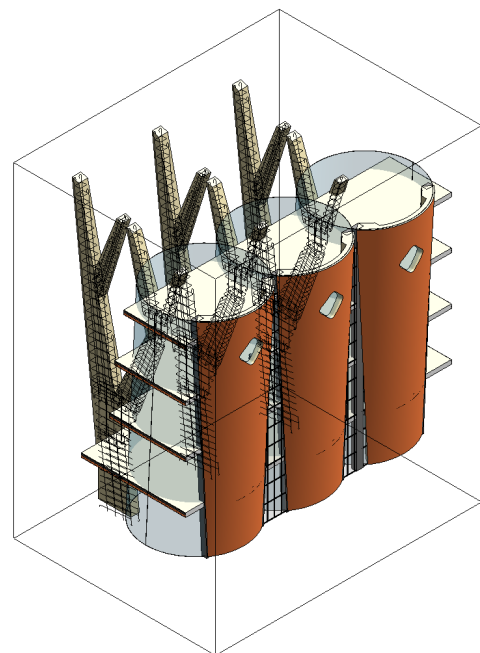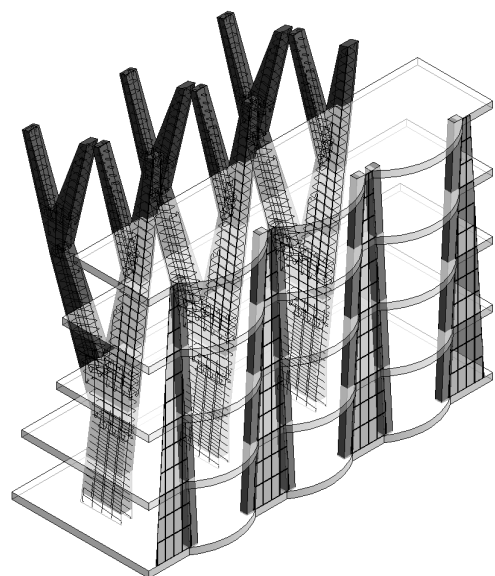
Figure 8.
A specimen of the BIM model developed according to the LOD 400 (Palmieri 2019).

capable of declining properties in respect of the attributes identified.

This (re)construction has not respected or reported the real morphological accidentality of the building, instead detected in detail by the laser scanner survey always available for consultation since it is the origin of the workflow. Yet, the information model has verified the applicability of an interdisciplinary operational collaboration becoming an effective tool for the sharing of objective data (numerical survey), for dialectical comparison on the quality of geometric-conceptual models, the evaluation of projects and for the dissemination of architectural heritage.

NOTES

1. Listed by the Legislative Decree N 42 of 22 January 2004 "Codice dei Beni Culturali e del Paesaggio" (code of the Cultural and Landscape Heritage).
2. Trimble S6 with Vision Technology.
3. Faro Laser Scanner Focus 3D 130 HDR. Phase shift laser scanner; precision +/- 2 mm; range: 0-130 m; integrated metric photo-camera (> 6 MP); integrated GPS antenna; acquisition speed: min. 976.000 pti/sec; scan angles: 360° horizontal - 300° vertical.

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