Reconstructive hypothesis of a historical phase of Caltanissetta Centrale Station.

Integration of 3D modelling with photogrammetry applied on historical images for cultural heritage

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Abstract: The recovery of past architecture through 3D modelling is an important challenge today to the preservation of heritage. Decisive support for the interpretation of architecture can certainly come from historical images and old photographs that fix a portion of space at a specific time, keeping it unchanged over the years. This acquisition is decisive for studying architectures of the past that can be reinterpreted and analysed. Photos, in fact, capture the advance of time and the life of a building at a precise historical moment, becoming essential documents for the study and knowledge of heritage. An additional advantage is when these old images can be processed through Structure for Motion procedures and, the results obtained, used as support for a 3D model of buildings that no longer exist. The work shows an interesting pipeline applied to the Caltanissetta Centrale Station and the possibility of "recovering", even if virtually, a phase of its architectural evolution through the integration of photogrammetry from historical images and 3D modelling. The case study is an opportunity to analyse the procedure still under development, as well as to identify the main difficulties encountered in this process and possible future developments.

Keywords: rediscovery; 3D Model; old photos; Structure for Motion; railway station; Sicily.

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1. Introduction

Throughout history, cities have undergone changes dictated by needs or catastrophes that inevitably make alterations to the existing buildings, losing the evolution of structures and traces of city memory.

Early evidence of the past comes to us from the images captured by artists, especially during the *Grand Tour*, who have immortalised city views and monuments over the centuries. These painters framed a portion of space, landscape, architecture, or details, important elements in recognising the memory of the city and how it had been perceived, passing this information down through time. Analysis of iconographic sources has often been useful in interpreting buildings (Sutera, 2009; Garofalo, 2020), especially in finding information before the advent of photography. The latter, in fact, stands as one of the most valuable tools for knowing the past. Whether souvenir or documentary photos, they capture scenarios by locking them in time, often showing fundamentals for the analysis and examination of monuments.

Several studies have focused on perspective restitution from pictures, either analogically or automatically through image rectification (Rapp, 2008; Morena and Talenti, 2021; Agnello, 2022). Further investigations have been conducted with the support of digital representation tools that today can also be used as a basis for the reconstruction, through processes of perspective restitution of one or more images, not only of the facades but also of the entire buildings directly in 3D space (Borin *et al.*, 2018; Barrale *et al.*, 2022).

Hence, historical images represent great potential because they contain essential information for deciphering the buildings. Nowadays, in addition, thanks to continuous technological evolution, they can also be elaborated with a photogrammetry process able to extract metric information that can be used for the restoration and virtual reconstruction of destroyed or altered objects. The alignment of historic imagery can also provide a previously unknown view of buildings and details that were not available only with two-dimensional images and that could be explored in a 3D space (Maiwald *et al.*, 2018). Indeed, the photogrammetric technique offers the possibility to not only accurately reconstruct the geometry of the object but also to collect important data such as texture, material, colour, damage, and knowledge about its structure. All this information is necessary for the study of the object. Under certain special conditions, without appropriate documentation, historical images are the only way to research and reconstruct the past (Bitelli *et al.*, 2017).

The restitution of dense or sparse point clouds from historical images, thus, represents an important support for the interpretation of architecture. The metric information that can be extracted from the photogrammetric model, in fact, are fundamental to the process of modelling and virtual reconstruction of the building. The modelling represents a critical moment to understand the structure, its characteristics and composition. An additional advantage of this process of representation, especially of non-existing heritage, is the possibility of restoring, albeit virtually, a historical phase. This aspect is crucial not only for the historical knowledge of architecture but also for facilitating the enjoyment of the asset (Avella, 2015; Girgenti, and Antonino, 2021). Furthermore, digital reproduction adds value to the representation by ensuring the construction of convincing visuals capable to involve a growing number of users, experts and non-experts, and delivering instantaneous information.

This paper aims to integrate the 3D modelling with the photogrammetry from historical images of the Caltanissetta Centrale Station in Sicily, particularly of an intermediary phase of the station that does not exist today, to rediscover a part of the evolution that the architecture has undergone over time. The building "surveyed" through this procedure, in fact, today is part of an enlarged station and, therefore, difficult to identify. The use of photogrammetry based on historical images allowed the possibility of extrapolating useful information to scale the model and hypothesise its shape and volume.

2. Case study: Caltanissetta Centrale Station

The introduction of railways in Italy was an important nineteenth-century event of a technological nature and represented a novelty with significant economic and social impact on the local reality. This occurred at different times and in different ways in each city, leading to equally diverse and not always favourable consequences. Of particular interest to this research work is the case of railroad networks in the region of Sicily, especially concerning the stylistic aspects of the architecture. Attention is focused on the Caltanissetta Centrale Station and its evolution, concentrating mainly on an intermediate phase of its history. The need during the years to enlarge the building and makes it take on different stylistic connotations inevitably led to an expansion of the station, causing its traces to be lost. This work represents one part of a more extensive study of historical knowledge of the building and focuses on this intermediate phase of the structure evolution due to the presence of an adequate photographic set that thus gives the opportunity to experiment with innovative methods of investigation. The realisation of the first project of the station, drawn up around

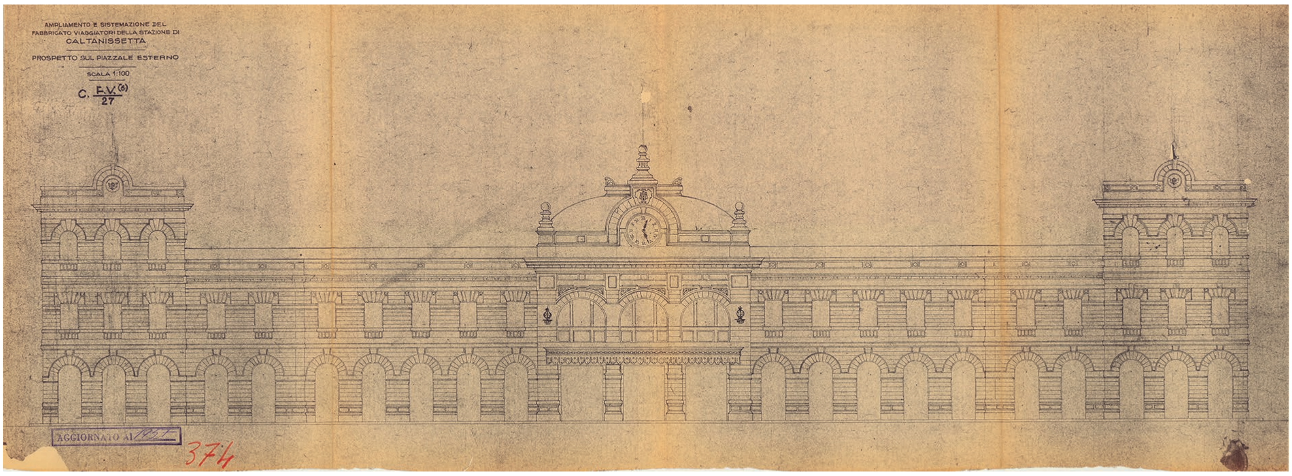

Figure 1 | Caltanissetta Centrale Station in Archivio Fondazione FS Italiane, collection Disegni di stazioni, “Stazione di Caltanissetta Centrale”, f. 376.

1869, was assumed to be in Calcare street; however, the distance from the centre inevitably entailed a variant, which was located near the built-up area, providing greater accessibility through a straight avenue (Sessa, 2004). Over the years, given its central location, the station has been subject to continuous evolution, adapting to the needs and urban transformations of the city. Archival documents, in fact, show how several studies were conducted to make changes to the structure, including in 1921 (Lima, 2004), a very articulate and complex project of which, however, to date, no photographic evidence ascertaining its realisation has been received. Differently, there is a historical phase of the station, of uncertain date but certainly before the transformations undergone as a result of the realisation of the project in the actual state (Fig. 1), of which there are various old photos.

According to historical pictures of this period, the Caltanissetta Centrale Station had a modest and very simple structure. The station in the photos had a central volume slightly overhanging, with a characteristic iron canopy and the usual clock. The side volumes are symmetrical and somewhat set back, gradually progressing from two to one level. The ornaments on the facade are relatively modest: a broad stringcourse divides the first level, and small, plain cornices ornament the windows and entrances. More plasticity can be seen in the centre body, whose surface is articulated by two pilasters and framed by cantonal that are repeated, along the side, this makes it appear that there are more volumes.

Currently, the building has undergone an expansion by incorporating the previous structure into itself. The Caltanissetta Centrale Station is presently a single building that appears modulated in many volumes symmetrical to the central core. The ornamentation is simple, and the overall impression is that of late modernism: the side bodies are marked by calibrated eurhythmics highlighted by slightly projecting stringcourses and variously moulded profiles at each level. The centre volume, which overhangs from the building’s sides, has wide apertures compared to the overall architectural scheme and is surmounted by a pavilion-vaulted roof. The three entrances partition the main elevation and seem from a distance as three huge archways separated by a central canopy. The latter are defined by mouldings that repeat the ashlar of the side volumes, assuring the building’s correct harmony and interconnection.

3. Processing historical images with photogrammetry: problems and open issues

Classical analytical photogrammetry has been dealing with the problem of processing historical images since their creation. More recently, the progress of new technologies has enabled the steps of calibration and orientation in the photogrammetric pipeline by performing them automatically. However, although the use of Structure from Motion (SfM), the position and orientation of the camera not always can be automatically estimated with these algorithms implemented on historical photographs. Calibrating these images is the key step and some critical factors could lead to processing failure.

The first problem is the difficulty of finding suitable material for photogrammetric processing with a good state of preservation (Condorelli and Rinaudo, 2018). Low archival quality due to inadequate procedures during transport or storage of the film (humidity, temperature, etc.), as well as inaccurate processing of the original films or paper copies in the field laboratories, can lead to problems during digitisation. In most cases, there is no information about the scanning process. The result is poor image quality in terms of resolution and radiometry (haze, image darkness, uneven brightness); the absence of image information (acquisition period, method, and location); the difficulty of finding accurate data such as constraints or control points (Bitelli *et al.*, 2017; Zawieska *et al.*, 2017; Maiwald *et al.*, 2018). Another challenge is that the historical images stored in the archives were not recorded to be used for metric documentation purposes and 3D reconstruction. In most cases, they consist of press and personal memories. For this reason, the images may be incomplete or have occlusions caused by objects located in front of the building to be reconstructed.

The major problem is that often the camera settings and the film information are missing. Inaccuracies or the complete absence of metadata about the internal orientation (focal length, coordinates of the principal point, etc.) and the additional parameters (i.e., distortion) are the most important issues. The problems increase when images of the same object are taken with different types of cameras that differ in exposure and image capture and are used in the same reconstruction.

4. Methodology

Commercial software cannot process historical images that present the problems outlined above. This is because it does not allow the algorithms underlying the processing to be customised, generating problems that lead to the failure of image alignment. For this reason, open-source software was used for data processing in this research, in particular COLMAP (Schönberger and Frahm, 2016) open-source Structure from Motion (SfM) and Multi-View Stereo (MVS) algorithm implementation, developed by ETH of Zurich (https://github.com/colmap/colmap, 2022).

Generally, from the photogrammetric processing of historical images, a sparse or low-density point cloud is obtained. In some cases, the number and quality of photos were not sufficient to orient enough points to obtain a point cloud. This case is common considering the problems in finding historical images and their low resolution, as previously pointed out, that dramatically affects the photogrammetric reconstruction and the obtaining of the final point cloud. For this reason, the proposed workflow aims to extract the coordinates of specific feature points to use them as a metric basis for the 3D modelling phase.

The proposed workflow is reported in Fig. 2 and is divided into two main phases. The first one concerns the extraction of specific feature points during the SfM pipeline introducing a manual step in the automatic implementation. The second is the 3D modelling phase starting from specific coordinates extracted from the historical images.

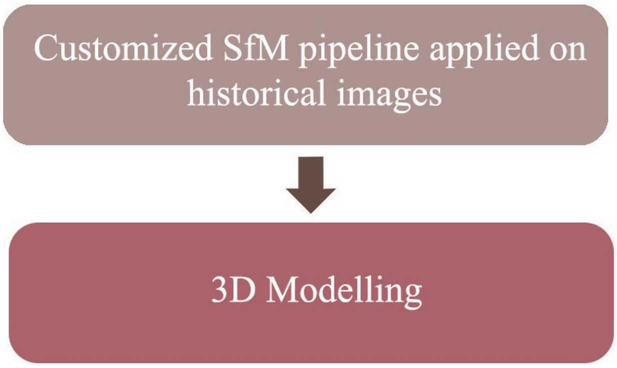

Figure 2 | The proposed workflow in which the first phase concerns the photogrammetric reconstruction of the object using a customised SfM pipeline applied to historical images, and the second phase concerns the 3D modelling of the object using feature points extracted during the previous step.

4.1 Proposed photogrammetric workflow using historical images

The standard SfM sequential processing pipeline for the iterative reconstruction in COLMAP is:

1. *Feature Detection and Extraction* that finds sparse feature points in the image;
2. *Feature Matching and Geometric Verification* that finds correspondences between the feature points in different images;
3. *Structure and Motion Reconstruction,* performed to obtain the final point cloud.

This standard pipeline was customised to extract the coordinates of specific points from historical images.

The presence of some specific known points, selected by the human operator, will allow the correct modelling of the object of study.

An additional step of *Manual selection of Feature Points* (highlighted in red in Fig. 3) was added, after the *Feature Detection and Extraction* phase in order to manually select the tie points to use during the subsequent *Feature Matching and Geometric Verification* step.

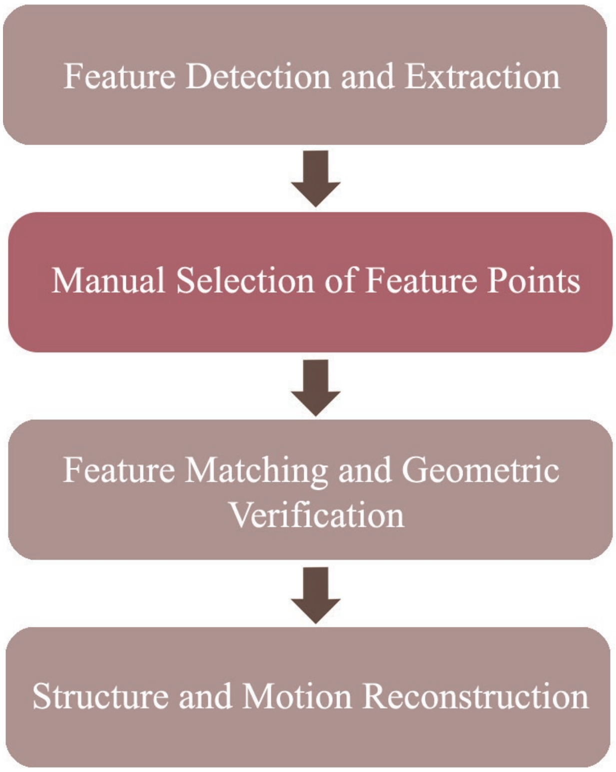

Figure 3 | Flowchart of the customised SfM pipeline applied on historical images in which a step (in red) of Manual selection of Feature Points was added to the standard SfM pipeline in COLMAP.

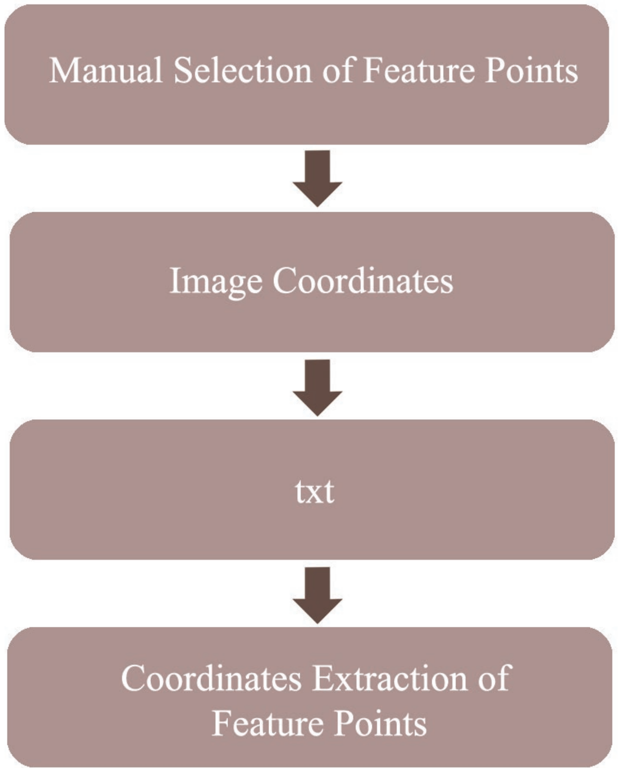

Figure 4 | Workflow of the Manual Selection of Feature Points.

The algorithm to detect and extract new features from images in COLMAP is deeply explained in Condorelli *et al.*, 2019. Here a summary is reported and sketched in Fig. 3. With the standard *Feature Detection and Extraction step*, COLMAP automatically detects key points in the images, but it could occur that some important radiometric corner in the picture, that also appears in other images, are missing. Introducing this step, it is possible to detect the feature point of interest manually and to extract their 3D coordinates.

The image coordinates of the searched point were measured with the WebPlotDigitizer tool (https://automeris.io/WebPlotDigitizer, 2022), as shown in Fig. 4, and inserted in the software. Data processed in COLMAP are stored in a customised database that can be easily managed.

It is possible to insert new coordinates of feature points not already detected by the automatic algorithm and that, for this reason, are not present in the database. Creating a text file in which the image coordinates (x, y) are expressed in pixels, and the scale and orientation information are indicated, writing one line per feature, it is possible to import known features (e.g. single points) in the database and use them in the matching stage.

This assisted processing allows the choice and the filter of highlight points such as corners and outline features. The matching algorithm searches for the selected feature point in each image to estimate the equipolar line in the other pictures.

4.2 Reconstructive hypothesis

Digital reconstruction makes it possible to create three-dimensional models of architectures that no longer exist to document and disseminate knowledge of the works so that it can increase their enjoyment and facilitate the understanding of their history and that of the city. The modelling phase, however, must consider several issues, especially when working with architectures that have now disappeared and where the sources available are varied and often even contradictory. Paintings and archival documents are just some data necessary to be able to proceed with reconstructive hypotheses of an artefact, as well as textual descriptions from which to extract information on materials and technologies used in construction.

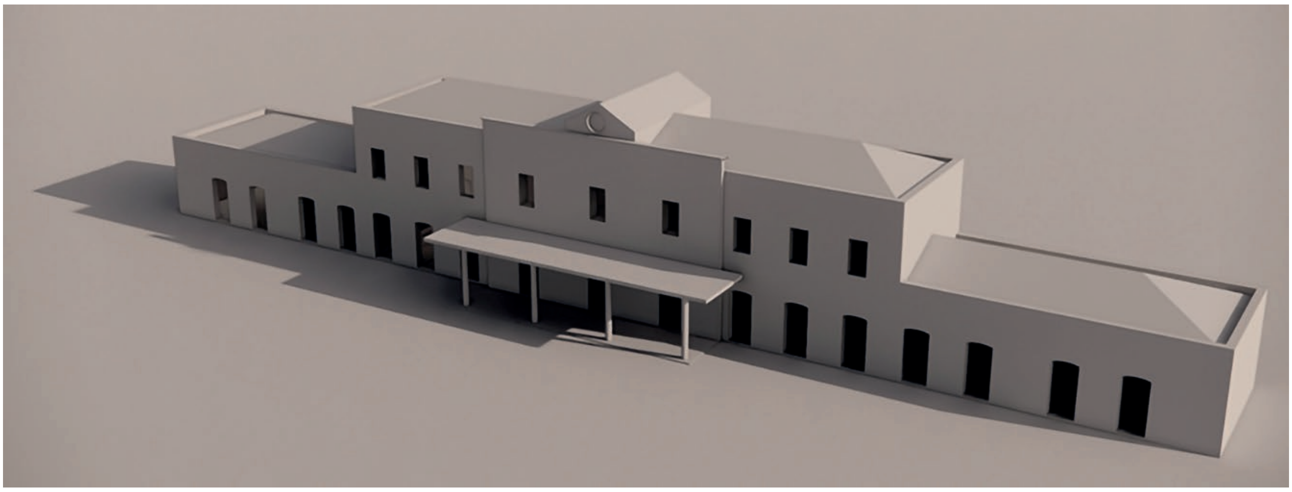

Figure 5 | Main volumes of Caltanissetta Centrale Station in its historical phase.

However, the sources found only sometimes correspond to what was accomplished over time, often making the representations unreliable. Unlike previous sources mentioned, photographic documentation is crucial for the historical analysis of an artefact as it helps to compare the sources with the reality of the time and, in this case study, to recover part of a heritage incorporated by the existing and no longer recognisable. Although the "revealed" buildings do not always present architectural features of great artistic prestige, they are valuable for the knowledge of architectural history and could also be important as a support for analysing urban changes in the city.

Three-dimensional modelling, in fact, has the advantage of making visual data of immediate impact and easy understanding as well as ensuring greater usability and accessibility; using 3D model, it is feasible to transmit information about a cultural heritage object, raise awareness of it, and develop new knowledge. Various software and methods exist for modelling cultural heritage that varies depending on the operator and object being worked on, as well as the levels of detail one wishes to pursue (Acosta, 2022; Cipriani, 2019).

In this case, the use of Non-Uniform Rational Basis Splines (NURBS) is considered advantageous for modelling the railway station. This type of modelling, in fact, has high flexibility and can adapt to a variety of profiles, both conventional geometric items and more complicated ones or those characterised by freeform typical of architectural decoration.

In the case study, the final model is generated with Rhinoceros software (version 6) by having as a basis the result obtained from the photogrammetric workflow using historical images. Generally, once the sparse cloud is scaled on metric information, it is used as support for three-dimensional modelling. In the present case, however, it is only possible to identify characteristic points essential for identifying main metric measures and, therefore, extract the main volumes that make up the station building (Fig. 5). The next phase of modelling, such as adding decorations and details, is conducted using historical two-dimensional images (Fig. 6). In addition, the photos found have black and white colours, reasoning that it is difficult to trace the original appearance and information on texture and material of the station.

For this reason, the final restitution to have a digital image derived from the three-dimensional model and performed with the real-time render Enscape plug-in is developed by deliberately trying to set a colouring, which, at least in part, would resume the historical and vintage effect of the photos used in the photogrammetric process. Thus, the model ensures immediate communication of the building that is no longer visible and could be used as a basis for innovative visualisation methods of heritage.

5. Results and discussion

The proposed workflow is implemented on the chosen case study for the extraction of characteristic point coordinates needed to extrapolate key metric information useful for modelling purposes. A set of only seven historical black and white images was collected from web crawling and online sharing platforms, reasoning that the generation of a dense cloud did not. Following the results of each step of the workflow are reported. With *Feature Detection and Extraction,* sparse feature points

Figure 6 | Caltanissetta Centrale Station 3D model with main decorations and details.

Figure 7 | Results of *Feature Detection and Extraction.*

Figure 8 | Results of the *Manual Selection of Feature Points.*

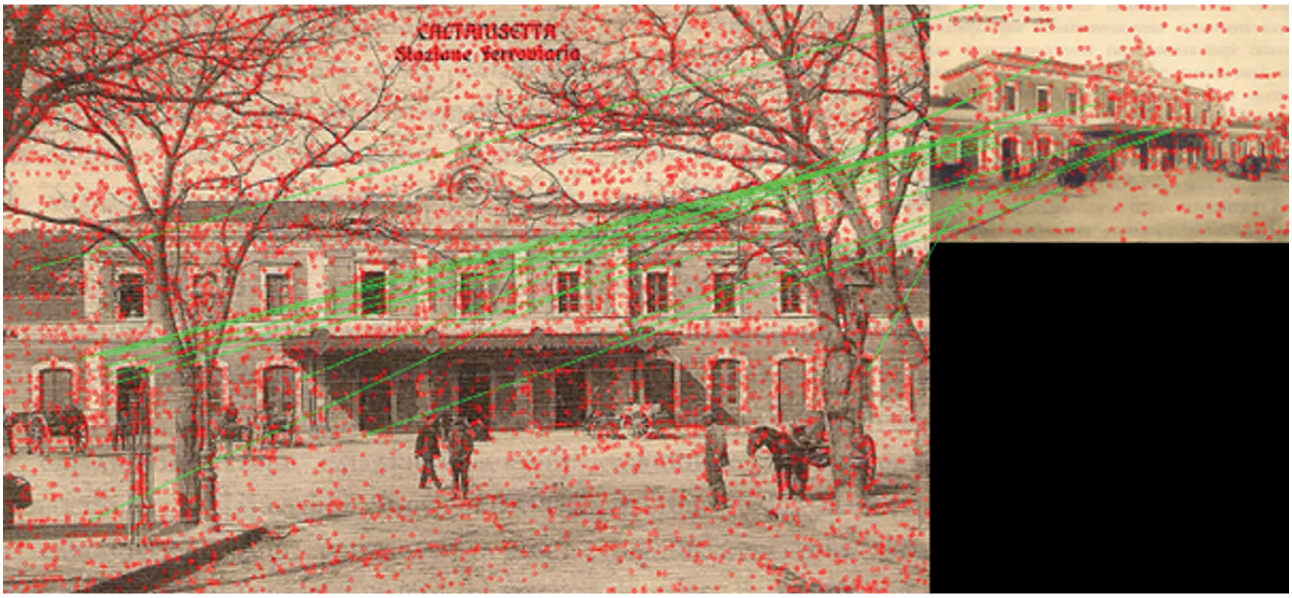

Figure 9 | Results of *Feature Matching and Geometric Verification.*

are automatically selected by the software in the image (Fig. 7). With the *Manual Selection of Feature Points* step four known points on the facade of the buildings are manually selected by the operator to ensure their presence in the final reconstruction. In Fig. 8, the results of this step are shown. The *Feature Matching and Geometric Verification* finds correspondences between the feature points in different images both those manually and automatically selected (Fig. 9).

After the *Structure and Motion Reconstruction,* the coordinates of these points are extracted and used for the 3D modelling of the building. Selected feature points are in common between the old and the current state of the

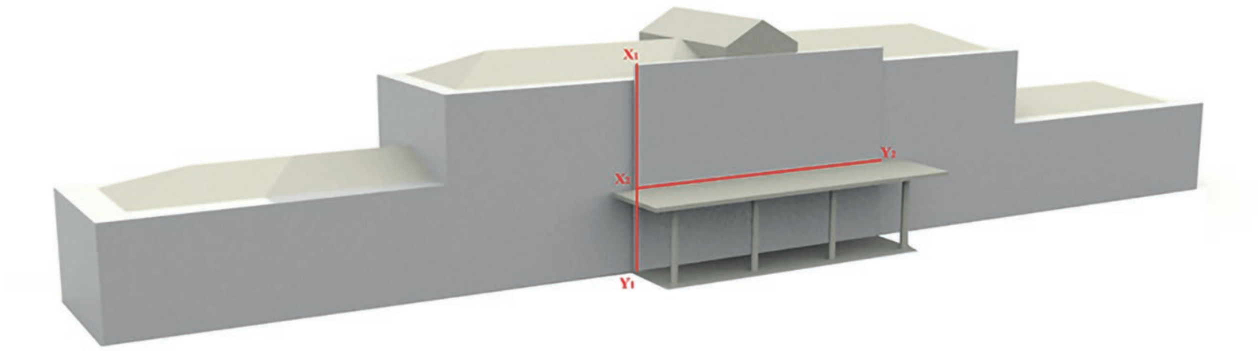

Figure 10 | Proportionate model based on the points extracted from the SfM.

Figure 11 | Rendered 3D model of the Caltanissetta Centrale Station.

station. For this reason, the coordinates of these points were measured both in the photogrammetric reconstruction and on the point cloud of the recent laser scanning survey, and these were used to scale the 3D model of the station before the transformation. The point coordinates extracted from the cloud were of particular importance for the modelling phase of the essential geometry that characterises the structure (Fig. 10). Since we did not have a dense point cloud but only discrete information, the modelling process was also based on decipherable assumptions from the collected images and comparison of the current state of the building (Fig. 11). The modelling performed by this method is, of course, a first step in the entire process in which following an initial extraction of the volumetric composition of the building one can, in subsequent studies, proceed to the generation of a complete and detailed 3D model of the entire building to be implemented in innovative applications.

6. Conclusions and future works

The research showed the potential of integrating photogrammetry from historical images with 3D modelling and the possibility of "survey" buildings that, due to various vicissitudes, have been modified over time. Specifically, based on metric references detected on the current state of the building and correspondences between old and new buildings, it was possible to scale the sparse cloud generated by the SfM process and subsequently employ it as the basis for modelling. However, since we could not operate directly on a dense cloud, for modelling we proceeded with the discretisation of information and on the export of point coordinates, from which distances could be derived. Although metric accuracy is difficult to ascertain, this method allows sufficiently proportionate modelling of the building. The results of this study, although still in the development stage, are very encouraging. In fact, working with historical images brings inherent difficulties, such as the lack of important information about the camera, the quality of the film used to photograph it, and the absence of an accurate metric reference when the monument is lost. The results presented in this paper show that the proposed automatic workflow can be effective even under these critical conditions. This evaluation is interesting because it shows how available historical material can be used in the event of heritage destruction by guaranteeing some reliability of 3D reconstruction from historical images, considering limitations inherent in primary data. The proposed workflow also has the great advantage of being replicable in other case studies, for example, to reconstruct heritage destroyed by war or which has undergone major alterations. Future research will explore new ways to integrate recent data such as contemporary images with historical ones to improve the 3D reconstruction process.

Author Contributions

All authors F.C. and S.M. conceived the presented research, verified the analytical methods, and discussed the results. Both F.C. and S.M. wrote “Introduction”, and “Conclusions and future works”. F.C. developed the photogrammetric workflow and the relative images and wrote: “Methodology”, “Processing historical images with photogrammetry: problems and open issues” and “Proposed photogrammetric workflow using historical images”. S.M. analysed the case study, developed the 3D model and the associated images and wrote: “Case study: Caltanissetta Centrale Station”, “Reconstructive hypothesis” and “Results and discussion”.

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