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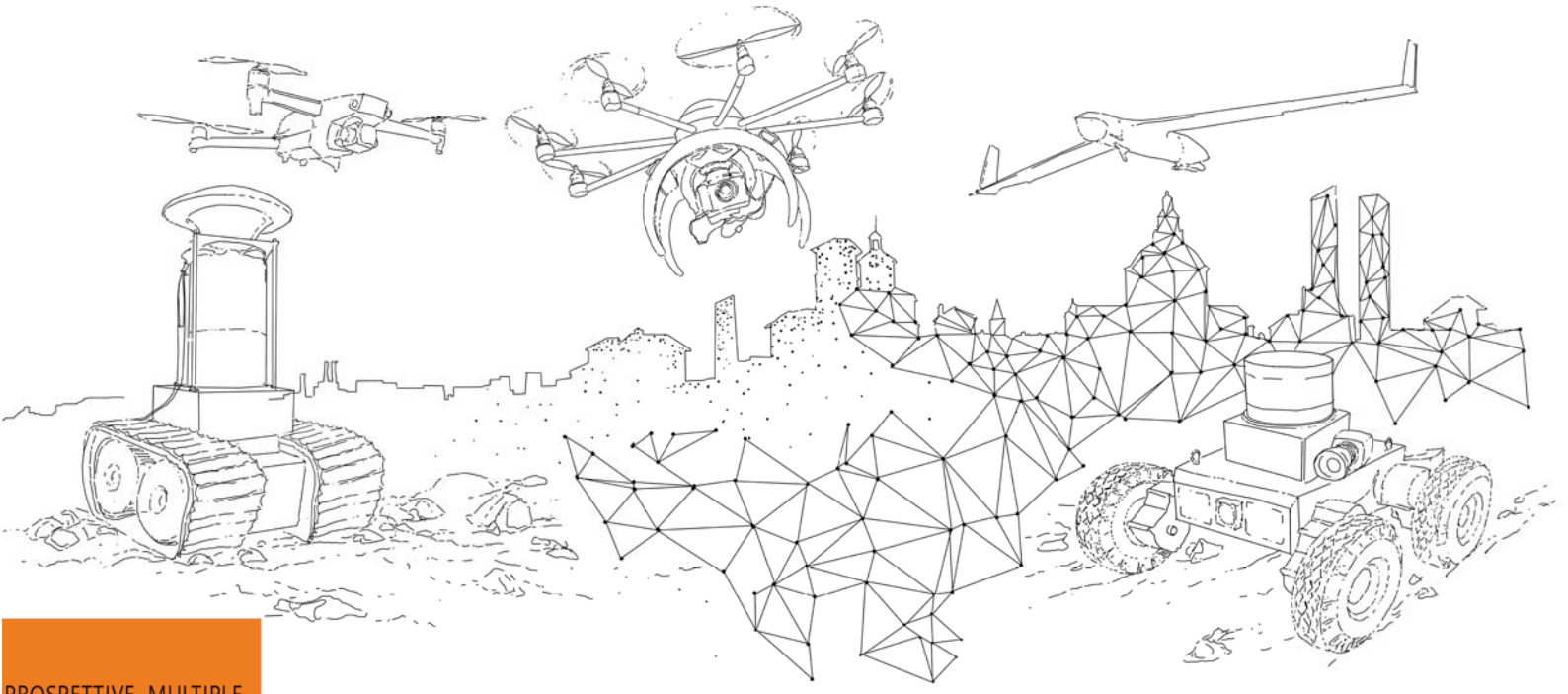
Salvatore Barba
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editors

D-SITE

Drones - Systems of Information on culTural hEritage for a spatial and social investigation

Volume 2



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PaviaUniversityPress

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Anna Dell'Amico

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Drones - Systems of Information on Cultural Heritage for a spatial and social investigation

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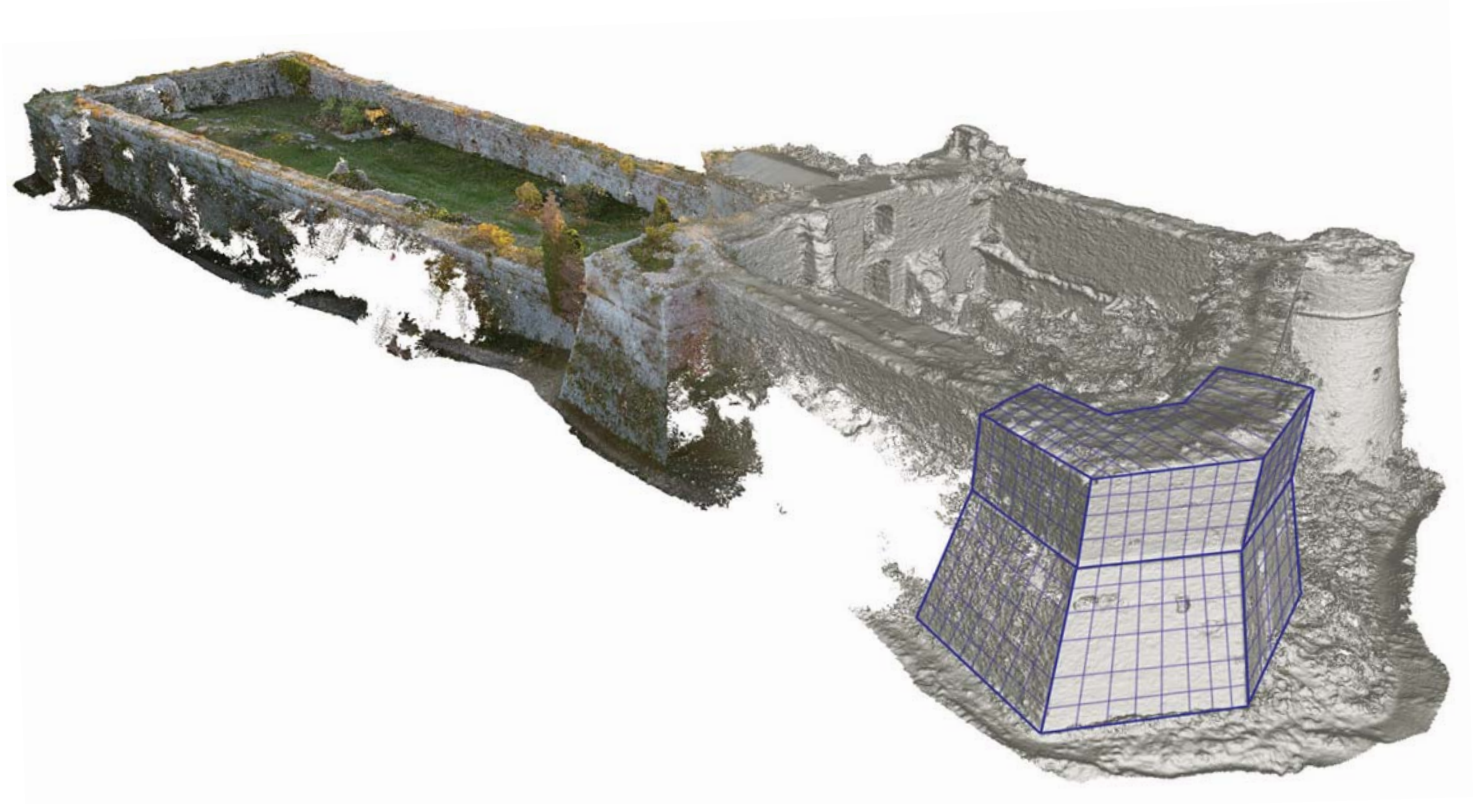
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Cultural Heritage, Digital Photogrammetry, GIS; Geometric Analysis, Landscape Analysis.

ABSTRACT

The 3D digital survey techniques are a real advantage for managing the complexity of the architectural heritage, for the UAV tools allow reach places that are difficult to access. Aerial photogrammetry also investigates and models the landscape of which the architecture is an integral part. This paper aims to analyze complex architectures and the landscape in which they are. It describes the first results of the architectural analysis with a geometric/metric algorithm that integrates the UAV cloud point models longitudinal and transverse sections, defining geometric deformations. The procedure is applied to the case study of San Casto castle in Sora, Lazio.

UAVs for the analysis of geometrical deformation of fortresses and castles. The case study of Sora Castle

1. Introduction

Surveying and drawing have always been privileged tools for investigating, knowing, and understanding the architectural and Cultural Heritage. As Migliari stated, "the architectural survey is the reconstruction of the project of the studied work. [...] Survey is a process of knowledge" (Migliari, Roma 1999, p.33). These disciplines are beneficial for understanding the design matrices of ancient and medieval architectural heritage based on the iterated use of recurring geometries. The interpretation of architectural complexity is today even more facilitated by the 3D virtual survey and the modeling technologies that iconically reproduce real objects, restoring a coherent perception of the artifact's raison d'être. SfM photogrammetric procedures, for example, and the use of UAVs are fundamental to document complex architectural systems such as fortresses or castles or any heritage located in difficult and sometimes inaccessible sites and to analyze the close relationship between architectural artifacts and place. SfM technology returns 3D models and digital orthoimages of objects with high precision by processing point clouds and recorded digital images. In particular, shortrange digital photogrammetry offers crucial opportunities, such as automatic orientation and measurement procedures, 3D vector data generation, digital orthoimaging, and digital surface modeling. In addition, the Unmanned Aerial Vehicle (UAV) and Structure from Motion (SfM) algorithms also meet the needs for versatility, effectiveness, and portability required by current analysis standards. Thus, precise documentation, or rather a photograph of state of the art of Cultural Heritage, is essential for its protection and vital for the scientific studies carried out during the restoration process. These new tools can then be used for knowledge and understanding but also to identify and describe degradation phenomena and any structural deformations that reduce the performance of existing structures.

The research aims to develop a systematic study that can serve as a qualitative and partly quantitative method for analyzing the deformation of architectural objects, focusing on the study of the individual components of the building.

The experimentation involved the San Casto Castle located in Sora, a small urban center in southern Lazio. The methodology involved a survey in the geographical region of all existing fortresses (towers or castles), including any linguistic repetitions in the organization of architectural spaces. The interest in this geographical area arises from the presence of numerous fortified architectures, which gave rise to the phenomenon known as the "construction of fortresses." Again, digital GIS technology was of great help. Subsequently, attention was paid to the single selected case study on which the digital surveys were performed, the drone photogrammetric surveys. The articulation of the postprocessing and the identification of the geometric algorithm capable of reading coherences or inconsistencies between the geometric digital model simplified on a theoretical basis and the empirical one, obtained with the acquisition of the state of things, are described in the paragraphs subsequent.

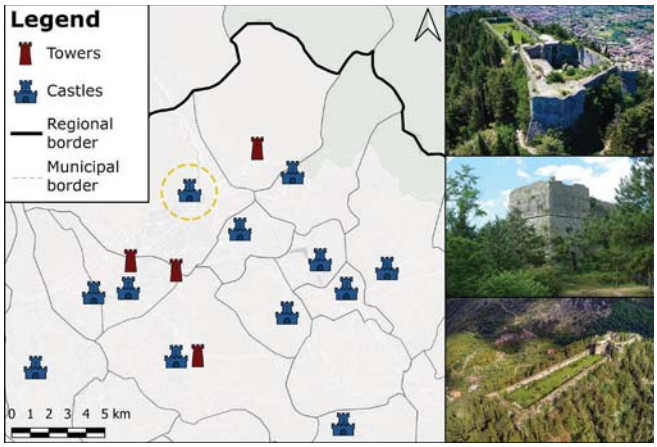


Figure 1. Geolocalization of the castle of San Casto in the database FortLiriGIS. It highlights how the Sorano Castle was a historical fulcrum of a defensive system around which satellite fortresses were articulated.

2. Case Study: The San Casto Castle

This paper focuses on the San Casto castle in Sora, in the region of southern Lazio, created for the control over a geographically significant territory. Rocca Sorella, subsequently transformed into the castle known as San Casto, had a fundamental role in the Duchy of Sora, which constituted a vital fiefdom located on the border between the Kingdom of the Two Sicilies and the Papal State (Beranger, 1981). It represented a critical gate, considered an ingressu regni because it allowed access to the Kingdom of the Two Sicilies (Rosa, 2010, p.19). The hypothetical historical evolution of the fortress is described in three main phases (as shown in figure 3). The architectural layout presents a first early medieval nucleus, most likely surrounded by circular towers; then it had a subsequent extension with the insertion of a keep in the more or less central area of the original core built with more regular masonry, and then bastions arose for the defense against firearms. Enlargements and transformation occurred over time due to violent earthquakes and destructions provoked by the struggles for control over territory. The Sorano castle was also equipped with numerous accessory fortifications,

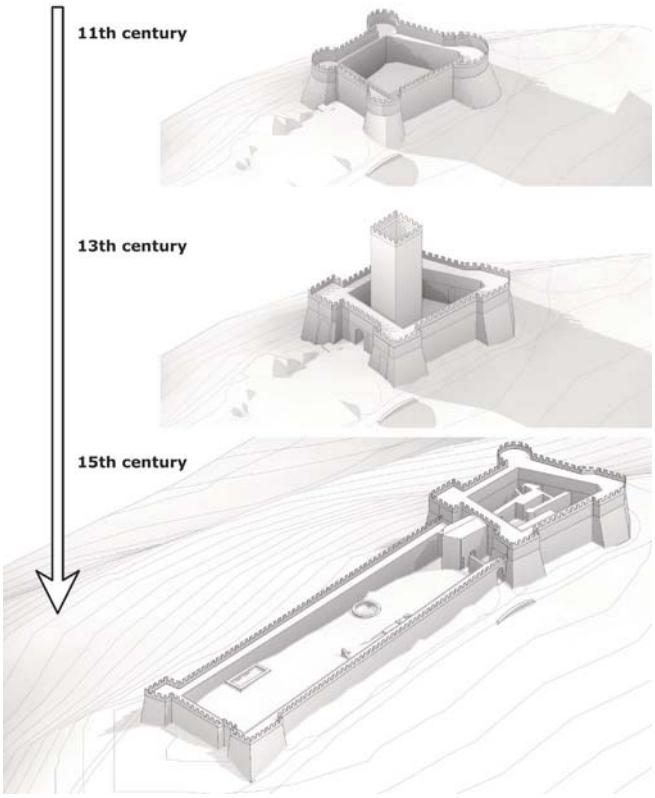


Figure 2. HBIM elaboration by the author. Historical evolution of the San Casto castle, based upon archival and historical research.

being at the top of a defensive system articulated on the mountain and formed over the centuries by various elements such as walls, isolated towers, and ground roughness. In the second half of the fifteenth century, the new buildings for military purposes were arranged to defend the fortress in the pivotal points of the entire hill of San Casto, and many of the existing walls were strengthened and extended. Judging by the remains, they also raised towers along the curtain walls. The defensive measures were accurate and updated to more modern canons of war engineering. The set of fortifications reached its peak in the viceregal period when a complete rationalization of the existing defenses was carried out, including the expansion of the castle.

3. METHODOLOGY

3.1 3D Digital documentation: tools and procedures

A digital photogrammetric survey was performed to reconstruct the geometry of the complex and coherent structure of the castle San Casto. The survey was carried out adopting the capturing scenario technique with the drone DJI Mavic Pro II, taking 581 frames in favorable sunlight conditions to limit shadows and no wind to guarantee at least 50% overlapping of images, using a camera with 12Mpx resolution. The drone has been set up to move at a speed of 2 m/s, taking photos every 2 seconds, in timedshooting mode. It followed two routes, starting at 3 pm till 6 pm on the 20th of November 2021; the flight altitude was 70mt.
The alignment of frames in the post-processing, using the open-source software Meshroom, generates a dense point cloud, subsequently transformed into a textured model. A return cloud point has been created, corrected, layered, and imported into 3D modeling software. Point cloud orientation operations were performed with Autodesk's ReCap Pro software. The subsequent processing phases were dedicated to sampling and rotation with the freeware CloudCompare software of the point clouds. The sampling process allows obtaining a regular distribution of the cloud points by removing redundant or superabundant points. The last phase of the elaboration process is dedicated to converting the point clouds into formats that allow their visualization and manipulation in the software used for the 3D drawing and modeling operations.

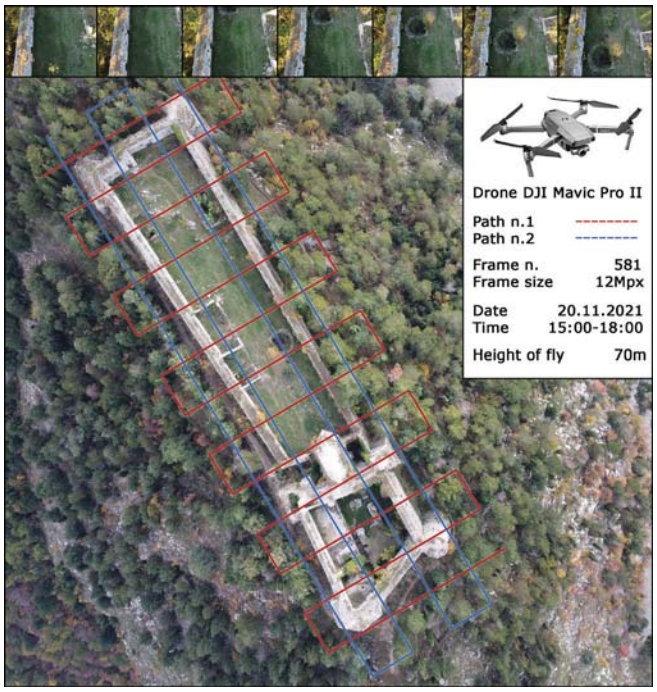


Figure 3. Project of the survey conducted on the case study San Casto Castle and flight technical data.

3.2. Elaboration of the theoretical model based on the digital reconstruction

The accurate digital reconstruction allowed the development of a 3D digital model, geometrically corresponding to the empirical one. Then it was possible to identify and isolate the different towers of the castle, defining the geometry for each type and creating a theoretical model to which they can refer (the circular tower, square and polygonal one).

3.3. Geometric algorithm for the comparison of theoretical and empirical digital models

The definition of a geometrical-mathematical-based model, elaborated after the digital reconstruction, constitutes a more precise reference for analyzing deformations occurring on the towers. This paper shows the procedure applied to the one circular tower remaining in the San Casto castle. The procedure consists of two stages. The first step concerns the 3D digital modeling of the architectural components of the building, which returns their most probable geometry based on the most recurrent architectural typologies

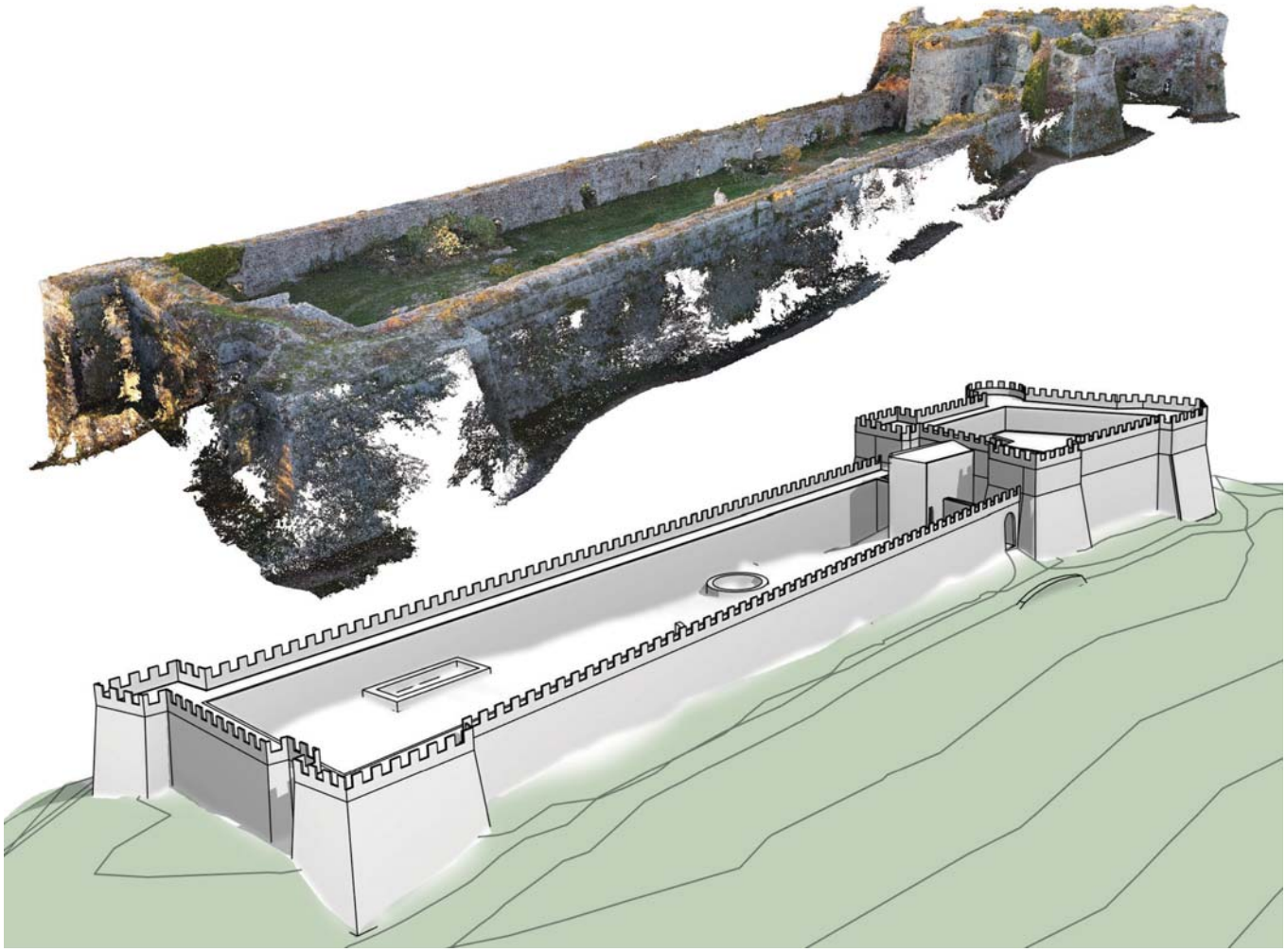


Figure 4. Elaboration of the HBIM model based on the digital reconstruction.

of the time. Based on the digital survey, the second phase models the state of the art, returning the actual geometry, which could contain any discrepancies to the geometric/theoretical model.

The crosssections and longitudinal sections were performed on the geometric model and then on the point cloud with the free Cloud software to understand the reliability of the theoretical model. Sections with a span of 2 m were obtained according to the size of the masonry blocks. Furthermore, the choice of the distance between two consecutive sections is also determined by the awareness that it is the minimum dimension in which any deformation of the legible element of the wall occurs. The shape of the different sections was reported and analyzed, on the same reference system allowing the comparison of the

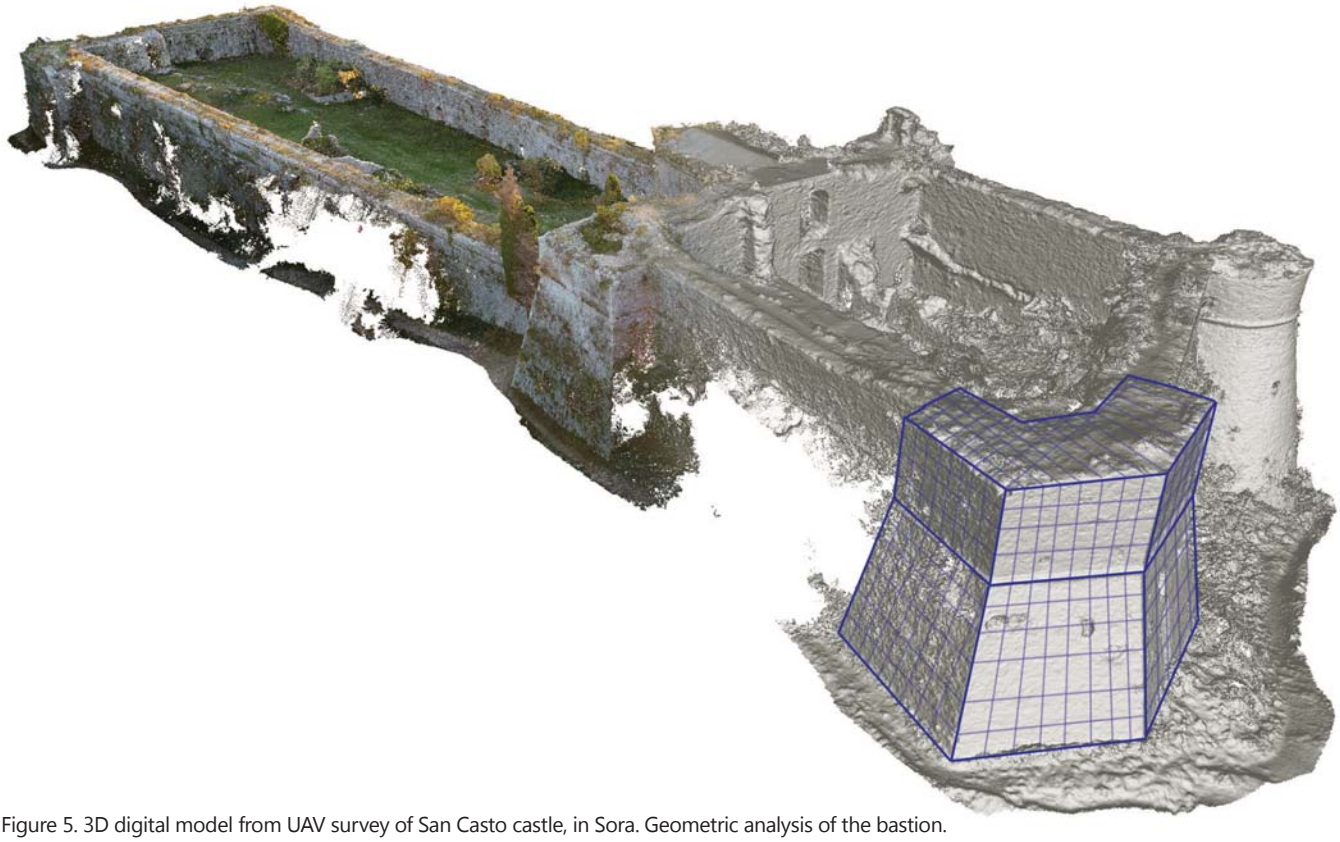


Figure 5. 3D digital model from UAV survey of San Casto castle, in Sora. Geometric analysis of the bastion.

tower's two models, theoretical and empirical. The overlapping makes it possible to subtract the area of the theoretical section from that of the empirical one, to indicate the deformation of the element. Figure 7 shows that the deformation is a typical tendency of the cylindrical structures, called "ovalization," giving a qualitative analysis of the deformation.

4. Conclusion

SfM technologies are of great help in enhancing the existing building heritage and in the increasingly accurate and complex analyses required by the current time. In this paper, the author tested a procedure based on digital photogrammetry from drones to verify the reliability of the geometric virtual models obtained with traditional processes and defined as theoretical because they are based on a simplified 3D reconstruction of the real object. The procedure, divided into two phases, through the use of a geometric algorithm, compares the theoretical model with the empirical model obtained from the digital photogrammetric survey.

This procedure allows us to appreciate any deviations between the two geometries and intercept any structural deformations. The identified procedure is relatively fast, inexpensive, and requires limited manual processing. Future developments concern the

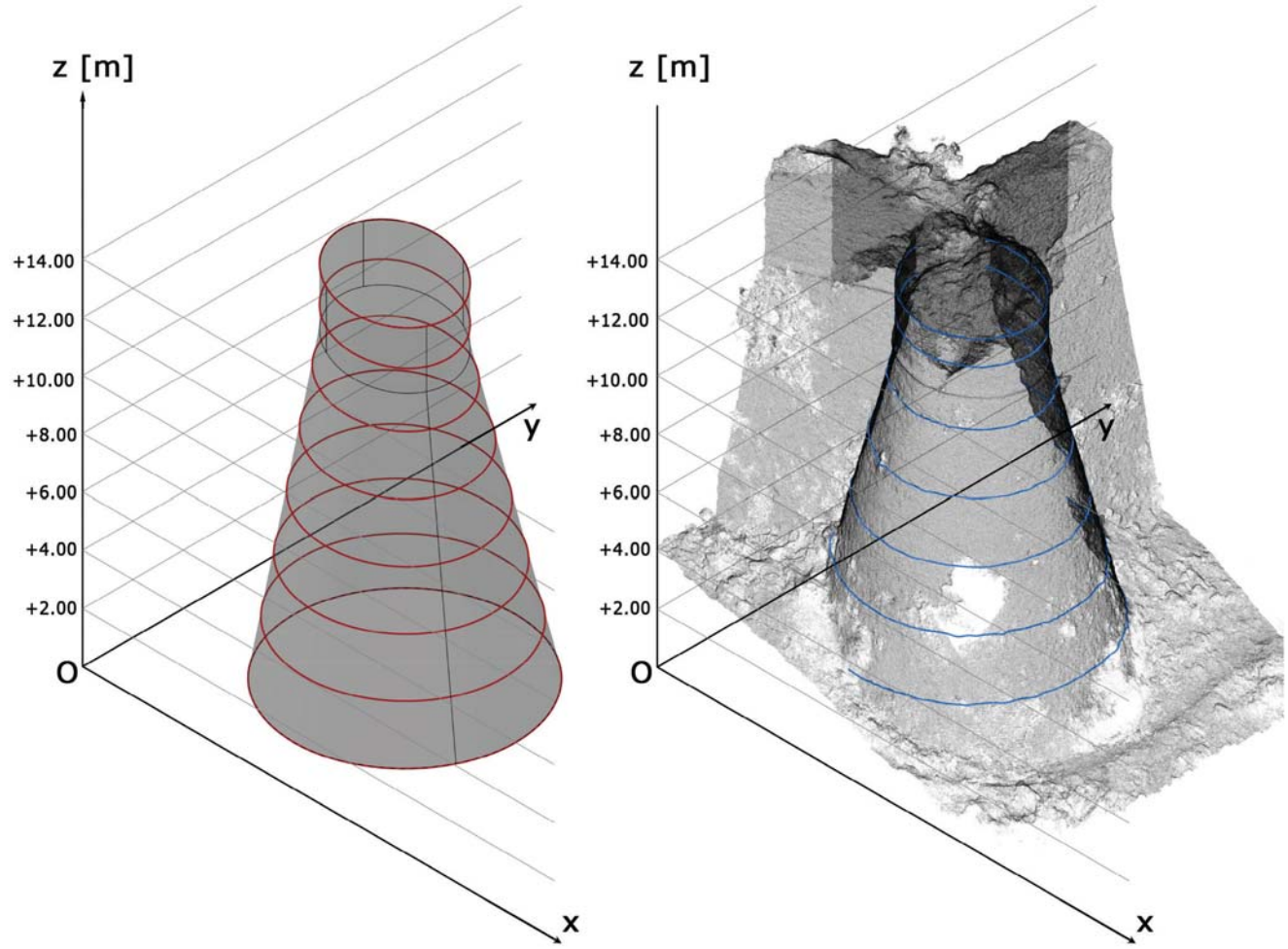


Figure 6. Geometric model and empirical model: Cross-sections in the XY plane with a span of 2 mt.

possibility of verifying, with the same methodology, any structural deformations with the insertion of fixed points on the building organism, iterating the procedure over time and experimenting with it both on the castle of San Casto and in other fortified structures of the apparatus, the defensive system of southern Lazio.

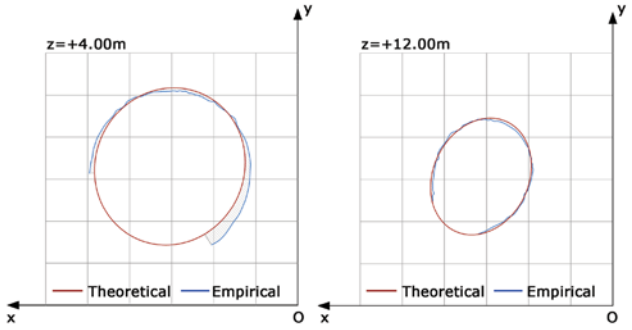


Figure 7. Comparison of the theoretic and empirical sections: deformation analysis.

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The use of UAVs is increasingly widespread in activities related to Heritage documentation. In recent years the development of methodologies of data integration, obtained through surveys that exploits drones to reach privileged observation points, has been witnessed by the numerous computation platforms, software and tools, that populate the exchange.
The definition of increasingly reliable methodologies and procedures of close-range photogrammetry has produced considerable results in the survey of Architectural Heritage.
Nowadays, several Universities and Research Centres, together with enterprises, are working to optimize documentation services whose goal is, in any case, the representativeness of technical data aimed at the project development. Parallel to aerial documentation, even the applications of remote-controlled terrestrial drone systems is renewing the inspection and survey practices in architecture and on territory, overtaking barriers and access dimensions to sites and emergency contexts otherwise impractical for human operators.
Surface rovers and submarine robotics, equipped with controlled cameras and implemented survey devices, in terms of stability and compartment, contribute to complete an extremely scientific and innovative field, where the central theme of robotics applied to Cultural Heritage documentation is expanded and consolidated in correspondence to the international categories of UAS (Unmanned Aerial Systems), USV (Unmanned Surface Vehicles) and UUV (Unmanned Underwater Vehicles). Drones, in the wider terms of their definition, are now used for documentation, management, protection, maintenance, and monitoring, integrating imaging systems and measuring instruments that contribute to define three-dimensional databases on Cultural Heritage. This conference is promoted with the aim of collecting recent experiences on that topic and of providing a moment of reflection between academic and enterprise realities for the promotion of updated frameworks for the development of research in the architectural survey field.



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