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LASER SCANNER AND UAV FOR THE 2D AND 3D RECONSTRUCTIONS OF CULTURAL HERITAGE

Maria Grazia Cianci, Sara Colaceci**

*Department of Architecture, Roma Tre University - Rome, Italy.

Abstract

The contribution exposes a research experience in which the acquisitions with laser scanners and UAVs are aimed at the integrated survey, documentation and reconstruction of 3D models of the Cultural Heritage. The Ex Mercato was designed by the Passarelli studio in 1960 within the Piano INA Casa di Torre Spaccata. It underwent modifications that altered the original spatial, perceptual and fruition characteristics. The client's request, the historical-urban context, the compromised state of affairs have conditioned the methodology of acquisition and reconstruction. The methodology undertaken concerns: historical-documentary research for the discovery of the original project drawings; data acquisition with laser scanners; data acquisition with UAVs; data processing to obtain the complete point cloud with data from laser scanners and UAVs; the 3D reconstruction of the Cultural Property using the mathematical model.

Keywords

Survey, laser scanner, UAV, virtual reconstruction, 3D modeling

1. Introduction

Currently, digital technologies allow the creation of virtual 3D models of Cultural Heritage (CH) through appropriate phases of 3D data acquisition, 3D data processing and 3D modeling.

Sometimes the reconstruction of 3D models is made difficult because the heritage is partially destroyed, or damaged, or not completely accessible. In this context, the 2D and 3D reconstructions of the CH take on a high value for the documentation, knowledge and enhancement of the heritage, but also to favor all those processes of reuse and restoration of the CH.

Investigations on CH through data acquisition with laser scanners and photogrammetry and virtual reconstructions with 3D models have a consolidated methodology thanks to the progress of ICT and are discussed in numerous national and international researches.

The investigations discuss the workflow used from data acquisition up to virtual reconstruction with 3D models for communication of the CH and restitution with conventional representations (Agnello et al., 2015; Cianci et al., 2021). The research aims at a reconstructive process of 3D modeling to make comparisons on the set of data and to evaluate the correct reading of the architecture (Apollonio, 2016; Apollonio et al., 2013; Russo & Bianchini 2018). In this regard, the questions concern the interpretation of the data and the methods of 3D reconstruction for a valid conceptual and typological modeling of the elements that make up the architecture (Apollonio, 2019; Centofanti et al., 2014; Gaiani, 2015; Gaiani et al., 2015). In fact, the phase of reading and interpreting the form is fundamental for the mathematical reconstruction of architectural models. It is necessary to consider the superimposition of anthropogenic and natural transformations to achieve the process of simplifying the shape and generating geometric surfaces (Camagni et al., 2019). Therefore, the transition from the numerical point model to the mathematical model is important (Clini et al., 2017).

Some researches use digital reconstruction tools starting from historical drawings, demonstrating the importance of integrating contemporary tools with historical representations to have data as complete as possible (Centofanti et al. 2022; Frommel et al., 2020; Zerbi & Mikolajewska, 2021).

The contribution exposes a research experience in which acquisitions with laser scanners and UAVs (Unmanned Aerial Vehicles), commonly known as drones, are aimed at the integrated survey, documentation and

reconstruction of 3D models of Cultural Heritage. Therefore, the research is part of the fields of data acquisition and processing methodologies of the CH, of virtual reconstruction with 3D models in order to test digital technologies for the documentation of the CH.

Specifically, the survey of the Ex Mercato di Torre Spaccata in Rome was conducted within the Agreement stipulated between Department of Architecture of Roma Tre University and Roma Capitale. The Agreement was aimed at preparing the dossier and competition material of the International Call Reinventing Cities - 2019 edition.

The Ex Mercato di Torre Spaccata was designed by the Passarelli studio in 1960 within the Piano INA Casa di Torre Spaccata. Despite having a compositional characterization of a semi-covered market, it underwent important modifications that altered the original spatial, perceptive and fruition characteristics (figs. 1-2).

These aspects, namely: i) the specific request of the client to have a current and complete survey; ii) the purposes of the survey aimed at the recovery of the Cultural Property within a public competition; iii) the historical-urban context in which it was born; iiii) the state of affairs of compromise and improper use conditioned the choices and methodologies of acquisition and reconstruction of the Cultural Property.

The research objectives concern the definition of an investigation methodology capable of integrating heterogeneous data (historical-documentary, two-dimensional graphics, 3D models), being bound by conditions of inaccessibility and compromise of the Cultural Heritage. In fact, to make the virtual reconstruction operation scientifically correct, it is necessary to integrate and cross-reference as much data as possible, especially where the data is partial.

2. *The Piano INA Casa of Torre Spaccata in Rome and the market*

The Piano INA Casa was one of the most significant experiences of post-World War II Italian architecture and town planning[1].

Fig. 1: Mercato di Torre Spaccata seen from the opposite hill: comparison between the photo from the 1960s (source: Centro Archivi di Architettura del MAXXI, Fondo Studio Passarelli, Album 3, n. 34) and the photo from 2020 (photo by the authors).

Fig. 2: Mercato di Torre Spaccata from via Filippo Tacconi: comparison between the photo from the 1960s (source: Centro Archivi di Architettura del MAXXI, Fondo Studio Passarelli, Album 3, n. 8) and the photo from 2020 (photo by the authors).

[1] The initiative was promoted by the Minister of Labor and Social Security Amintore Fanfani and was implemented with the approval of law n. 43 of 1949 *Measures to increase worker employment. Homes for workers.*

It was born following the political will to build public housing and lasted from 1949 to 1963 throughout Italy. The initiative favored the employment of a large number of unemployed and made it possible to build housing for low-income families in the transition period from post-war reconstruction to the economic boom of the 1960s (Beretta Anguissola, 1963).

Ten plans of INA Casa were built in the city of Rome and its surroundings from 1949 to 1960 (Vittorini, 2002). The Piano INA Casa di Torre Spaccata, created between 1958 and 1960, was coordinated by Plinio Marconi and was drawn up by ten groups of designers. It included residences, kindergartens, kindergartens, elementary school, shops, community center, offices, cinema (unrealized), church and market. Each group dedicated itself to a specific lot (Storelli & Currà, 2003).

The Passarelli studio (Vincenzo, Fausto and Lucio Passarelli, Fabrizio Falchetti, Alessandro Samuelli Ferretti) designed the Mercato di Torre Spaccata in 1960 on the L-shaped area that forms the corner between viale dei Romanisti and via Filippo Tacconi (Lenci, 2006).

3. *Methodology*

The research methodology on the Ex Mercato di Torre Spaccata is developed through different phases of investigation: historical-documentary research for the discovery of the original project drawings; data acquisition with laser scanners; data acquisition with UAVs; data processing to obtain the complete point cloud (numerical model of points) with data from laser scanners and UAVs; the 3D reconstruction of the Cultural Property using the mathematical model[2]; the two-dimensional graphic restitutions.

The current situation of the Ex Mercato di Torre Spaccata, compromised by superfetations, perimeter closures and illegal occupation by a neighborhood association, conditioned the research, since it was not possible to freely acquire metric-dimensional data of the entire building, despite full support from the Capitoline institution. For these reasons, it was necessary to integrate the heterogeneous 1D, 2D and 3D information to combine partial data, to arrive at the most in-depth knowledge possible and to respond adequately to the client's requests.

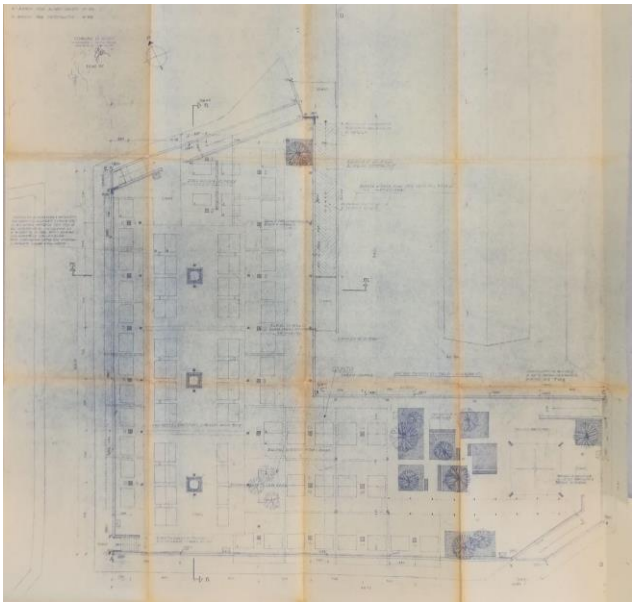

Fig. 3: Plan of the upper level of the Mercato di Torre Spaccata designed by the Passarelli group, 1960 (source: Archivio della Conservatoria del Patrimonio del Comune di Roma, pos. 2042).

3.1 Historical-documentary research

The research of the original project drawings was essential for the understanding of the original overall project and to ascertain the internal composition. The project drawings and vintage photos allow you to understand the design concept, the spatial qualities, the volumetric characteristics and the perceptual aspects (fig. 3).

The project drawings show a composition consisting of 23 minor modules and 3 major modules formed by a central pillar that supports an inverted pyramid as a cover. In the smaller modules the pillar is simple and the pyramid is 7 x 7 m, while in the larger modules the pillar is

[2] Three-dimensional models can be divided into numerical or polygonal models and mathematical models. In the first case, the geometric shapes consist of simple plane figures, generally triangles, and the representation is of the discrete type. The point cloud can be considered a numerical model of points if we assume each point as the vertex of a triangle. The mesh can be considered a numerical model for surfaces. In the second case the NURBS geometric shapes are described through polynomial parametric formulas and the representation is of the continuous type. See Migliari, 2009.

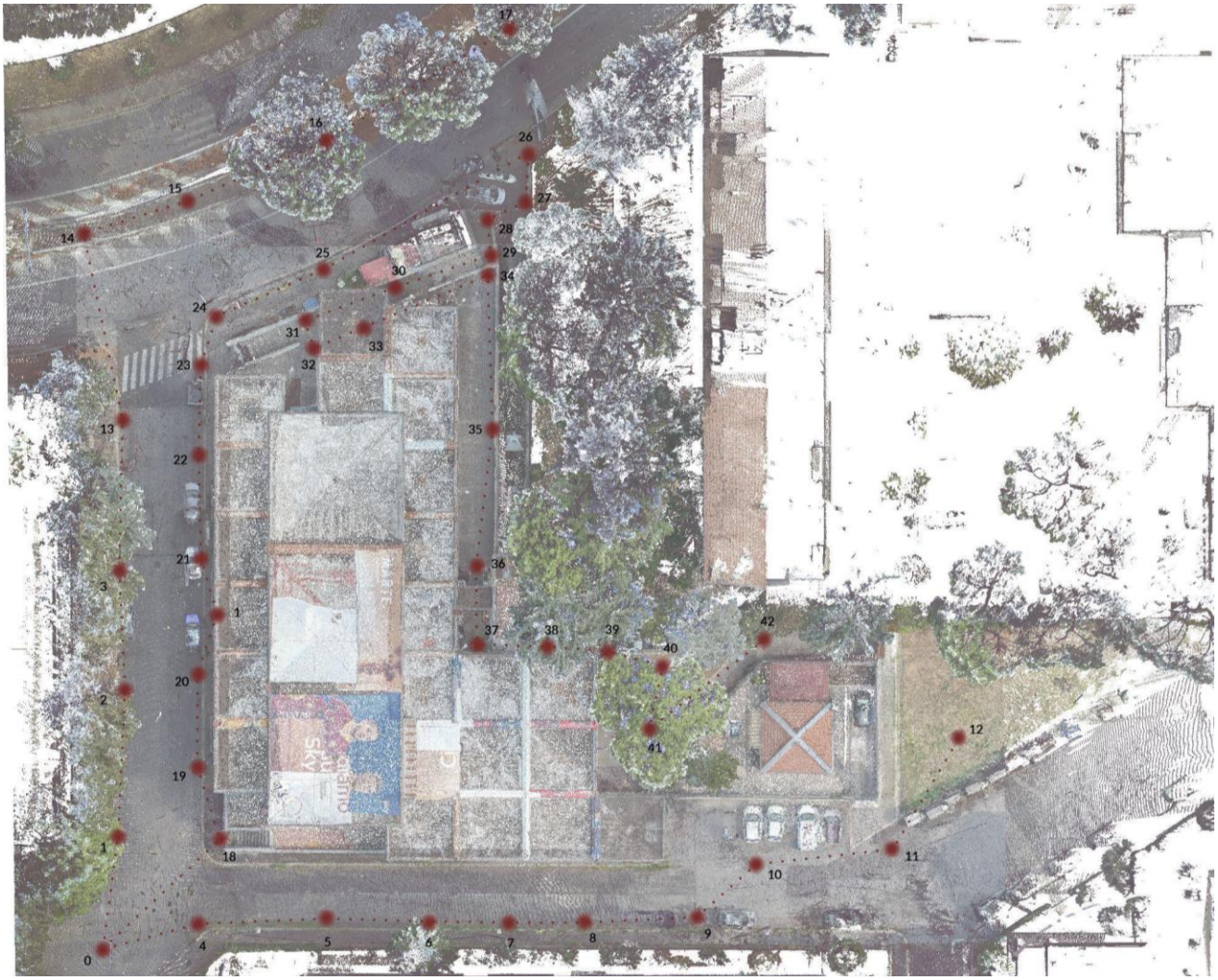

Fig. 4: Complete cloud of points obtained by laser scanners and UAVs in which the station points of the laser scanner are indicated (graphic elaboration by the authors).

larger and hollow and the pyramid is 14 x 14 m. The space, therefore, is defined by three-dimensional and volumetric elements (called "funghi") through the regular repetition of the aforementioned modules, without any internal subdivision. The composition is made slightly articulated by the presence of the larger ones, which are twice the size of the smaller ones, as well as being taller.
Vintage photos of the market show what it looked like immediately after its construction.
The "funghi" were clearly visible from the outside with their concrete roofs and their clean and clear geometry of an inverted pyramid supported by a central pillar. We note the semi-covered character and the mixture of closed spaces and more open spaces. The project drawings, period photos and survey made in the 1980s (made before of the realization of the perimeter closures) allow to compare the original situation with the current situation and, consequently, allow to understand the transformations that have taken place and the loss of the original characters.
These documents were useful in the subsequent phase of interpretation and reconstruction of the architecture.

3.2 Acquisition with laser scanner and UAV and data processing

The acquisition phase with the FARO Focus3D X 330 laser scanner made it possible to acquire the exteriors through 43 scans and, partially, the interiors (fig. 4).

The acquisition phase with DJI Spark Custom 300 g drone made it possible to acquire the coverage formed by the repetition of inverted pyramid modules, through 223 photographic

Fig. 5: Walls of the Ex Mercato di Torre Spaccata with the closures added in the 1980s: metric data and RGB data of the point cloud obtained by laser scanners.

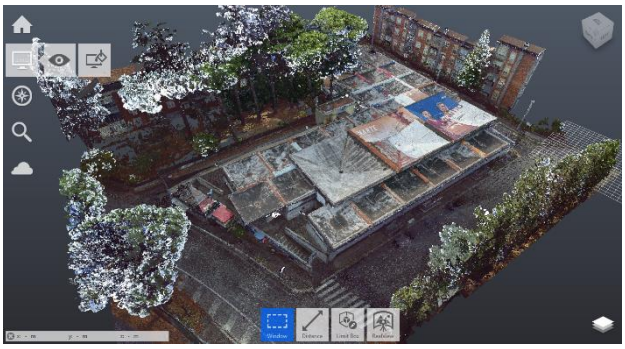

Fig. 6: Roof of the Ex Mercato di Torre Spaccata with the major modules and the minor modules characteristic of the composition: metric data and RGB data of the point cloud obtained by UAV.

images, taken at a lower altitude of 25 meters and markers on the ground[3].

This phase was fundamental because these modules, which constituted the concept of the original project, are currently not perceptible from the outside, if not from above, due to the perimeter closures in iron and glass added in the 1980s. The aerial photogrammetric acquisition made it possible to obtain morpho-metric data that cannot be acquired with a laser scanner. This acquisition was useful in the subsequent phase of integration of heterogeneous data and data from different sources. The union of the point cloud derived from laser scanner acquisition with that derived from UAV acquisition was conducted thanks to the presence of markers on the ground (figs. 5-6); the orthophotoplanes were obtained from the point cloud.

The orthophotoplanes obtained from the point cloud allow us to understand the current situation in the conformation of the state of affairs and in the dimensional relationship with the urban context.
Subsequently, a phase of evaluation of the point cloud followed, since it allows to evaluate metric data and formal data of the architecture. Thanks to this evaluation, it was possible to understand the global external volumetric articulation; the relationship between the major and minor modules; the connection between the perimeter closures added in the 1980s and the original building, the geometry, rhythm and compositional grid of the modules.

4. 2D vector graphic reconstruction and 3D model reconstruction

The elaboration of the points cloud, integrated with the data obtained from the instrumental method and the aerial photogrammetric method, was preparatory for the subsequent phase of graphic restitution 1:50 and construction of the NURBS model. The point cloud was imported into Autodesk Autocad to obtain the plans of the two levels, the roof plan, the sections and the elevations. The metric-dimensional restitution obtained so far was partial, since it lacks the internal areas, due to the impossibility of acquiring the interiors with laser scanners as they are occupied by a neighborhood association.

Therefore, it was necessary to integrate the restitution obtained from the acquisitions with contemporary tools (instrumental and aerial photogrammetry) with the reconstruction of the interior spaces obtained from the original project drawings. In this regard, the positioning of the internal pillars was obtained starting from the geometric center defined by the roofs, which was compared with the measurements indicated in the project drawings. The size of the internal pillars, on the other hand, was exclusively deduced by following the measurements indicated in the project drawings, particularly in the plan of the upper level. In CAD the vector graphic elements have been distinguished according to the architectural typological hierarchy and

[3] Technical data: UAV: DJI Spark Custom 300 g. Image pixels: 3968 x 2976 px. Flight altitude: 25 meters. Number of shots: 223. Frame overlay: approx. 75%. Acquisition time: 1 hour. Area acquired: about 40 x 60 meters. GSD: 2cm / pixel. Consultation with ArcheoDigital S.r.l.s., responsible Simone Gianolio for the flight of the aircraft.

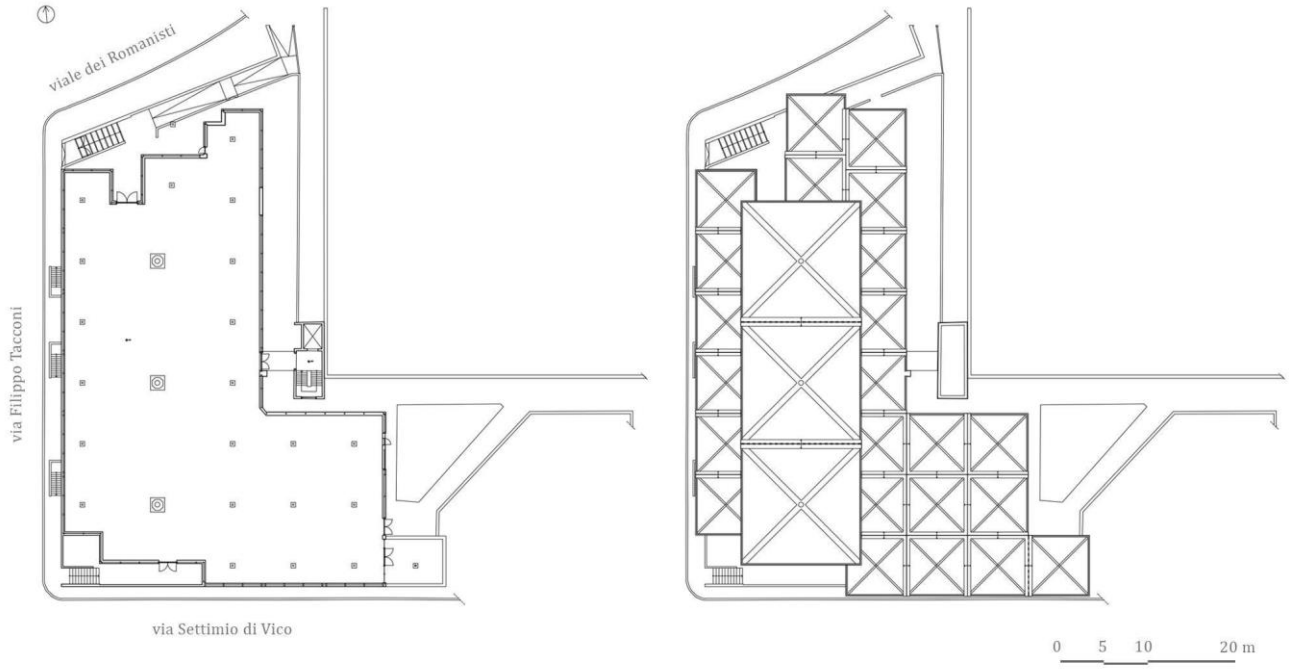

Fig. 7: Reconstruction of the ground floor plan and the roof plan (graphic elaboration by the authors).

according to the source of the restitution (from contemporary survey or from reconstruction from the original project drawings). The integration of the current metric data with the original graphic data made it possible to obtain the two-dimensional vector graphic restitution in 1:50 scale of the entire building (fig. 7).

The comparison between the orthophotoplanes obtained from the point cloud, the current graphic restitution and the survey of the 1980s allows us to understand the current architectural configuration, the transformations that have taken place and the relationship between the actual state of the architecture and its original state. Furthermore, the orthophotoplanes clarify the dimensional relationships between the architectural parts and the urban context.

Specifically, figure 8 shows the comparison between the 1980s survey, the orthophoto and the restitution of the elevation on via Filippo Tacconi. It highlights the entrance, the minor "funghi" (the only module of the original project identifiable from the outside on this street) and the continuous iron wall with windows, which rises on the original wall along the side. The series of the three major "funghi" partially visible above the perimeter closures is well understood. A comparison with the survey made before the renovation shows the drastic change obtained. This transformation was decisive because it made it impossible to recognize and perceive the initial project of the 1960s, definitively closing the market and losing those characteristics of openness and relationship with the neighborhood that it originally had. This condition remains to this day.

Figure 9 shows the comparison between the 1980s survey, the orthophoto and the restitution of the elevation on Via Settimio di Vico. It presents the external walls in iron and glass made during the reconstruction phase and their stepped pattern to follow the profile of the inverted pyramids, the perimeter wall with a broken line, the minor free "fungo" (the only module free from superfetations) and the private house (which occupies the grounds of the flower and newspaper kiosk that was initially present). The walls that prevent the view of the structural elements are evident, the demolition of the covered walkway between the market and the kiosk and the removal of the ramp on via Settimio di Vico. Therefore, it is clear how the two architectural elements, namely the original wall and the subsequent closure, coexist in continuity with one another.

Subsequently, the three-dimensional reconstruction phase of the Ex Mercato di Torre

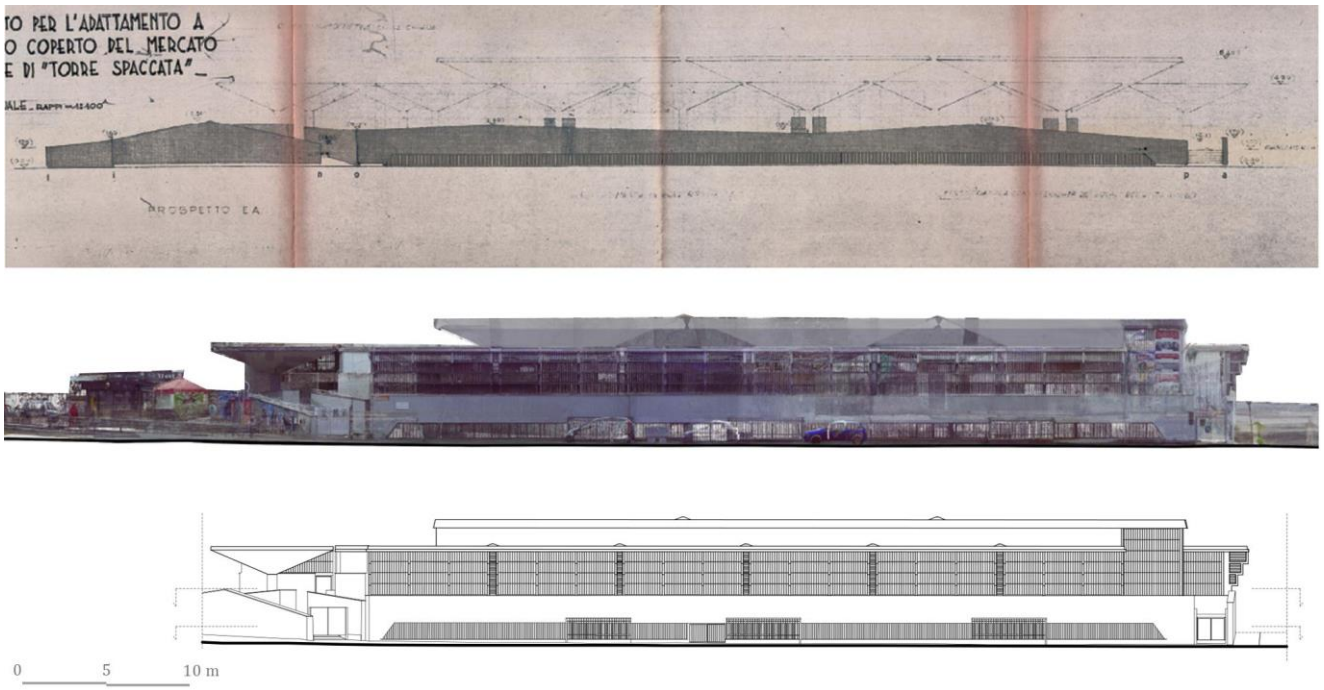

Fig. 8: Facade on via Filippo Tacconi: comparison between the survey of the 1980s, the orthophoto and graphic restitution of 2020 (graphic elaboration by the authors).

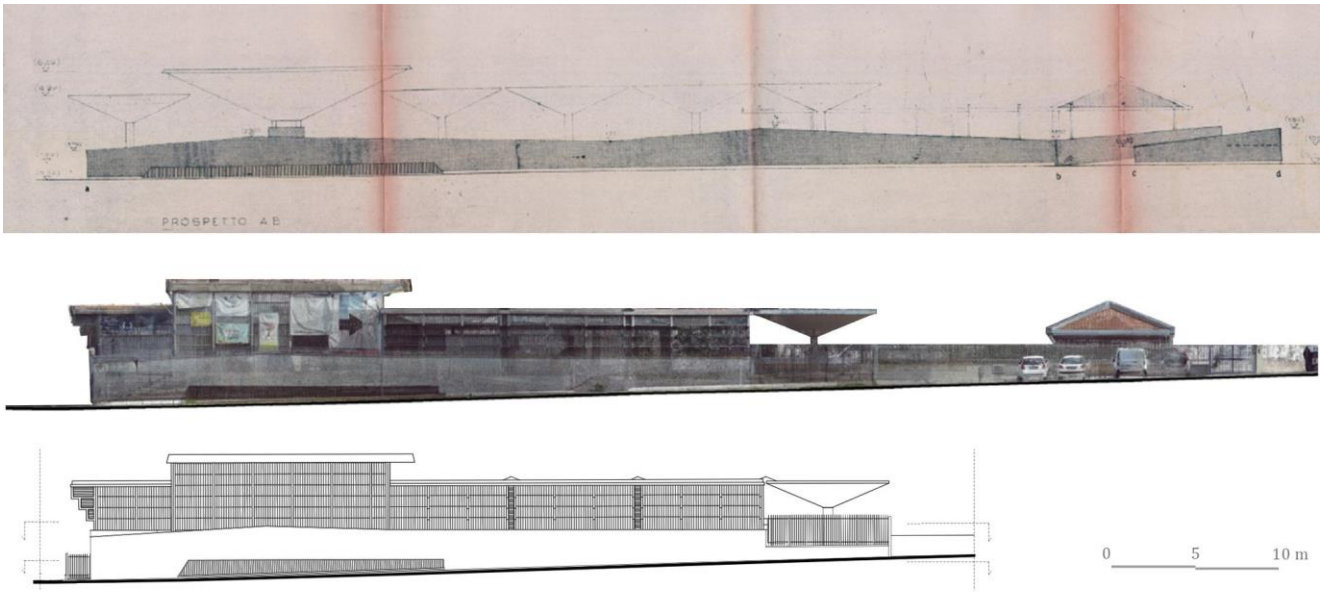

Fig. 9: Facade on via Settimio di Vico: comparison between the survey of the 1980s, the orthophoto and graphic restitution of 2020 (graphic elaboration by the authors).

Spaccata was started, using the mathematical model developed with a 3D modeling software. The 3D model was created starting from the dimensional data of the graphic restitution, modeling the original elements and the perimeter closures. This allows you to navigate and view the current overall situation, but also to view and understand the original volumetric articulation (fig. 10).

Through horizontal section planes at different heights it is possible to understand the quality of the architectural space, the compositional

variation, the modularity and the rhythm of the "funghi" made up of an inverted pyramid on a pillar, the relationship between the major and minor modules (fig. 11). Through vertical planes it is possible to understand the volumetric articulation, the three-dimensional volume, the relationship between the "funghi" and the perimeter closures, the structural functioning of the "funghi" (fig. 12). The 3D model establishes a dialogue with the architecture, thanks to its construction by hierarchical components. During the modeling and navigation phases of the model, it requires a continuous analysis of the architecture, resulting from the process of aggregation of the elements that compose it.
The navigation of the 3D model is aimed at the correct reading of the architectural work, the deciphering of the original concept, the evaluation of the compositional language and the interpretation of the transformations undergone. This is possible because, by its nature, the 3D model implies a comparison with the geometric qualities of the architectural space.

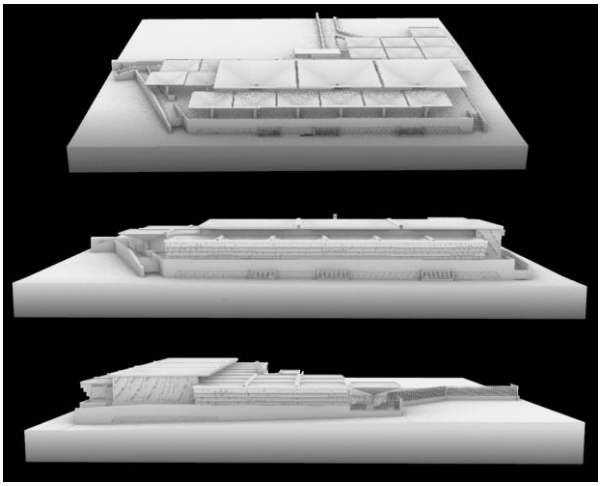

Fig. 10: Virtual reconstruction with 3D model of the Ex Mercato di Torre Spaccata (graphic elaboration by the authors

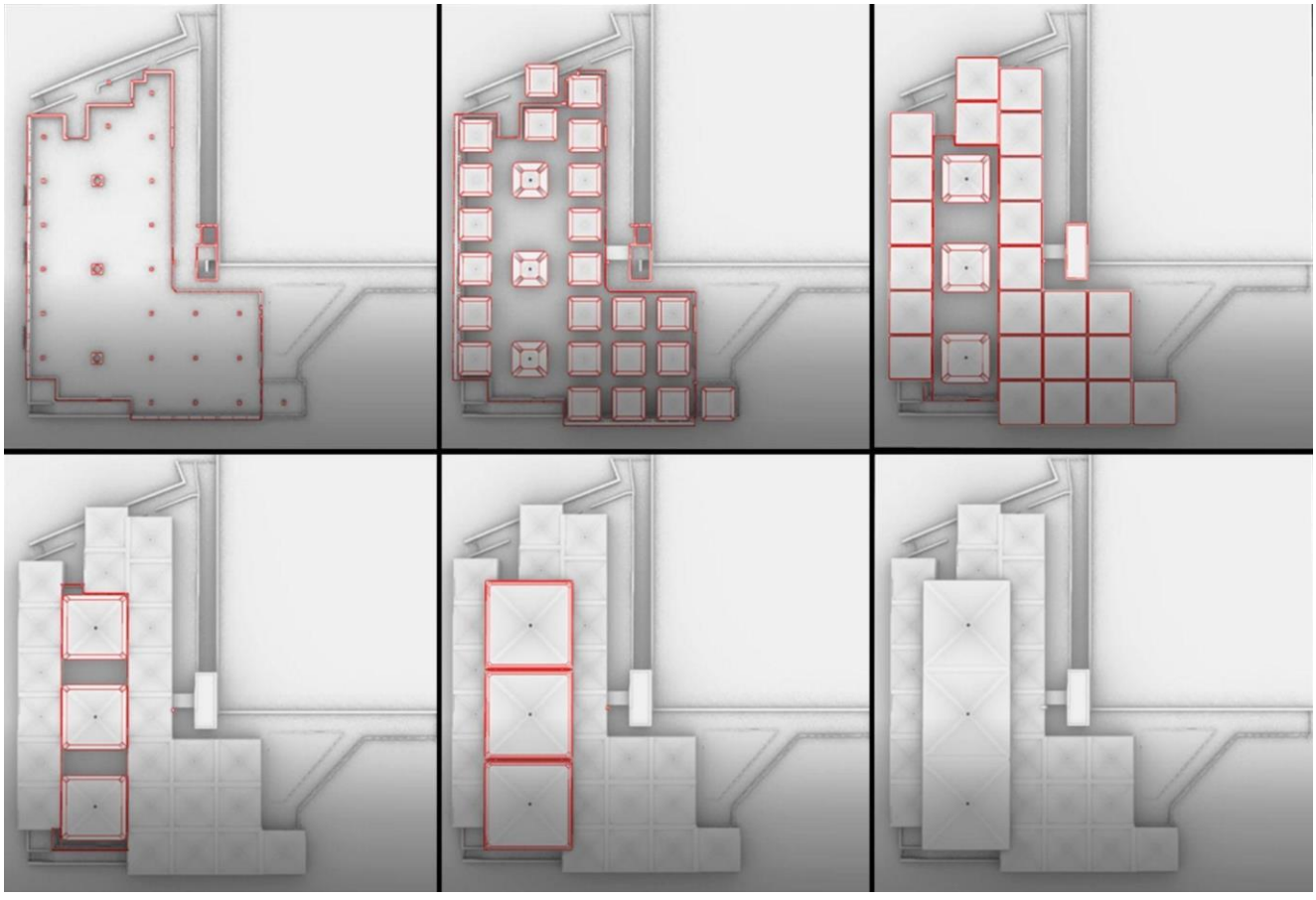

Fig. 11: Horizontal sections extracted from the 3D model (graphic elaboration by the authors).

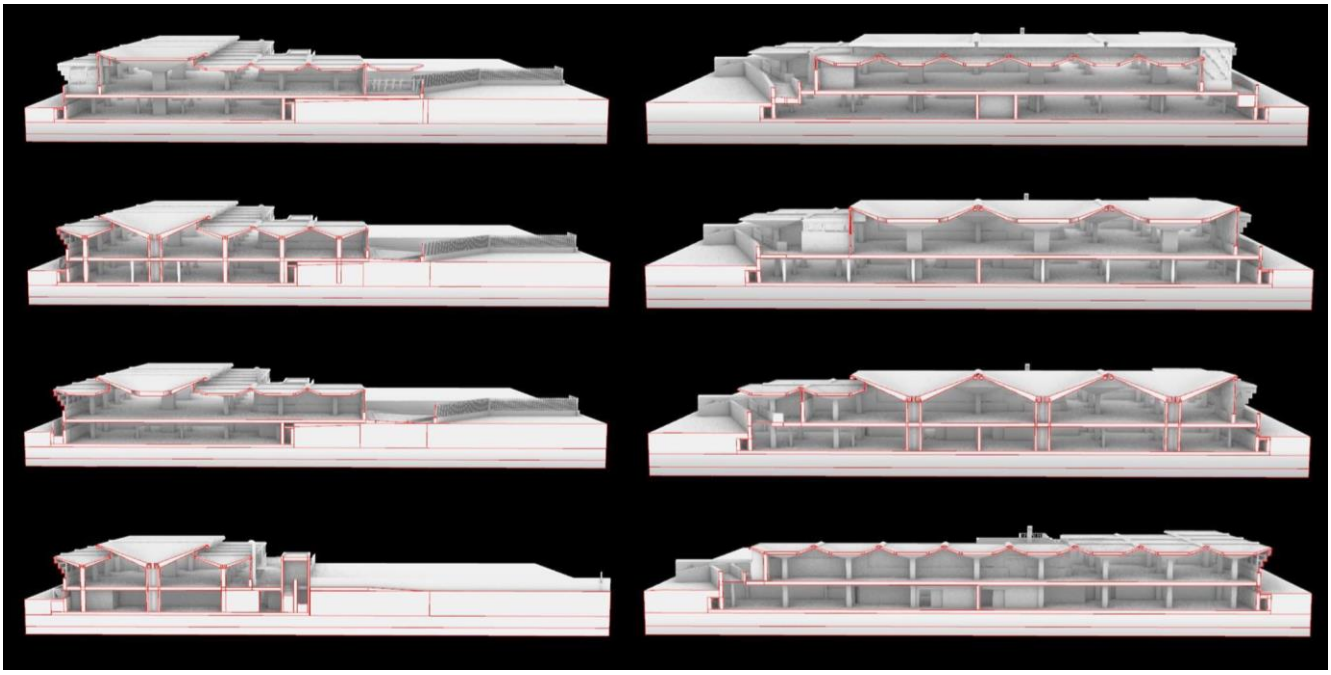

Fig. 12: Vertical sections extracted from the 3D model (graphic elaboration by the authors).

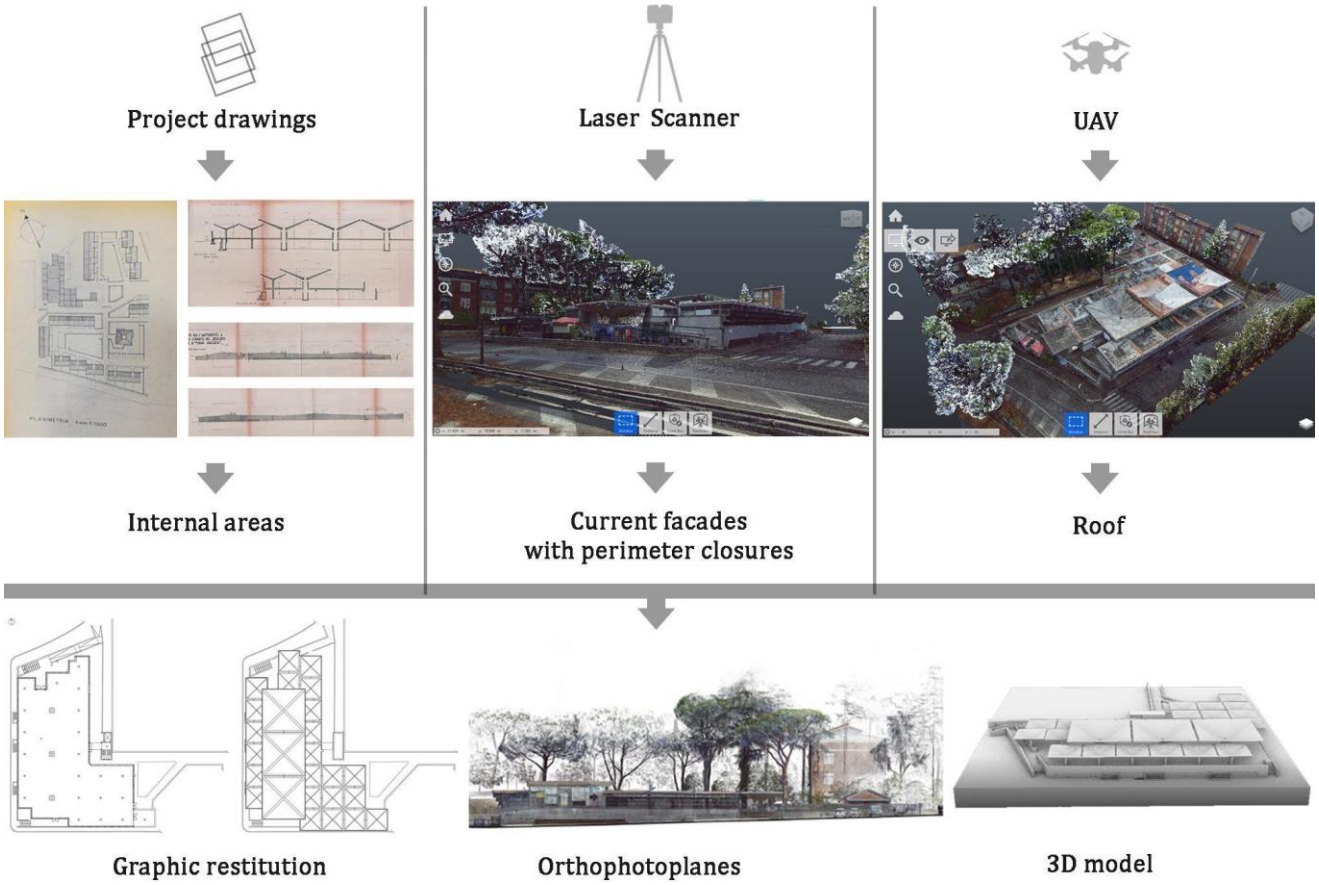

Fig. 13: Scheme of the methodology used (graphic elaboration by the authors

5. Conclusions

The research is placed purely in the architectural field of the CH, based on the integrated survey aimed at the documentation, knowledge and rediscovery of the original project of the Ex Mercato di Torre Spaccata carried out by the Passarelli studio in 1960. The research is preparatory to an international call aimed at the recovery and restoration of a historical asset that has lost its original identity.
The research results are articulated on three different levels.

The first highlights the survey methodology integrated with laser scanners and UAVs for the acquisition and processing of metric data aimed at the graphic restitution of 1:50 and the processing of orthophotoplanes of the Cultural Property. These elaborations provide not only the dimensional datum, but also the formal datum of the architecture, on which to start the interpretative phase.

The second highlights the need to have 3D models of the CH, through which it is possible to face a more comprehensive and correct reading of the architectural work. This aspect indicates how much the metric data needs to be integrated by the architectural interpretation process.

The third highlights the process of integrating and systematizing heterogeneous data from different sources in order to arrive at an in-depth and exhaustive knowledge. In this research, the data from historical and documentary sources, from laser scanners and UAVs are to be read within a global process of rediscovery and re-identification of the original project. For example, the use of the drone has not simply provided metric data not otherwise obtainable, but has made it possible to arrive at a "rediscovery" of specific and distinctive design components of the Property. The use of the drone is an indispensable tool for the acquisition of data that is otherwise unreachable and as part of a broader process based on the connection of different data and aimed at an overall and in-depth knowledge of the Property.

The graphic documents, on the other hand, are valuable for understanding the original building and the subsequent transformations that currently make it difficult to read and recognize the building.

In the methodological process, some difficulties were encountered in integrating and interpreting the data. These concerned not so much the union of point clouds from different instruments, but rather the integration of data from different sources: instrumental and cartographic, contemporary and historical.

In particular, the obligation to use the metric data of the internal pillars and of the internal distribution belonging to historical sources to complete the acquired data. In the graphic restitution process it was decided to distinguish the architectural elements according to the type of source data (elements from contemporary instrumental acquisition or elements deduced by comparison with project data).

The distinction is appropriate to validate all interpretation processes. Integrating data means, initially, reading historical drawings to understand the space and, subsequently, managing contemporary data.

These two interdependent moments must be addressed to a correct representation and a valid interpretation of architecture.

In this sense, the importance of connecting documentary and graphic, historical and contemporary, two-dimensional and three-dimensional information derived from different tools, processes and methodologies is evident, aimed at a scientific reconstruction of the Cultural Heritage (fig. 13).

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