

Thesis title: Ontology-based semantic database for parametric modelling of complex architectures in their enhancement process.

The case of the fortified system along the ancient border between the Kingdom of Two Sicilies and the Papal State, in Italy.

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Abstract

This thesis, entitled "Ontology-based semantic database for parametric modelling of complex architectures in their enhancement process: The case of the fortified system along the ancient border between the Kingdom of Two Sicilies and the Papal State, in Italy," proposes a comprehensive methodology for the digital documentation, analysis, and valorisation of fortified architecture. The study is centered on the fortresses located along the historical border between the Kingdom of the Two Sicilies and the Papal States, a region characterized by a rich fortified heritage but suffering from a lack of comprehensive historical documentation. Through the integration of digital tools such as Scan-to-BIM, GIS, and ontology-based semantic databases, the thesis aims to create an operational framework for both scholarly research and practical conservation efforts. The issue of stable defence arose with the first sedentary human settlements, dictated by the need to safeguard a social group's rules of coexistence from external hostile agents, both natural and human. For this reason, the art of defence is as old as humanity itself and has evolved in parallel with the progress of human knowledge. Early fortifications relied on natural geographical features for defence, but as offensive techniques advanced, artificial defences became necessary. Military architecture, thus, revolves around the relationship between building elements, balancing their defensive and offensive values. Throughout history, the enclosure—a physical barrier like walls, towers, or moats—remained the most visible manifestation of defensive needs. The evolution of fortification techniques, particularly with the advent of artillery and firearms in the 15th and 16th centuries, profoundly transformed these defensive structures, as exemplified by the shift from vertical "plunging" defence to horizontal "grazing" defence, especially evident in bastioned fortresses. This marked a transition phase towards modern military architecture, rooted in ancient principles but evolving rapidly due to new technologies. The first part of the thesis establishes the theoretical and scientific foundations by reviewing the literature on Italian fortifications. It explores how the art of defence evolved in response to technological advances, particularly artillery, and how military architects such as Francesco di Giorgio Martini contributed to this transformation. The study also addresses how modern scholars approach the terminology of military architecture, noting the complexity and evolution of terms like fortress, castle, citadel, and bastion, which were often used interchangeably but referred to different structural elements or defensive purposes.

In addressing the scientific problem, the thesis formulates key research questions regarding the preservation and documentation of fortifications in the absence of adequate historical records. The research hypotheses suggest that a multi-disciplinary approach combining archival research, digital surveys, and structured ontologies can compensate for gaps in historical data, providing a more comprehensive understanding of these sites. The aim is to develop a universal methodology that can be applied to other regions and historical periods, enhancing both academic and public engagement with fortified heritage.

The core of the thesis lies in the application of an ontology-based semantic database procedure, termed FORTdigiTALE, which integrates various forms of data—historical, geographical, and architectural—into a unified parametric model. This procedure begins with data acquisition, utilizing photogrammetry

and Structure-from-Motion (SfM) techniques to create accurate 3D models of fortifications. These digital models are then incorporated into a Heritage Building Information Model (HBIM), allowing for the detailed representation of architectural elements. The use of GIS further enhances the territorial understanding of these structures, illustrating their strategic positioning and visual interconnections across the landscape.

A significant contribution of the research is its exploration of how ontological analysis can be applied to fortification studies. By constructing a semantic database, the thesis systematically organizes the diverse data sets into a coherent framework that enhances both scholarly knowledge and practical conservation efforts. This methodology is tested through detailed case studies of five fortifications in Southern Lazio: San Casto in Sora, Vicalvi Castle, Alvito Castle, Rocca Janula in Cassino, and the Angevin Castle in Gaeta. For each site, the thesis provides an in-depth historical analysis, complemented by GIS cataloging and photogrammetric modeling, culminating in the creation of HBIM-based ontological models. These case studies serve as both a demonstration of the methodology and as contributions to the broader understanding of the region's fortified heritage.

The detailed case studies also shed light on the complex historical, geographical, and political factors that shaped the fortification system in Southern Lazio. The thesis examines the impact of key historical figures and events, such as Frederick II's fortification programs and the Angevin reorganization of castles, on the development of the region's defensive architecture.

The broader implications of the research are discussed in the concluding chapters, where the thesis reflects on the potential for applying this methodology to other contexts, both geographically and temporally. The FORTdigiTALE procedure offers a scalable and adaptable framework that can support not only academic research but also public outreach by transforming the digital models into accessible resources for education and tourism. The thesis advocates for a more inclusive approach to heritage conservation, one that integrates both scholarly research and community involvement.

In summary, this thesis contributes to the fields of digital heritage conservation and fortified architecture studies by developing an innovative, ontology-based methodology for documenting and analyzing fortifications. It bridges the gap between historical documentation and modern digital techniques, providing a valuable tool for both researchers and practitioners in the field. The operational model created through this research has the potential to enhance decision-making processes for restoration and valorisation efforts, ensuring that these historical structures are preserved for future generations.