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Digital survey and representation for built historical heritage protection. The case of Gerace (Reggio Calabria)

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Abstract

Historic centers contain a large amount of unquantified cultural heritage that today is often considered at risk. Due to their nature and intrinsic characteristics, they require protection and safeguard interventions. This article describes how representation, considered as a knowledge process based on architectural survey and 3D modeling, constitutes a fundamental instrument of investigation. Digital survey allowed to collect and systematize a large amount of information related to the oldest part of the historic center of Gerace, a medieval historic centre located in the province of Reggio Calabria (Italy). The work is part of a larger research project, called GENESIS (acronym for Seismic risk management for the tourist enhancement of the historic centers of Southern Italy), promoted by several research groups from numerous Italian universities.

The main goal of the project is to promote safe and informed use of cultural heritage, starting from a deep understanding of their history and characteristics, and to encourage accessibility to places and monuments by visitors, scholars, and tourists through innovative forms of management and dissemination. The work conducted in Gerace concerns urban, architectural, and detailed scales. In this context, we present the work carried out using aerial photogrammetry by UAVs, and its possible developments.

The instrumental survey, carried out at different levels of detail (entire historic center, urban area, single building, morphostructural and decorative elements), was a fundamental tool for starting subsequent investigations, in particular:

- analyses related to the seismic risk of the settlement;
- structural assessment of single buildings;
- study of the characteristics of the materials used for construction, and study of degradation.

The graphic representations of the surveys were essential for the implementation of the platform that collects all the project data (https://genesis.tabsrl.com/) and for the creation of virtual tours of the historic center and the main monuments within it.

Keywords

Digital survey; Photogrammetry; Cultural heritage dissemination; Three-dimensional urban model, Architectural database.

1. Introduction

This essay describes a multi-scalar investigation process applied to the historical center of Gerace (Reggio Calabria). The work is part of a larger research project (GENESIS - seismic risk management for the touristic enhancement of the historical centers of Southern Italy). The main objective of the project is to support the safe and conscious visits of cultural heritage in seismic areas, starting from the knowledge of their history, morphological and construction characteristics of the architectural and artistic heritage, of the potential on which to leverage - also through innovative forms of management, based on the use of new media - to insert them into wider tourist circuits. The studies carried out in different fields (both in terms of representation scales and thematic insights) have been merged into an IT platform capable of systematizing the collected data, simulating damage scenarios useful for managing emergencies, and promoting new ways of enjoying them based on the renewal of the offer and the valorization of new historical-artistic destinations.

The workflow can be schematically divided into three phases:

1. acquisition of morphological and metric data;

2. processing of surveys and graphic restitution for seismic studies and the purposes of valorization of the architectural and urban heritage;

3. Configuration of the communication system.

These are three closely interconnected phases; however, in this paper, only the first is described. The safety and valorization of the architectural heritage are strategic choices for the economic revitalization of a territory; therefore, they must refer to documentation based on solid scientific and methodological bases, which, in this case, have the instrumental survey as a cornerstone. The scientific documentation of the actual state is essential to prepare correct protection interventions and to make certain and structured data available to the scientific community in an open, replicable, implementable, and integrable system with different knowledge.

As previously stated, in the following, we will focus on the urban scale survey of the historic centre of Gerace. The aerial photogrammetric survey of the centre was carried out using a Remotely Piloted Aircraft aimed at drafting documentation and analysis documents of the building fabric.

An initial survey of the historic centre was carried out, aimed at understanding the internal urban distribution, the relationship between architecture and reference context, and creating an initial contact with the object to be surveyed. In this preliminary phase, the take-off and landing points of the aircraft were identified, and a flight mission was planned.

A flight test was then conducted (take-off point: latitude 38°16'24.15" N and longitude 16°12'55.99" E) aimed at defining the schemes and suitable flight altitudes at which to operate. The survey operations involved an area of approximately 13 hectares. A point cloud from aerial photogrammetry was developed, georeferenced in the WGS 84 reference system (EPSG: 4326).

The photogrammetric survey, integrated with direct surveys and the historical-critical analysis of the individual artifacts, constitutes the basis for reconstructing the construction phases, modifications, transformations and alterations, and damage suffered over time. In particular, two key parameters will be identified for defining vulnerability using simplified methods, in particular those relating to the quality of the walls and structural regularity.

2. Cultural Heritage: history, representation, and project

Our country is a continuous discovery of artistic and historical treasures, an inestimable wealth that has its roots in time. However, this heritage is fragile, subject to deterioration, at the risk of catastrophic events, and to the pressure of unprepared tourist use. A static vision of the knowledge of the existing heritage is anchored to its conservation, while the projection desired by sustainable development promotes, alongside an indispensable knowledge/conservation, its use, enhancement, and management understood with a critical spirit, regardless of scalar and chronological factors.

Digitalization has emerged as a powerful tool capable of preserving this heritage, making it accessible and enhancing it. It is not just a matter of ‘conserving’ works of art and artefacts, but of ‘safeguarding’ our identity, culture, and history through their memory. Digital, indirect detection practices, modeling, and prototyping represent an investment in the field of knowledge, an opportunity to create new models of cultural fruition and territorial development. The digitalization of cultural heritage has been considered for over twenty years a crucial activity to promote accessibility to historical, artistic, and documentary heritage, preparing it to face the countless opportunities offered by new technologies.

Through digital technologies and methodologies, whose possibilities in recent years have entered even more forcefully into research experiences and everyday practices, scientific research is experimenting with the possibility of making extraordinary leaps in spatial and dimensional scale and of verifying increasingly sophisticated vision and representation systems: from augmented, mixed, immersive reality, we can measure and appreciate the material consistency of things through the immaterial of the virtual, we can enjoy a condition of identification with the works and artifacts of art, we can generate other and further types of reality for the works of our historical-artistic heritage, we can project the memory and knowledge of our cultural assets into the production of a new and original heritage.

With digital tools, we can all enter a 'place of everywhere' where all art becomes accessible and culture is transformed into an instrument of open, inclusive, and democratic knowledge. Our discipline deals historically with drawings, surveys, representations, visual translations of concepts, projects, narratives, as drawing is an expression of non-verbal languages, and for this reason it is called to confront the human sciences and the hard sciences, between digital worlds and analogical traditions, between signs and history, between semiotics and technology, between archaeology and computer science.

Reporting our reflections on Drawing for cultural heritage, the connection between knowledge therefore appears to be a necessity to bring reasoning back into the framework of global processes that highlight its reticularity, complexity, but also the richness and potential that they can assume in the context of the cognitive heritage that we have available and that we can use. The ancient - and always necessary - relationship with history is a prerequisite for the contents of analysis, and is a preparatory tool for recovery, restoration, and design.

Cultural Heritage is a field that requires rigorous research on complex issues that involve human cognitive processes, and the possible ways of relating their immaterial and material products, it requires an interdisciplinary approach, a connection between knowledge understood as valorization of the contribution that different disciplines can offer for the reading of problems that cannot be understood in their complexity if not through the convergence of different points of view, adequately articulated among themselves; an interdisciplinarity of concepts for which research and project models are born with more complete and in-depth interpretation keys, with the risk (or opportunity) that these models can be partially reinterpreted and modified.

3. Multiscalar study of the historical center of Gerace. Analysis methods, tools, techniques

The town of Gerace is made up of four historical nuclei, called: the Compact historical nucleus (in red); Borgo Maggiore (in blue); Borgo Minore (in yellow); Castle (in green) (Figure 1).

This study focuses exclusively on the compact historical nucleus, located in a higher position; the portion of the historical center thus identified appears recognizable by homogeneous characteristics, with the residences that lie compactly on the morphology of the territory. Inside the Compact historical nucleus, it is possible to identify the main crossing roads – Via Duomo-Via Zaleuco and Via Caduti sul Lavoro – with the ancient city gates at their ends, and directly connected to the main external routes, to the inhabited core, and to the car parks. These roads, in addition to dividing the urban core into fairly homogeneous sectors from a morphological and construction point of view, represent the main escape routes in the event of a seismic event (Figure 2).

The first operation carried out consists of the aerial photogrammetric survey of the Compact historical nucleus, aimed at producing documentation and analysis graphs. The survey allowed us to obtain a 2D/3D, multi-scale, multiprecision model, navigable with different visualization modes (point cloud, mesh, solid model, and textured model). It also allows for the detailed analysis of numerous aspects: metric data (volume-area-length), elevations and differences in level, georeferencing, orthogonal views, horizontal and vertical sections.

The model can also be implemented with GIS data and can be integrated with additional data from different sources (geospatial, topographic, orthophotographic, from sensors, etc.); this integration allows us to obtain, again through vector-type information, a database of topologically structured and georeferenced data, which is constantly updateable. Integrating point cloud data with GIS enables better planning across various applications and provides a combination of spatial analysis, visualization, and decision support, enabling more informed and efficient workflows.

In the next phase, the Compact historical nucleus was divided into five sections, delimited by the main routes that cross the town. This subdivision, in addition to the possible implications in the event of evacuation following an earthquake, is functional for subsequent survey operations. In each sector, the structural building units have been identified, understood as a homogeneous or non-homogeneous set of single units, interconnected with each other with a structural connection, or even simply in mutual adherence. Furthermore, the five sectors were the basic units for the detailed architectural scale survey of the individual building units (which is not described here) (Figure 3).

For each building-structural unit, a sheet was filled out. The building-structural units were further divided into sub-units with homogeneous characteristics from an architectural, morpho-typological, and structural point of view.

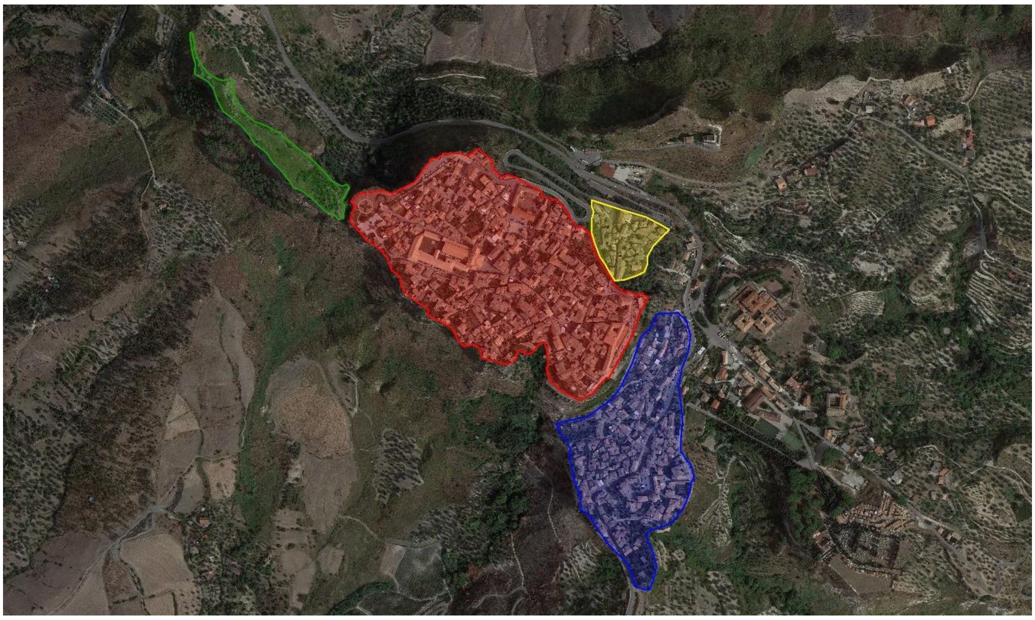

Figure 1: Subdivision of the historic center of Gerace into homogeneous areas.
Compact historical nucleus (red); Borgo Maggiore (blue); Borgo Minore (yellow); Castle (green). (Graphic elaboration by D. Colistra.)

The next step consisted of a detailed survey of two architectural emergencies taken into consideration for further investigation: the church and convent of S. Francesco, and the church of S. Giovannello. These two medieval monuments, different in size, construction, and structural characteristics, have been the subject of highly detailed seismic, structural, and construction analyses, and have therefore been the subject of particularly accurate instrumental surveys which have not been documented in this section (Figure 4). The surveys were carried out using range-based and image-based techniques (terrestrial and aerial photogrammetry). The detailed phases of the survey are described in the next paragraph. The graphic restitution, carried out at different representation scales (1:100, 1:50, 1:20, with morpho-structural insights at 1:10 scale), was developed using two representation techniques:

- black and white wireframe;

- grayscale wireframe overlaid on the point cloud.

The first mode ensures the best readability of quantitative data (thickness, dimensions, etc.) and morpho-structural elements. It also allows a comparison with the restitution of surveys already carried out previously (direct and instrumental methods). The second mode favors the interpretation of qualitative data (materials, degradation, colors, etc.), maintaining metric rigor and an easier reading of the constituent elements of the monument.

Furthermore, volumetric modelling was carried out at a scale of 1:100 of the church and convent of S. Francesco and at a scale of 1:20 of S. Giovannello, aimed at a reading of the volumetry and the morpho-structural elements, and parametric modelling (BIM model, georeferenced model integrated with physical, performance, material and functional data) of San Giovannello.

Figure 2: Main crossing roads of the Compact historical nucleus.

Figure 3: The sections that comprise the historical nucleus.(Graphic elaboration by D. Colistra)

Figure 4: The convent and the church of S. Francesco (left), the church of S. Giovannello (center). View of the textured mesh obtained by the union of different survey techniques (terrestrial photogrammetry, aerial photogrammetry, laser scanner). (Graphic elaboration by L. Pizzonia.)

The 3D textured mesh, derived from the point cloud of the two monuments, has been made available for dynamic and interactive visualization. Starting from the textured mesh data, a system is currently being implemented, based on software/apps already available and applied to the church and convent of S. Francesco and the church of S. Giovannello. With this device, it will be possible to:

- take a remote virtual tour of the internal and external spaces of the two monuments, both on the Genesis project IT platform and via a multi-platform mobile app;

- view additional information (texts, images) of a historical-informative nature on the 3D model, via a multi-platform app in Virtual Reality and Augmented Reality;

explore the model in Mixed Reality, with the possibility of viewing hypotheses of the original configuration of the monuments.

4. Digital aerial survey and integrated techniques

The survey operations were conducted at multiple scales. At the territorial scale, the aerial photogrammetric technique was employed with a UAV. "The UAV platforms are a very important alternative and solution for studying and exploring our environment, in particular for heritage locations or rapid response applications" (Nex et al., 2014, p. 2). The "flexibility of use and the ability to acquire images from inaccessible viewpoints make them a critical instrument in multiple fields of application at both urban and architectural scales" (Russo et al., 2022, p. 1). A workflow was followed for this process (Figure 5), organized in several phases, from the acquisition to the post-processing of data. For a territorial extension, photomodeling has allowed us to obtain high results in terms of accuracy in a short time. It consists of extracting directly from the photographs all the information necessary for these different phases: coordinates, distances, characteristic points, for the two-dimensional restitution of plans and elevations; vertices and profiles for the three-dimensional reconstruction of the elements; textures to visually enrich the volumes created (De Luca, 2011, p.20)

A plan was produced starting from the aerial photogrammetric survey of the urban fabric (Figure 6). From this general survey of the Città Alta, it is possible to obtain data relating to the measurement and more generally useful information for various sectors involved in the research project. The aerial photogrammetric survey of the center of Gerace is aimed at documenting and analyzing the urban and building fabric (Grubesic & Nelson, 2020, p. 25), with respect to issues relating to seismic risk management and tourism promotion, and it is functional to give an overall view. In the survey project, some aspects related to the territory were preliminarily considered. The morphology of Gerace is imprinted on the surrounding environment as a recognizable visual point. The city stands on a flat part of a cliff, 150m high, in the castle area. (Balbo et al.,1993, p.1129). The upper city (Città alta) is densely built up and is the result of a profound historical stratification.

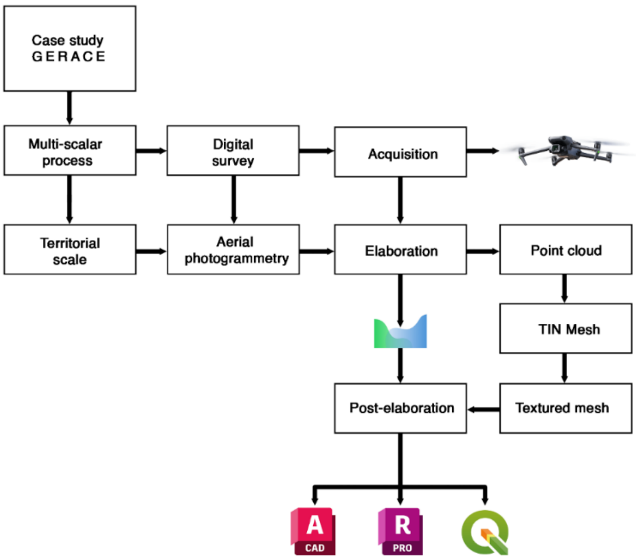

Figure 5: Workflow of the operations carried out for the Gerace case study, at the territorial level. (Graphic elaboration by L. Pizzonia.)

An initial site inspection of the historic center was carried out, aimed at understanding the internal urban distribution, the relationship between architecture and the reference context, mostly concentrated in the areas surrounding the case studies of San Francesco and San Giovannello, and creating an initial contact with the object to be surveyed. In this preliminary phase, the take-off and landing points of the aircraft were identified, and a flight mission was planned. The survey operations carried out in the urban center of Gerace involved an area of approximately 13 hectares. After consulting the current regulations regarding the flight area, we proceeded with the operational phases. The photographic shots were taken following a double grid scheme: a first for the acquisition of nadir photogrammetric images and a second, aimed at a better definition of the architectural elevations, with the optical axis inclined by 45°. The entire area of the center was covered with an overlapping degree of approximately 70%, in order to achieve a good level of accuracy, and avoid the presence of gaps in the documents produced. The acquired data were processed using the *Agisoft Metashape* software. It was chosen for precision and versatility. Following the canonical processing steps, point clouds, mesh viewable both in wireframe and solid mode, and textures were developed (Figure 7). In total, 489 cameras were acquired and subsequently processed. The first phase involved the calculation of the *tie points*, equal to 211,593. A *dense cloud* composed of 32,423,737 points was therefore processed. The processed data allowed the development of a 3D mesh model of the TIN triangulated irregular network type. In the case of the 3D model, it is possible to visualize it according to the solid and wireframe modes. Thanks to the presence of photographic acquisitions, the mesh model has been textured. The texture allows photorealistic visualization of the color on the model.

The model is being integrated with other types of acquisitions, such as range-based laser scanning and detailed terrestrial photogrammetry. Survey operations executed with UAS "shares the advantage of effective data acquisitions while enabling the survey of complementary parts of the building: the roofs" (Perfetti et al., 2023, p. 1217). The integration between the survey techniques allows for moving from the general of the urban grid to the detail of the significant architectures identified in a complex, irregular urban fabric. "Those spatial characteristics imply the definition of a strategy for a detailed photographic close-range acquisition from the ground. The SfM acquisition will be aimed at the optimization of SLR camera movement to generate chunks of high-density points and completeness of each surface" (Parrinello & Picchio, 2019, p.590). Detailed point clouds acquired through terrestrial photogrammetry are aligned to the point cloud produced by laser scanners. The range-based point cloud ensures better metric precision, with millimetric tolerances. The integrated cloud is, in turn, aligned to the aerial photogrammetric survey, which instead preserves better geospatial characteristics. This process led to a geolocalized and metrically correct final product. This model has been prepared to be integrated into a GIS platform; it allows the execution of metric, morphological, qualitative, and quantitative analyses related to both the current state and predictive ones. The point cloud can also be integrated into a BIM environment for the execution of Heritage-BIM procedures.

The produced documents are useful for communicating the investigated heritage. They can be integrated and explored in AR/VR environments, or can give rise to the production of videos and other illustrative materials useful for disseminating the project. Interoperability allows the use of the models by the various operators involved; point clouds and three-dimensional mesh models are functional for the development of analyses and operational proposals relating to conservation, to the study of climate impact, to structural analysis, and a multiplicity of others intentions. "Also, 3D models help to protect the architectural heritage of cities by analyzing the impact of new developments on historic buildings or areas of cultural interest" (Vangu et al. 2025, p. 169).

Figure 6: Aerial photogrammetric plan of the surveyed urban fabric, point cloud. Gerace, *Città alta*. (Graphic elaboration by L. Pizzonia.)

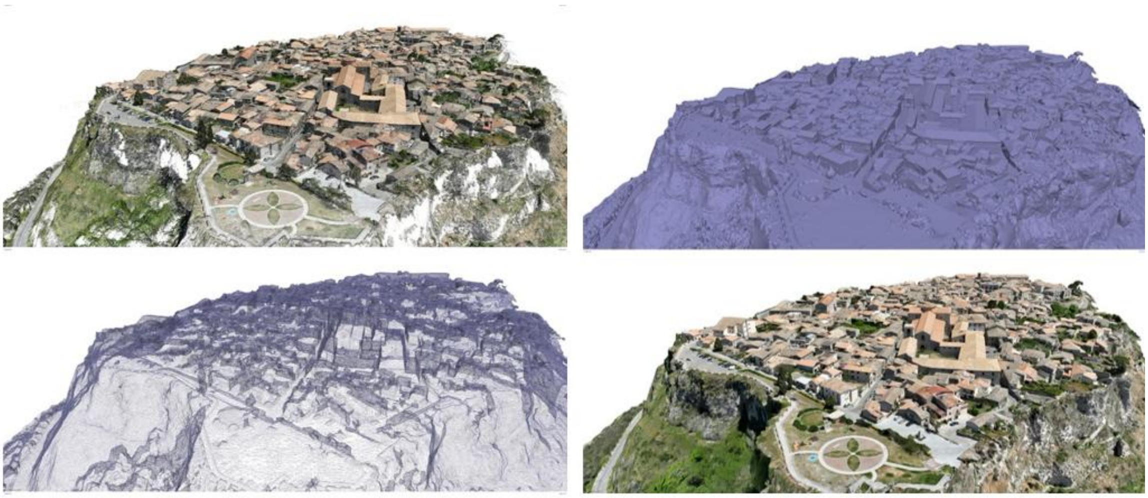

Figure 7: Digital survey, processing phases. From top to bottom: point cloud, TIN mesh, solid mesh, textured mesh. (Graphic elaboration by L. Pizzonia.)

5. Conclusions

The work carried out is related to research still in the development phase and shows some of the potential offered by the tools currently used for the survey and representation of monuments and historical heritage. The integrated system of surveys at multiple scale levels, performed with different techniques and integrated with detailed survey sheets on individual buildings, constitutes an integrated knowledge process in reference to the construction phases, modifications (expansion, transformation, and/or alterations), and damage suffered by the artifacts over time.

The "raw" data of the survey (point clouds) represented the documentary starting point from which to draw up graphic restitutions aimed at the two main objectives of the research: the mitigation of seismic risk and the enhancement of the architectural and urban heritage. With reference to this last objective, an explorable three-dimensional model is being developed (zoom-in and zoom out functions, orbit functions), aimed at an exploration at the overall level and of the main morphostructural elements of the historic center and of the two churches being studied in depth. The models constitute digital twins of the real context, in reference to the geometries and materials. Furthermore, starting from the survey data, the BIM model of the church of S. Giovannello was implemented (georeferenced three-dimensional model integrated with physical, performance, material, and functional data). Alongside the potential more closely connected with survey and representation, there are also those offered by the dissemination and communication tools, which will be the subject of the next phase of the research. Artificial intelligence, the diffusion of digital archives, and access to open data further expand an already complex scenario, allowing an ever greater interaction between those who process the information and those who are intended to use it.

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Conflict of interest.

The author(s) declare that there is no competing interest.

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