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Multi-scalar digital approaches for heritage knowledge. Integrated documentation strategies of the Morella fortifications in the cultural route of Jaime I

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Abstract

Over the centuries, the fortified complex of the city of Morella, in the province of Valencia, has been shaped by numerous conflicts and political changes, preserving and at times adapting its defensive system. This adaptation reflected the various military strategies of the wartime periods that influenced sites along the coast and inland areas of the Valencian province, integrating urban structures with the natural ruggedness of the surrounding terrain. However, the fortifications reveal their historical significance not only through the tangible presence of walls, towers, and fortresses but also through the resilience of a community that has transformed a defensive apparatus into a symbol of cultural identity and historical memory. This contribution presents the research activities undertaken within the European H2020 Prometheus project, aimed at structuring methodological protocols for multiscale acquisition and restitution for the documentation and morphometric analysis of sites along cultural routes, including the fortified structures of Morella's defensive works. Establishing a new standard for understanding fortified heritage through its digitization allows for the preservation of the architectural and historical complexity of Valencia's fortifications in digital format, while making them accessible to an international audience and strengthening interest in the historical heritage of this and other sites along Europe's cultural routes.

Keywords: multiscale documentation, integrated survey, fortified heritage preservation, Castle of Morella.

1. Introduction

The analysis of the fortified structures of the city of Morella highlights the adaptation of the medieval centre to the historical policies that have shaped the area over the centuries. The defensive system of the walls remains evident in the city's urban layout and in the configuration of its infrastructure, which extends within the village to the base of the promontory where the monumental complex of the castle is located. Originating from Roman times and further developed during the Arab rule and the Christian *Reconquista*, the Castle of Morella represents a remarkable example of military architecture, characterized by its strategic position relative to the terrain's topography, with hills and steep slopes providing natural defense. The layered design of the defensive system ensured effective resistance to military sieges over the centuries, serving as a tangible and irreplaceable testimony to spanish military history. The events that shaped the city's cultural significance are reflected in its various evolutionary phases, from a military fortress to a historical icon, preserving over time a significant part of the historical memory within the context of what can be considered a cultural route linked to the figure of Jaime I. This research, developed within the framework of the European H2020 PROMETHEUS project (*Protocols for Information Models Libraries Tested on Heritage of Upper Kama Sites*),

Fig. 1- The historical centre of Morella and its fortified monumental system. The core has 17 defensive elements including control towers and monumental portals, defending the central fortress Graphic elaboration by Francesca Picchio, Francesca Galasso, 2024.

describes the multiscale approaches adopted for documenting Morella's defensive heritage, focusing on a dual analysis: tracing and mapping the fortified system around the historical city and relating it to the urban context. In addition to a descriptive database of the territorial fortified level, a level of documentation at an architectural scale is included, focusing on specific points along the fortified perimeter for territorial control and detailed architectural documentation of monumental elements and their construction features. For this reason, the multiscale database of the fortified layout aims to serve as a starting point for developing informative applications that can support professionals in managing architecture and monuments.

2. The fortified system

Although Morella's urban center originated during Roman times (Segura Barreda, 1868), its fortified system dates to the 8th century under Arab rule. During the 11th century, the city was conquered by Christians, becoming a stronghold against Muslim incursions. The fortress's importance in Christian times was due to its location at the geographic center of the Crown of Aragon, over 1,000 meters above sea level. Jaime I of Aragon himself recognized its strategic military, geographic, and political value, solidifying its hegemony (Dalmases Balañà & Pitarch, 1983; Ortí Miralles, 1958). In the 13th century, the city's urban morphology began to take its current shape, expanding beyond the castle walls and following the mountain's natural slope. Over the following centuries, Morella became a significant medieval fortress where the castle and walls played a crucial role in defending against invasions. During the War of Spanish Succession (1701–1714), Morella aligned itself with Bourbon forces, playing a strategic role in the region. In 1711, the city and its castle resisted a siege led by Habsburg troops under the command of Archduke Charles of Austria, further solidifying its reputation as a fortified stronghold. (Gaspar, 2001). During the Spanish War of Independence (1808–1814), Morella witnessed clashes between Napoleonic forces and Spanish rebels (Gaspar, 1992). The damage sustained during these conflicts led to the strategic and military decline of the city and its castle, which were abandoned by the early 1900s after the Carlist Wars. Today, Morella's historic center and castle have become tourist sites and cultural symbols of the region's rich and complex history (Portela et al. 2020).

2.1. Morella's Castle

The monumental castle complex stands as a tangible and irreplaceable testament to Spain's defensive history. By focusing on the structural and architectural features of the castle, it is possible to carefully examine its design, considering the influence of its geographic location and surrounding topography. Its placement on a promontory provides a commanding view, facilitating the monitoring of access routes and offering a strategic vantage point to detect potential threats. The terrain's

morphology served as a natural deterrent against attacks, making the Castle of Morella a naturally well-defended fortress (Gaspar, 2003).

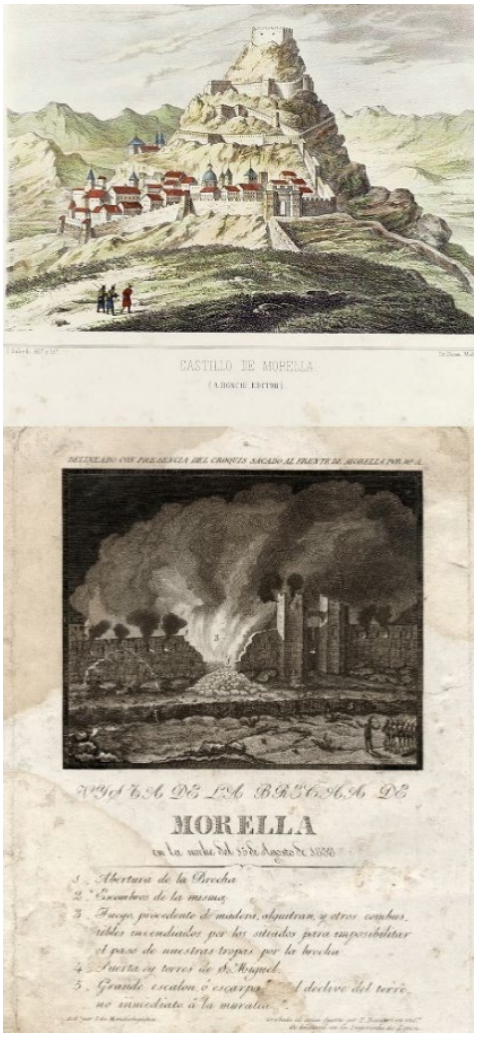

Fig. 2- Some historical images of the urban centre of Morella from the Biblioteca Valenciana Above, 1874 engraving by Salcedo y Echevarría. Below, view of the Morella breach on the night of 15 August 1838 by Rocafort Tomás.

This strategic approach is reflected in the architectural structure, which leverages rather than challenges the topographical context to enhance its defense. The fortress is designed across three levels, integrating architectural and defensive elements. The first level, at the base of the promontory, features robust circular masonry, ideal for resisting frontal assaults and ensuring uniform defense. The second level, the functional heart of the castle, is marked by imposing walls, semi-circular towers, and guardhouses that strengthen the structure and provide elevated platforms for observation and defense. The third level culminates with the parade ground and the keep, the most secure and strategically vital part of the castle. Between the castle and the medieval town lay the *Albacara*, an open space crucial for defense, serving as a buffer zone to slow down assailants.

2.2. The defensive system of the walls, historical gates and fortified towers

Built in the 14th century during the reign of King Peter IV, Morella's defensive walls were constructed on the remnants of earlier Islamic defenses (Alanya I Roig, 2000). Over the following centuries, the walls were reinforced and modified to adapt to advancements in siege warfare. Despite these changes, the fortifications retain much of their original Gothic character (Gaspar, 1992). The walls, spanning over 2.5 km and enclosing an area of approximately 0.5 km^2 are dotted with 14 watchtowers. Along their length, the walls incorporate advanced defensive features such as angular bastions and arrow slits, reflecting the military strategies of the era (Dualde Viñeta, 2016).

A key feature of Morella's walls is the *Paseo de Ronda*, a walkway along the fortifications that allowed defenders uninterrupted access to all sections of the walls (Dualde Viñeta, 2016). The monumental gates served not only as defensive bastions and observation points to monitor surrounding territories but also as administrative centers for managing access to the city. Each gate functioned as an entry point and checkpoint to regulate movement.

3. Multiscale documentation strategies for Morella's defensive system

From the castle's summit, where the majestic *Plaza d'Armes* opens, a cultural itinerary unfolds, harmoniously linking the monumental fortress's architecture with the historical gates that punctuate the fortified walls. Each distinctive element of this route, clearly visible from the height of the main rock, contributes to outlining a high-value path designed to enhance and deepen knowledge of the city's precious fortified

heritage. Documenting the current condition of the site and its monuments becomes a key objective not only for territorial monitoring but also for defining digital tools for storytelling and valorization (Florio, 2024; Parrinello et al. 2024). Past research and experimentation conducted within the PROMETHEUS project (Picchio et al., 2024; Picchio et al. 2023; Pettineo et al. 2023) have allowed for testing and optimizing digital documentation procedures. These efforts aim to standardize a survey method for the cultural routes targeted by the project, tailored to the specific realities of preserved, abandoned, or ruined architectural complexes along the spanish route (Parrinello & Pettineo, 2024).

Fig. 3- Acquisition and photogrammetric processing of the city's perimeter defence system Graphic elaboration by Francesca Picchio, Francesca Galasso, 2024.

The documentation activities for Morella's fortified system sought to implement an interdisciplinary approach for recording and structuring information on its architectural and urban heritage. This included training students and researchers on the historical and constructive value of Jaime I's cultural route. The research experience in Morella focused on implementing a strategy to test integrated digital survey methods, both terrestrial and aerial, to develop reliable 3D models and new operational programs. Adopting a digital survey methodology provides a foundational framework for structuring and certifying metric databases and photographic, critical, and supplementary census data on architectural and territorial components (Parrinello & Porcheddu, 2024; Tanduo et al. 2023; D'Agostino et al., 2022; Barba et al. 2021; Rinaudo & Scolamiero, 2021). The integration of LiDAR (7) and photographic (8) instruments ensures comprehensive coverage of the context and is conducted at multiple observation levels, including territorial, architectural, and structural stratifications.

3.1. Documentation of the monumental castle complex

For the Castle of Morella, the primary goal of the methodological work was to structure an operational workflow for integrated documentation that would cover the various architectural levels of the fortified complex, ensuring an accurate and detailed digital representation of the site. Its complexity presents specific challenges for 3D documentation, both during acquisition and processing, requiring a targeted approach for each architectural level within the fortified system.

UAV photogrammetry provided a series of images offering an overview of the castle and its territorial context (9). However, acquisition campaigns were significantly hindered by constant wind currents and the presence of birds, necessitating manual image capture through multiple trajectories at low altitudes around the castle's summit (but able to guarantee a GSD of 2cm/pix). Subsequent processing of the photogrammetric model identified data voids in the northern sections of the walls, characterized by steep, almost vertical rock faces. For close-range terrestrial surveys, a 360° camera system was employed to evaluate the feasibility of performing rapid photogrammetric surveys on the move (Janiszewski et al. 2022; Teppati Losè et al. 2021). The quality of the data was influenced by lighting conditions: intense sunlight created sharp shadows on buildings and walls, complicating transitions between well-lit areas and shaded zones. Consequently, slow-paced acquisition was necessary to allow the camera's sensor to adjust in real-time to changes in light (10). Finally, digital survey activities were carried out using parallel acquisition phases with Terrestrial Laser Scanners (TLS) and Mobile Laser Scanners (MLS). TLS provided detailed, high-precision data on primary structures, while MLS enabled rapid coverage of linear paths and connection areas (11). This combination allowed the architectural complexity of the site to be addressed by integrating the strengths of both technologies to achieve comprehensive and reliable documentation within relatively short timeframes.

3.2. Urban acquisition systems and mobile tools

The configuration and complexity of Morella's urban system determined operational choices

during the territorial documentation phase. The planned activities were structured into different operational phases, considering the defensive system along the city's perimeter and the internal connections linking it to the castle (Maragno et al. 2024; La Placa & Dell'Amico, 2024). Given the extent of the walls, a mobile system was used to document the internal and external portions of the fortifications in a short time (12).

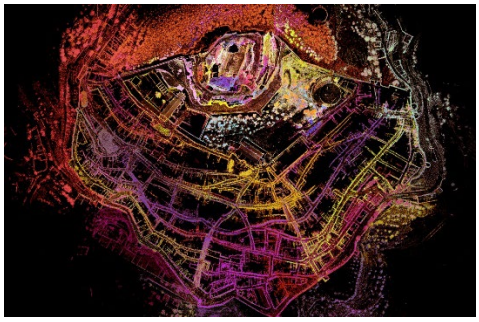

Fig. 4- Integration of the database obtained from TLS and MLS scans of the Morella city centre and Castle. Each colour highlights a different scan, highlighting the large number of scans taken to document the fortified systems of the walls and castle Graphic elaboration by Francesca Picchio, Francesca Galasso, 2024.

However, due to the inability to obtain closed-loop paths that would control errors during acquisition, it was necessary to program each open path based on the duration and volume of data to be captured. To mitigate the risk of deviation errors, city gates and towers along the defensive perimeter were used as control points to link the interior and exterior, ensuring connections between segments. The collected data provided a clear understanding of the city walls' development and their connections to the landscape and the urban centre. Upon completing documentation of the fortified perimeter, attention shifted to the internal pathways within the urban fabric.

These surveys documented internal urban connections to ensure error control in linear, non-closed paths (La Placa & Doria, 2022). Survey planning accounted for strategic overlap points between contiguous scanning segments and intersections with secondary streets. Factors such as scanning duration and acquisition techniques were influenced by the tourist flow characteristic of the area during the summer. To avoid interruptions from people and other elements that could introduce noise into the data, scans were scheduled during less crowded times of the day, resulting in homogeneous and easily interpretable data.

4. Data processing and integration for accurate heritage documentation

From the digital products generated through various documentation techniques, each dataset was processed following registration and data treatment procedures, resulting in point clouds that digitally represent the locations. Datasets were aligned using TLS data as a reference, ensuring orientation and integration with point clouds generated from MLS and photogrammetric elaborations.

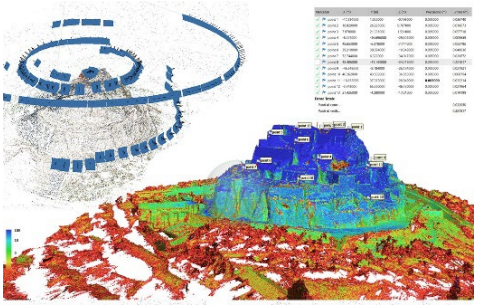

Fig. 5- Photogrammetric processing of the castle dataset and checking the accuracy of the digital product obtained. The points in blue underline the reliability of the data, confirmed by the average alignment error on the control points Graphic elaboration by Francesca Picchio, Francesca Galasso, 2024.

The use of homologous points across datasets ensured accurate alignment, though not without limitations. Processing TLS data at full resolution reduced errors but did not eliminate them entirely, particularly in linear structures where open-path documentation prevented the creation of closed-loop trajectories that would have improved model strength. Close-range photogrammetry using a 360° camera for rapid photogrammetric acquisition produced an initial fragmented dataset that was difficult to interpret.

This issue was attributed to the speed of acquisition during image capture, compromising data quality and the coherence of the point cloud. To address this limitation, a new dataset of images was created by extracting individual frames from field-acquired videos. This method

enabled detailed management of the number of images processed, optimizing coverage and ensuring higher quality in the final dataset (13). Despite these challenges, the integration of multiple techniques underscores the importance of combining diverse methods to overcome individual limitations and enhance the overall quality of the documentation. The post-production processes and error control resulted in a highly reliable metric database (14), serving as a crucial resource for assessing the site's current state and deeply supporting the planning, conservation, valorisation, and management of the fortified heritage.

5. Conclusion

The digitalization strategy for Morella's fortified structures goes beyond material preservation, aiming to create a tool that digitally qualifies the identity of the space. Integrating the walls and fortifications into the database of Jaime I's Route strengthens the connection between local heritage and European collective memory, transforming Morella into a focal point for rediscovering the medieval and military origins of this itinerary.

A database structured in this way becomes the knowledge base for structuring transversal knowledge paths, which exploit homogeneous data or use integration from different data sources. From the 360° panoramas it is possible to navigate in VR (Zerlenga et al. 2023) and access 3D models uploaded on specific platforms, as well as to develop integrated BIM or GIS models able to systemise the evolutionary history of the castle and the city (Pettineo et al. 2024; Dell'Amico, 2023; De Fino et al. 2020). Morella's fortified system serves as an emblematic case demonstrating the effectiveness of contemporary documentation techniques applied to historical and cultural contexts. Integrating these practices into the Jaime I Cultural Route represents an opportunity to promote conservation, research, and public engagement. It contributes not only to safeguarding shared heritage but also to enhancing its narrative and scientific potential.

Notes

(1) The project PROMETHEUS - Protocols for Information Models Libraries Tested on Heritage of Upper Kama Sites is part of Horizon 2020 Marie Sklodowska-Curie Actions, Research and Innovation Staff Exchange (RISE), Proposal number: 821870. The project involves creating digital platforms for sites along several cultural routes in Europe at different scales, historically rooted in their respective territories: the territorial route of salt merchants in Upper Kama (Russia), the provincial route of sites conquered by Jaime I (Spain), and the urban fortification system of Gdansk (Poland).

(2) The castle was declared a national historical monument by the Spanish state on June 4, 1931. For further details, see the Decree of June 3, 1931, declaring Historical-Artistic Monuments belonging to the National Artistic Treasury, Gaceta de Madrid (155): 1181-1185.

(3) Although there is no specific information about Jaime I's actions in Morella, his figure remains relevant in the broader context of the Reconquista and the formation of the Crown of Aragon.

(5) Among the many gates, Puerta del Forcall stands out for its simple construction and direct access to trade routes.

(6) The first documentation mission for Jaime I's Route was carried out in July 2022, involving researchers from the Polytechnic University of Valencia and researchers and students from the University of Pavia. Specifically, the research activities in Morella began during the International Summer School "The Route of Jaime I: Survey and Analysis for Evaluation, Enhancement, and Management of European Cultural Heritage Routes," organized by the DAda Lab Research and Teaching Laboratory. It was promoted by the University of Pavia, the Polytechnic University of Valencia, and other academic and industry partners. The Summer School took place from July 24 to 31, 2023, in Valencia and Morella, Spain, with the participation of students, PhD candidates, and researchers from the University of Pavia.

(7) The tools used during the acquisition campaign included a Terrestrial Laser Scanner (TLS), Leica RTC360, and two Mobile Laser Scanning (MLS) systems: a Leica BLK2GO and a Stencil KAARTA.

(8) The documentation campaign utilized a Ricoh Theta 360° camera and DJI Mavic Mini 2 Pro lightweight drones.

(9) Three acquisition sessions were conducted manually, following a concentric path around the monumental site. A total of 493 images were collected.

(10) After manually setting acquisition parameters, two types of data capture were performed: the first through automatic shooting

of one panoramic image per second, generating a total of 170 images; the second by recording three videos at 24fps.

(11) TLS documentation included 157 high-resolution scans to capture the entire castle and some accessible buildings. MLS surveys were carried out in closed circuits and short paths, with 25 closed-loop scans lasting up to seven minutes each.

(12) Documentation of the walls using the Stencil KAARTA involved numerous scans, manoeuvring the tool along various axes to capture as much detail as possible. For further details on acquisition methods, see (Dell'Amico, 2023).

(13) By defining the number of images to extract, a semi-automated dataset of about 500 images was created, producing a dense point cloud with approximately 103 million points.

(14) The integration of all databases resulted in an average registration error of around 30 cm. Given the site's scale and the high volume of integrated data, the error is considered acceptable.

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